Working Group

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FLOOD DAMAGE MITIGATION MEASURES FOR BARAK VALLEY IN SOUTH ASSAM INCLUDING EFFECTS OF CLIMATE CHANGE

Abstract: In the present study attempt has been made to determine the extent of flow regulations required in the upstream catchments to have safe flow at important downstream damage locations in Barak river system. There are a number of gauged and ungauged catchments in the study area and downstream flow simulation model incorporating flows from all the upstream gauged and ungauged catchments have been developed for the river system. To determine the existing flow capacity of the sections in the tributary river systems as well as in the main river the sections are surveyed at a regular interval and at all critical sections along a river course and the required channel parameters and other sectional details such as flow area, top width etc are determined/computed. Expected maximum rainfall intensity for different return periods for the study area is obtained by applying L-moment techniques for the homogeneous zone identified by applying fuzzy C-means based clustering techniques.

Three flood events considering availability of rainfall records in the study area are selected and used to conduct flood movement analysis for the river system. Stage-discharge relationships for all gauging stations are developed applying regression technique and are used to express the flow depths measured at a gauging station in terms of the discharge value. Flow contributions from the ungauged catchments are obtained by using GIUH approach. Important morphological parameters for the tributary river systems required for developing the GIUH models are derived using the DEM, stream network, slope map and data obtained by direct field measurements. The IUHs obtained for the catchments are lagged using s-curve technique to derive 1-hour unit hydrograph. Contributions from the important ungauged catchments are determined by using 1-hour unit hydrograph for the catchments and the rainfall excess for the storm events during the selected flood periods. Flow

contributions from the gauged and ungauged catchments are integrated using equivalent inflow for a number of upstream flows applicable to the river networks in the study area. Sediment flow simulation model for the river system are developed using the sediment concentration and sediment discharge data collected for the river system. The model is used to assess the relative contributions of the catchments in sediment load in the river reaches. Downstream flow rate and flow top width forecasting models have been developed for the river system that can be applied to forecast downstream flow conditions well in advance on the basis of upstream flow rates recorded at several upstream sections. Linear Programming model is formulated for the river networks having outflow at Annapurnaghat and Badarpurghat to determine effects of upstream flows on the downstream flows. The model is applied for two cases: (i) when upstream flows from the major ungauged catchments are regulated (ii) when flows from all upstream catchments are regulated. The effects of climate change on the flow rates are incorporated in the LP model and for the changed climatic conditions flow controls required in all major catchments upstream of the potential damage sections at Annapurnaghat and Badarpurghat are evaluated. Based on the survey works, field trips and laboratory works conducted to asses existing flow capacity of the channel systems, functioning of the sluice gates in the districts of Cachar, Karimjang and Hailakandi and status of existing embankments along the river courses etc. some observations/recommendations are forwarded that may be considered for further study and / implementation for improving overall flood condition in the valley

1.0 Introduction:

The Barak river system is the second largest system in the North Eastern region of India and falls within hydro meteorological sub zone, 2c of India. The river system drains 26,193 Sq. Km in India with approximately 6562 Sq. Km from the state of Assam. The area is quite undeveloped compared to other parts of India. The main river Barak receives a large number of minor tributaries and 20 major tributaries out of which 12 are wholly in India. Flood and erosion problems in Barak valley is a major cause of concern, every year there is colossal flood losses in the valley. The GOI is considering various steps for alleviating the problem of natural disasters like flood, and landslide in this area.

The main river Barak has an approximate length of 900 km out of which 532 km is in India and nearly 129 km is in the state of Assam. The valley has an average width of 25-30 km and is situated in the route of south-west monsoon. Highest annual rainfall for the valley= 4194 mm recorded at Silchar in 1989. Maximum discharge for the Barak river system= 7786.08 m^3/s recorded at Badarpur in 1976. As per available records, nearly 3.50 lakh hectares of land area in the valley is flood prone and some protection against flood damages is available to 57% of the flood prone areas only. There are 26 nos of major sluice gates in the valley and approximately 738 km long embankments along the main river and its tributaries exist to help reduce the impact of flood. But, as most part of these embankments has outlived the life span the embankments develop large breaches regularly during monsoon seasons causing huge flood damages.

Some of the main factors that acting singly or in combination causes flood in the valley are:

(i) High incidence of rainfall, (ii) Deforestation in the upper catchments (iii) Inadequate natural drainage system (iii) Reduction in natural reservoirs (iv) Heavy encroachment in the riverine area (v) Large scale construction activities without proper planning

To improve flood scenario reducing flood related losses in the valley it is imperative that some actions be initiated against the controllable factors mentioned above. Some of the recommendations may be construction of embankments in the existing gap positions, raising heights of the existing embankments, afforestation in the upper catchments and adoption of suitable watershed management plans to reduce sediment load in the channels. To tackle flood problems in the valley solution is to be achieved incorporating due weightage to all hydrologic and hydraulic factors effecting flood movement in the river system. A comprehensive and integrated mitigation plan should be prepared based on the hydraulic, hydrologic factors and local conditions of natural reservoirs, drainage system etc. In the present study different possible measures for mitigating flood damage in the Barak valley comprising three districts namely, Cachar, Karimganj and Hailakandi using available and generated hydrologic and hydraulic information on the study area is investigated. The study is aimed at evaluatingeffects of different sub catchments on the downstream flood scenarios at important locations, namely at Annapurnaghat and at Badrapurghat for different possible actions in the upstream catchments and river reaches. To formulate comprehensive flood damage mitigation plan investigations that need to be conducted under the study are:- examination of (i) existing flow capacity for different channels in the system, (ii) Adequacy of existing embankments and sluice gates (iii) Sediment load in the river system and erosion potential of different sub catchments and (iv) Development of an efficient tool for improved flood forecasting incorporating flow contribution from gauged and ungauged catchments in the river systemand (v) Assessment of effects of climate change on flood flow in the river system.

1.1 Study Area and Data Used

In the present report investigation works conducted for recommending suitable flood damage mitigation measures for Barak valley with the main river running from Phulertal at Lakhipur to international boarder point in Karimganj district along with study results and findings are presented. The main river reach from Lakhipur to Karimganj town receives a number of medium and small tributaries as shown in Map of the study area given in figure 1(a) and figure 1 (b). A few of the tributaries in the study area are gauged while, the rest are ungauged for which pertinent hydrologic and hydraulic information required for flow and erosion modeling are not available. Details of the major and minor tributaries joining the main river Barak from Fulertal at Lakhipur to Bangladesh border at Karimjanj district are given in Table-1. River flow and stage data for different gauging stations in the study for the period 2000-2010 are collected from CWC, Shillong. The collected stage and corresponding flow data for different river sections are used to develop stage vs discharge relationships for the gauging stations. Using recorded hourly stage/flow value for different sections downstream flow simulation models for the study area are developed. Hourly rainfall intensity records for different raining gauging stations in Barak valley are collected from RMC Guwahati. The rainfall values are used to compute runoff from the ungauged catchments during the selected storm events; annual maximum rainfall records for different stations is used to determine expected maximum rainfall intensity for different return periods in the study area. Daily sediment discharge versus water discharge data are collected from CWC Shillong for the period 2000-2010. The collected data are used to develop Sediment routing model for the river system.

1.2**Watershed Data**:

To accomplish the proposed investigations pertinent data for the gauged and ungauged catchments are extracted using Geographic information system (GIS). GIS technique is utilized to develop digital elevation models (DEM), slope map, drainage maps for different sub watershed. Features and characteristics of the sub basin extracted applying GIS technique are utilized for developing rainfall-runoff model by applying Geomorphic Instantaneous Unit Hydrograph (GIUH) technique. The DEMs are developed using Survey of India Topo Maps in 1:50000 scales obtained from SOI, Shillong office. The 1-hr unit hydrograph developed for the important ungauged catchments in the study area are used to compute direct runoff hydrograph for these catchments for a set of identified storm events during the period 2000-2010.

1.3 River Networks

The Barak river network in the study area that drains three districts in the valley: Cachar, Karimganj and Hailakandi districts is segmented into a upper network and a lower river network. The upper networkterminates at *the* downstream gauging station at AnnapurnaGhat in the River Barak and *receives* flows from the upstream ungauged sub catchments of *Jiri,, Chiri , Madhura and gauged subcatchments of Dholai and Maniarkhal apart from the upstream flows gauged at Fulertal in Barak at Lakhipur. T*he lower network consists of the main river Barak from the upstream point at Annapurnaghat to the downstream point at Badarpurghat. The downstream flow at Badarpurghat is due to the inflow at Annapurnaghat, flows from the ungauged subcatchments *Jatinga*, *Ghagra* and flow from the tributary Katakhal with gauging station at *Matijuri*. To simulate and forecast water and sediment discharge at two important downstream locations namely, Barak at AnnapurnaGhat, near Silchar town and Barak at BadarpurGhat near Badarpur in Karimganj District water and sediment discharge simulation and forecasting models for the upper network with downstream station at AnnapurnaGhat and for the complete river network with Badarpurghat as the downstream station are developed.

Table 1.1: Details of Major Tributaries of River Barak in the study area

Name of the main River	Left Bank/Right Bank Tributary	Confluence (District)
Jiri	Right	Cachar
Chiri	Right	Cachar
Sonai	Left	Cachar
Badri	Right	Cachar
Madhura	Right	Cachar
Ghagra	Left	Cachar
Dhaleshwari	Left	Cachar
Katakhal	Left	Hailakandi
Jatinga	Right	Cachar
Longai	Left	Karimganj
Ghumra	Right	Cachar

Figure 1.1:Ariel map of the study area

1.4 Objectives of the present study:

The majorobjectives of the present work are to study effectiveness of the existing flood control measures in Barak valley and to recommend suitable measures for mitigating flood damages. Following are the major objectives of the present study

(i) Assessment of existing flow capacity for different channels in the river system.

(ii) Assessment of effectiveness of existing embankments in the study area

(iii) Improvement works for lateral channels and natural reservoirs

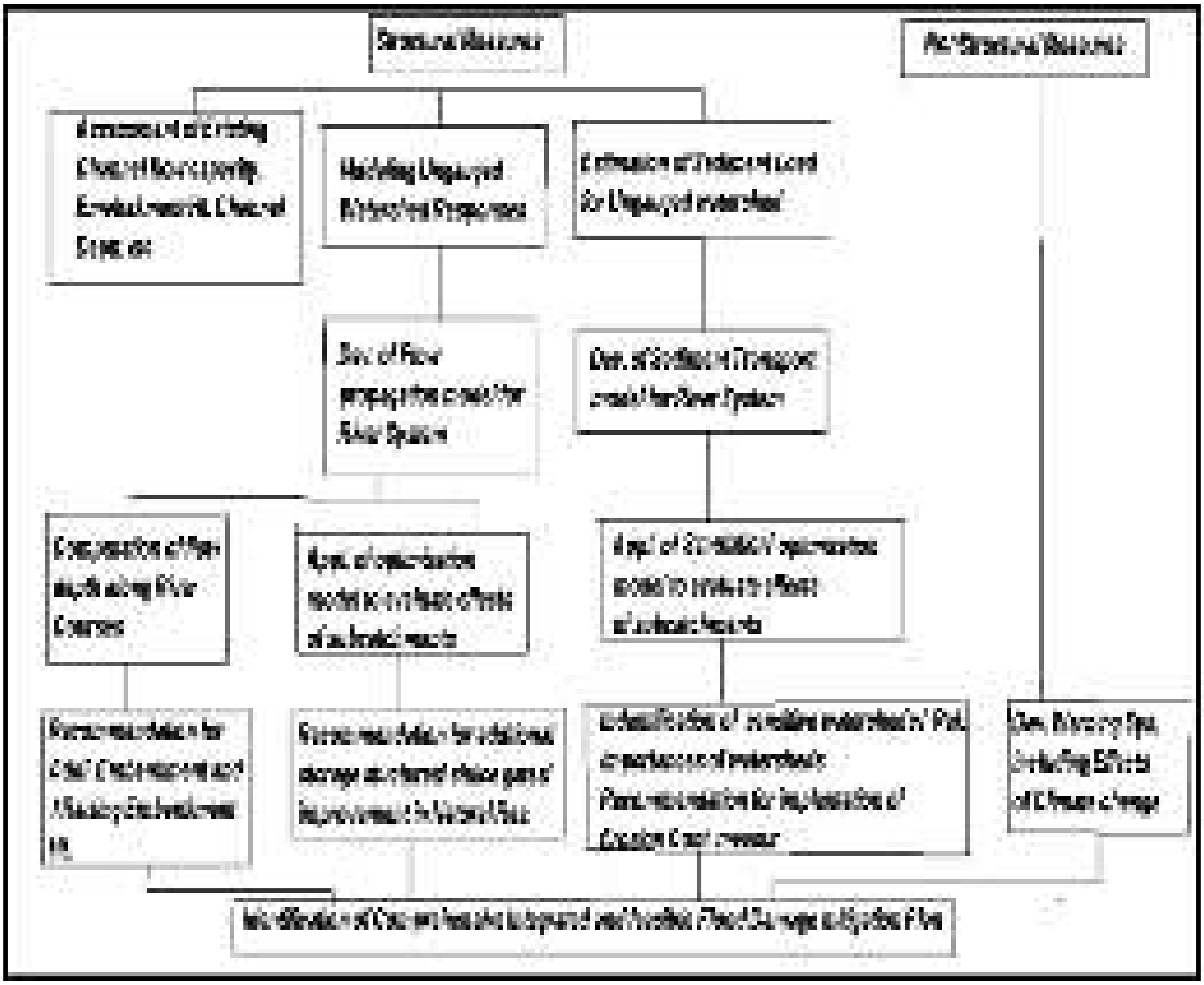
(iv) Investigation on sediment load in the river system and erosion potential for different sub catchments.

(v) Evaluation of impacts of flows from upstream catchments on downstream flood flows

(vi) Development of an improved flood forecasting tool for the study area incorporating flow contribution from gauged and ungauged catchments

(vii) Evaluation of effects of climate change on flood flows in the river system.

Flow Chart depicting development of flood damage mitigation plan for the study area consisting of three districts in south Assam, Cachar, Karimgajj and Hailakandi is presented in the figure given next



1.5 Outline of the present study

To achieve the above mentioned goals following field and laboratory works have been conducted.

I) Survey of main channel Barak from Lakhipur to Bangladesh border point near Badrapur in Karimganj District and survey of all important tributary channelsystems to determine existing flow capacity and other important channel parameters.

II) Study of existing embankments along the main course upto International border with Bangladesh from Lakhipur and along the major tributary river systems.

III) Development of Stage- Discharge relationship for the gauging stations in the study area.

IV) Estimation of T-year rainfall intensity for the study area by applying L-moment techniques.

V) Development of Slope Map, Drainage Map, Digital Elevation models for important subcatchments in the study area and extraction of geomorphologic parameters, hydraulic and channel parameters by using Geographic Information System (GIS)

VI) Development of 1-hr unit hydrograph for the ungauged subcatcments in the study area

VII) Development and application of flow routing modelsfor the upper network and the complete river network in the study areato simulate flood flow rates at Annapurnaghat near Silchar and Badarpurgaht near Badarpur in Karimganj district.

VIII) Development and applications of sediment flow routing model to simulate downstream sediment discharge and sediment concentration at important downstream locations and assessment of relative effects of erosion from different subcatchments.

IX) Formulation and applications of optimization models to assess impacts of flows from different sub catchment on downstream flood flows and to evaluate suitable control measures for protecting the important downstream locations.

X) Development of flow forecasting model to forecast common downstream flows on the basis of upstream flows/ river satages.

XI) Development of Climate change module to evaluate effects of climate change on flood flow in the study area and to recommend suitable control measures under the changed scenarios.

Detailed description of the studies conducted to achieve the targets is presented in the subsequent sections and subsections.

2.0 Assessment of Flow Capacity of Different Channels in the River SysteminBarak Valley

2.1 Main Channel: River Barak

To assess flow capacity of the main channel Barak from Lakhipur in Assam, India upto international border with Bangladesh various data and maps available with the department of water resources, GOA have been utilized. Digital data and images collected from NRSA are used with GIS technique to identify critical and vulnerable channel locations; to extract different morphometric and geomorphologic characteristics of the channel system such as, length, slope, areas etc and to estimate channel width at different locations. On the basis of preliminary assessment made using digital images field measurements for flow depth, cross sectional areas, flow velocity etc. have beenundertaken at the identified and other critical location to estimate existing flow capacity for the channels in the river system. The main river course from Lakhipur to Badarpurghat have been surveyed to assess channel flow capacity at an interval of 2 km approximately covering critical locations such as sharp bend, narrow widths etc. M/S M.S Survey, Hoogly, Kolkata was entrusted to job of survey works. The agency surveyed the main river course in two parts and covered the channel stretch upto international border with Bangladesh. Some representative survey details of the main river is included in the following sections and full details submitted by the agency is sent separately along with this report.

2.2 Tributary River Systems:

The important tributary channel systems that have been surveyed to estimate flow capacity and other pertinent details includes the right bank tributaries, Jiri, Chiri,Badri, Madhura and Jhatinga and the left bank tributaries Sonai, Ghagra, Katakhal and Longai. A team of technical and non technical staff from the department of Civil Engineering completed the survey works of the important tributary channel systems in the study area. Relevant section details of the tributary drainage systems such as top with, maximum flow depth, average flow area etc. at a regular interval and at all critical locationsare obtained by direct measurement and / laboratory computation. The detailed description of the tributary river system along with pertinent details is presented subsequently.

2.3 Details of Existing Embankments and Sluice Gates in the Study Area:

The survey team traversed through the river network in the study area collected details of the existing embankments along the main river and along the tributaries. Details of existing sluice gates in the subcatchments as well as existing water bodies were also recorded /measured by the team. Distance of the existing embankments from the central axis of the river course, height of the embankment, length of the embankment etc have been measured/computed for the entire river networks.Details of the embankments along the main river course from Lakhipur to Bhanga in Karimganj district and along the tributary channels in the major sub catchments are as follows:flow areas of section along the river courses in the valley are presented in Tables 2.1 through 2.10; map of the river courses and section details are given in figures 2.1 through figures 2.20(c); Details of existing embankment along the major tributary river systems and along the main river Barak is given in Table-2.21 and list of the existing major sluice gates in the study area is available in Table-2.12

Fig 2.1 : Main River Barak from Lakhipur to Bhanga (upto Bangladesh Border)

Table 2.1 : Flow area Details of Barak River system(Jiri Muk to Bangha)

Sl. No	Ch	Top Width (m)	Average Depth (m)	Maximum Depth (m)	Safe Flow Area (Sq.m)	Dist. Between station	Embankment Details (Distance from central line; Height in metre)		Remarks	
							Left Bank	Right Bank	Left Bank	Right Bank
1	0	250.00	11.842	15.818	3835.250	0.000	Nil	Nil	Hill	Forest
2	4	261.50	16.151	23.033	3785.130	4.000	Nil	Nil	Forest	Forest
3	8	215.00	11.529	11.495	2457.930	4.000	Nil	Nil	Village/hill/Pineapp le garden	Forest
4	12	220.85	12.727	17.445	2787.688	4.000	Nil	Nil	Residential Area	Residential Area
5	16	212.48	10.589	13.086	1983.738	4.000	D= 90.00 , H = 2.50	Nil	Agriculture Land	Agriculture Land
6	20	234.94	11.76	15.868	2682.150	4.000	D = 70.00 , H = 3.00	Nil	Paddy Land	Paddy Land
7	24	255.10	10.18	14.67	2544.010	4.000	D = 192.00 , H = 3.20	Nil	Paddy Land	Paddy Land
8	28	200.86	8.729	18.803	1724.126	4.000	D = 344.00 , H = 3.00	Nil	Paddy Land	Residential Area/Paddy land
9	30	263.27	8.378	16.31	1859.470	2.000	D= 353.00 , H = 2.50	Nil	Hut/Residential Area	Paddy Land
10	32	306.27	7.516	12.278	2199.628	2.000	D= 321.00 , H = 2.00	D = 40.00 , H = 2.90	Agriculture Land	Agriculture Land
11	36	201.95	9.736	13.286	1999.194	4.000	D = 1 Km , H = 3.00	D= 210.00 , H = 3.10	Agriculture Land	Residential Area
12	40	273.48	7.056	14.078	1930.570	4.000	D = 265.00 , H = 2.70	D = 850.00 , H = 3.20	Paddy Land/Village	Agriculture Land
13	42	287.00	8.164	13.662	2361.694	2.000	D= 220.00 , H = 3.00	D = 650.00 , H = 3.10	Agriculture Land	Agriculture Land
14	44	215.40	11.39	25.936	2332.043	2.000	D = 183.00 , H = 2.70	D = 85.00 , H = 3.20	Paddy Land	Vill/Paddy Land
15	46	208.21	10.519	18.839	2291.650	2.000	D= 30.00 , H = 2.90	Nil	Residential Area	Vill/Paddy Land
16	50	259.93	10.871	10.871	2675.210	4.000	Nil	D = 1 KM , H = 3.20	Vill/Paddy Land	Agriculture Land
17	53	258.94	8.85	16.17	2237.346	3.000	D = 129.00 , H = 3.00	D = 440.00 , H = 3.10	Paddy Land	Paddy Land
18	60	207.6	9.613	15.852	1998.14	7.000	D= 10.00 , H = 1.80	D= 280.00 , H = 3.00	Residential Area	Residential Area

Table 2.1: Contd. (Jiri Muk to Bangha)

Sl. No	Ch	Top Width (m)	Average Depth (m)	Maximum Depth (m)	Safe Flow area (Sq.m)	Dist. Between station	Embankment Details (Distance from central line; Height in metre)		Remarks	
							Left Bank	Right Bank	Left Bank	Right Bank
19	66	221.65	12.596	23.087	2788.289	6.000	D= 40.00 , H = 2.90	D = 192.00 , H = 2.60	Village	Village
20	69	190.7	13.02	25.415	2526.145	3.000	D = 4.00 , H = 2.20	D = 560.00 , H = 2.90	Residential Area	Residential Area
21	72	254.36	8.032	12.65	2680.89	3.000	D= 96.00 , H = 1.50	D= 180.00 , H = 2.00	Paddy Land	Paddy Land
22	74	234.04	11.48	18.65	2676.366	2.000	Nil	D = 314.00 , H = 2.80	Residential Area	Paddy Land
23	77	283.14	5.564	15.037	2377.168	3.000	D= 186.00 , H = 2.90	Nil	Residential Area	Paddy Land
24	80	265.73	8.563	12.602	2218.328	3.000	D = 160 km , H = 3.00	Nil	Residential Area/Paddy land	Residential Area/Paddy land
25	83	235.39	10.714	14.832	2430.426	3.000	D = 1.2 km , H = 3.20	Nil	Paddy Land	Vill/Paddy Land
26	86	243.74	8.123	13.912	2025.81	3.000	D = 185.00 , H = 3.30	D = 194.00 , H = 2.90	Residential Area	Residential Area
27	90	345.27	7.428	11.425	2450.537	4.000	D = 28.00, H = 3.00	D = 25.00 , H =3.00	Residential Area	Residential Area
28	97	249.17	9.896	15.139	2430.551	7.000	D = 360.00 , H = 3.20	D= 48.00 , H = 2.70	Paddy Land	Residential Area
29	100	255.43	10.025	14.972	2522.875	3.000	D = 289.00 , H = 2.90	Nil	Agriculture Land/Vill	Agriculture Land/Vill
30	102	288.54	11.158	15.656	3265.021	2.000	Nil	Nil	Paddy Land	Paddy Land
31	108	224.19	12.67	22.879	2753.388	6.000	Nil	D = 680.00 , H = 3.00	Paddy Land	Paddy Land
32	110	394.04	6.572	11.317	2426.054	2.000	Nil	D = 110.00 , H = 2.85	Paddy Land	Residential Area/Paddy land

Table 2.1: Contd.(Jiri Muk to Bangha)

Sl. No	Ch	Top Width (m)	Average Depth (m)	Maximum Depth (m)	Safe Flow area (Sq.m)	Dist. Between station	Embankment Details (Distance from central line; Height in metre)		Remarks	
							Left Bank	Right Bank	Left Bank	Right Bank
33	112	224.31	9.395	13.326	2242.05	2.000	Nil	D = 390.00 , H = 2.50	Paddy Land	Agriculture Land/Paddy land
34	115	189.26	10.346	13.243	1981.264	3.000	Nil	D= 12.00 , H = 2.90	Paddy Land	Paddy Land
35	119	227.87	12.462	16.962	3002.5	4.000	Nil	D = 65.00 , H = 1.70	Vill/Paddy Land	Residential Area
36	120.3	417.45	9.58	16.50	4550.40	1.30	Nil	D = 75.00 , H = 1.50	Residential Area	Paddy Land
37	123	321.80	12.22	18.21	4151.87	2.70	Nil	D = 163 , H = 1.70	Residential Area	Residential Area
38	126.5	362.74	8.28	12.34	3143.27	3.50	Nil	Nil	Paddy Land	Paddy Land

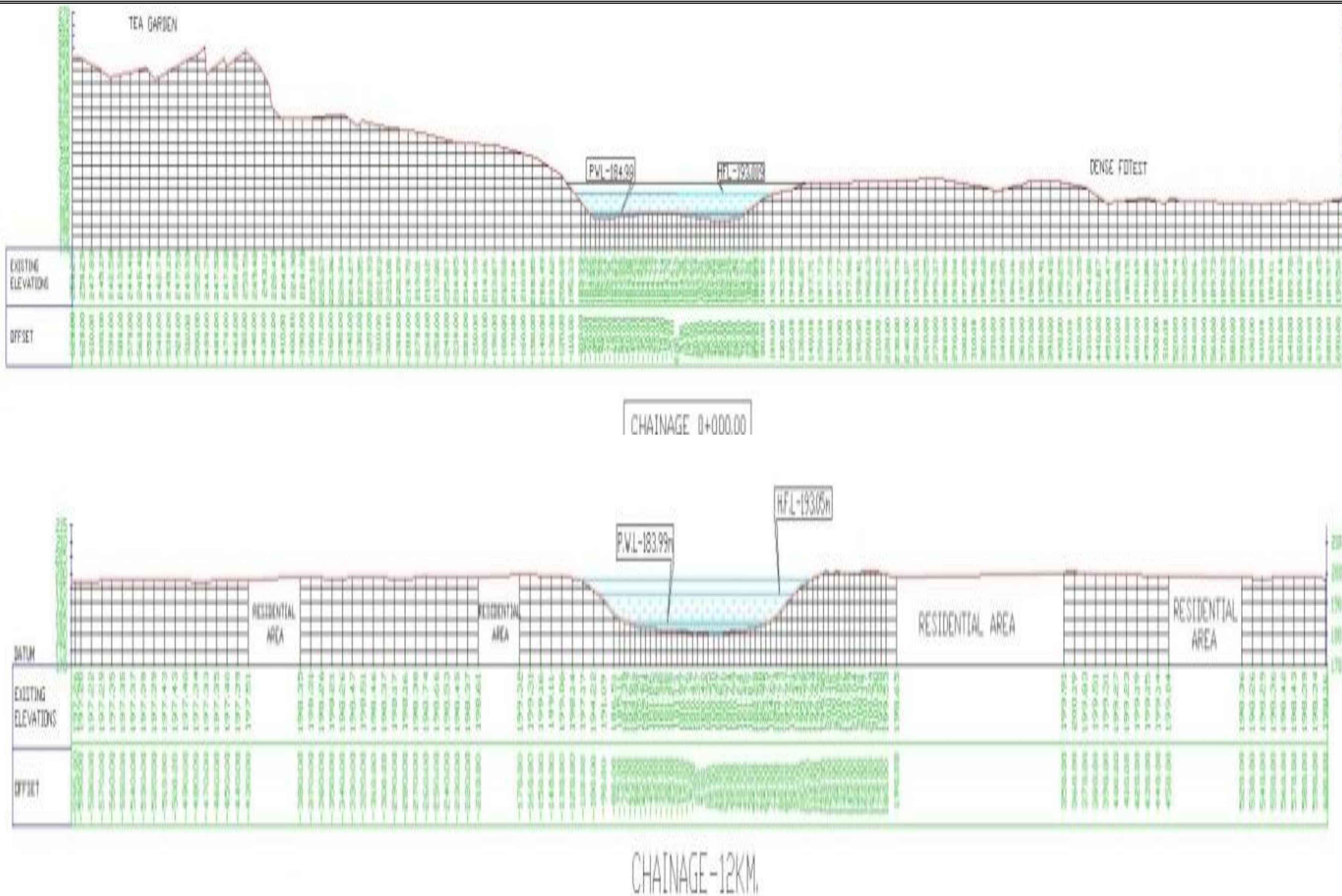


Fig. 2.2(a): Section Details of Barak River upto 500m in the countryside

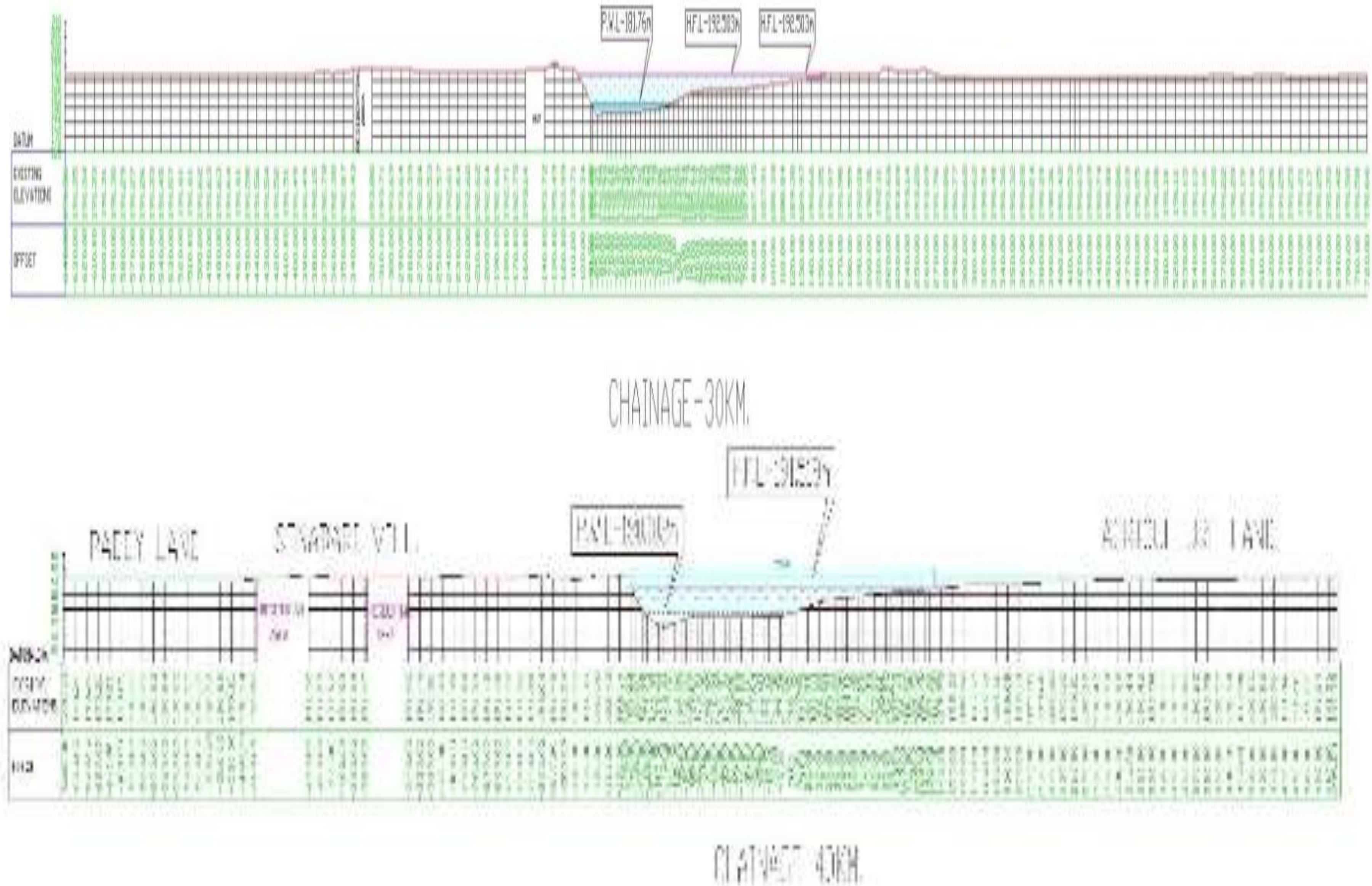
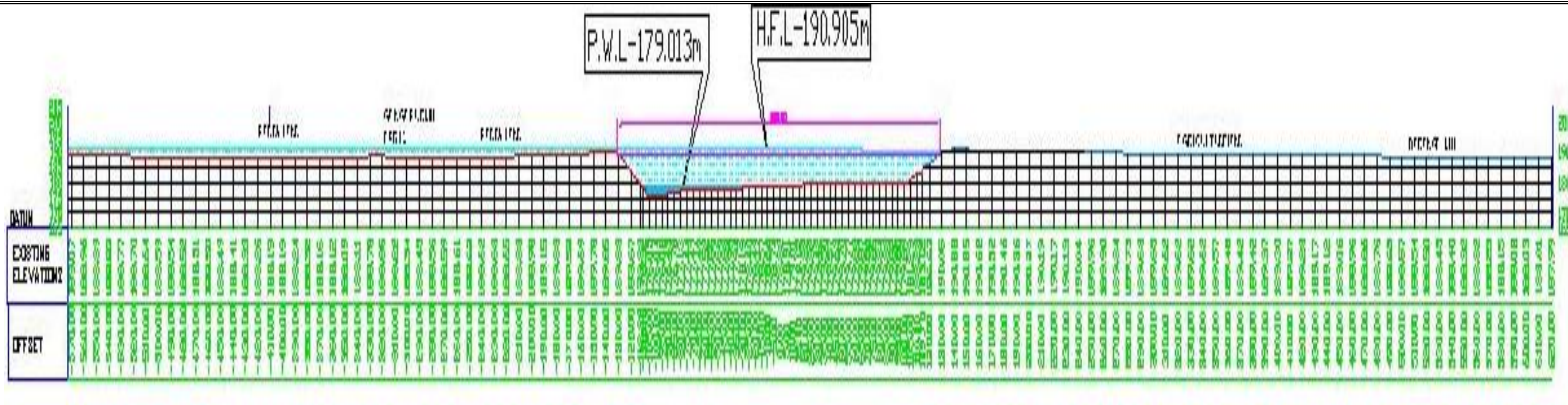
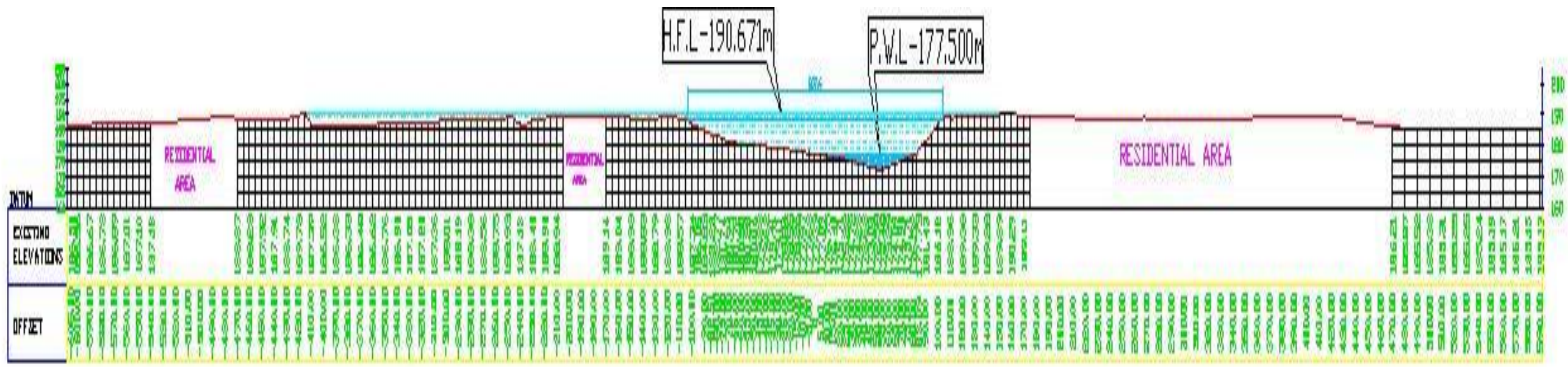


Fig. 2.2(b) : Section Details of Barak River upto 500m in the countryside

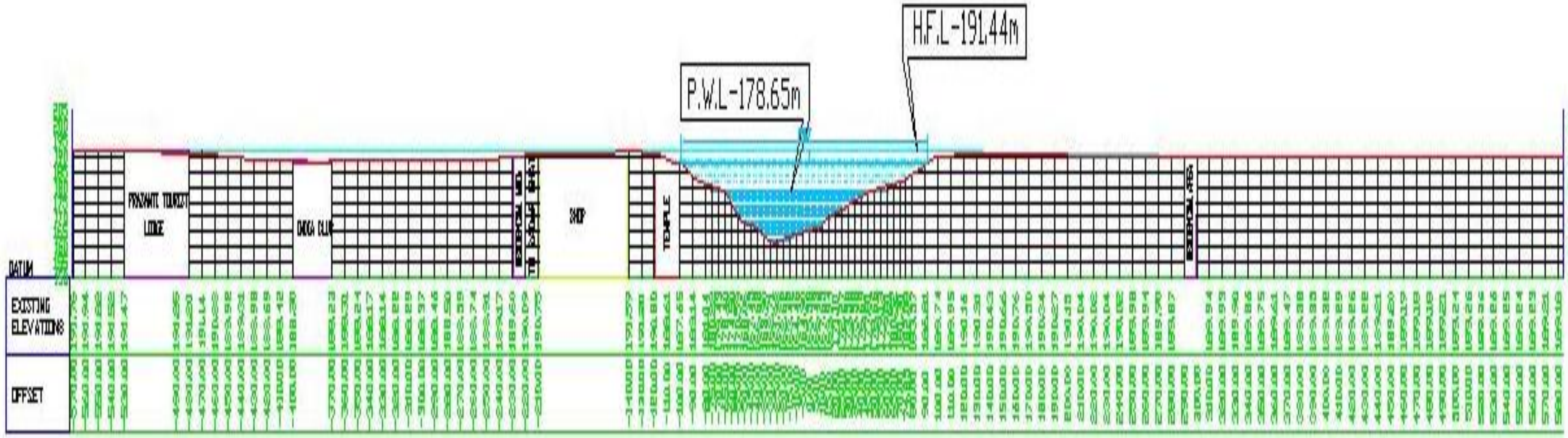


CH 50.000

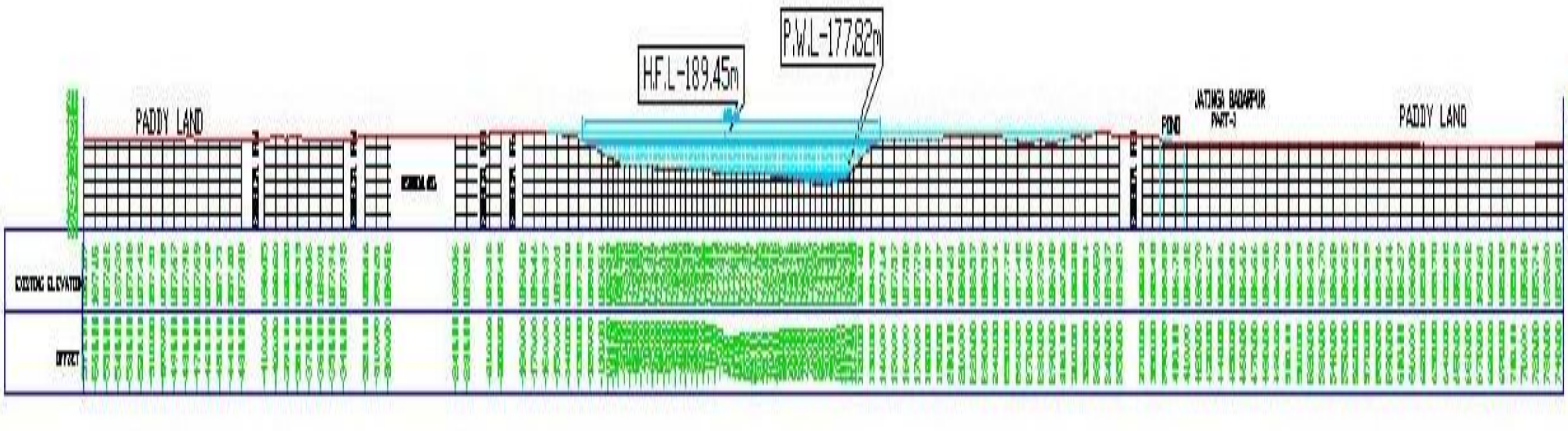


CH 60 KM.

Fig. 2.2(c) : Section Details of Barak River upto 500m in the countryside



CH 69KM



CH-80.00KM

Fig. 2.2(d): Section Details of Barak River upto 500m in the countryside

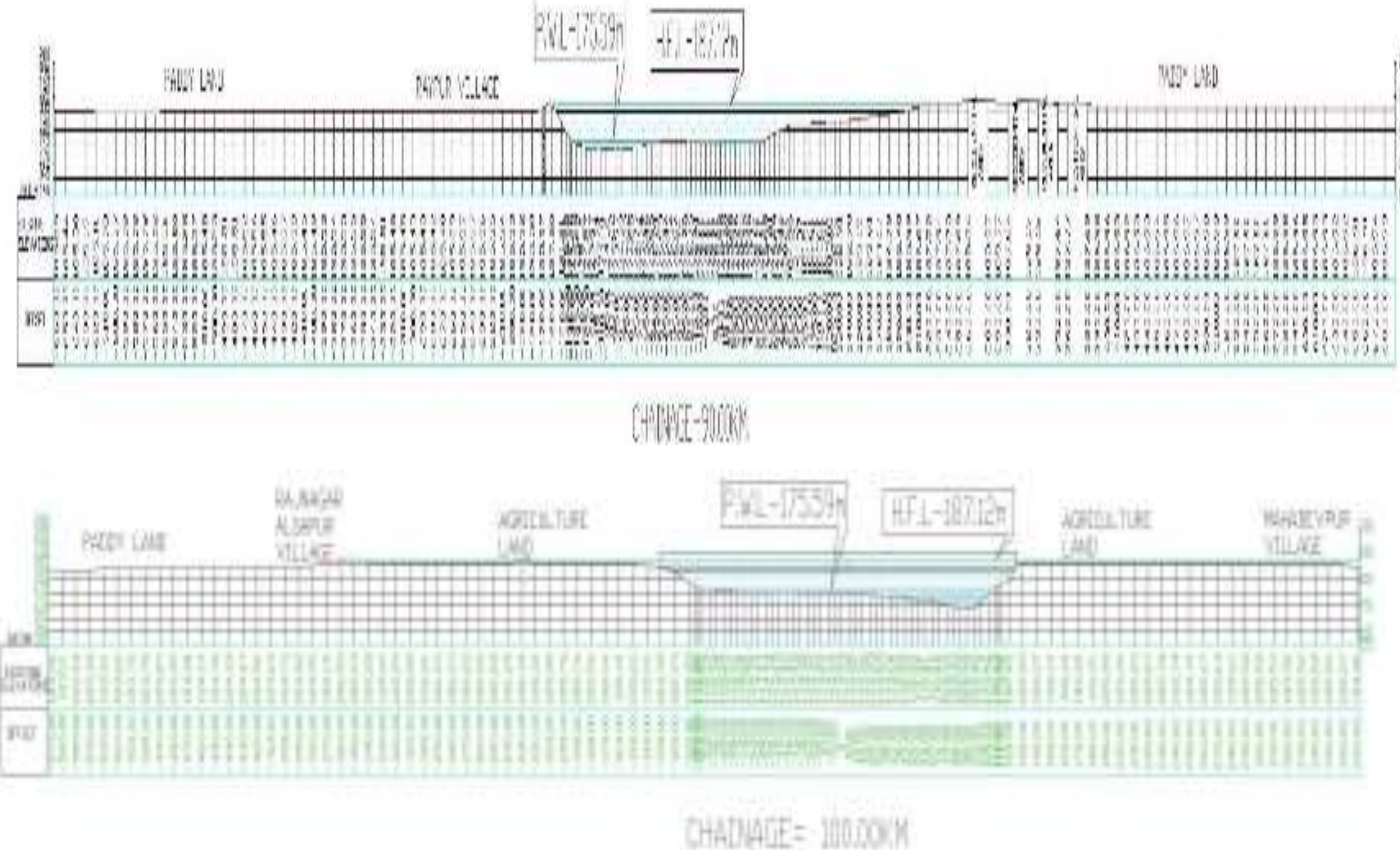
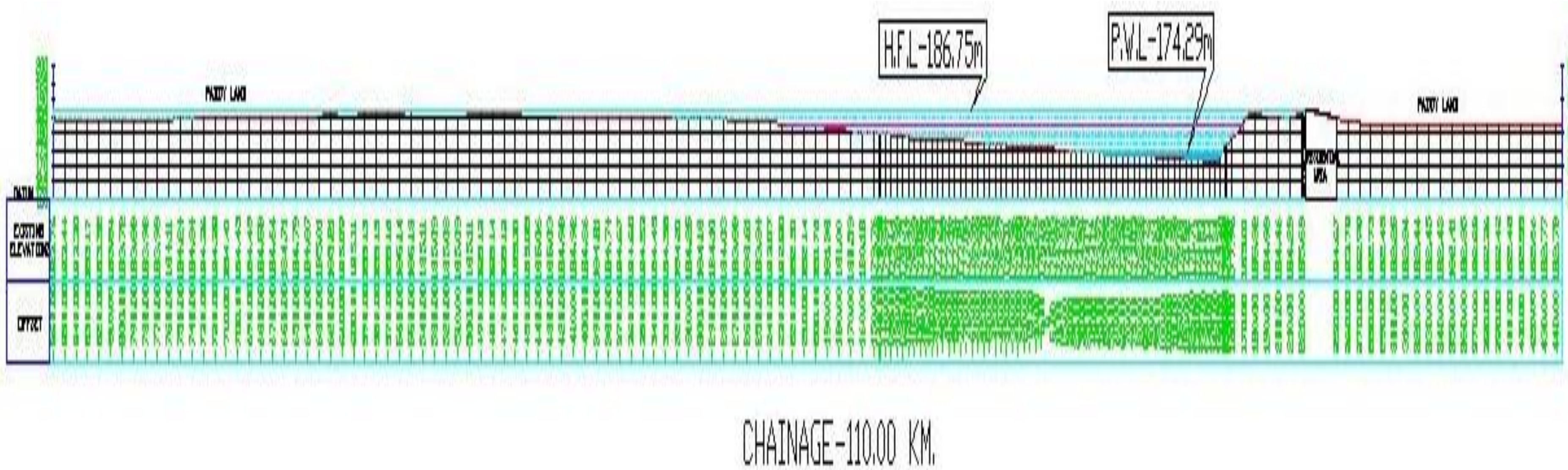


Fig. 2.2(e): Section Details of Barak River upto 500m in the countryside



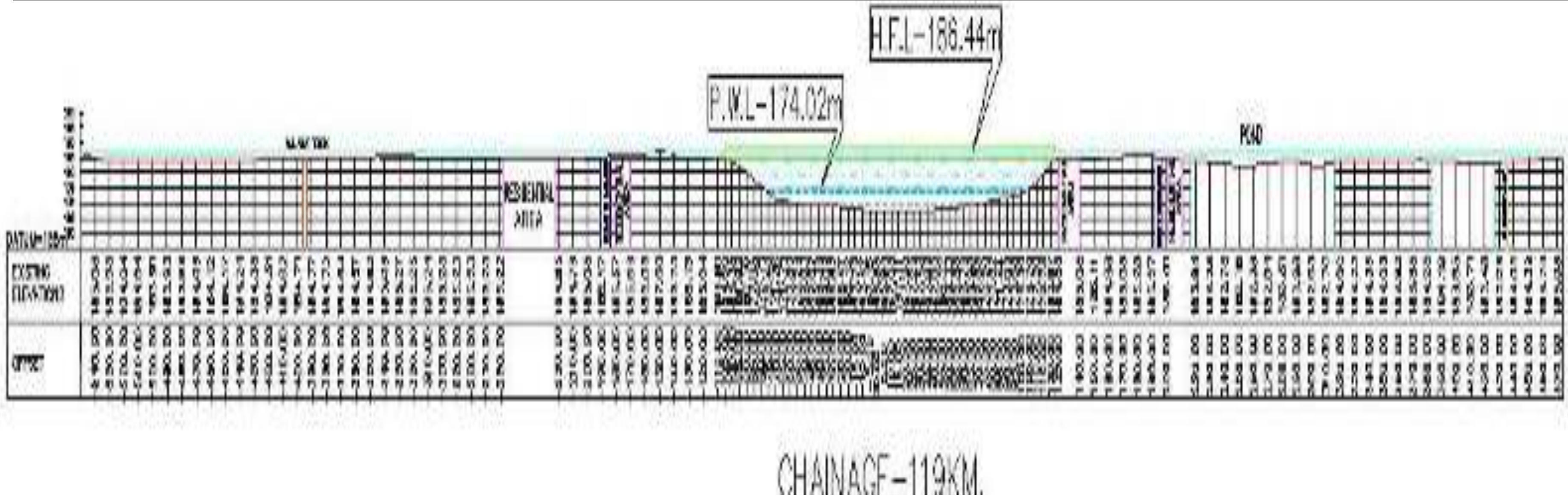


Fig. 2.2(f) : Section Details of Barak River upto 500m in the countryside

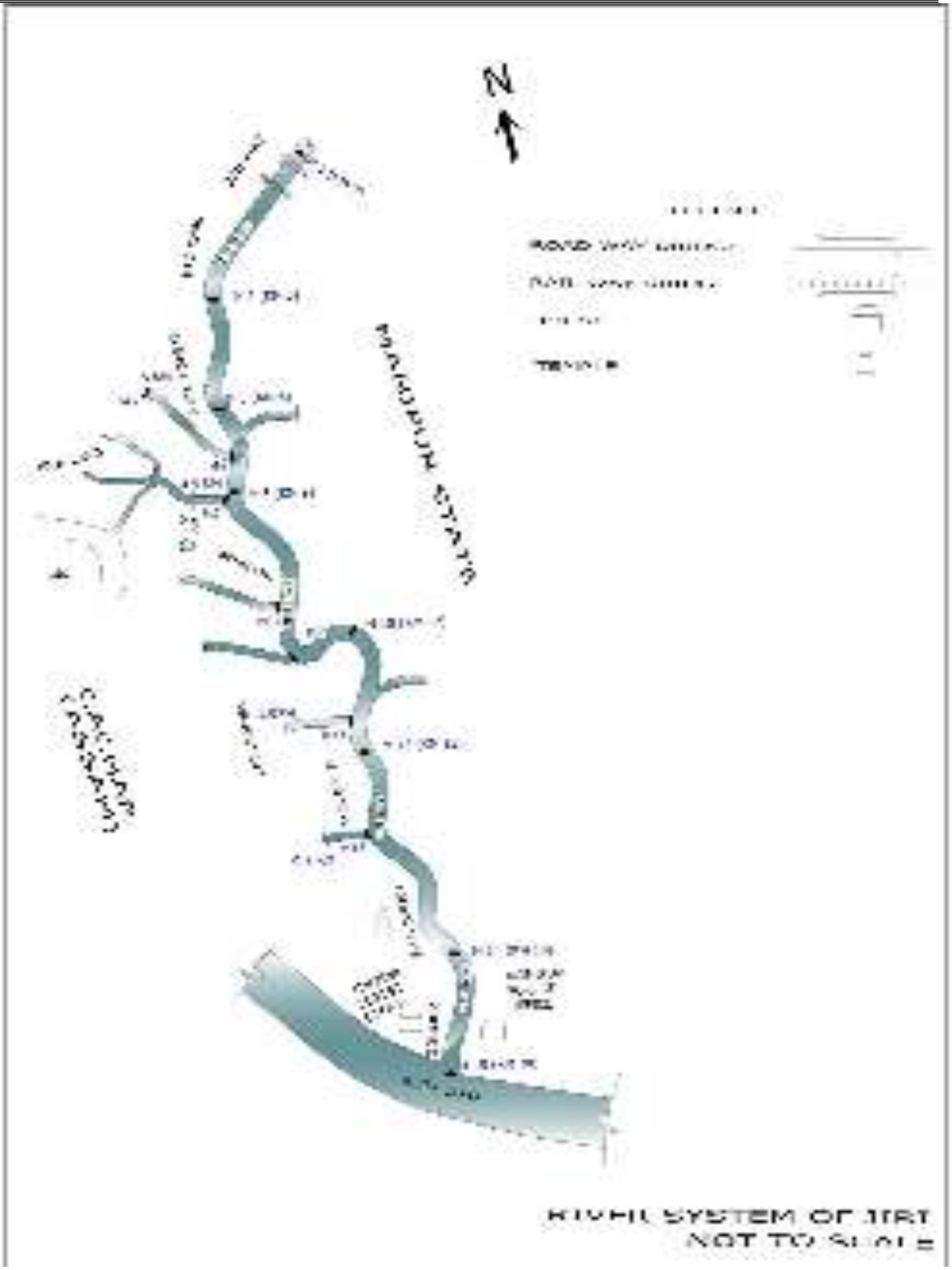


Fig. 2.3: Name of the sub water shed:-Jiri, Approximate catchment Area: 1052.85 km^2

Table 2.2 :Flow area Details of Jiri River system

Maximum Top width = 113.05 m

Average Top width = 55.65 m

Name of station	Distance from confluence point with Barak in kM(Approx)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth(m)	Flow area (Approx) in Sq.m	Embankment details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L Bank
MS 1	20.00	83.20	5.40	7.50	10.80	12.60	9.50	12.60	165.11	Nil	Nil
MS 2	17.00	99.10	6.30	7.65	8.10	8.60	6.90	8.60	157.71	Nil	Nil
MS 3	14.00	78.42	8.80	10.50	10.40	8.50	6.90	10.40	161.40	Nil	Nil
MS 4	12.50	17.10	2.50	4.30	4.85	5.10	3.10	5.10	36.48	Nil	Nil
MS 5	17.50	14.40	2.90	4.80	4.10	3.70	2.40	4.80	31.56	Nil	Nil
MS 6	11.00	74.20	7.30	9.10	8.87	6.70	4.90	9.10	124.78	Nil	Nil
MS 7	10.85	14.40	2.20	4.20	5.50	5.30	3.40	5.50	36.72	Nil	Nil
MS 8	9.80	25.20	3.80	4.80	4.90	5.00	3.70	5.00	45.15	Nil	Nil
MS 9	8.80	12.50	3.00	4.00	4.60	3.50	1.90	4.60	29.30	Nil	Nil
MS 10	8.00	113.05	12.10	14.50	13.30	9.60	7.50	14.50	259.45	Nil	Nil
MS 11	5.50	22.44	2.80	4.00	5.30	4.20	2.10	5.30	36.16	Nil	Nil
MS 12	5.00	87.47	7.10	8.70	10.40	8.50	6.40	10.40	153.60	Nil	Nil
MS 13	4.00	14.40	2.00	5.00	4.80	4.00	2.70	5.00	33.24	Nil	Nil
MS 14	2.00	80.97	6.50	7.50	7.90	7.60	5.80	7.90	128.99	Nil	Nil
MS 15	0.00	97.90	10.80	14.70	16.04	13.80	10.50	16.04	262.85	Nil	Nil

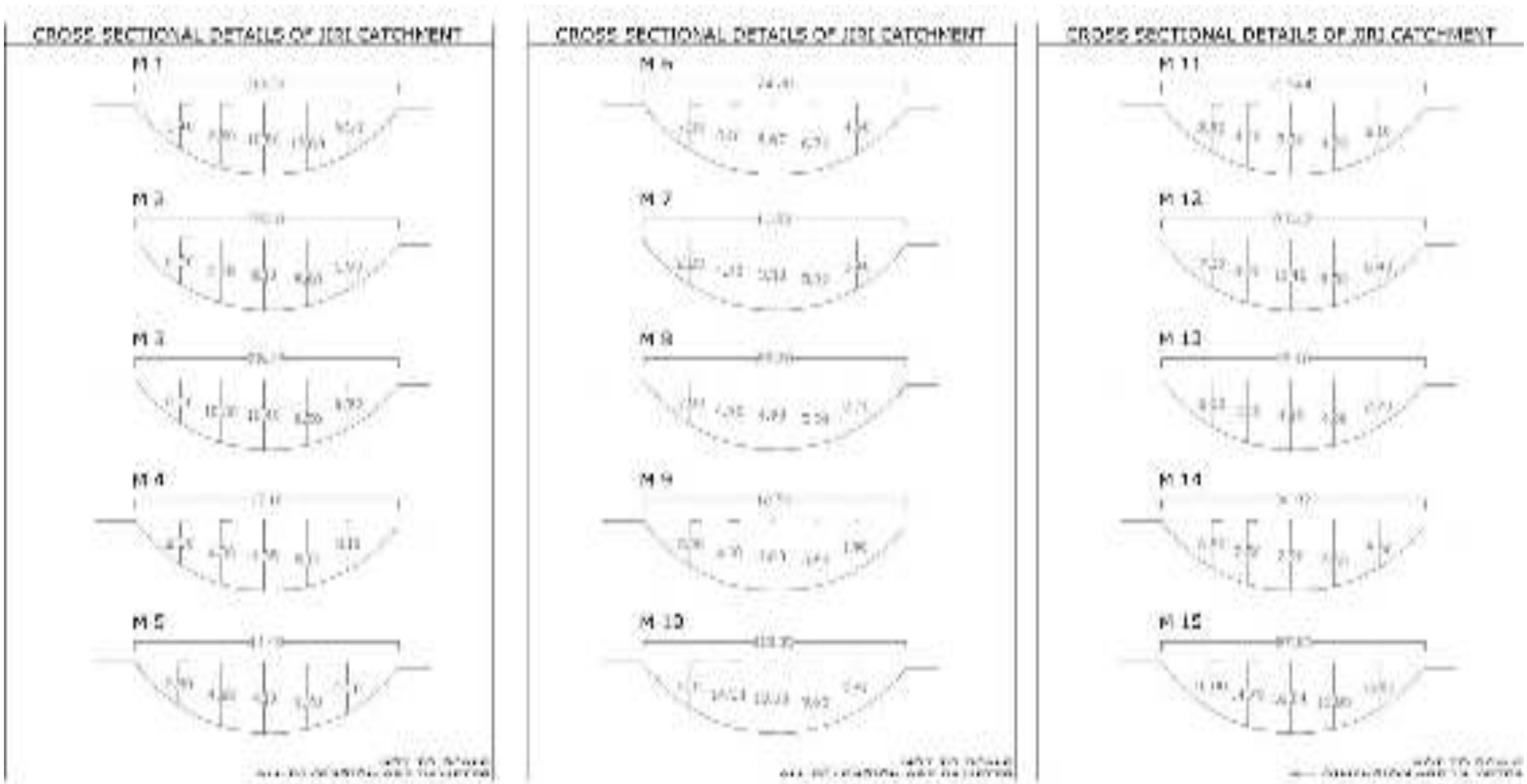


Fig. 2.4 : Section Details of Jiri River system

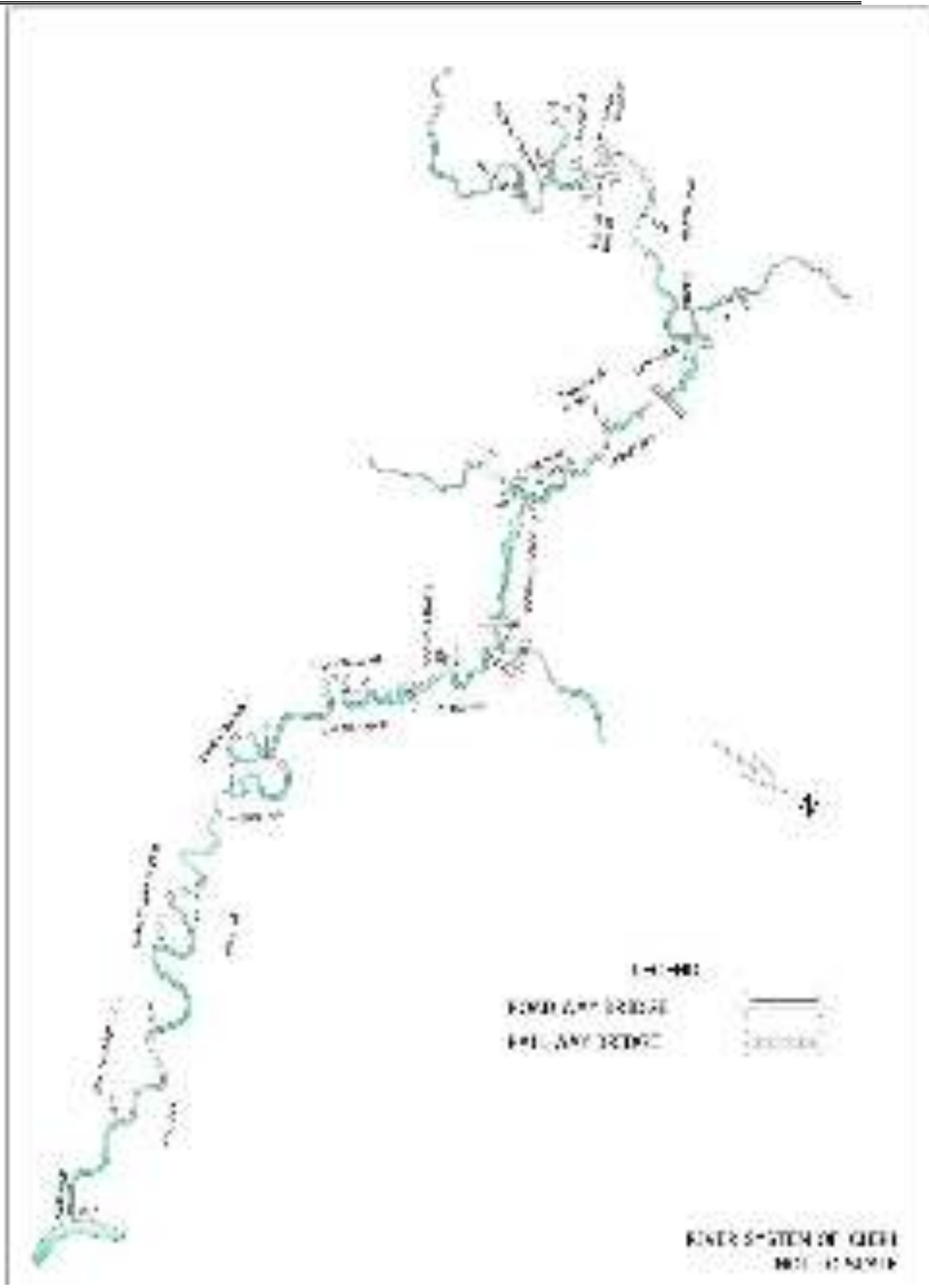


Fig 2.5 : Name of the sub watershed:- Ciri, Approximate catchment Area : 438.66 km^2

Table 2.3: Flow area Details of Ciri River system

Maximum Top width = 109.50m

Average Top width = 60.72 m

Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth (m)	flow area (Approx) in Sq.m	Embankment Details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L Bank
MS 1	38.00	67.50	6.10	7.00	6.60	4.20	2.90	7.00	86.23	Nil	Nil
MS 2	37.00	29.70	2.50	3.60	6.30	7.30	6.80	7.30	57.42	Nil	Nil
MS 3	37.50	24.10	2.80	3.90	5.30	5.30	4.20	5.30	43.06	Nil	Nil
MS 4	38.00	27.40	3.60	4.80	6.20	6.00	4.20	6.20	51.81	Nil	Nil
MS 5	35.00	64.20	3.60	5.30	6.25	6.50	3.90	6.50	76.23	Nil	Nil
MS 6	32.00	53.70	5.40	6.50	7.40	4.30	3.90	7.40	78.02	Nil	Nil
MS 7	32.00	34.50	3.80	4.90	5.50	6.90	5.90	6.90	62.49	Nil	Nil
MS 8	33.00	31.40	3.10	4.30	5.10	5.50	3.60	5.50	47.33	Nil	Nil
MS 9	34.00	35.50	4.50	5.80	6.70	4.90	3.80	6.70	59.35	Nil	Nil
MS 10	29.00	70.00	3.70	5.10	6.00	6.20	4.50	6.20	82.43	Nil	Nil
MS 11	26.00	32.10	4.50	5.10	7.70	6.00	5.10	7.70	63.28	Nil	Nil
MS 12	27.00	29.50	4.70	4.90	6.60	5.30	4.20	6.60	55.48	Nil	Nil
MS 13	26.00	75.10	6.50	7.50	6.20	7.60	5.80	7.60	119.58	Nil	Nil
MS 14	23.50	26.50	3.20	4.20	5.70	3.40	2.70	5.70	39.63	Nil	Nil
MS 15	23.00	78.00	3.20	5.40	6.10	5.70	3.40	6.10	77.30	Nil	Nil
MS 16	20.00	85.50	4.60	5.70	6.80	3.90	3.40	6.80	89.80	Nil	Nil
MS 17	17.00	70.50	6.30	8.50	7.10	5.20	4.10	8.50	102.70	Nil	Nil
MS 18	14.00	63.50	5.30	6.60	5.40	4.20	3.10	6.60	76.85	Nil	Nil
MS 19	11.00	91.50	4.20	5.80	6.60	4.70	3.50	6.60	92.91	Nil	Nil
MS 20	8.00	95.50	3.20	4.50	5.80	6.20	4.60	6.20	95.08	Nil	Nil
MS 21	6.00	109.50	4.50	6.90	4.80	2.60	1.70	6.90	85.18	Nil	Nil
MS 22	4.00	91.20	3.90	5.10	6.30	5.30	4.20	6.30	94.96	Nil	Nil
MS 23	2.00	88.50	2.10	6.20	6.90	5.40	3.00	6.90	74.61	Nil	Nil

MS 24	0.00	82.30	7.50	8.70	11.20	8.90	8.10	11.20	164.59	Nil	Nil

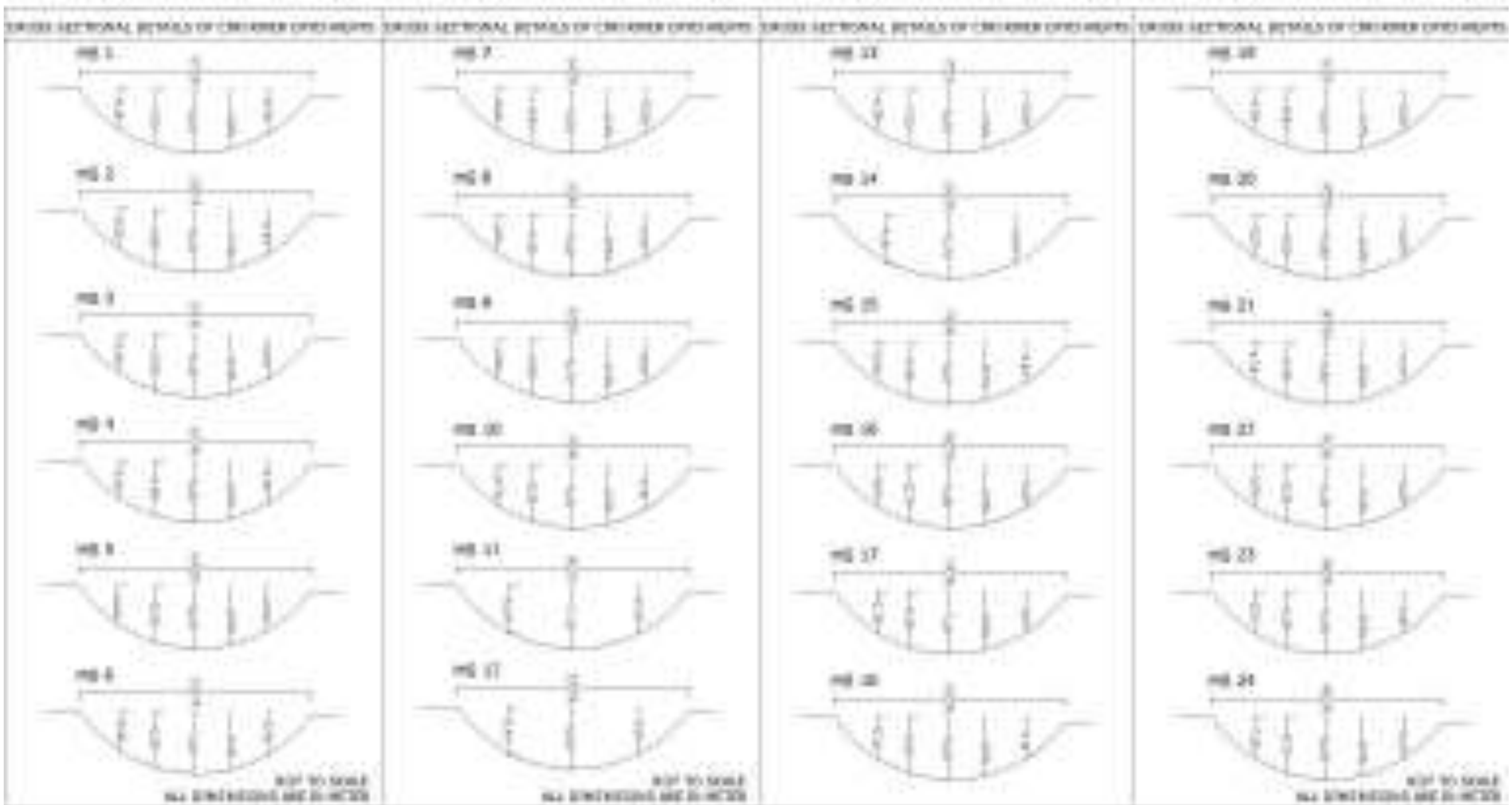


Fig 2.6: Section Details of Ciri River system

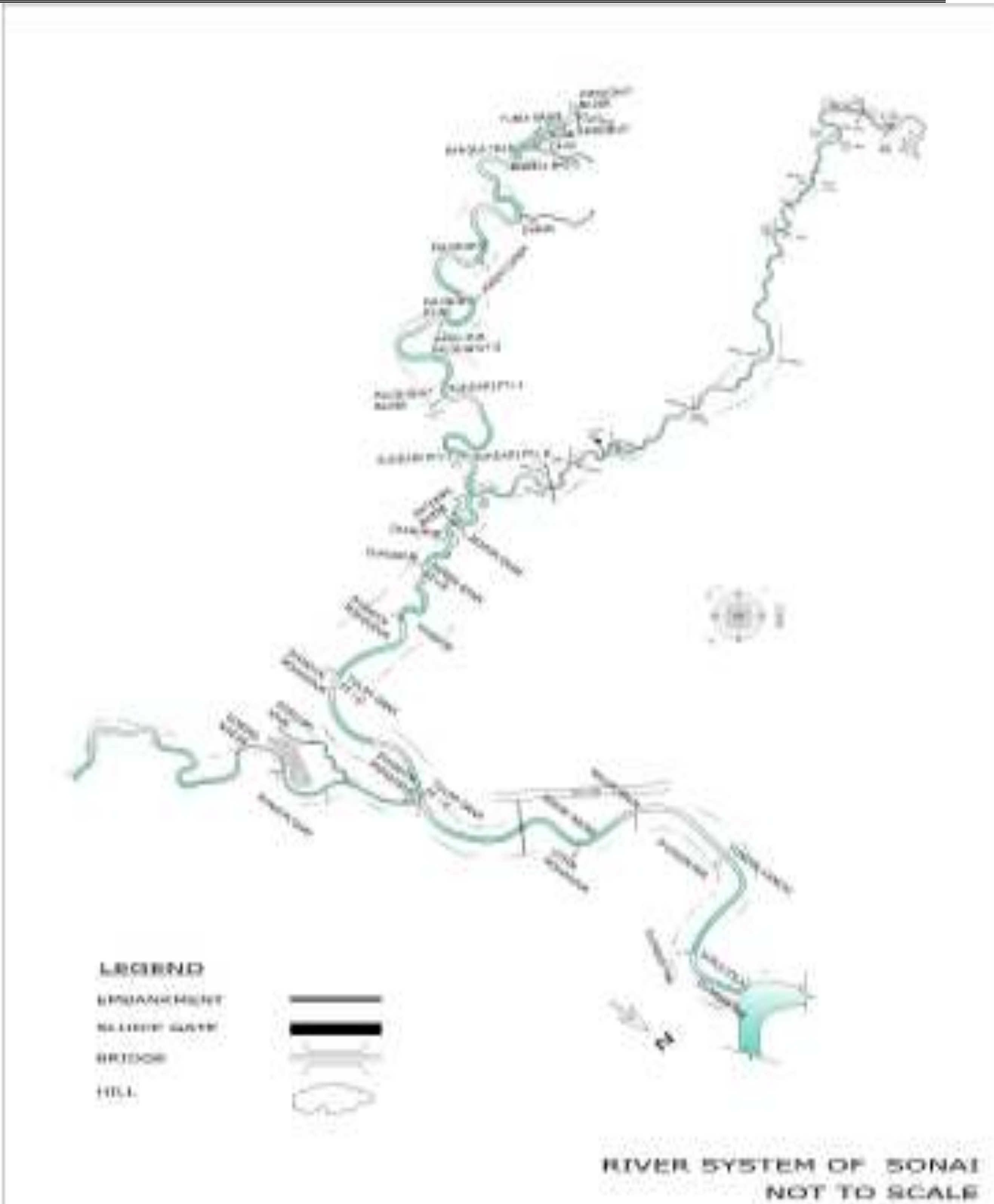


Fig 2.7: Name of the sub watershed:- Sonai, Approximate catchment Area : 488.249 km^2

Table 2.4 : Flow area Details of Sonai River system

Maximum top width = 163.20 m

Average top width = 80.22 m

Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in(M)	Vertical depth (m)					Maximum depth(m)	flow area (Approx) in Sq.M	Embankment Details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L bank
MS 1	52.00 (Right side 2)	92.50	6.20	9.15	12.02	11.25	9.20	12.02	183.55	Nil	D=66.25M H=1.00 M
MS 2	51.00 (Right side 2)	98.40	8.30	8.90	14.35	10.10	9.50	14.35	212.66	Nil	D=166.20 M H=0.30M
MS 3	49.50 (Right side 2)	75.50	5.40	6.50	7.54	5.20	4.40	7.54	100.14	Nil	D=62.75M H = 2.70M
MS 4	46.50 (Right side 2)	60.10	5.00	5.90	6.30	6.50	5.20	6.50	88.49	D=520.05M H=0.90	D=66.55M H=0.70 M
MS 5	43.50 (Right side 2)	59.50	4.10	6.20	9.20	9.50	7.20	9.50	105.83	D=149.75M H=1.00 M	H=232.7M H=2.30 M
MS 6	40.50 (Right side 2)	61.50	5.10	7.60	9.30	4.00	2.00	9.30	78.19	D=64.25M H=1.20 M	D=555.75 H=1.00M
MS 7	37.50 (Right side 2)	52.50	5.00	5.20	7.85	5.20	3.40	7.85	73.25	D=435.75 M H=1.40	D=62.25M H=2.50 M
MS 8	34.50 (Right side 2)	68.70	7.20	8.70	6.30	3.50	2.20	8.70	90.82	D=72.35 M H=1.50M	D=132.3M H=1.20 M
MS 9	31.50 (Right side 2)	60.50	5.20	5.30	8.10	5.70	4.30	8.10	86.10	D=111.25 M H=1.50	Nil
MS 10	28.50 (Right side 2)	58.80	4.00	5.20	7.70	6.40	4.90	7.70	82.21	D=83.40M H=0.70	D=179.4M H=1.10 M
MS 11	25.50 (Right side 2)	64.50	6.50	9.20	6.20	5.30	4.30	9.20	99.45	D=119.25 H=3.00 M	D=60.75M H=1.50 M
MS 12	22.50 (Right side 2)	61.50	6.50	9.20	6.20	5.80	4.30	9.20	97.75	Nil	D = 2KM H=2.50

MS 13	37.50 (Left side)	52.40	9.10	11.50	15.10	9.50	7.30	15.10	143.81	D=96.20 M H=0.90M	Nil

Table 2.4 : Sonai River system:Contd

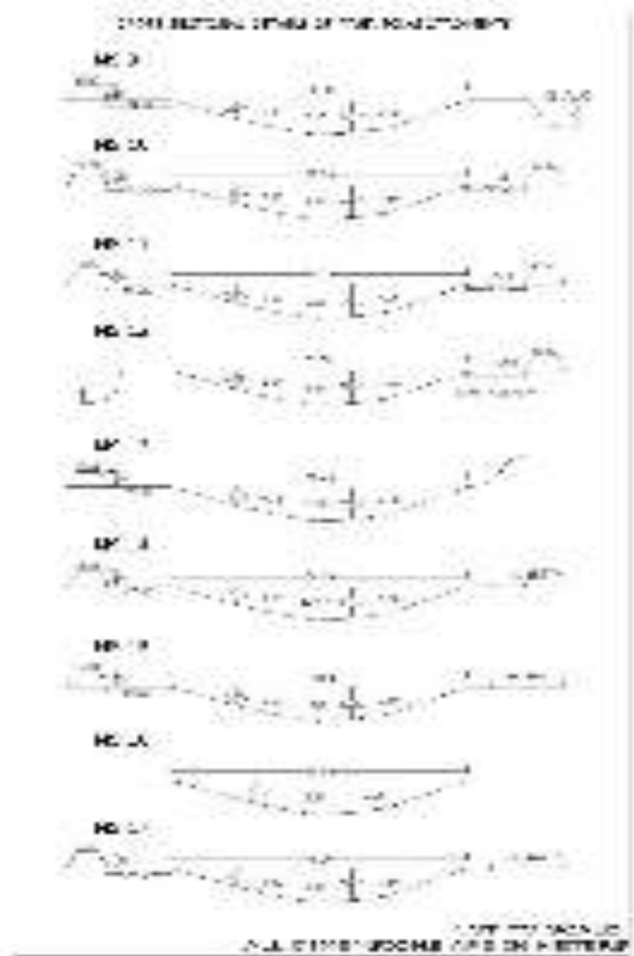
Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in(M)	Vertical depth (m)					Maximum depth(m)	flow area (Approx) in Sq.M	Embankment Details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L bank
MS 14	36.50 (Left side)	56.60	8.10	9.50	14.55	10.30	8.30	14.55	146.05	D=48.30 M H=0.90M	PWD RD
MS 15	35.50 (Left side)	110.00	6.90	8.80	10.10	10.20	7.50	10.20	190.20	D=139.00M H=1.20 M	PWD RD
MS 16	34.00 (Left side)	22.20	3.50	5.50	6.80	4.70	2.80	6.80	45.66	Nil	Nil
MS 17	33.50 (Left side)	70.20	4.80	6.30	9.60	5.60	4.20	9.60	95.65	D=209.60 M H=0.30 M	PWD RD
MS 18	31.70 (Left side)	25.20	2.80	5.00	6.10	4.80	3.10	6.10	44.19	Nil	Nil
MS 19	31.50 (Left side)	91.20	6.00	7.60	10.20	7.10	4.90	10.20	132.64	D-128.10 M H=2.10 M	D = 129.60M H=0.30
MS 20	29.50 (Left side)	106.20	4.00	5.20	7.70	6.40	4.90	7.70	117.37	D=93.60 M H=1.10	D=323.1M H=1.20 M
MS 21	27.50 (Left side)	82.50	7.30	8.80	10.20	5.80	4.20	10.20	128.66	D-127.25 M H=1.20 M	D = 186.25M H=1.20M
MS 22	25.50 (Left side)	79.50	4.50	6.10	7.40	5.70	4.20	7.40	96.04	D-62.25 M H=2.30 M	D = 129.75M H=1.30 M
MS 23	23.50 (Left side)	89.50	4.50	6.50	7.80	8.50	6.10	8.50	124.66	D-1 kM H=1.20 M	Nil
MS 24	22.50 (Left side)	85.50	5.20	6.70	8.20	6.20	4.90	8.20	114.16	D-77.75 M H=1.90 M	D = 2 km H= 2.50 M
MS 25	20.50	103.50	4.80	6.50	8.90	5.90	4.50	8.90	122.81	D-581.75 M H=0.80 M	D = 144.25 M H=1.20M
MS 26	18.50	101.50	4.50	6.00	7.80	5.70	4.10	7.80	111.74	D-83.25 M H= 2.20 M	D = 66.25M H=2.10 M

MS 27	16.50	108.00	5.80	7.10	8.80	6.30	4.30	8.80	135.30	D-774 M H=2.00 M	D = 153.50 M H= 3.00

Table 2.4 : Flow area Details of Sonai River system-Contd

Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in(M)	Vertical depth (m)					Maximum depth(m)	flow area (Approx) in Sq.M	Embankment Details	
			1/6.T	**2/6.T**	**3/6.T**	**4/6.T**	**5/6.T**			**R Bank**	**L bank**
MS 28	14.50	107.10	6.10	7.20	10.10	5.70	4.80	10.10	143.28	Nil	D = 122.50 M H= 3.00
MS 29	12.50	148.50	4.10	6.20	8.30	7.10	5.70	8.30	164.48	D-150.25 M H=2.10 M	D = 103.25 M H= 2.20 m
MS 30	10.50	91.20	4.20	5.90	7.30	6.50	5.20	7.30	110.84	D-48.60M H= 1.20 M	D = 43.10M H=1.50 M
MS 31	10.5 (Right side 1)	54.10	3.70	5.90	9.50	6.40	4.80	9.50	81.92	D-105.55 M H= 0.90 M	katcha Rd
MS 32	11.50 (Right side 1)	45.80	3.10	5.40	6.80	4.90	4.10	6.80	61.68	Nil	Nil
MS 33	12.00 (Right side 1)	50.30	3.90	5.20	7.55	5.70	4.20	7.55	70.85	D-34.55 M H= 2.10 M	Nil
MS 34	12.70 (Right side 1)	51.80	5.10	6.50	7.10	4.80	3.40	7.10	73.49	D = 82.90 M H=2.00 M	Nil
MS 35	8.50	106.50	5.40	6.70	8.10	7.00	5.50	8.10	140.34	D= 209.25 M H= 0.90 M	PWD RD
MS 36	6.50	108.50	6.80	8.50	8.00	6.10	4.80	8.50	150.08	D=86.45M H= 0.90 M	D = 167.25M H= 4.00 M
MS 37	4.50	133.00	10.20	14.60	9.30	5.30	4.10	14.60	216.89	D= 0.00 M H= 0.00M	D = 157.50 M H = 1.50 M
MS 38	2.50	163.20	2.05	3.10	8.00	10.40	7.80	10.40	176.96	D= 269.10 M H= 1.10 M	D = 289.10M H=1.20 M

MS 39	0.00	70.50	7.10	9.20	10.10	5.10	4.50	10.10	116.95	D=222.75 M H= 1.10 M	D = 1 km H=2.00 M



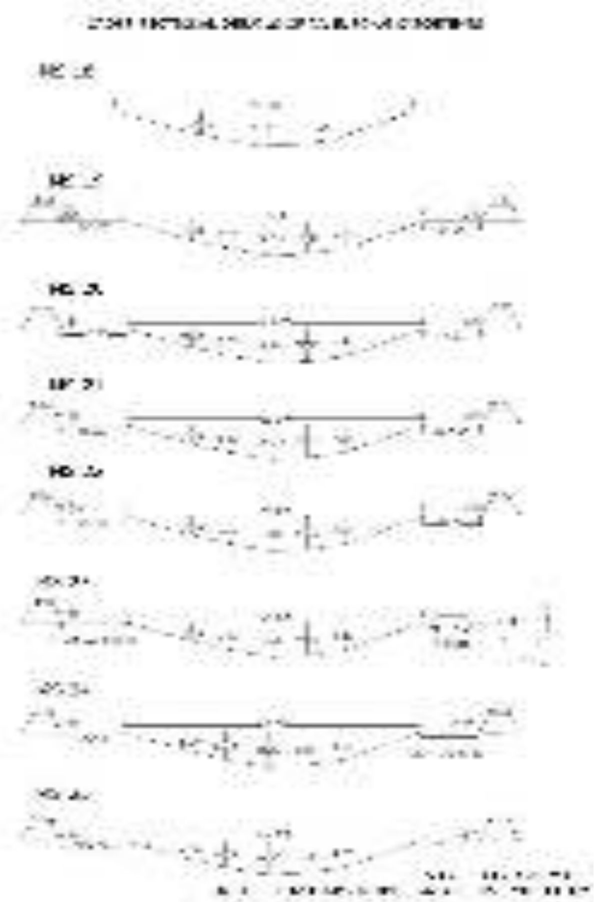
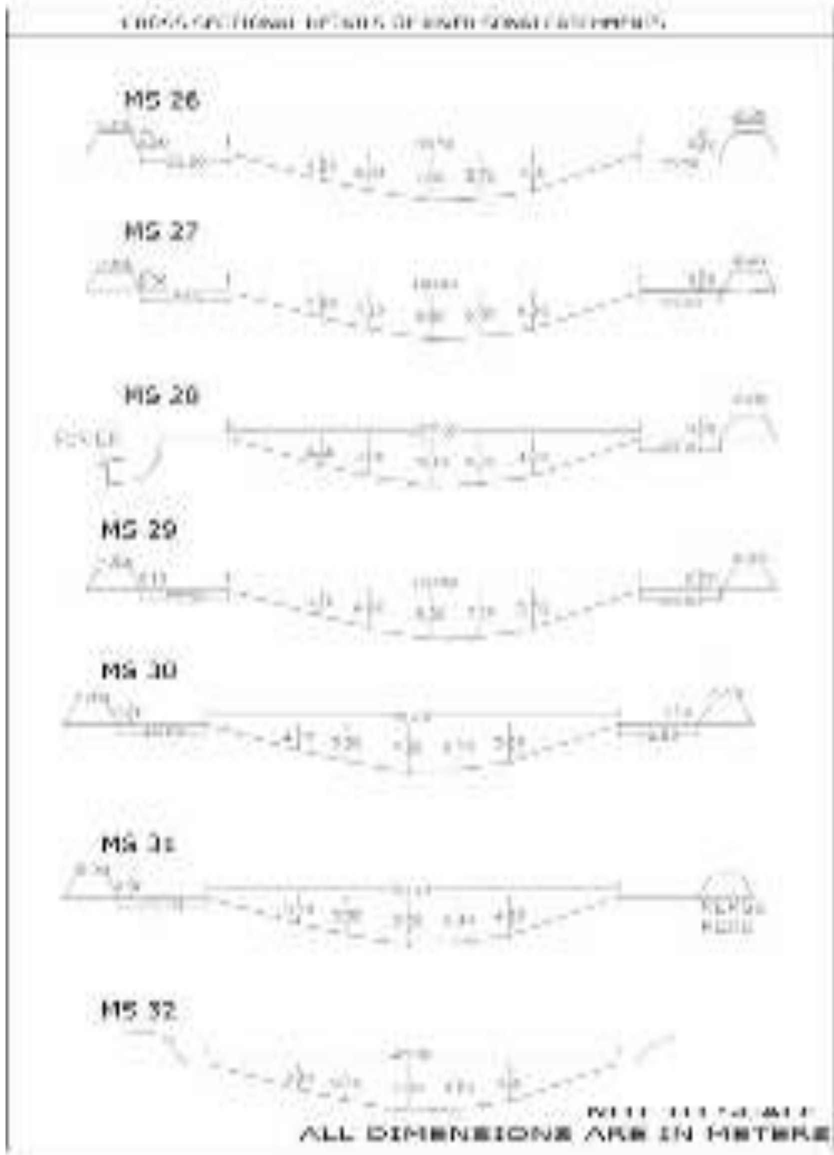


Fig 2.8(a) : Section Details of Sonai River system


MS 26
MS 27
MS 28
MS 29
MS 30
MS 31
MS 32
ALL DIMENSIONS ARE IN METERS

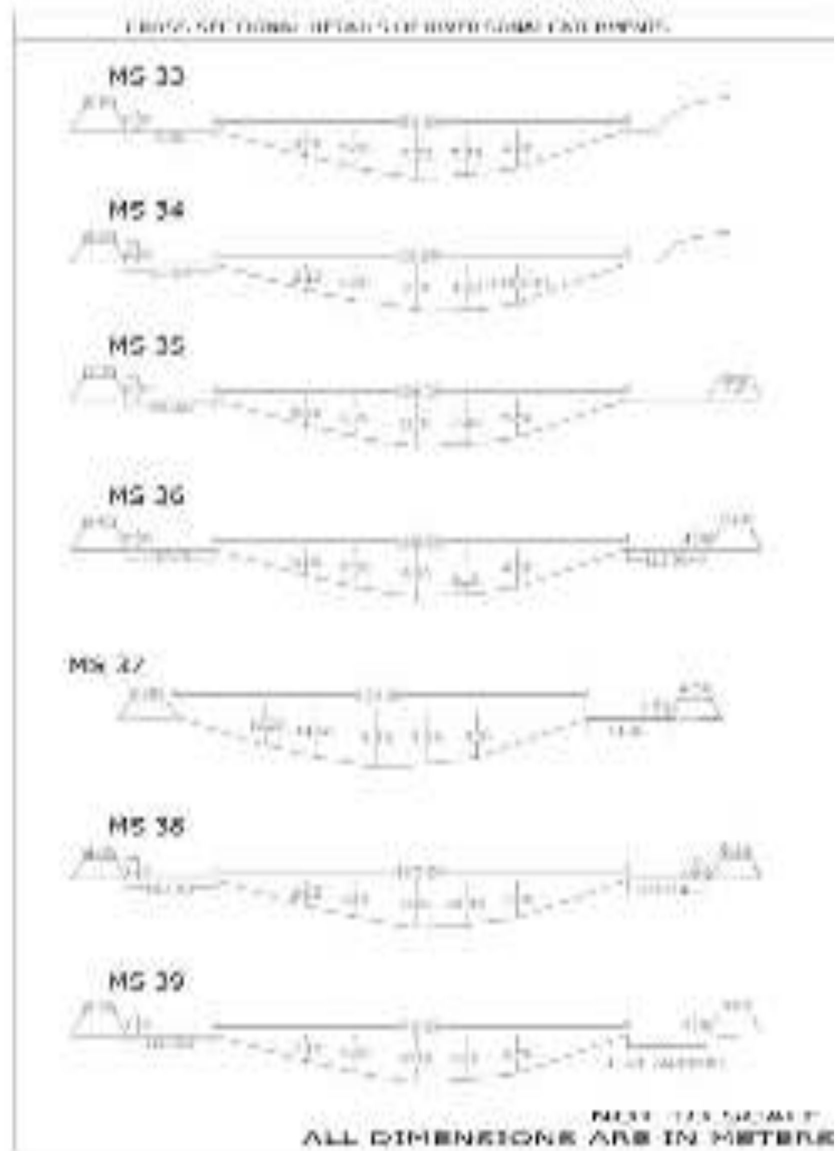

MS 33
MS 34
MS 35
MS 36
MS 37
MS 38
MS 39
ALL DIMENSIONS ARE IN METERS

Fig 2.8(b) : Section Details of Sonai River system-Contd

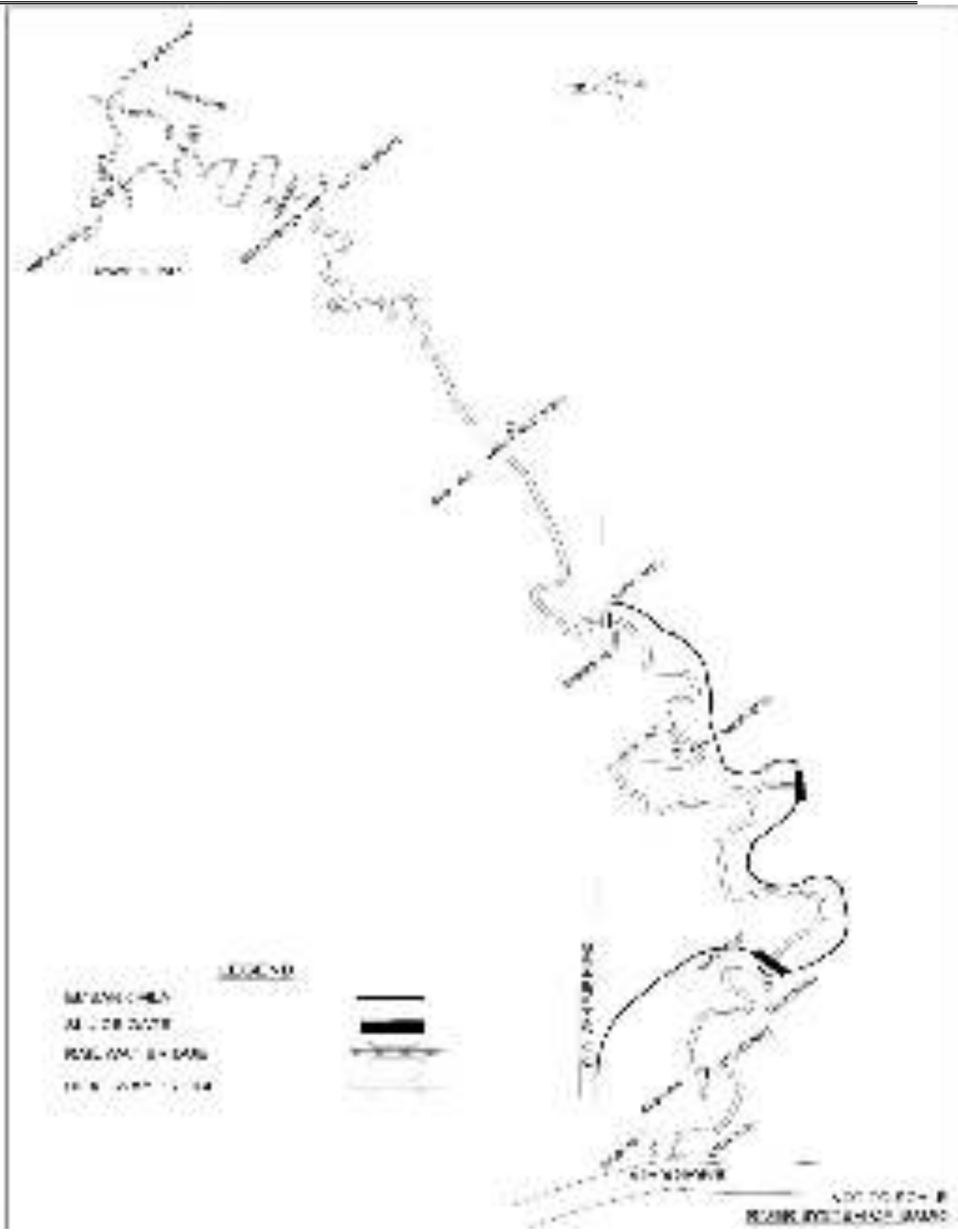


Fig 2.9 : Name of the sub watershed:- Badri, Approximate catchment Area : 338.66 km^2

Table 2.5: Flow area Details of Badri River system

Maximum top width = 103.50 M ,Average top width = 50.08 m

Name of station	Distance from confluence point with borak in kM(Approx)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth (m)	flow area (Approx) in Sq.m	Embankment Details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L Bank
MS 1	0.00	46.00	3.70	5.80	8.10	3.70	6.00	8.10	72.38	Nil	Nil
MS 2	1.00	79.60	5.20	6.05	7.70	5.50	4.10	7.70	100.19	Nil	D=390M H=0.45 M
MS 3	2.00	103.50	4.80	11.50	13.40	13.60	7.30	13.60	181.36	Nil	D =72.00 H=4.10
MS 4	6.00	65.10	7.20	11.20	12.10	10.80	6.35	12.10	141.71	D =35.75 H=1.00	Nil
MS 5	7.50	50.20	6.70	8.55	10.50	9.00	5.80	10.50	108.39	D =43.60 H= 1.10	Nil
MS 6	9.00	45.50	4.40	6.02	7.20	5.30	4.00	7.20	68.89	Nil	Nil
MS 7	12.00	40.50	2.90	3.95	5.10	4.50	2.40	5.10	44.99	Nil	Nil
MS 8	16.00	37.10	1.20	2.00	2.92	2.55	1.80	2.92	24.22	Nil	Nil
MS 9	17.00	27.30	2.15	2.90	3.20	2.65	1.93	3.20	26.78	Nil	Nil
MS 10	17.00	24.60	1.96	2.41	3.30	2.60	1.60	3.30	23.92	Nil	Nil
MS 11	17.00	31.50	1.75	3.10	3.60	2.42	2.07	3.60	28.27	Nil	Nil

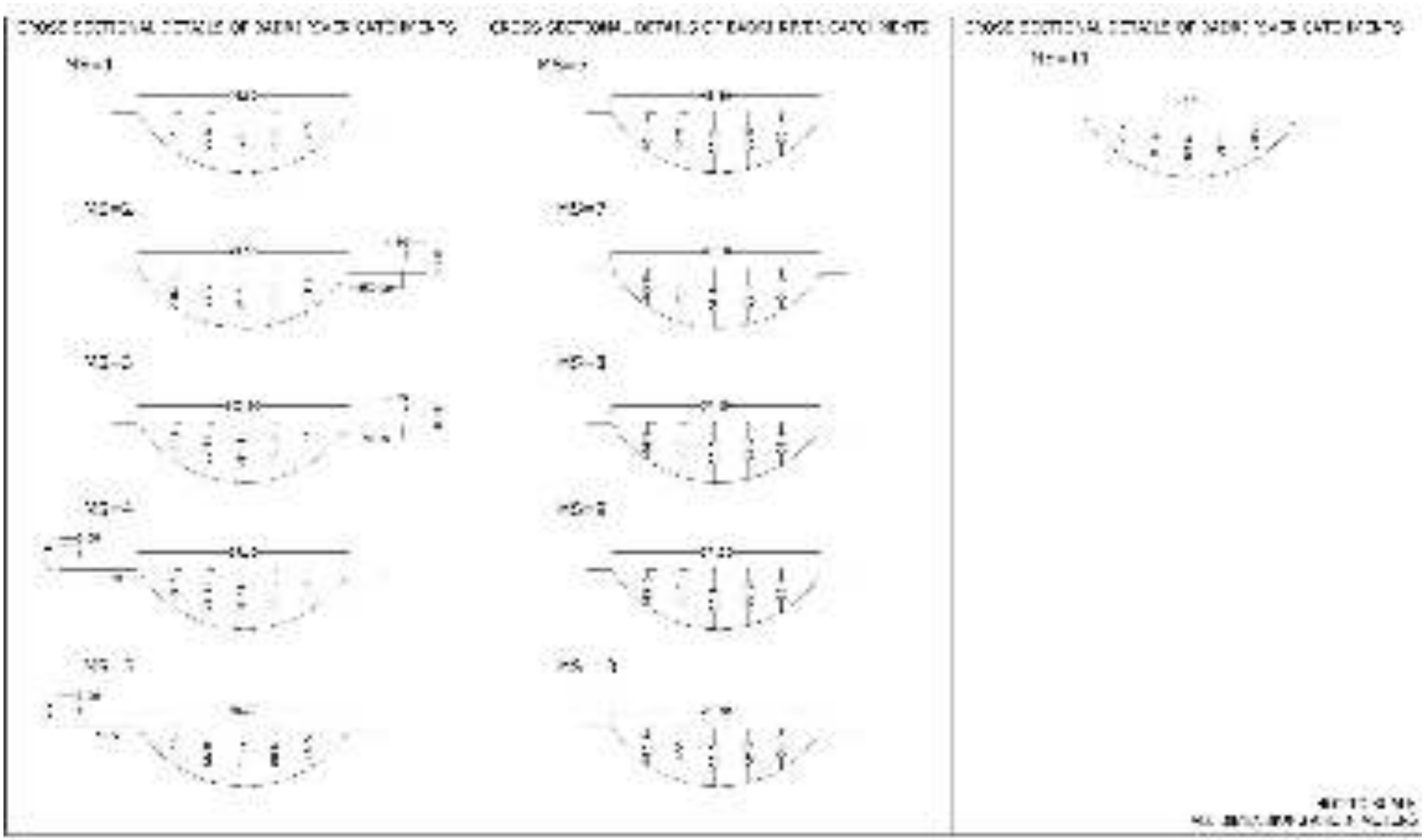


Fig 2.10 : Section Details of Badri River system

Fig 2.11: Name of the sub watershed:- Madhura, Approximate catchment Area : 349.43 km^2

Table 2.6 :Flow area Details of Madhura River system

Maximum top width = 88.20 M, Average top width = 64.11 m

Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth (m)	flow area (Approx) in Sq.m	Embankment details	
			1/6.T	**2/6.T**	**3/6.T**	**4/6.T**	**5/6.T**			**R Bank**	**L Bank**
MS 1	27.00	68.50	4.20	5.20	5.00	5.10	5.50	5.50	85.97	Nil	Nil
MS 2	25.50	73.00	3.50	4.10	5.00	5.40	6.10	6.10	87.40	Nil	Nil
MS 3	24.00	71.00	3.40	4.60	5.10	5.40	6.70	6.70	89.96	Nil	Nil
MS 4	23.00	86.50	2.50	3.60	4.30	4.70	4.50	4.70	75.66	Nil	Nil
MS 5	23.00	36.10	4.10	5.30	6.10	6.20	6.30	6.30	66.49	Nil	Nil
MS 6	24.00	33.50	5.40	5.60	5.60	4.90	4.40	5.60	59.56	Nil	Nil
MS 7	21.00	78.50	5.70	6.00	6.20	6.30	6.50	6.50	116.81	Nil	Nil
MS 8	19.00	75.50	2.55	3.20	3.85	4.00	4.30	4.30	65.20	Nil	Nil
MS 9	17.00	66.40	4.00	4.90	6.30	6.50	4.90	6.50	84.65	Nil	Nil
MS 10	15.00	43.30	5.00	8.20	9.20	6.40	5.50	9.20	85.49	Nil	Nil
MS 11	14.00	67.00	6.40	6.70	7.15	5.50	4.30	7.15	98.44	Nil	D = 83.00 M H = 1.50 M
MS 12	12.00	68.50	5.10	5.30	6.65	5.20	4.90	6.65	91.38	Nil	D = 42.00 M H = 2.00 M
MS 13	10.00	70.00	6.90	7.90	8.55	5.70	4.70	7.90	111.97	Nil	D = 134.00 M H = 1.80 M
MS 14	8.00	67.40	6.75	7.50	8.60	7.00	6.30	8.60	119.50	D = 68.70 M H = 1.80 M	D = 107.20 M H = 1.60 M
MS 15	5.00	88.20	6.20	8.50	11.30	9.50	7.30	11.30	157.83	PWD RD	D =84.60 M H = 2.80 M
MS 16	4.00	30.50	3.30	5.30	7.00	7.70	6.10	7.70	63.89	Nil	Nil
MS 17	2.00	70.50	5.80	8.40	10.20	8.10	5.30	10.20	118.61	D = 51.05 M H = 1.80 M	D = 11.75 M H = 3.30 M

MS 18	0.00	59.50	6.40	7.10	8.55	6.70	5.20	8.55	102.22	D = 180.75M H = 2.00 M	D = 233.250 M H = 5.70 M

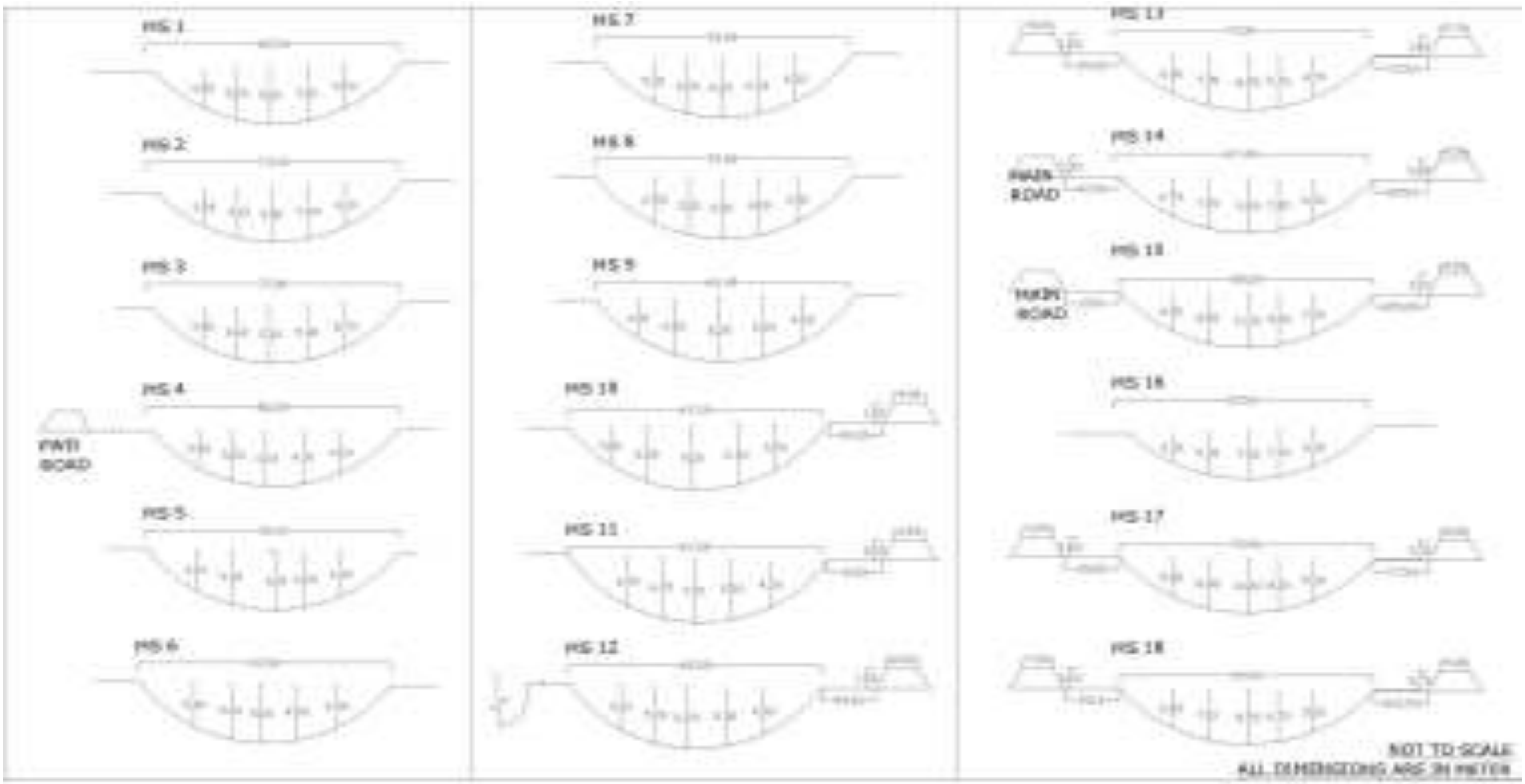


Fig 2.12 : Section Details of Madhura River system

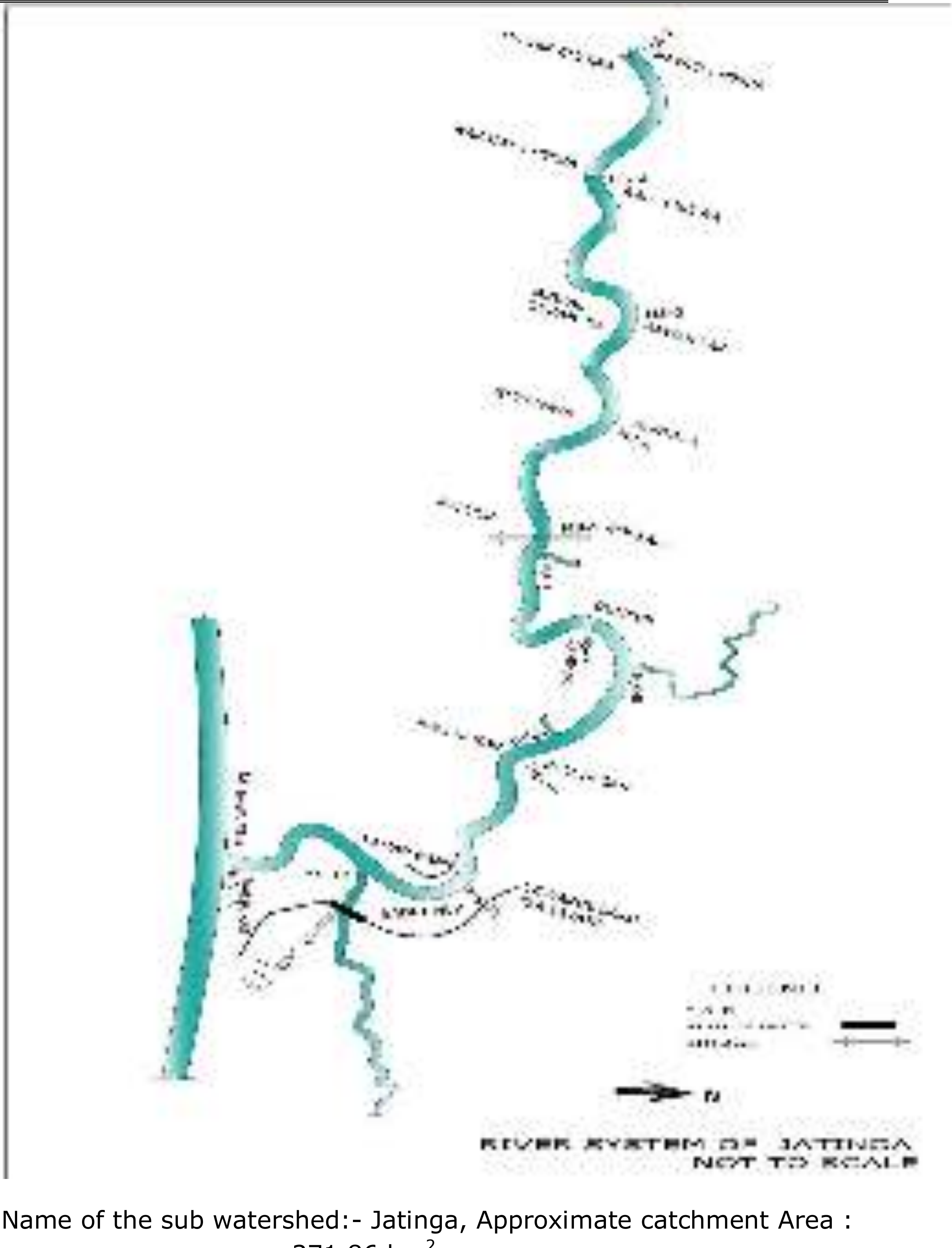


Fig 2.13 : Name of the sub watershed:- Jatinga, Approximate catchment Area : 371.86 km^2

Table 2.7 : Flow area Details of Jatinga River system

Maximum top width = 98.40 m, Average top width = 66.65 m

Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in(M)	Vertical depth (m)					maximum depth (m)	flow area (Approx) in Sq.M	Embankment details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L bank
MS 1	16.00	92.50	6.20	9.15	12.02	11.25	9.20	12.02	183.55	Nil	Nil
MS 2	14.00	98.40	8.30	8.90	14.35	10.10	9.50	14.35	212.66	Nil	Nil
MS 3	12.00	75.50	5.40	6.50	7.54	5.20	4.40	7.54	100.14	Nil	Nil
MS 4	10.00	60.10	5.00	5.90	6.30	6.50	5.20	6.50	88.49	Nil	Nil
MS 5	8.00	59.50	4.10	6.20	9.20	9.50	7.20	9.50	105.83	Nil	Nil
MS 6	7.50	61.50	5.10	7.60	9.30	4.00	2.00	9.30	78.19	Nil	Nil
MS 7	6.00	52.50	5.00	5.20	7.85	5.20	3.40	7.85	73.25	Nil	Nil
MS 8	5.40	68.70	7.20	8.70	6.30	3.50	2.20	8.70	90.82	Nil	Nil
MS 9	4.50	60.50	5.20	5.30	8.10	5.70	4.30	8.10	86.10	Nil	Nil
MS 10	4.00	58.80	4.00	5.20	7.70	6.40	4.90	7.70	82.21	Nil	Nil
MS 11	2.00	64.50	6.50	9.20	6.20	5.30	4.30	9.20	99.45	Nil	Nil
MS 12	1.00	61.50	6.50	9.20	6.20	5.80	4.30	9.20	97.75	D=105.5M H= 1.60 M	D=168 M H= 1.8M
MS 13	0.00	52.40	9.10	11.50	15.10	9.50	7.30	15.10	143.81	Nil	D=165M H= 1.8M

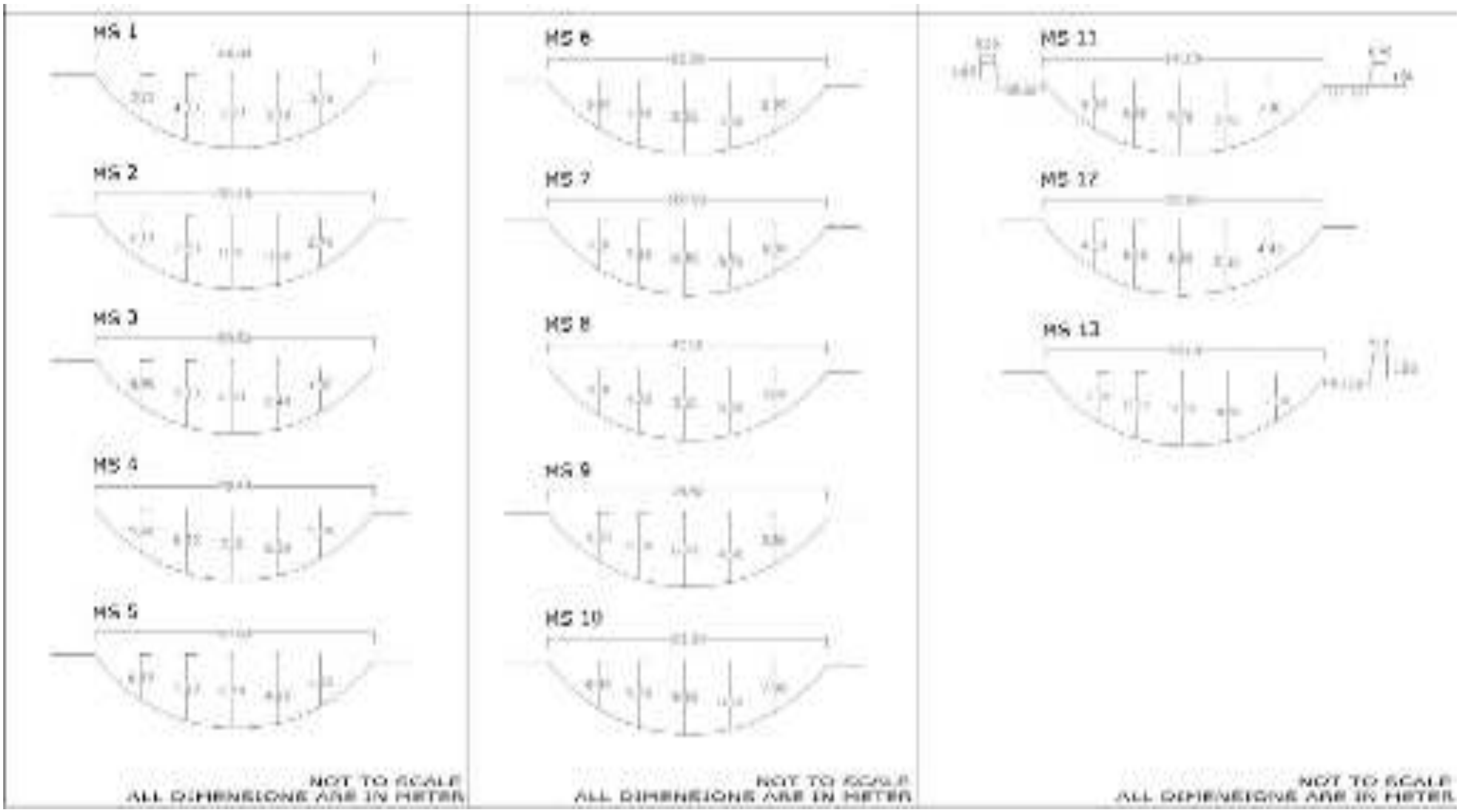


Fig 2.14 :Section Details of Jatinga River system

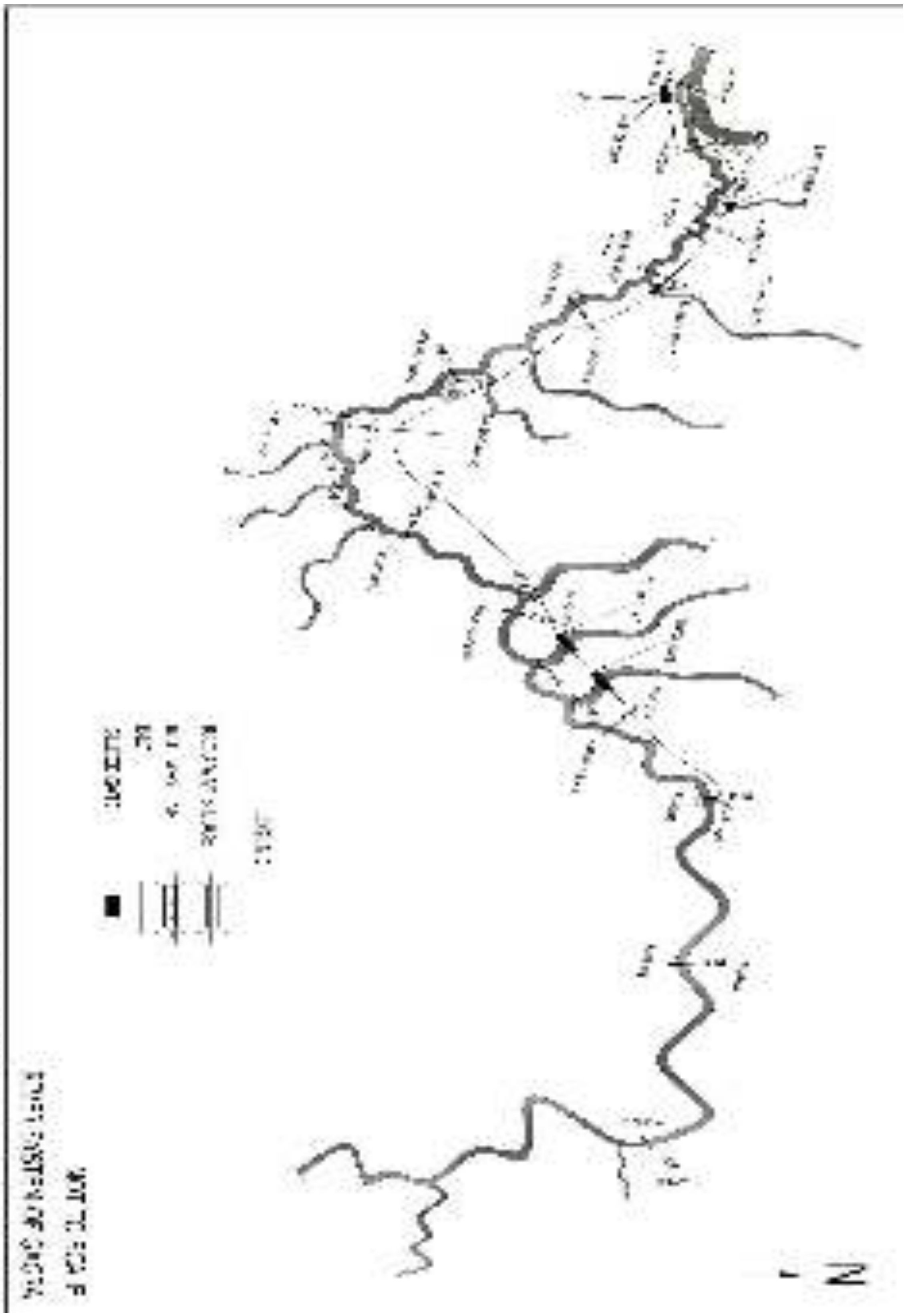


Fig 1.15 : Name of the sub watershed- Gagra, Approximate catchment Area : 409.30 km2

Table 2.8 : Flow area Details of Gagra River system

Maximum top width = 71.00 m,

Average top width = 49.95 m

Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth (m)	flow area (Approx) in Sq.m	Embankment Details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R bank	L Bank
MS 1	22.00	62.50	3.90	4.50	5.20	2.70	2.20	5.20	56.57	Nil	Nil
MS 2	21.00	65.50	4.20	5.10	5.55	4.10	3.00	5.55	68.80	Nil	Nil
MS 3	19.50	68.20	4.80	6.90	9.50	6.50	5.20	9.50	102.63	D= 49.00 M H= 2.10 M	Nil
MS 4	18.00	55.20	5.20	6.90	7.50	6.20	5.70	7.50	91.34	D= 53.10M H= 2.10 M	Nil
MS 5	17.50	28.20	2.70	3.20	4.70	4.00	3.10	4.70	37.43	Nil	Nil
MS 6	17.00	20.50	3.90	4.50	5.20	2.70	2.20	5.20	35.22	Nil	Nil
MS 7	16.00	48.40	3.80	5.90	6.80	5.70	4.50	6.80	70.28	D= 229.20 M H= 1.90 M	Nil
MS 8	15.50	19.10	2.50	3.80	4.80	3.90	3.20	4.80	34.07		Nil
MS 9	14.00	71.00	4.20	5.70	7.60	4.70	3.40	7.60	80.97	D= 535 M H= 1.70 M	Nil
MS 10	13.50	18.00	3.30	4.40	4.10	3.50	3.00	4.40	33.45	Nil	Nil
MS 11	13.00	15.60	2.70	3.70	4.30	3.70	2.80	4.30	30.55	Nil	Nil
MS 12	12.50	27.50	3.00	3.20	4.00	2.70	2.50	4.00	32.40	Nil	Nil
MS 13	12.00	55.10	4.20	5.90	7.20	4.20	3.70	7.20	70.87	Nil	Nil

MS 14	10.00	56.50	3.70	5.10	8.10	5.80	4.00	8.10	74.25	Nil	Nil

Table 2.8 : Flow area Details of Gagra River system-Contd

Name of station	**Distance from confluence point with barak in kM(Approx)**	**Maximum top width (T) in (M)**	**Vertical depth (m)**					**Maximum depth (m)**	**flow area (Approx) in Sq.m**	**Embankment Details**	
			1/6.T	**2/6.T**	**3/6.T**	**4/6.T**	**5/6.T**			**R bank**	**L Bank**
MS 15	8.00	71.00	4.10	6.20	7.50	5.70	4.50	7.50	89.68	D= 76.50 M H= 2.10 M	Nil
MS 16	6.00	66.40	4.50	5.90	6.20	5.40	4.90	6.20	87.01	D= 143 .00M H= 1.70 M	Nil
MS 17	4.00	52.40	6.60	7.50	8.20	6.40	5.30	8.20	96.16	Nil	Nil
MS 18	2.00	87.50	4.70	5.80	8.20	7.10	6.10	8.20	120.95	Nil	D= 140 .00M H= 1.50 M
MS 19	0.00	60.70	5.40	7.20	7.50	6.80	5.80	7.50	99.65	Nil	D= 60.50 M H= 1.70 M

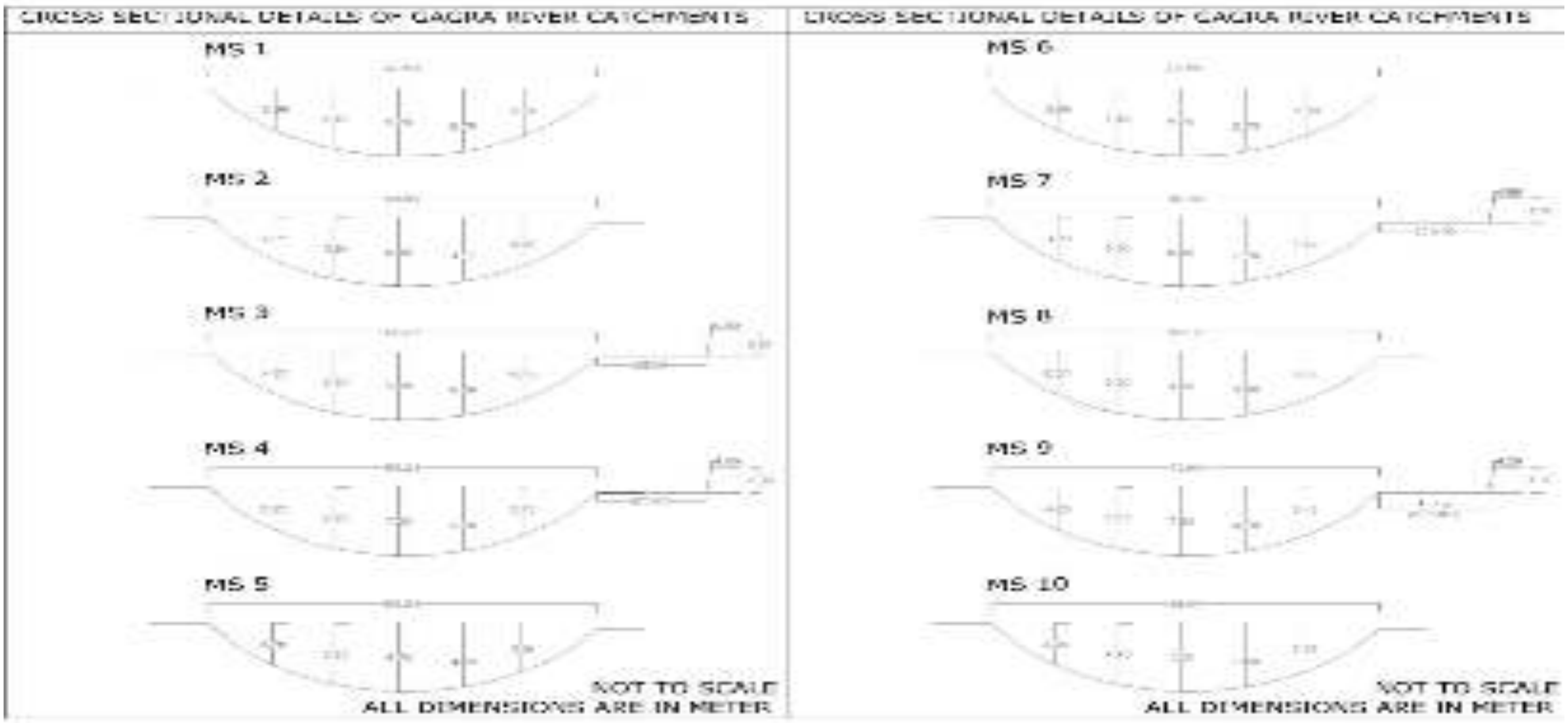

CROSS SECTIONAL DETAILS OF GAGRA RIVER CATCHMENTS
MS 1
MS 2
MS 3
MS 4
MS 5
NOT TO SCALE
ALL DIMENSIONS ARE IN METER
CROSS SECTIONAL DETAILS OF GAGRA RIVER CATCHMENTS
MS 6
MS 7
MS 8
MS 9
MS 10
NOT TO SCALE
ALL DIMENSIONS ARE IN METER

Fig 2.16 (a) : Section Details of Ghagra River system

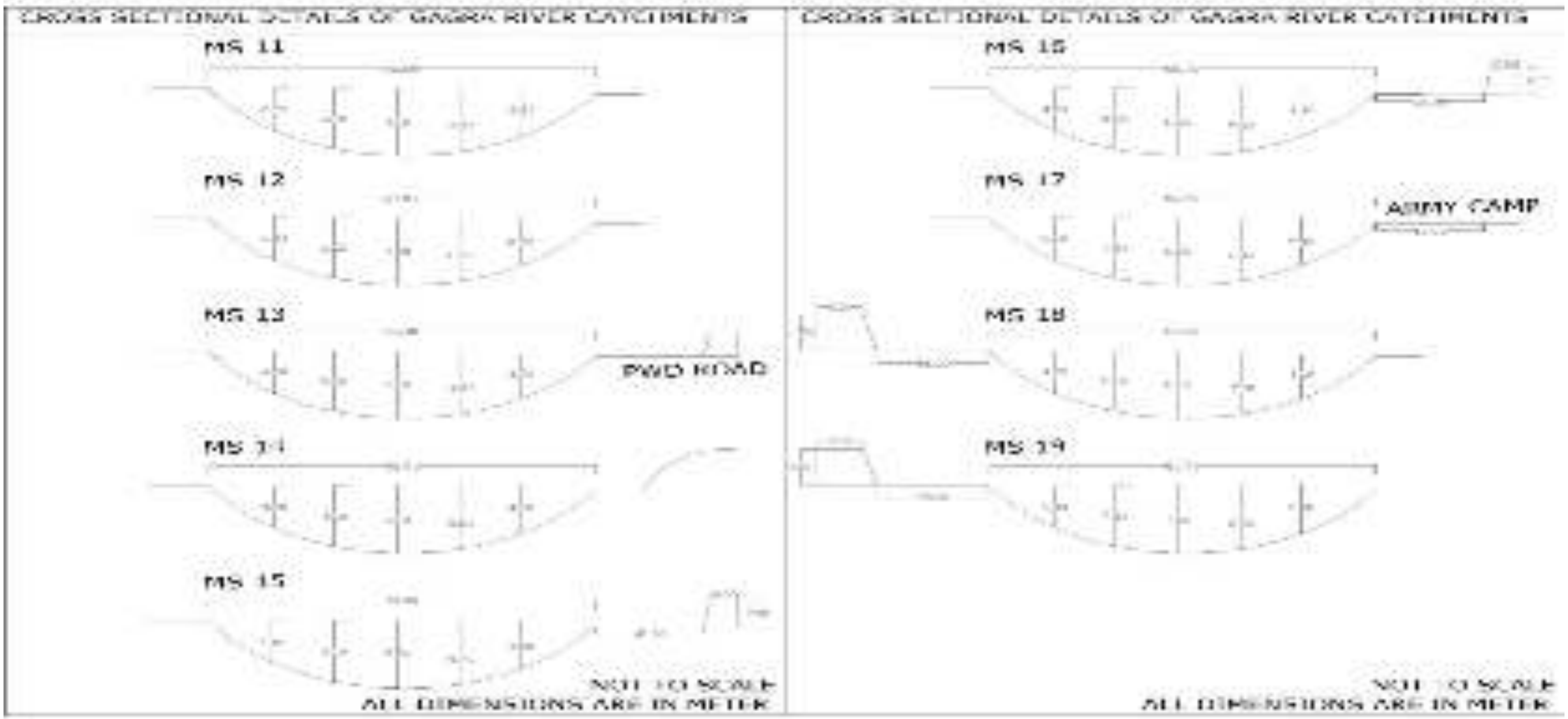


Fig 2.16 (b) : Section Details of Ghagra River system-contd

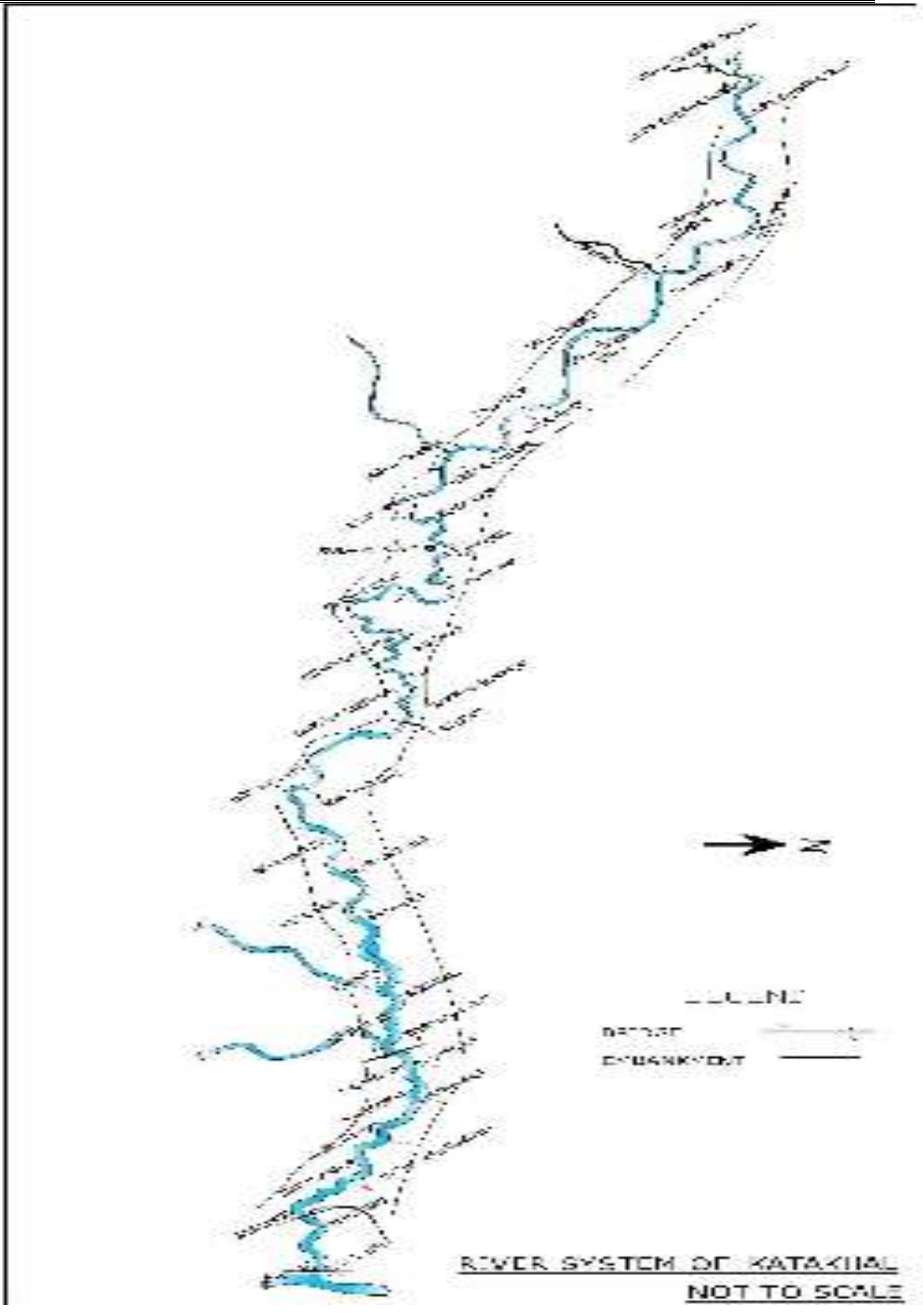


Fig 2.17 : Name of the sub watershed:- katakhal, aproximate catchment Area : 1504.68 km^2

Table 2.9 : Flow area Details of Katakhal River system

Maximum top width = 151.40 m
Average top width = 102.78 m

Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth (m)	flow area (Approx) in Sq.m	Embankment Details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L Bank
MS 1	72.00	39.00	6.70	8.00	9.10	7.30	6.00	9.10	90.08	Nil	Nil
MS 2	71.50	34.50	4.00	4.70	7.50	5.90	4.60	7.50	60.93	Nil	Nil
MS 3	71.00	40.50	7.40	10.20	11.70	7.80	6.10	11.70	104.96	Nil	Nil
MS 4	71.00	151.40	9.90	12.70	14.60	15.90	12.50	15.90	369.01	D = 425.70m H = 0.45m	D = 113.70m H = 0.30m
MS 5	61.00	139.00	9.10	10.90	13.00	8.90	7.10	13.00	253.25	D = 134.50m H = 1.20m	D = 123.50m H = 2.00 m
MS 6	63.50	37.80	5.10	6.50	8.70	7.50	5.80	8.70	79.74	Nil	Nil
MS 7	63.00	136.00	7.20	8.50	9.20	8.00	6.50	9.20	206.67	D = 102.50m H = 0.80m	D = 178.00m H = 0.45 m
MS 8	60.00	133.00	8.20	10.50	11.65	15.40	12.10	15.40	300.09	D = 416.50m H = 1.50m	D = 106.5 m H = 1.20 m
MS 9	58.00	42.40	2.70	3.80	6.20	6.80	5.20	6.80	61.51	Nil	Nil
MS 10	57.00	143.50	6.50	8.70	11.10	10.30	8.60	11.10	240.77	D = 134.50m H = 1.10 m	D = 194.00m H = 1.20 m
MS 11	54.00	119.50	9.80	12.10	12.30	9.50	7.90	12.30	244.06	D = 240.00 m H = 1.80 m	D = 125.00 m H = 0.70 m

MS 12	51.00	146.00	8.40	9.30	10.10	8.80	7.60	10.10	251.07	D = 81.00 m H = 1.10 m	D = 221.00 m H = 2.50m

Table 2.9 : Flow area Details of Katakhal River system-contd

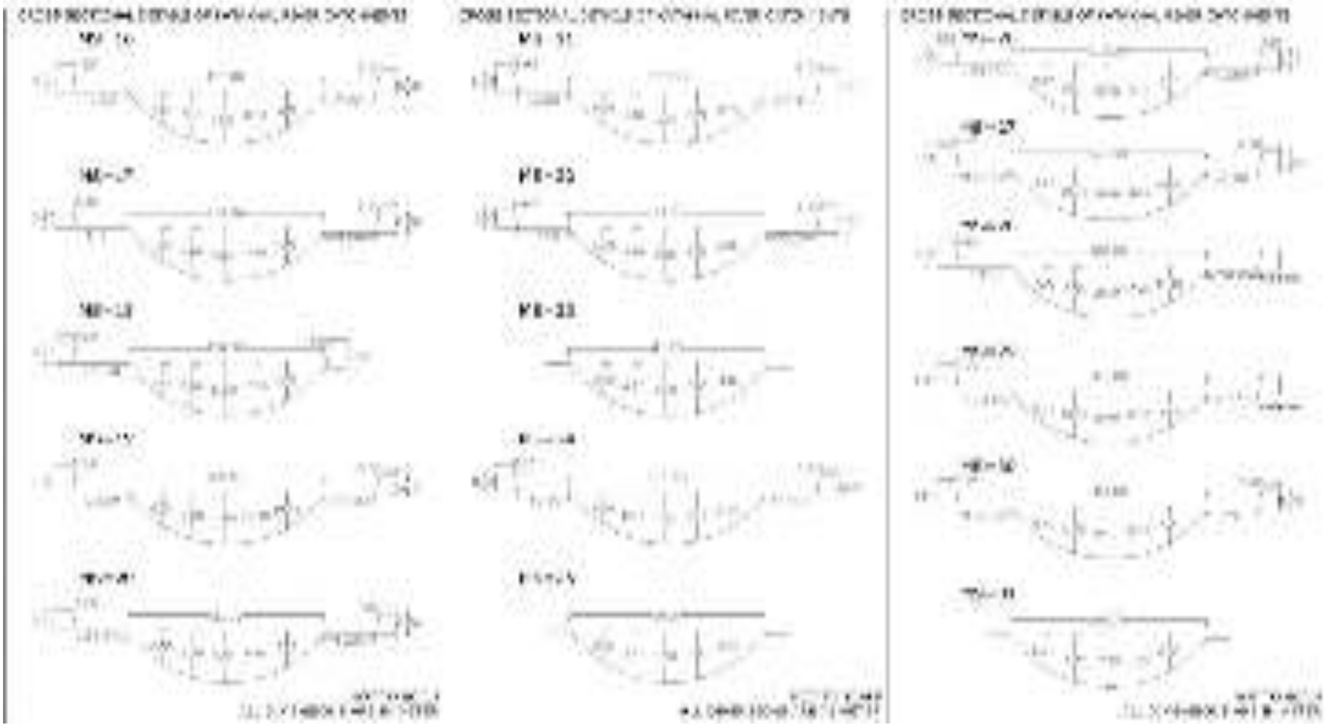
Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth (m)	flow area (Approx) in Sq.m	Embankment Details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L Bank
MS 13	48.00	132.50	8.40	10.00	12.70	12.80	10.20	12.80	276.38	D = 132.00m H = 1.20m	D = 93.00 m H = 0.60 m
MS 14	45.00	151.00	5.80	7.10	8.10	6.50	5.00	8.10	179.30	D = 245.00m H = 0.70 m	D = 150.50m H = 1.10 m
MS 15	42.00	107.70	8.80	10.50	11.40	9.80	9.20	11.40	224.95	D = 303.00 m H = 0.50 m	D = 74.00m H = 1.20 m
MS 16	39.00	120.00	7.50	9.10	10.10	8.40	6.90	10.10	199.20	D = 65.00 m H = 0.90 m	D = 66.50 m H = 0.60 m
MS 17	36.00	110.50	7.20	8.60	9.50	9.10	8.20	9.50	196.21	D = 62.00 m H = 0.80 m	D = 68.00m H = 0.70 m
MS 18	33.00	100.50	7.10	8.80	11.20	10.30	8.70	11.20	192.93	D = 50.00 m H = 1.00 m	D = 75.00m H = 0.40 m
MS 19	30.00	125.50	6.50	7.20	11.00	12.40	10.70	14.40	241.08	D = 233.00m H = 1.00 m	D = 131.00m H = 1.00 m
MS 20	27.00	111.00	6.80	8.30	9.90	8.90	7.20	9.90	183.70	D = 90.50m H = 0.90m	D = 67.80 m H = 0.70 m
MS 21	24.00	105.50	8.20	9.10	11.80	9.70	8.70	11.80	209.78	D = 95.00m H = 0.70m	D = 66.00 m H = 0.30 m

MS 22	21.00	112.00	6.20	8.10	9.00	7.50	6.10	9.00	164.00	D = 111.00m H = 0.90m	D = 73.20 m H = 1.00m
MS 23	20.00	41.20	3.80	4.70	5.80	5.00	4.10	5.80	58.12	Nil	Nil

Table 2.9 : Flow area Details of Katakhal River system-Contd

Name of station	Distance from confluence point with barak in kM(Approx)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth (m)	flow area (Approx) in Sq.m	Embankment Details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L Bank
MS 24	18.00	104.50	8.20	10.10	11.20	8.10	6.90	11.20	190.30	D = 562.00m H = 1.20 m	D = 100.00m H = 0.65 m
MS 25	17.00	30.50	3.10	3.70	4.90	4.00	3.50	4.90	41.98	Nil	Nil
MS 26	15.00	115.50	8.70	10.50	10.30	11.70	9.10	10.50	236.33	D = 71.00m H = 1.00 m	D = 151.0m H = 1.00 m
MS 27	12.00	123.00	9.80	10.70	10.80	11.50	10.40	11.50	273.05	D = 97.5 m H = 1.20 m	D = 191.5m H = 1.00 m
MS 28	9.00	108.00	7.80	9.30	10.60	12.80	11.40	12.80	238.20	Nil	D = 91.50m H = 0.90 m
MS 29	6.00	120.00	8.70	10.40	10.80	8.80	8.10	10.80	228.00	Nil	D = 463.50m H = 1.40m
MS 30	3.00	104.00	8.20	9.70	10.10	8.30	7.30	10.10	190.53	Nil	D = 160.0 m H = 1.80 m

MS 31	0.00	100.70	8.40	9.90	12.40	10.20	8.60	12.40	207.66	Nil	Nil



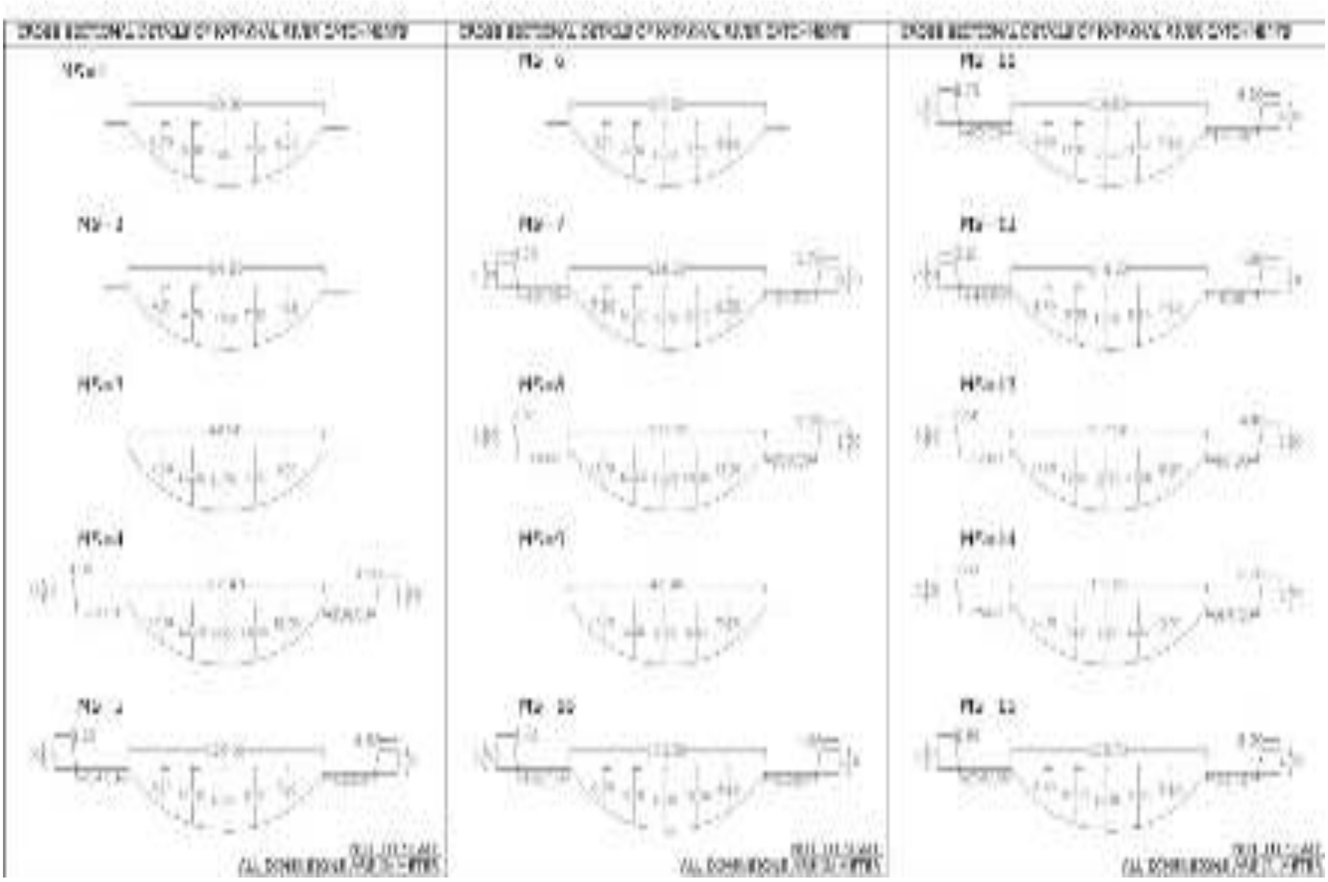


Fig 2.18 :Section Details of katakhal River system

Fig 2.19: Rivers of the sub watershed: Longai, Approximate catchment Area: 371.06 km2

Table 2.10 : Flow area Details of Longai River system

Maximum top width = 120.70 m
Average top width = 61.90 m

Name of station	Distance from bangladesh border(Latu Bridge)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth(m)	flow area (Approx) in Sq.m	Embankment Details	
			1/6.T	2/6.T	3/6.T	4/6.T	5/6.T			R Bank	L Bank
MS 1	0.00	120.70	7.70	6.90	5.83	5.20	4.10	7.70	154.55	Nil	Nil
MS 2	2.00	76.80	5.20	6.95	7.20	6.30	5.33	7.20	108.29	Nil	Nil
MS 3	4.00	79.30	6.52	6.40	8.65	6.73	6.00	8.65	126.30	Nil	Nil
MS 4	6.00	75.00	4.00	4.93	7.52	7.40	6.80	7.52	107.20	Nil	Nil
MS 5	8.00	73.50	8.20	8.95	9.32	7.83	7.50	9.32	148.36	Nil	Nil
MS 6	10.00	77.55	6.80	7.92	8.70	5.88	5.30	8.70	123.20	Nil	Nil
MS 7	12.00	70.00	6.50	7.20	7.85	6.35	5.57	7.85	113.21	Nil	Nil
MS 8	14.00	66.40	6.10	6.80	6.84	7.00	6.50	7.00	111.00	Nil	Nil
MS 9	16.00	89.40	5.97	6.72	5.90	4.70	4.05	6.72	109.29	Nil	Nil
MS 10	18.00	82.00	4.85	5.80	7.03	8.92	7.80	8.92	129.94	Nil	Nil
MS 11	20.00	71.00	7.02	8.10	8.60	5.67	5.00	8.60	115.86	Nil	Nil
MS 12	22.00	69.80	8.10	9.92	9.67	4.95	4.03	9.92	119.64	Nil	Nil
MS 13	24.00	93.20	5.70	6.45	6.50	5.82	4.77	6.50	118.86	Nil	Nil
MS 14	29.00	45.50	2.92	3.80	6.52	4.95	6.94	6.94	67.93	Nil	Nil
MS 15	34.00	38.30	2.85	3.70	5.92	4.00	3.51	5.92	47.54	Nil	Nil
MS 16	39.00	42.80	3.60	4.85	5.83	4.44	3.60	5.83	55.92	Nil	Nil
MS 17	42.00	57.00	3.00	3.95	5.80	5.30	4.80	5.80	67.15	Nil	D = 78.50 M H = 1.20 M

MS 18	45.00	56.30	4.22	5.10	5.60	5.92	3.44	5.92	69.18	Nil	Nil

Table 2.10 : Flow area Details of Longai River system-Contd

Name of station	Distance from bangladesh border(Latu Bridge)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth(m)	flow area (Approx) in Sq.m	Embankment Details Name of station	
			1/6.T	2/6.T	3/6.T	4/6.T	1/6.T			R Bank	L Bank
MS 19	50.00	56.50	3.10	3.55	4.52	5.05	5.80	5.80	68.14	D= 58.25 M H = 1.30 M	D = 48.25 M H = 1.20 M
MS 20	55.00	33.50	4.44	6.00	5.02	5.25	4.40	6.00	57.22	D = 56.75M H = 1.80 M	D = 73.75M H = 1.50 M
MS 21	60.00	37.00	3.30	5.32	6.85	4.88	2.80	6.85	52.91	Nil	D = 70.5.00 H 1.80 M
MS 22	65.00	39.20	4.90	5.20	5.65	3.33	2.50	5.65	52.53	D = 24.60M H = 1.80 M	D = 79.60 M H= 1.00 M
MS 23	70.00	50.40	8.10	9.50	5.55	3.27	2.90	9.50	82.84	D= 66.20 H = 2.00 M	D = 25.40 M H = 1.00
MS 24	75.00	79.72	4.50	4.95	4.90	3.12	2.60	4.95	73.11	D = 241.86M H 2.20 M	D = 52.86 M H= 2.00 M
MS 25	80.00	66.40	4.85	5.05	4.50	4.80	4.10	5.05	78.22	D = 50.70 M H = 2.08 M	D = 200.20 H=1.50 M
MS 26	85.00	44.10	4.10	5.80	6.00	5.10	3.90	6.00	63.20	D = 27.05 M H = 1.50 M	D =192.05 M H= 1.70 M
MS 27	90.00	54.35	4.90	5.52	3.90	3.65	2.85	5.52	61.24	Nil	D = 97.88 M H= 1.60 M
MS 28	94.00	60.10	4.00	4.75	4.50	3.12	2.77	4.75	58.65	Nil	Nil
MS 29	99.00	45.40	2.92	4.30	4.46	4.05	3.10	4.46	48.40	Nil	Nil
MS 30	0.00	70.20	4.10	4.70	7.33	5.20	4.10	7.33	82.43	Nil	Nil

MS 32	6.00	65.30	4.60	5.30	7.80	6.20	5.80	7.80	95.19	Nil	Nil
MS 33	9.00	63.00	5.10	5.75	8.80	4.95	4.05	8.80	87.04	Nil	Nil

Table 2.10 : Flow area Details of Longai River system-Contd

Name of station	Distance from bangladesh border(Latu Bridge)	Maximum top width (T) in (M)	Vertical depth (m)					Maximum depth(m)	flow area (Approx) in Sq.m	Embankment Details Name of station	
			1/6.T	2/6.T	3/6.T	4/6.T	1/6.T			R Bank	L Bank
MS 34	12.00	57.50	4.80	5.95	8.95	6.83	5.50	8.95	92.81	Nil	Nil
MS 35	16.00	63.70	4.30	5.20	6.30	5.90	4.98	6.30	84.06	Nil	Nil
MS 36	18.00	58.80	4.90	5.80	7.40	6.20	5.40	7.40	89.27	Nil	Nil
MS 37	20.00	65.30	3.90	5.80	8.40	6.85	5.75	8.40	94.61	Nil	Nil
MS 38	22.00	57.20	2.95	4.52	4.85	3.80	3.10	4.85	55.18	Nil	Nil

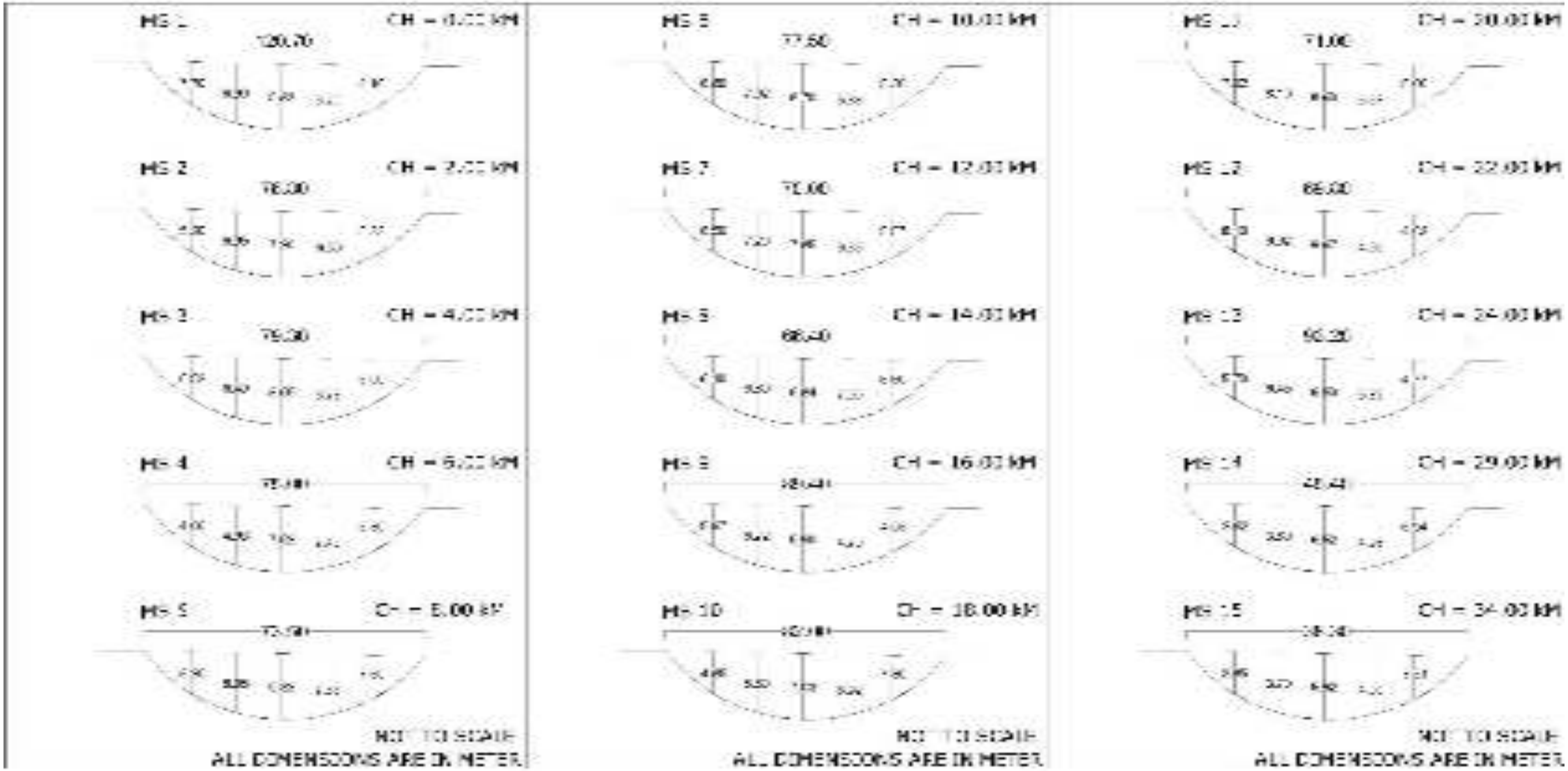

CH = 10.00 KM
CH = 12.00 KM
CH = 14.00 KM
CH = 16.00 KM
CH = 18.00 KM
NOT TO SCALE
ALL DIMENSIONS ARE IN METER

Fig 2.20(a) : Section Details of Longai River system

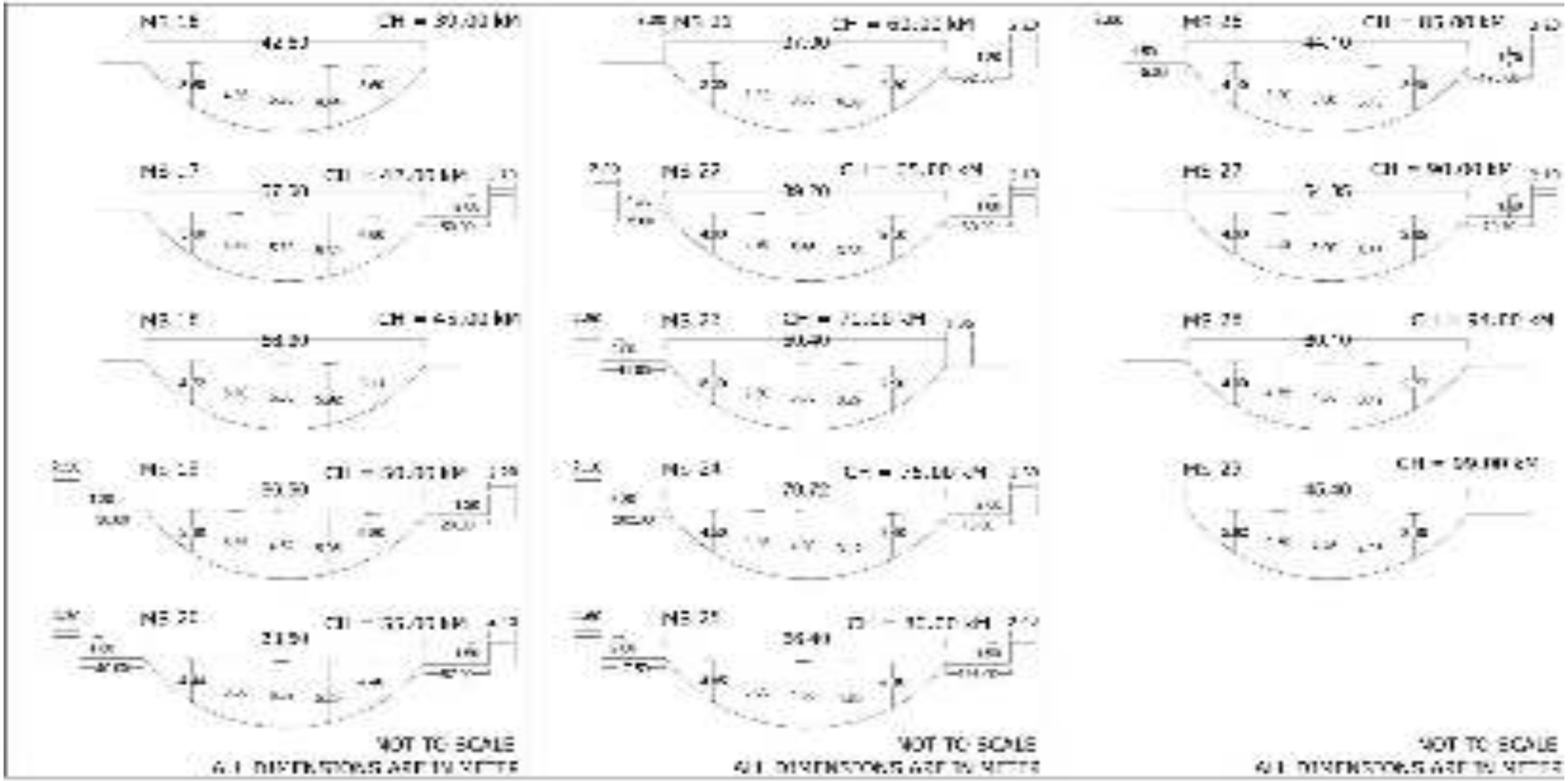


Fig 2.20(b) Section Details of Longai River system–contd

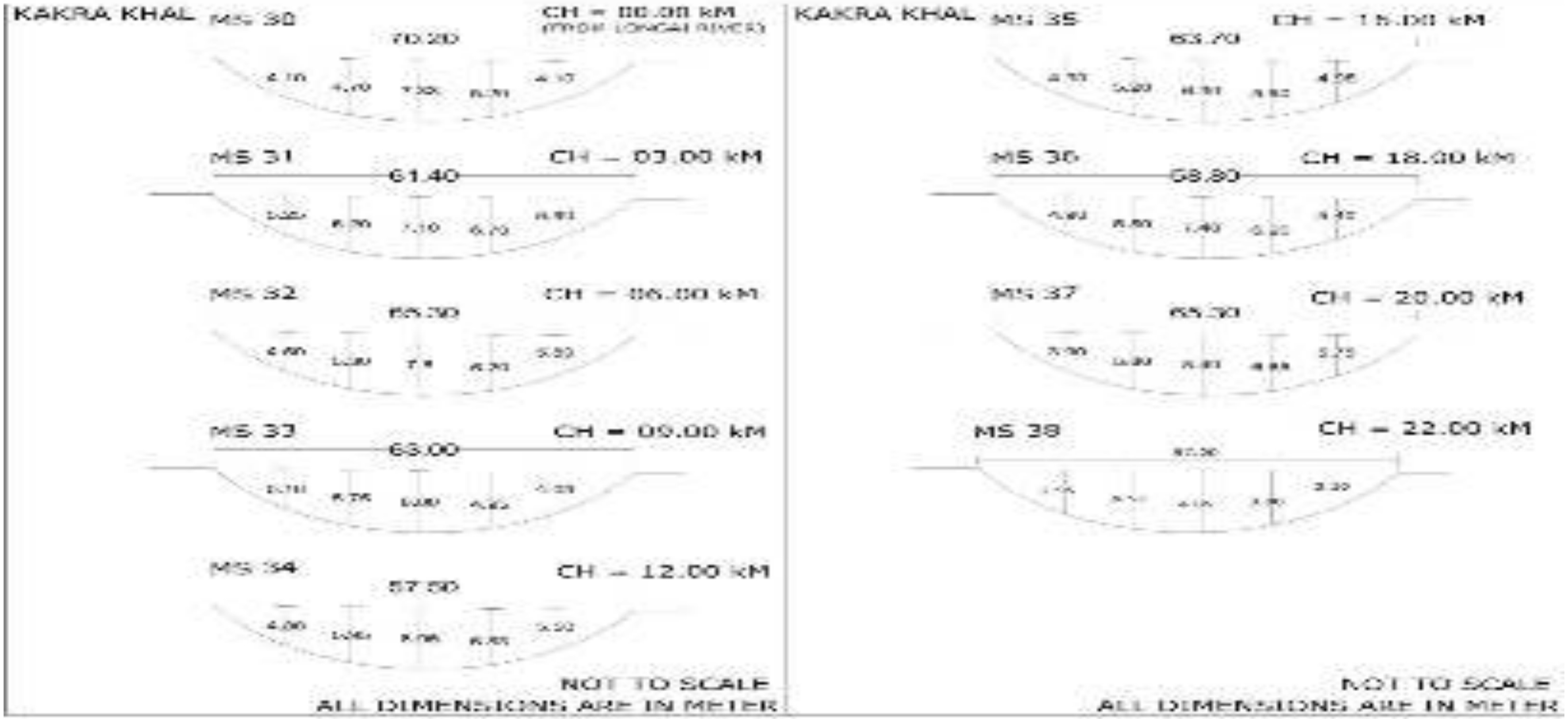


Fig 2.20(c) Section Details of Longai River system-contd

Table 2.11: Details of the existing embankment

Name of the river - Barak

Left bank			Right bank		
From	to	Approx length	from	to	Approx length
Dilcush village	Rajnagar	84 Km	Barenga	Masughat	42 Km
			Ujan Gram	Katigorah	40 km

Name of the river - Rukni

Left bank			Right bank		
From	To	Approx length	from	to	Approx length
Baga	Nadir gram	30.50 Km	Gagla ghat	Roy para	24 Km

Name of the river - Sonai

Left bank			Right bank		
From	To	Approx length	from	to	Approx length
Borali basti	Jarul gram toal	33.50 Km	Amraghat	Dungir par	38.00 Km

Name of the river - Badri

Left bank			Right bank		
From	To	Approx length	from	to	Approx length
Mach para	Badri basti	2.00 Km	Old lakhipur road	Machpara	1.50 Km

Name of the river - Madhura

Left bank			Right bank		
From	To	Approx length	from	to	Approx length
Rongpur	Istampur	14.00 Km	Dudhpatil	Pachmile	8.00 Km

Name of the river - Gagra

Left bank			Right bank		
From	To	Approx length	from	to	Approx length
Rothur gram	6 A.P camp	19.50 Km	Suktara	Srikona	2.00 Km

Name of the river -jatinga

Left bank			Right bank		
From	To	Approx length	from	to	Approx length
Badripar	dolu	3.00 Km	-	-	-

Name of the river –katakhal

Left bank			Right bank		
From	To	Approx length	from	to	Approx length
kaligange	Rupacherra	71.00 Km	kaligange	Rupacherra Bagan	71.00 Km

Name of the river –Longai

Left bank			Right bank		
From	To	Approx length	from	to	Approx length
Gandhri	Baitar Ghat	57.00 Km	Nilambazer	buringa	49.00 Km

Table- 2.12 Details of existing major sluice gates in Barak Valley

Sl no.	Sluice Gate	River/ Channel	Outfall
1.	Surface Sluice(Five Openings)	Suktara Channel	Ghagra
2.	Larsing Sluice(Single Opening)	Larsing Channel	Madhura
3.	Paku Sluice(Double Opening)	Amjur River	Sonai
4.	Boile Badri(old)(Double shutter)	Bolie Badri	Jatinga
5.	Boile Badri(new)(Double shutter)	Bolie Badri	Jatinga
6.	Punir Mukh Sluice(Duoble Shutter)	Rukni River	Rukni
7.	Rangirkhari Sluice (Single Shutter)	Rangirkahri Channel	Ghagra
8.	Purkhai Sluice(Single Shutter)	Purkhai	Borak
9	PirNagar Sluice gate (multiple Shutter)	Baleshwar	Surma
10	Sluice gate (Village Muraure)	Churia Jhumjhumi Channel	-
11	Pola Sluice(Shutters:4 nos)	Pola Chnnel	Barak
12	Hatia Diversion Sluice(Single Shuttter)	Dhaleshwar	Dhaleshwar
13	Lalatol Sluice (Shutters:2 nos)	Katakhal River	Katakhal

3.0 Rainfall Analysis:

The Barak Valley is situated in the southern part of Assam and consists of Cachar, Hailakandi and Karimganj districts. The entire area of this valley lies within the hydro-meteorological Sub-Zone 2(C) of India. Reliable rainfall frequency analysis for the sites can be carried out if the available data are of longer periods as compared to the desired return periods. In order to gather rainfall affecting information from those of the ungaged areas roughly 14 numbers of (1^0 latitude X 1^0 longitude) grid points are selected to cover the entire study area. The large scale atmospheric variables affecting rainfall and seasonality of rainfall data for each of the grid points are extracted from NCEP Operational Plotting Page (www.esrl.noaa.gov/psd/data/hisdata/) and GPCC Precipitation Data Set (www.esrl.noaa.gov) which are used along with the location parameters (latitude and longitude) as attributes for the regionalization of the Sub-Zone into two homogeneous regions by Fuzzy c-means clustering. The use of large scale atmospheric variables as attributes can form reliable regions than the use of site data alone because these variables give information from the ungauged areas. The two delineated regions are tested for discordancy and regional homogeneity using the site data available in the grid points. L-moment based index-rainfall approach (Hosking and Wallis 1990, 1993, 1997) is used for the rainfall frequency analysis of this Valley. In case of the gauged sites a regional rainfall frequency relationship for the estimation of rainfall of various return periods was derived using the selected distributions whereas for those of the ungauged sites a regional mean rainfall relationship with latitude and longitude of the sites was developed using multiple linear regression. The objectives of this study is to conduct regional extreme rainfall frequency analysis for Barak Valley of India using L-moments approach.

3.1 Study Area and Data Collection

This study area lies within 22^0 N to 27^0 N and 90^0E to 95^0 E which covers the states of Meghalaya, Manipur, Nagaland, Mizoram, Tripura, North Cachar Hills and Barak Valley of Assam. The entire study area can be roughly covered by 14 numbers of 1^0 Latitude x 1^0 Longitude grid points. The maximum annual daily rainfall data from 1990 to 2010 for 13 nos. of stations in this valley are collected from Regional Meteorological Centre, Gauwahati. The 14 grid points with the stations in the grid are in Table 14. The gridded (1^0 x 1^0) large scale atmospheric variables affecting rainfall in the grids of the study area are extracted from NCEP (National Centre for Environmental Prediction) Operational Plotting Page (www.esrl.noaa.gov/psd/data/hisdata/) and gridded (1^0 latitude x 1^0 longitude) precipitation data from Global Precipitation Climatory Centre (www.esrl.noaa.gov).

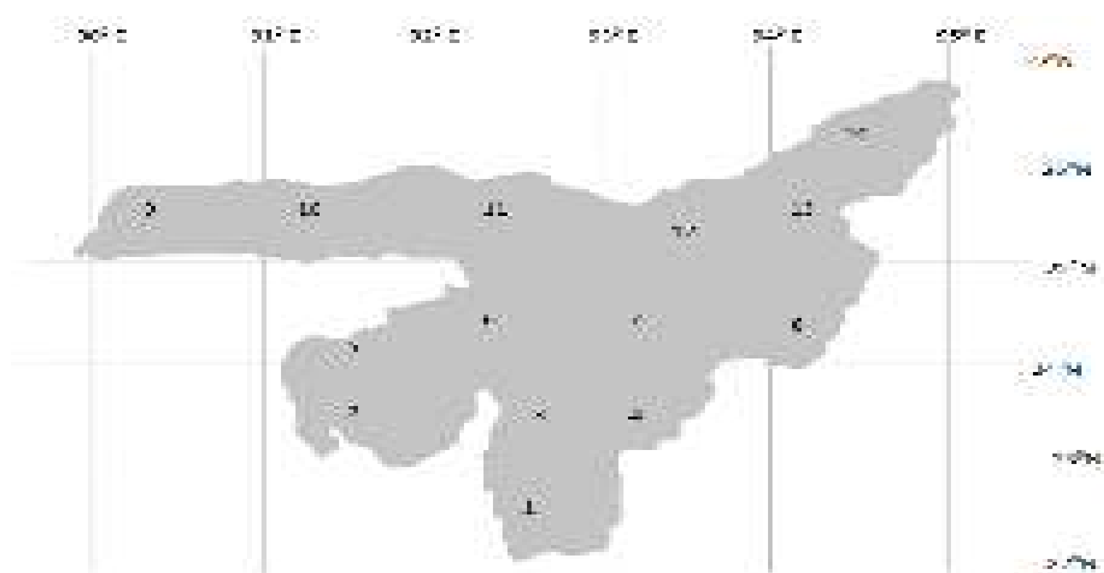


Figure-3.1: Grid Points Covering the Study Area

Grid Points	Latitude Longitude	Stations in the Grid	Latitude	Longitude	Length of Record

Table- 3.1: Rainfall gauging station in the selected Grids

1	22^0N x 23^0N 92^0E x 93^0E	1.Lengpui	22.88^0 N	92.75^0 E	10
2	23^0N x 24^0N 91^0E x 92^0E	2.Agartala	23.88^0 N	91.25^0 E	21
3	23^0N x 24^0N 92^0E x 93^0E	3.Aizwal	23.73^0 N	92.71^0 E	21
4	23^0N x 24^0N 93^0E x 94^0E	-			
5	24^0N x 25^0N 91^0E x 92^0E	4.Kailashahar	24.31^0 N	92.00^0 E	20
6	24^0N x 25^0N 92^0E x 93^0E	5.Gharmura	24.36^0 N	92.53^0 E	21
		6.Karimganj	24.86^0 N	92.35^0 E	21
		7.Dholai	24.58^0 N	92.85^0 E	21
		8. Silchar	24.81^0 N	92.80^0 E	21
7	24^0N x 25^0N 93^0E x 94^0E	9. Imphal	24.76^0 N	93.90^0 E	21
8	24^0N x 25^0N 94^0E x 95^0E	-			
9	25^0N x 26^0N 90^0E x 91^0E	-			
10	25^0N x 26^0N 91^0E x 92^0E	10. Shillong	25.56^0 N	91.88^0 E	21
		11. Cherrapunji	25.25^0 N	91.73^0 E	21
		12 Mawsynram	25.30^0 N	91.58^0 E	14
11	25^0N x 26^0N 92^0E x 93^0E	-			
12	25^0N x 26^0N 93^0E x 94^0E	-			
13	25^0N x 26^0N 94^0E x 95^0E	13.Kohima	25.63^0 N	94.16^0 E	21

14	26^0N x 27^0N 94^0E x 95^0E	-			

3.2 L-moments Approach:

L-moments are linear combinations of probability weighted moments (PWM). The probability weighted moments are calculated from the ranked observations $X_1 > X_2 > X_3$ ……………> X_n. Greenwood et al (1979) summarizes the theory of probability weighted moments and defined them as

$$b_r = N^{-1}\sum_{j=r+1}^{N}(x_j)\frac{(j-1)(j-2)\ldots\ldots\ldots(j-r)}{(N-1)(N-2)(N-3)\ldots\ldots(N-r)}$$

The first four L-moments are

$\lambda_1 = \beta_0 \lambda_2 = 2\beta_1 - \beta_0 \lambda_3 = 6\beta_2 - 6\beta_1 + \beta_0 \lambda_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_0$

where λ_1 is the L-mean which measures the central tendency, λ_2 is the L-standard deviation which measures the dispersion. Again,(Hosking, 1990) defined the dimensionless L-moment ratios

τ = L- coefficient of variance, L-cv = $\frac{\lambda_2}{\lambda_1}$, τ_3 = L- skewness = $\frac{\lambda_3}{\lambda_2}$, τ_4 = L-kurtosis = $\frac{\lambda_4}{\lambda_2}$

3.3 Discordancy measure

Hosking & Wallis (1993) defined discordancy measure of sites to detect the discordance sites among other sites as $D_i = \frac{1}{3}(u_i - \bar{u})^T A^{-1}(u_i - \bar{u})$ where, $u_i = (\tau, \tau_3, \tau_4)^T$ is a vector containing τ, τ_3, τ_4 values of site i, the superscript T denotes transpose of a matrix or vector,

$\bar{u} = \frac{1}{N} \sum u_i$ be the (unweighted) group average of u_i, A^{-1} is the inverse of the covariance matrix A of u_i The elements of A^{-1} are given by the relation,

$A = \frac{1}{N} \sum_{j=1}^{N} (u_i - \bar{u})(u_i - \bar{u})^T$,where N is the number of sites in the region.

The discordancy (D_i) of the 13 sites are determined and the station Lengpui has its D_i value greater than the critical value of 2.869 for 13 stations. The valley has to be sub-divided into regions to see whether the D_i value of this site can be adjusted below the critical value by combining with some other sites and to form hydrologically similar homogeneous regions using Fuzzy c-means clustering.

3.4Fuzzy c-means clustering -

In this study Fuzzy c-means clustering is carried out in MATLAB using large scale atmospheric variables affecting rainfall, location parameters and seasonality of rainfall as attributes. Two regions are formed by assigning the membership of each grid points in the clusters equal or greater than to a threshold; T_i = max { $\frac{1}{c}$, $\frac{1}{2}$[max (μ_{ij})]}, where c = no. of clusters and μ_{ij} = maximum membership of the i^{th} grid point in the j^{th} cluster. These two regions consist of grid point 1 to 5 in region I and 6 to 14 grid points in region II. The D_i values for the sites in the two regions are less than their respective critical values i.e.1.333 for Region I and 2.329 for Region II which indicates that there are no discordance sites.

Annual maximum rainfall intensity for the rain gauging stations in the valley for last 21 years from 1990 to 2010 is collected from RMC Guwahati. The annual maximum rainfall in recorded for various station are used to estimate 10,20,30,40,50,75 and 100 year return period rainfall intensity for the gauging stations. Estimation of extreme rainfall intensity for this valley is obtained from the regional extreme rainfall frequency analysis of the sub-zone. Here, L-moments based regional frequency analysis approach is used. The discordancy(D_i) measure for screening out the data of the unusual sites was conducted. Fuzzy c-means clustering analysis with location parameters, seasonality of rainfall and large scale atmospheric variables affecting rainfall in the study area was used as attributes for regionalization of the Sub-Zone into homogeneous regions. Heterogeneity measure has been conducted by carrying out 500 simulations using a 4-parameter Kappa distribution. Five extreme value distributions Generalized Pareto (GPD), Generalized Logistic (GLO), Generalized Extreme Value (GEV), Pearson Type III and Log Normal (LN3) were used to select the best fit distribution for the regions. Based on Z^{DIST} statistics and L-moment ratio diagrams GLO for region I and GPD for region II were selected as the best fit distributions. Regional rainfall formula for the estimation of rainfall for various return periods was derived for the gauged sites using the selected distributions and growth factors for the regions were derived. For the ungauged sites a regional mean relationship with latitude and longitude of the sites were developed using multiple linear regression. Brief methodology applied in analyzing the extreme rainfall events is summarized below:

3.5 Brief Methodology:

L-moment approach analysis (Hosking & Wallis, 1990) consists of the following steps-

(a) Screening of data using a discordancy measure.

(b) Formation of homogeneous regions using clustering method and refinement by conducting homogeneity test.

(c) Choice of distribution using Goodness of fit test – Z^{DIST} statistics and L-moment ratio diagram.

(d) Establishment of rainfall frequency relationship using index-flood/rainfall method and Development of regional growth curves.

The discordancy (D_i) measure of the 13 sites are conducted and one of the sites has its D_i value greater than the critical value of 2.869 for 13 sites (Hosking & Wallis). To adjust this D_i value below the critical value and to include this site in the analysis, the study area has been clustered into two regions- region I comprising the grid points (1, 2, 3, 4 & 5) and region II comprising the grid points (6, 7, 8, 9, 10, 11, 12, 13 & 14) respectively using Fuzzy c-means clustering in MATLAB with large scale atmospheric variables affecting rainfall, location parameters and seasonality of rainfall as attributes and refinement by conducting homogeneity test. The heterogeneity measure has been conducted by carrying out 500 simulations using a 4-parameter Kappa distribution in a computer programme written in JAVA. From the result of Goodness of fit test using Z^{DIST} statistics and L-moment ratio diagram, GLO for region I and GPD for region II have been selected as the best fit distribution. The parameters of the selected distributions are estimated using L-moments and regional growth factors are derived by index-flood procedure(Dalrymple, 1960) with the development of regional rainfall formula for the two regions as –

Region I

$$X_T = [0.43096 + 0.50370 \{\frac{(1-F)}{F}\}^{-0.26895}] \cdot \overline{X} \quad (3.1)$$

Region II

$$X_T = 1.69161 - 1.10411 (1- F)^{0.59644} \cdot \overline{X} \quad (3.2)$$

Where, $\overline{X}$ = at site mean rainfall, F = $(1 - \frac{1}{T})$ and T = return period.

T-year rainfall intensity for Barak Valley of Assam is carried out using (3.2) as this valley lies within region II.

Table-3.2 : Estimated T-year rainfall intensity for Barak Valley

Station Year→	10	20	30	40	50	75	100
Silchar	170.17	181.05	185.63	188.26	190.01	192.66	194.19
Dholai	174.72	185.89	190.59	193.30	195.09	197.81	199.38
Karimganj	244.75	260.39	266.98	270.77	273.28	277.09	279.29
Gharmura	176.77	188.07	192.83	195.57	197.38	200.14	201.73

3.6 **Development of Regional mean rainfall relationship** -

The regional mean rainfall relationship is established by relating rainfall with latitude and longitude of the sites using matrix method of linear regression. The rainfall means for the observed data for the two stations in region II i.e. Cherrapunji and Mawsynram have extremely high values than the rest of all stations. So region II have been divided into two regions based on mean values and geographical locations of the grids as region II (a) comprising of grid points (6,7,8,12,13 and 14) and region II (b) comprising of grid points (9,10 and 11). Three linear equations have been developed as in (3.3), (3.4) and (3.5) for the estimation of mean rainfall for the sites in these regions.

Region I $\bar{X} = 2630.3 + 3.7(\text{Lat.}) - 28.1(\text{Lon.})$ (3.3)

Region II (a) $\bar{X} = 2630.3 + 3.7(\text{Lat.}) - 28.1(\text{Lon.})$ (3.4)

Region II (b) $\bar{X} = 2630.3 + 3.7(\text{Lat.}) - 28.1(\text{Lon.})$ (3.5)

where (Lat.) is latitude and (Lon.) is the longitude for the site.

Regional mean rainfall for Barak Valley of Assam is estimated using (3.4) as this valley lies within region II(a).

Table-3.3: Estimation of mean rainfall using regional mean relationship

Station	Observed mean (Q)	Lat	Lon	Estimated mean(E)	$\chi^2 = \frac{\sum(Q-E)^2}{E}$
1.Silchar	128.58	24.81	92.80	144.84	1.8250
2. Dholai	132.02	24.58	92.85	133.44	0.0152
3. Karimganj	184.93	24.86	92.35	175.07	0.5556
4. Gharmura	133.57	24.36	92.53	145.79	1.0246
Chi- Square χ^2					3.4204

The Chi-Square values for the estimated mean and observed means for region II (a) is 3.4204 against the critical values of 7.815 at 95% significance level with 3 degrees of freedom. This shows that there is no significance difference between the estimated mean and observed mean.

4.0 Watershed Modeling:

4.1 Geographic Information System (GIS)

Geographic information system is an advanced software system engineered to enable creation, use, and management and sharing of geographic information viz.: geographic data set and data models, maps and globes, geoprocessing models and scripts, GIS methods and workflows and metadata. GIS combines a powerful visualization environment with a strong analytic and modeling framework that is rooted in the science of geography. GIS software supports several views for tackling with the geographic information categorized as the geodatabase view, the geovisualization view and geoprocessing view. In geodatabase view, GIS acts as a spatial database that connects datasets representing geographic information in terms of features, rasters, attributes, terrains, networks, etc. In geovisualization view, GIS acts as an advanced maps and other views that show features and feature relationships on the earth's surface which enable storing, querying, analyzing, and displaying of geospatial data. Lastly, in geoprocessing view it acts as information transformation tools that can extract new data set from existing information. These geoprocessing functions take information from existing datasets, apply analytic functions, and write results into new derived datasets. Geoprocessing also involves the ability to program and to automate a sequence of operation on geographic data to create new information. The ability of GIS to handle and process geospatial data in which the characteristics variables varies spatially distinguishes GIS from other information system. ArcGIS Desktop is a professional GIS application that comprises of three main software products: ArcView, ArcEditor, and ArcInfo which provides a scalable framework for implementing GIS techniques in prominent field like hydrology, environmental sciences, etc.

Applying GIS techniques DEM models for the entire Earth surface have been generated by different agencies that are available free of cost. The United States Geological Survey (USGS) is the primary distributor of The Shuttle Radar Topography Mission (SRTM), developed jointly by the National Aeronautics and Space Administration (NASA) and the National Geospatial Intelligence Agency (NGA), providing elevation datasets. The SRTM is projected into a geographic coordinate system (GCS) with the WGS84 horizontal datum and the EGM96 vertical datum (USGS, 2006). The

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an advanced multispectral imager that was launched on board NASA's Terra spacecraft in December, 1999. The ASTER Digital Elevation Model (DEM) product is generated using bands 3N (nadir-viewing) and 3B (backward-viewing) of an ASTER Level-1A image acquired by the Visible Near Infrared (VNIR) sensor. Apart from the DEM developed by discretizing the top maps these DEMs though may have some imperfections can be used as an input to quantify the characteristics of the land surface after rectification

4.2 Geomorphologic parameter estimation using GIS aided techniques

Estimation of geomorphologic parameters for a watershed can be achieved using different tools like hydrology, 3D analysis, Statistics, etc. in ArcGIS . These tools can be applied individually or used in sequence to create stream network to delineate watersheds. The process of estimation of geomorphologic characteristics of a watershed using GIS techniques involves the following sequential stepsas shown in the chart given in the next page:

4.3 Development of Digital Elevation Model (DEM) for the watersheds:

Digital Elevation Model for the important watershed in the study area are developed using GIS technique by applying ArcGIS software. Generation of DEM using topographic map can be accomplished by following the steps and applying different GIS tools as shown in the above chart. Survey of India (SOI) provides topographic maps of different scales like 1:25,000, 1:50,000, etc. Topographic maps for the study area were collected from the office of Survey of India, Shillong. The maps were processed and brought to GIS environment in .tiff format. Using GIS software ArcGIS, coordinate system are defined for the topographic maps using suitable projected/ geographic coordinate system available in GIS software. The georeferenced map is used as input in GIS platform and contour digitization is done using Editing tool. The completed vector data of digitized contour is used with 3D analysis tool to generate Triangulated Irregular Network (TIN). Further using generated TIN as input in 3D analysis tool, DEM for the watersheds are generated. In the present study

DEM for Watersheds of Chiri, Jiri, Ghagar, Madhura, Jhatinga etc. are developed and given in the figures 4.2 to 4.6.

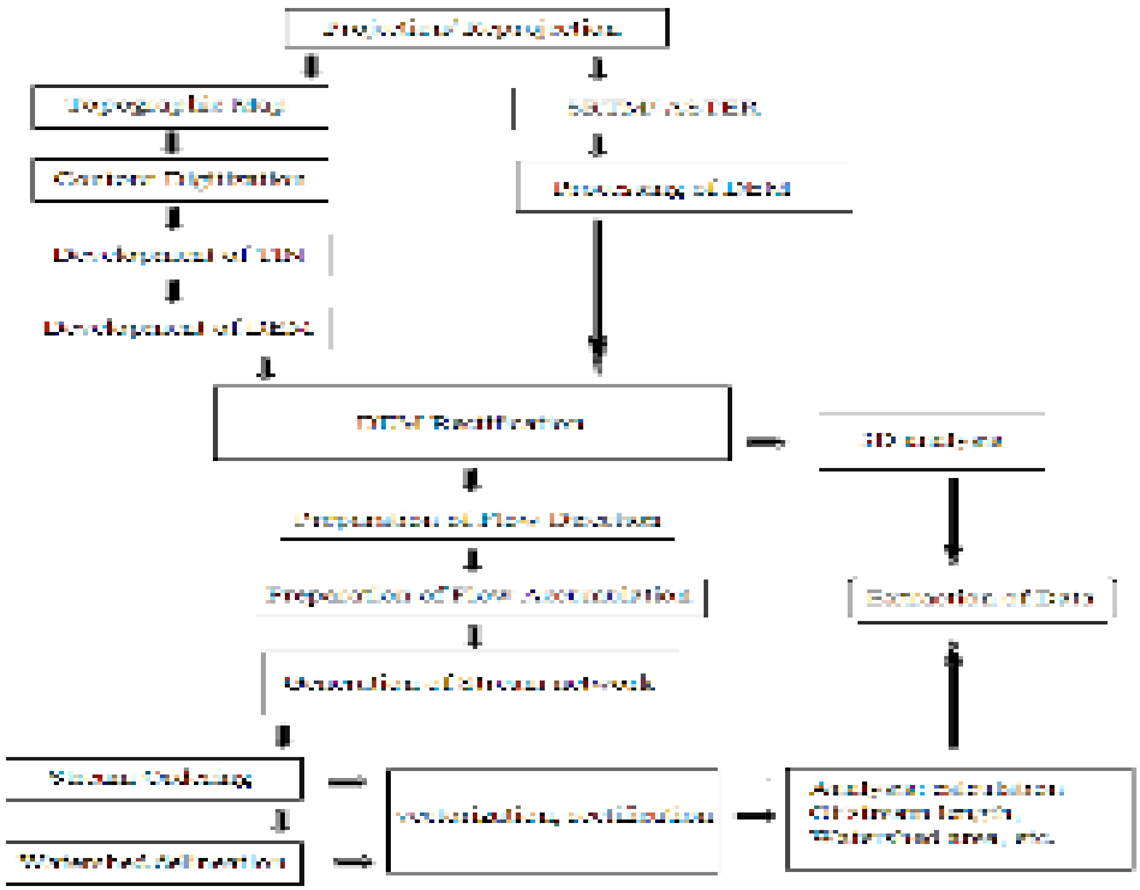


Figure-4.1: Flow chart for GIS application.

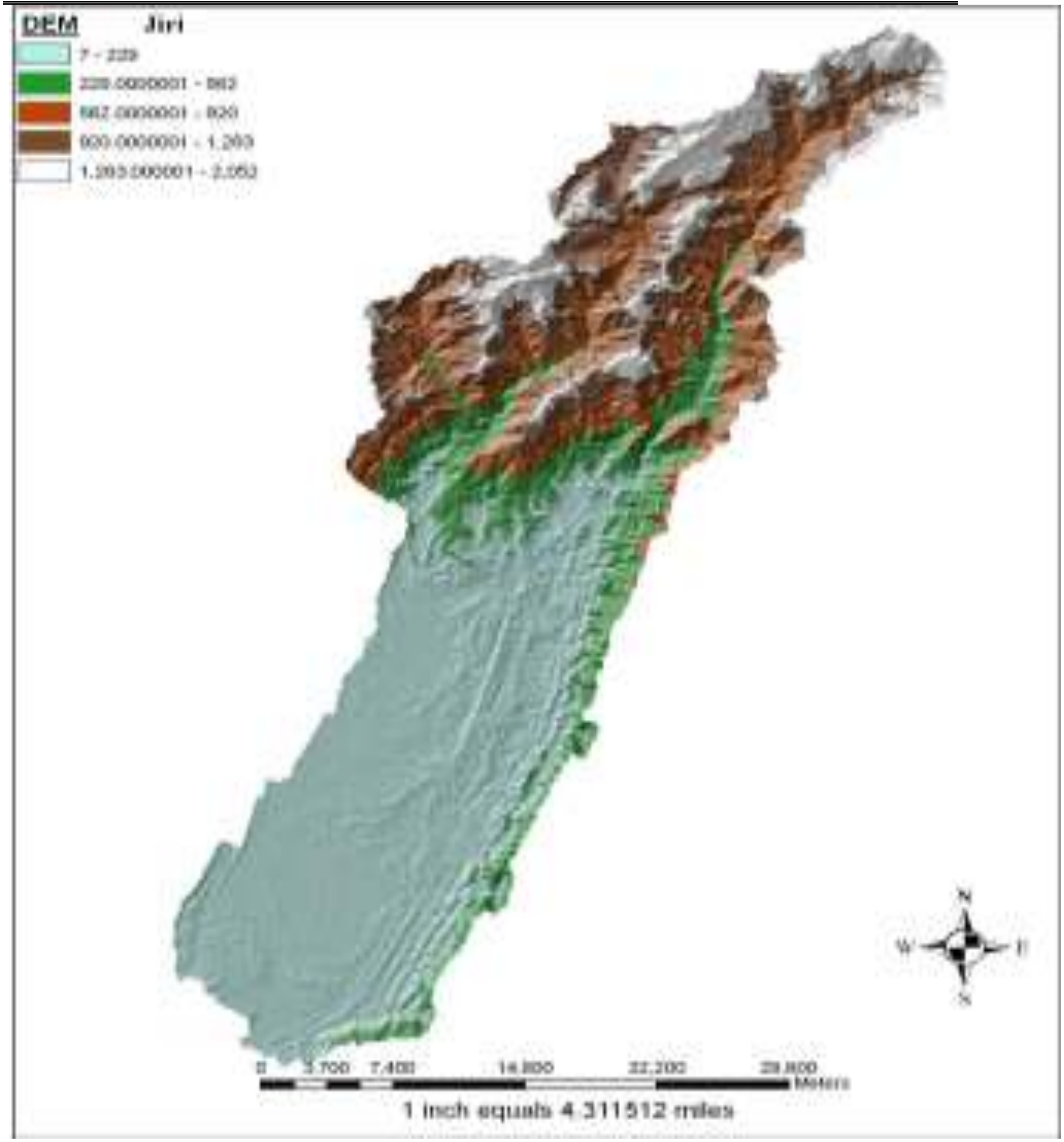


Figure-4.2: Digital Elevation Model of Jiri sub basin

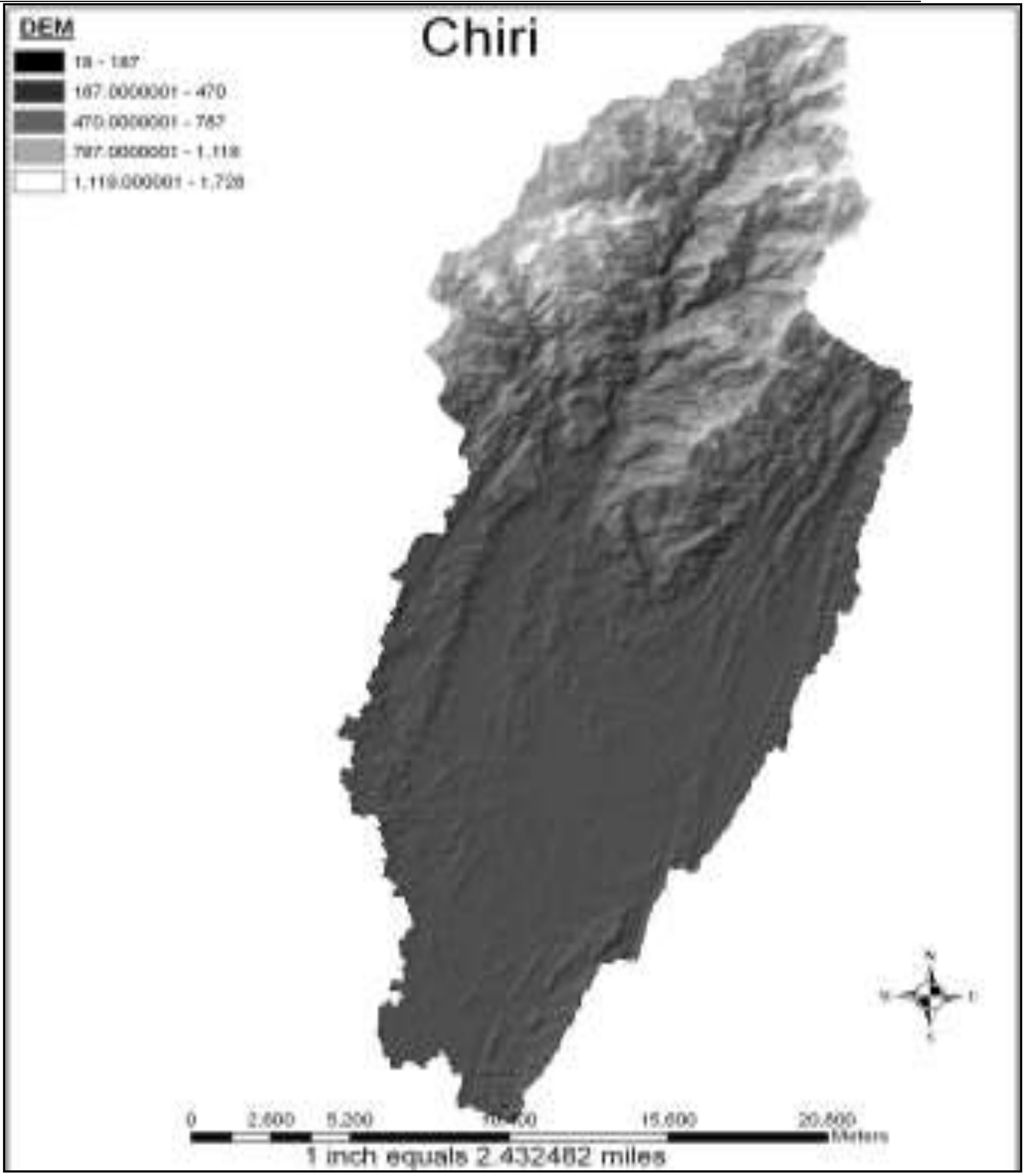


Figure-4.3: Digital Elevation Model of Chiri sub basin

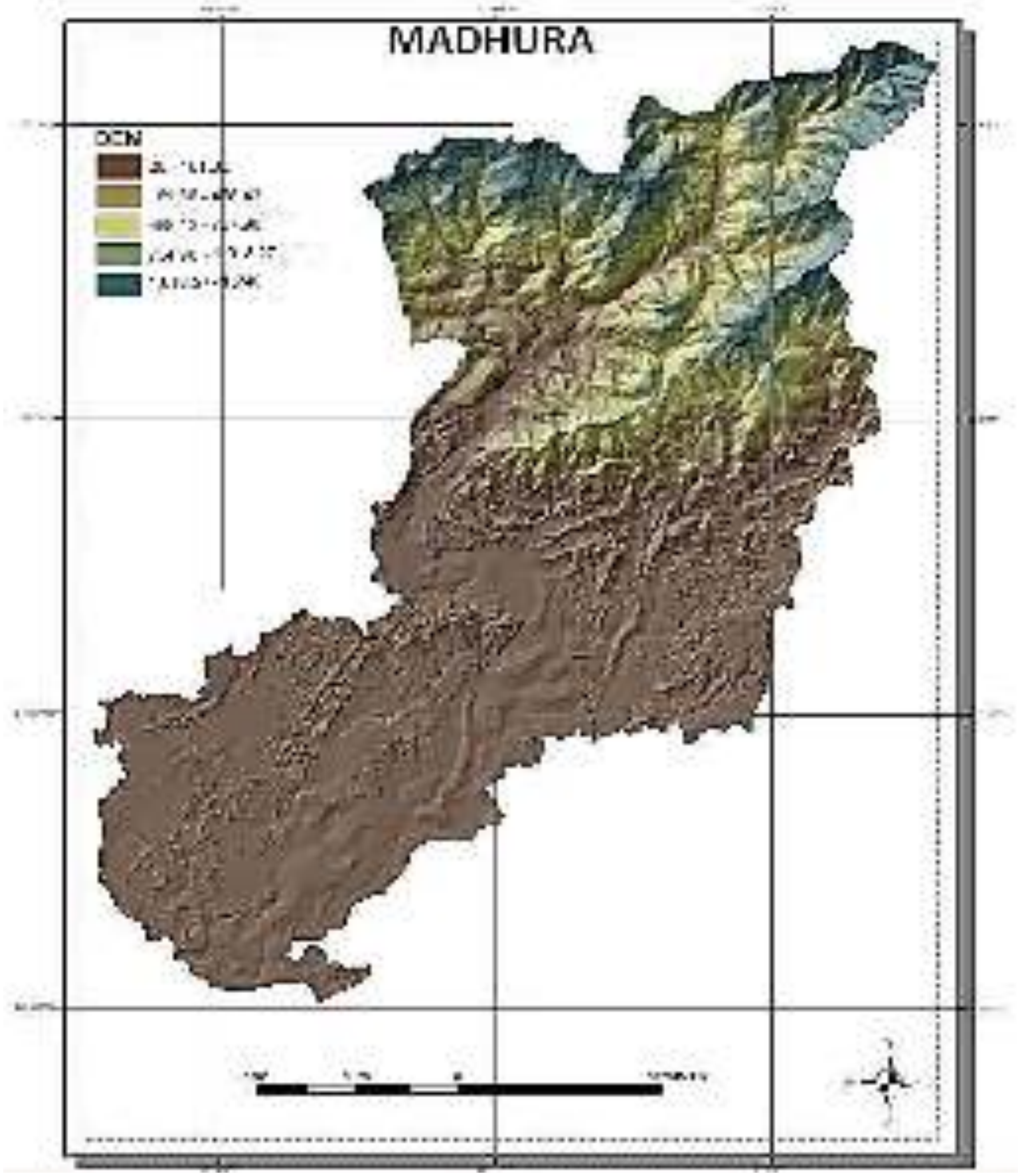


Figure-4.4: Digital Elevation Model of Madhura sub basin

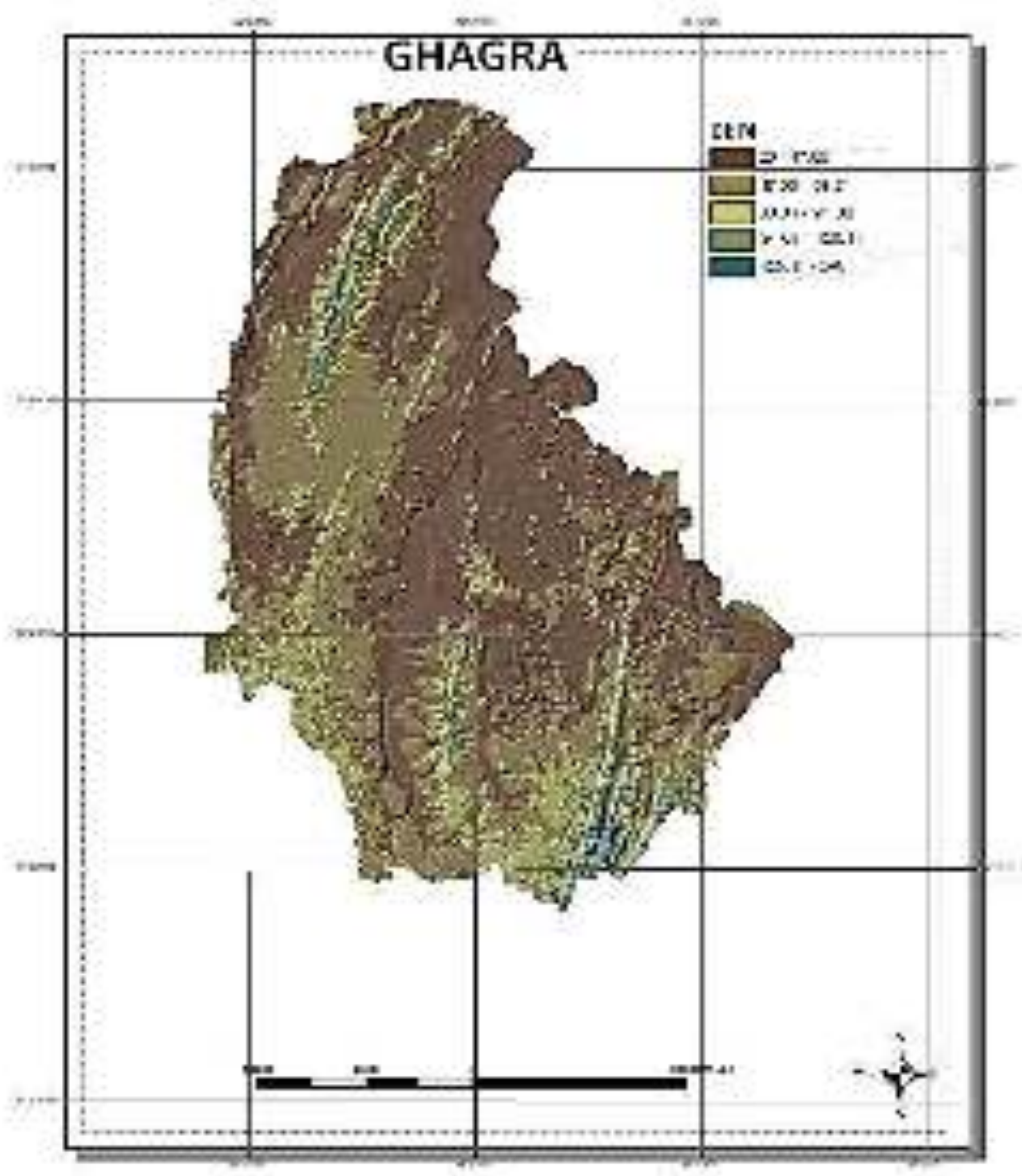


Figure-4.5: Digital Elevation Model of Ghagra sub basin

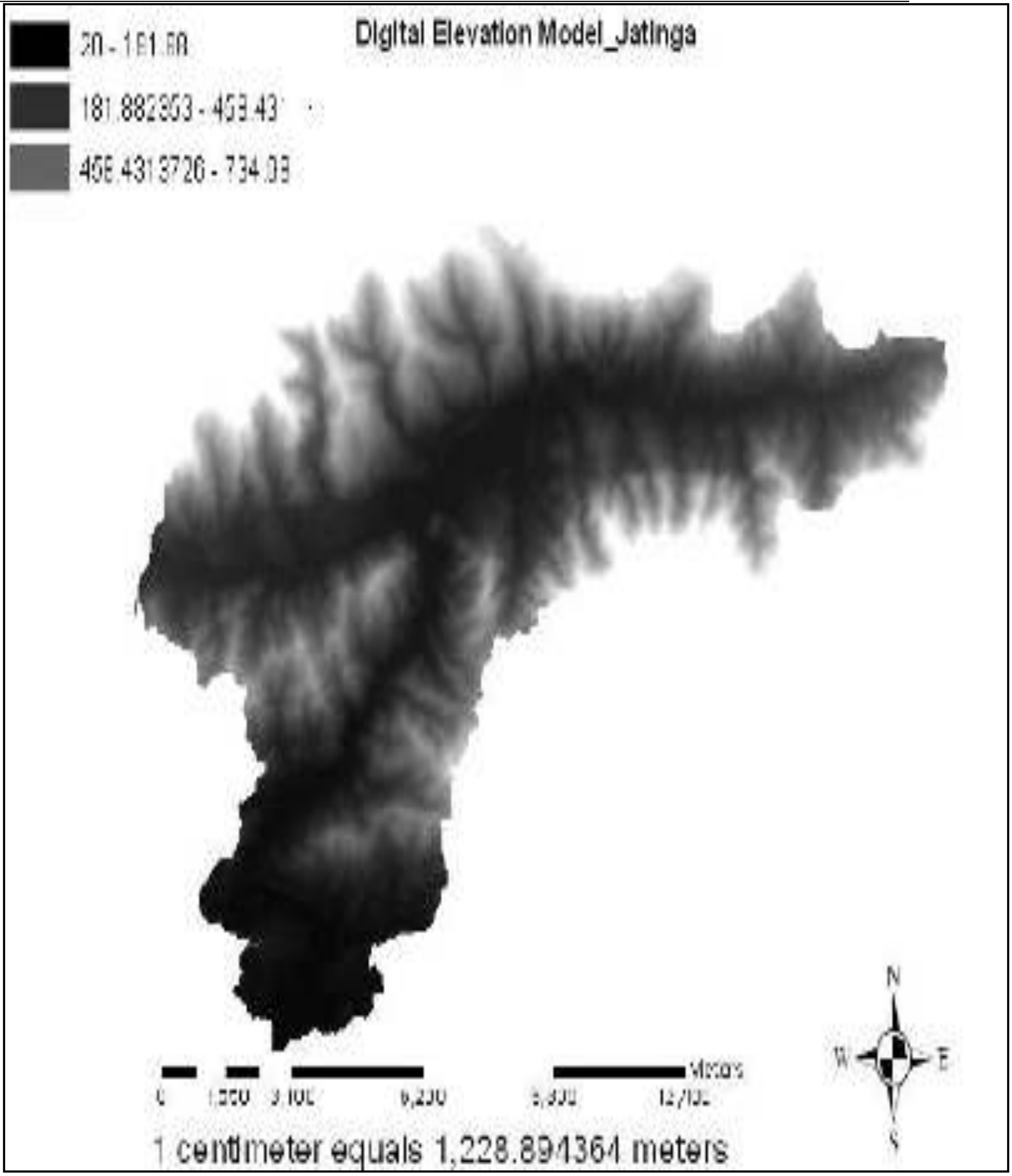


Figure-4.6: Digital Elevation Model of Jatinga sub basin

4.4Development Stream Network for the watersheds

For watersheds in the study area the corresponding DEMs are used to develop the stream network for these watersheds. The generated DEM are analyzed using, Calculate statistic GIS tooltaking the DEM as an input. The spatial analysis tool is used to develop depressionless DEM for the watersheds. Using the rectified DEM a raster of flow directions from each cell to its steepest downslope neighbor cell is created. Flow direction is generated using DEM as an input to Hydrology tool. The output of the flow direction tool is used to generate flow accumulation raster which is determined by accumulating the weight for all the cells that will flow into each cell. The generation of flow accumulation raster is achieved by using the generated flow direction raster as an input to Hydrology tool "flow accumulation". A threshold value that gives the minimum number of upslope cells contributing to a downstream cell is required. The stream network raster for the watershedsare generated using Map Algebra/ Conditional tool. The generated stream networksare ordered using Strahler stream ordering tool in the ArcGIS.. It adopts Strahler' Stream ordering law (Strahler, 1952) for ordering the stream network. In the Strahler ordering method, all streams with no tributaries are assigned an order of one and are referred to as first order. When two first-order streams intersect, the downslope stream is assigned an order of two. When two second-order streams intersect, the downslope stream is assigned an order of three, and so on. When two streams of the same order intersect, the order will increase. Strahler order method is the most common method used for ordering stream network. On the basis of the ordered stream network and flow direction map watershed area draining through different streams are delineated by using hydrology tool.

4.5 Generation of Slope map for watersheds using Topographic Map, SRTM/ASTER DEM.

The slope map of a watershed represents the degree of steepness (slope) of the watershed surface at different locations. The Slope map in slope percent for the watersheds is developed using rectified DEM in 3D analysis tool. Detailed description of the sub basins in the study area, drainage networks and slope map for the sub basins are presented in the tables and figures listed below.

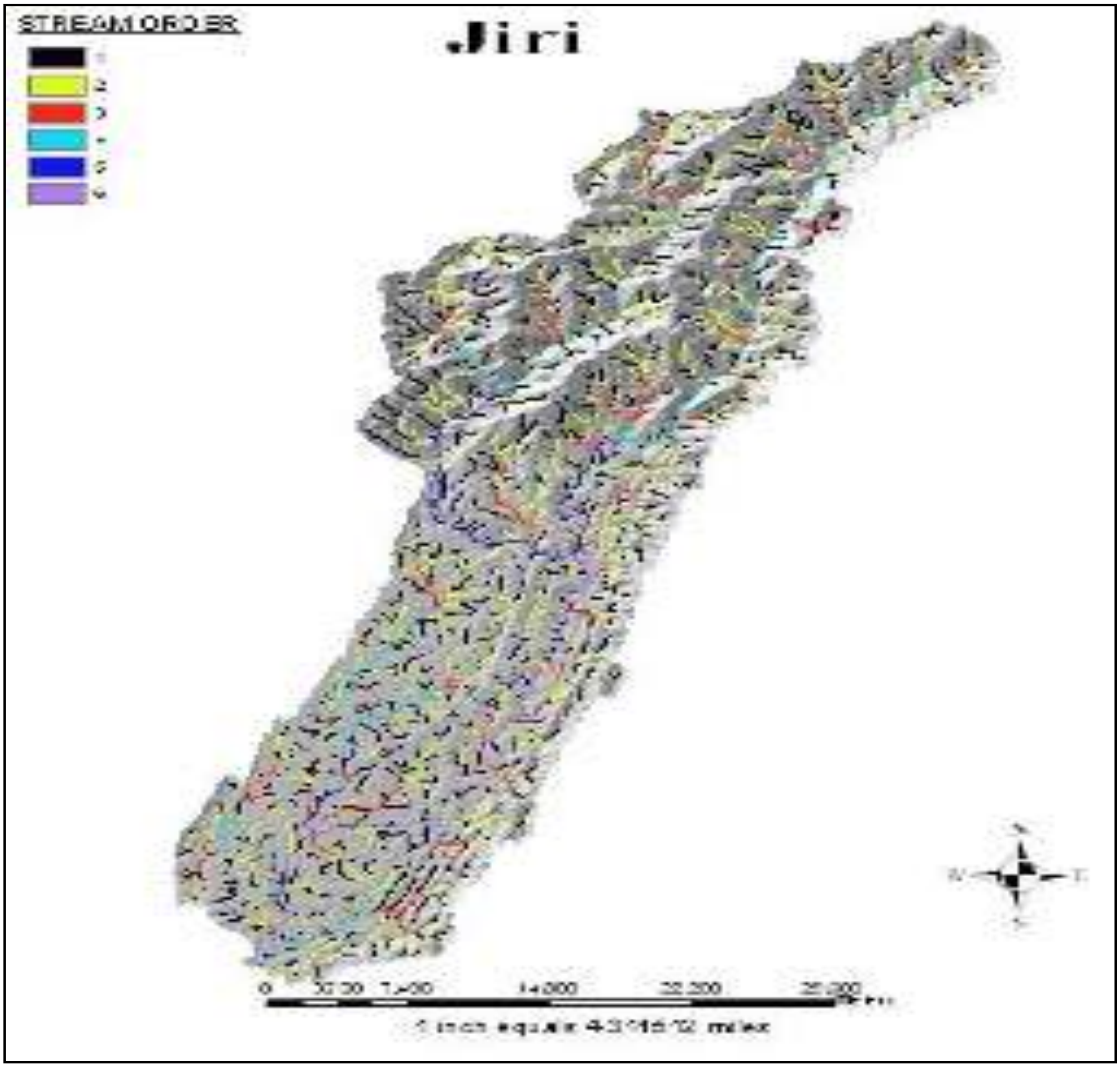


Figure-4.7: Drainage network in Jiri sub catchment

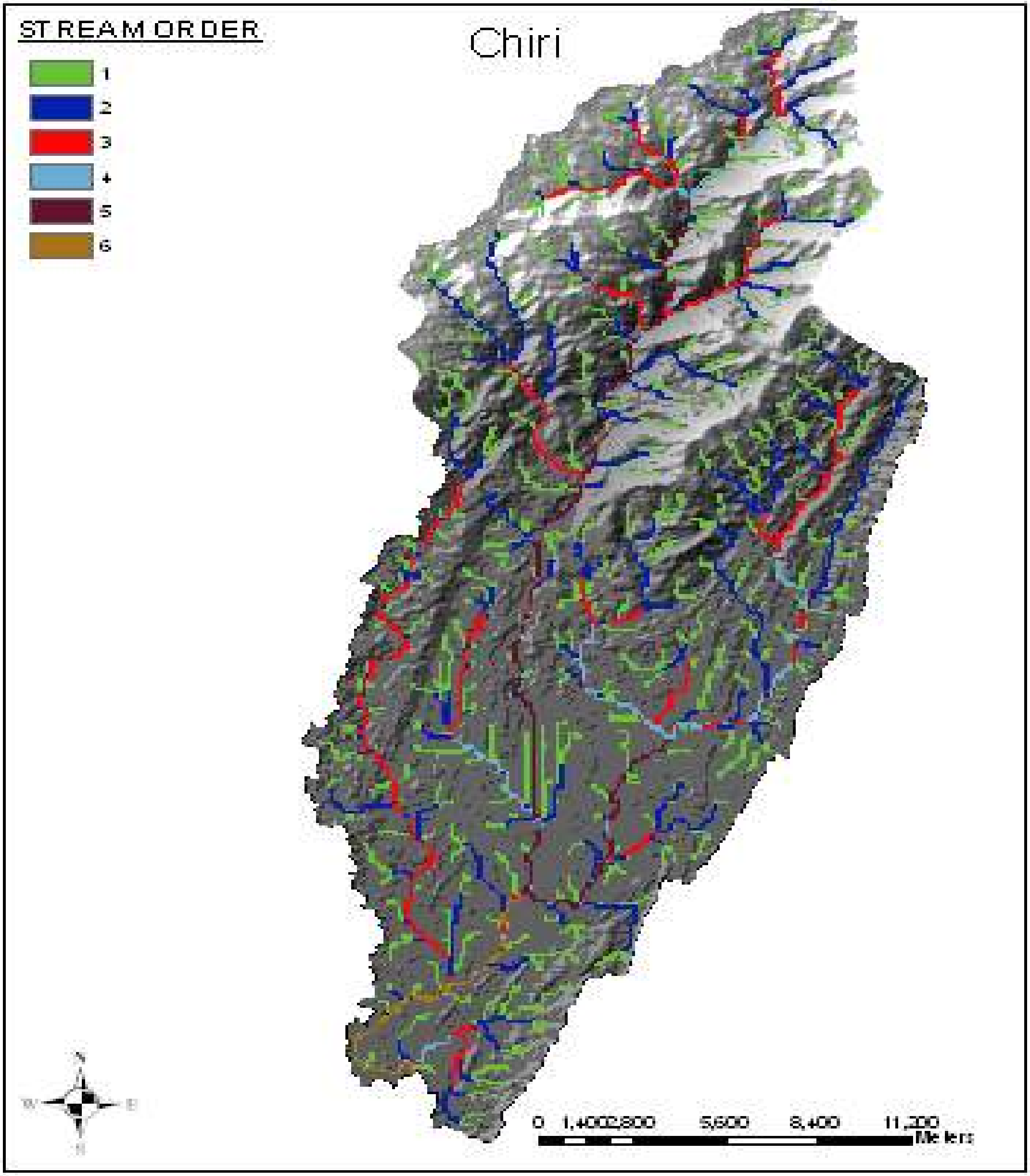


Figure-4.8: Drainage network in Chiri sub catchment

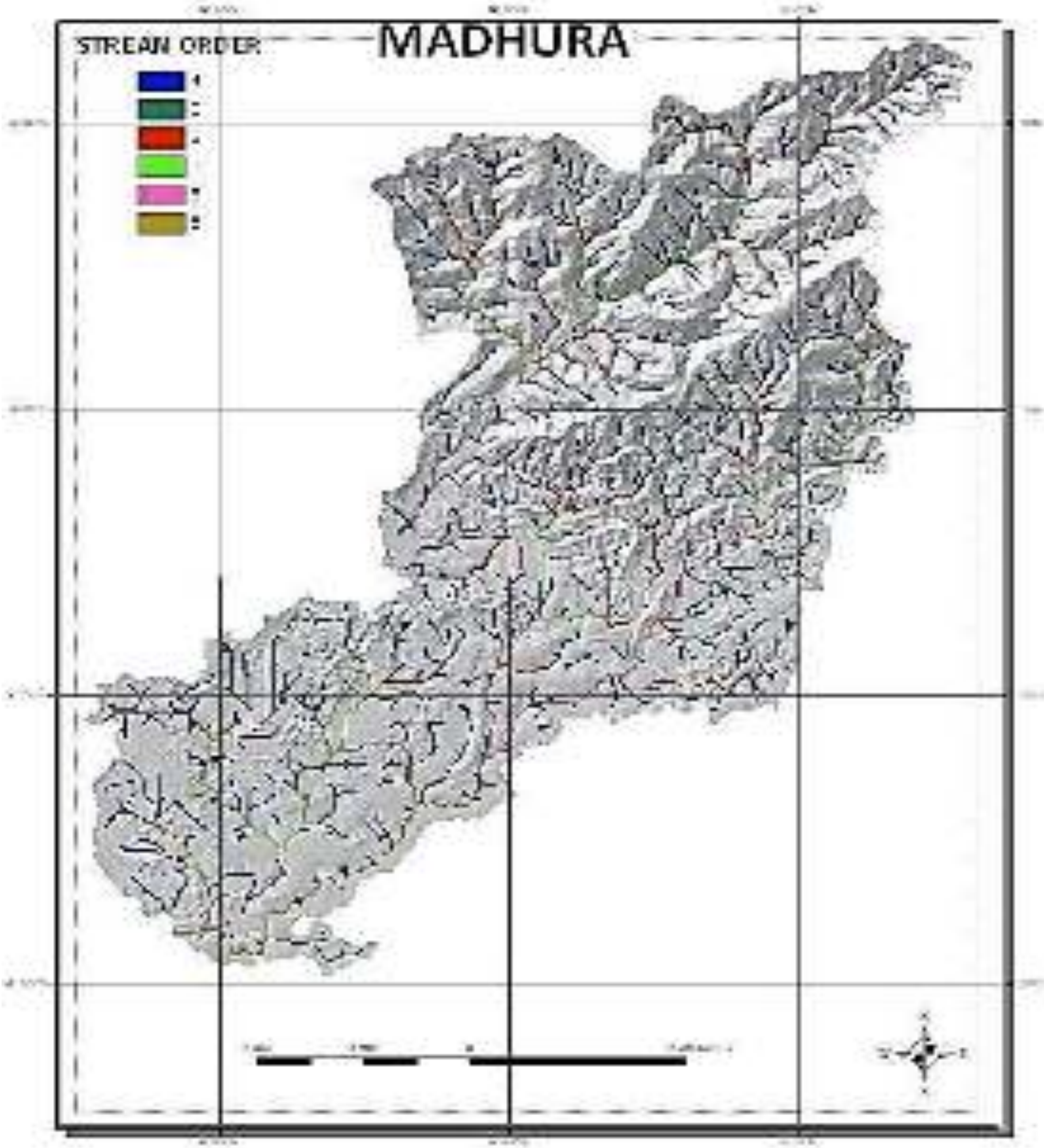


Figure-4.9: Drainage network in Madhura sub catchment

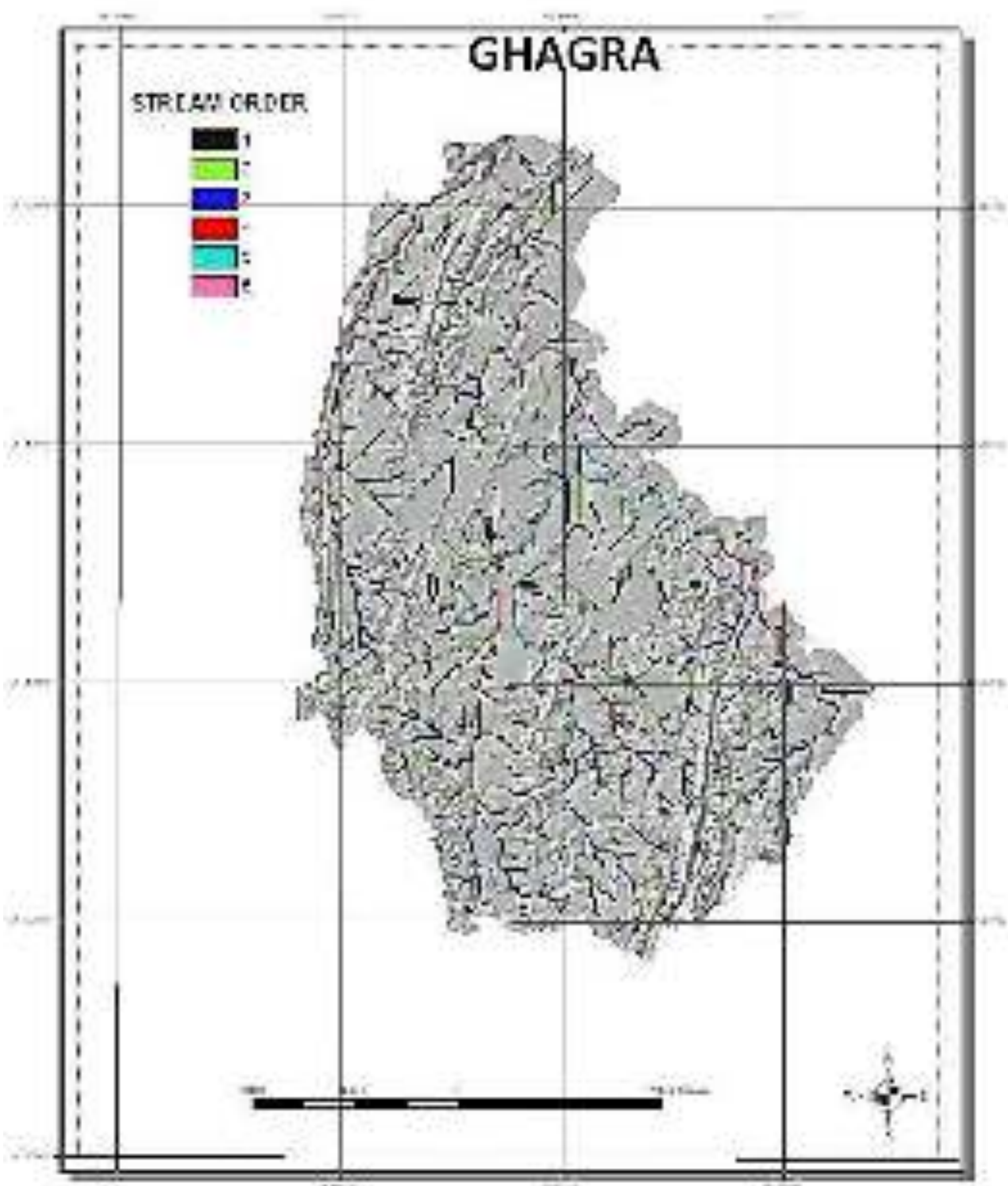


Figure-4.10: Drainage network in Ghagra sub catchment

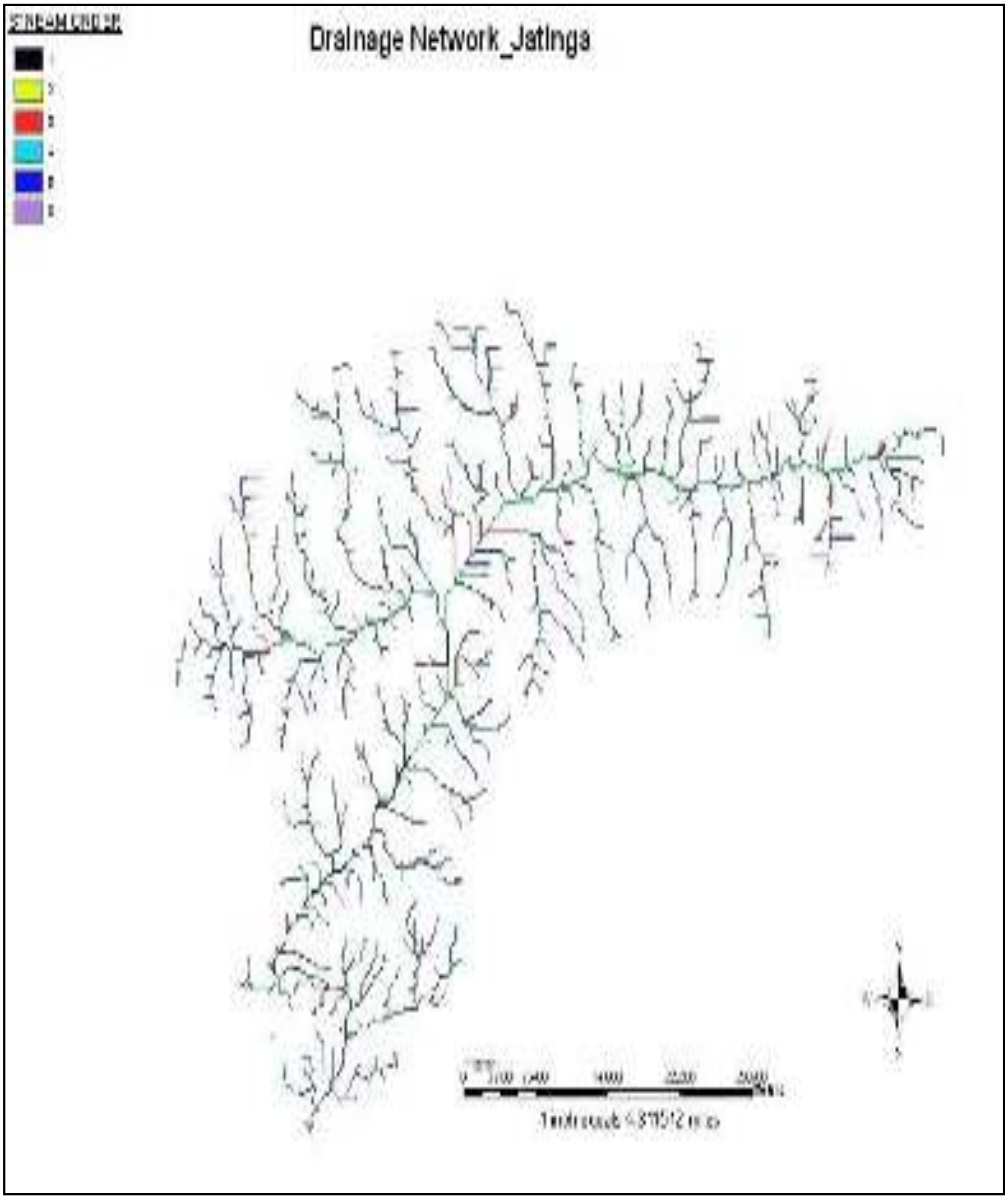


Figure-4.11: Drainage network in Jatinga sub catchment

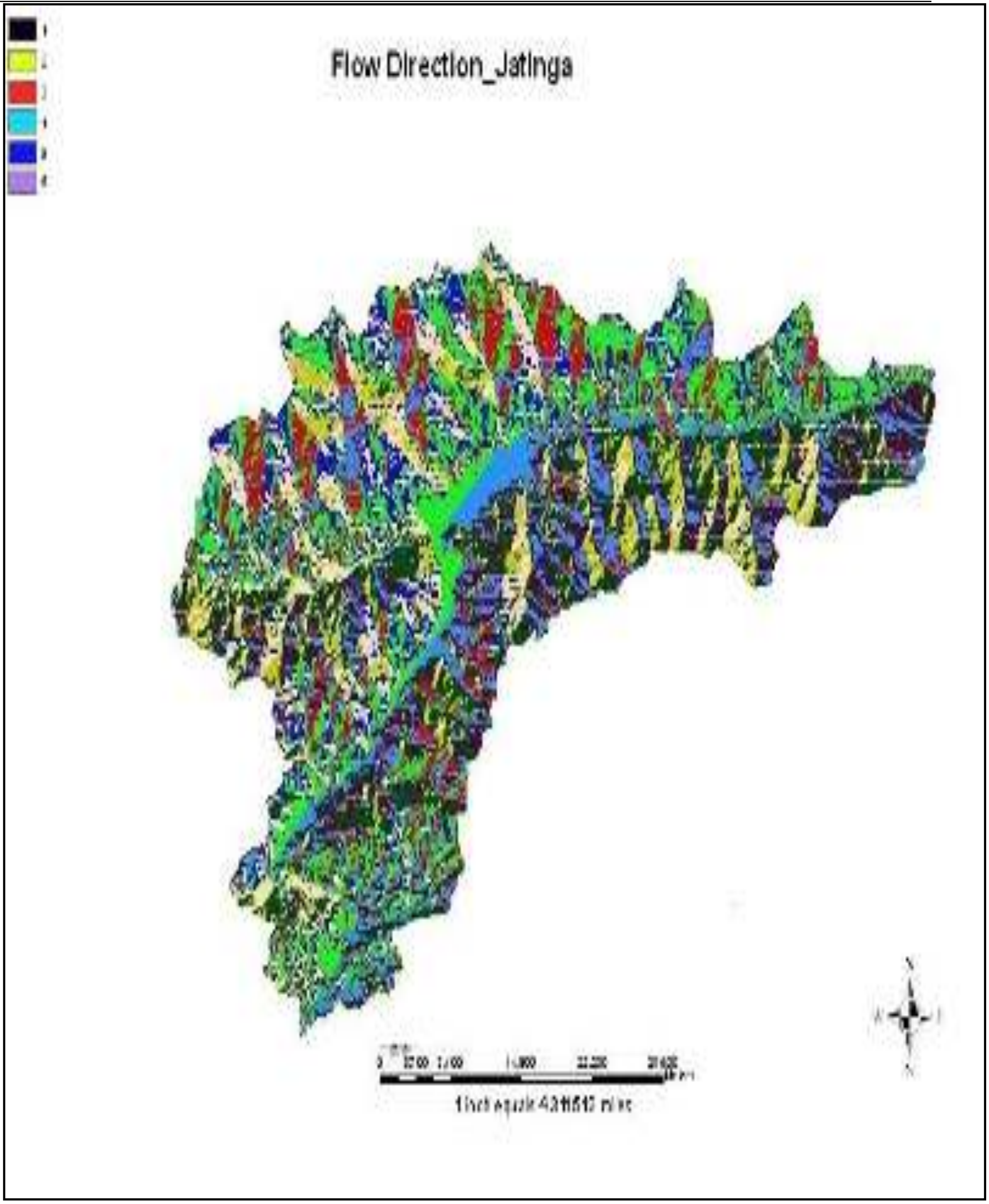


Figure-4.12: Flow direction in Jatinga sub catchment

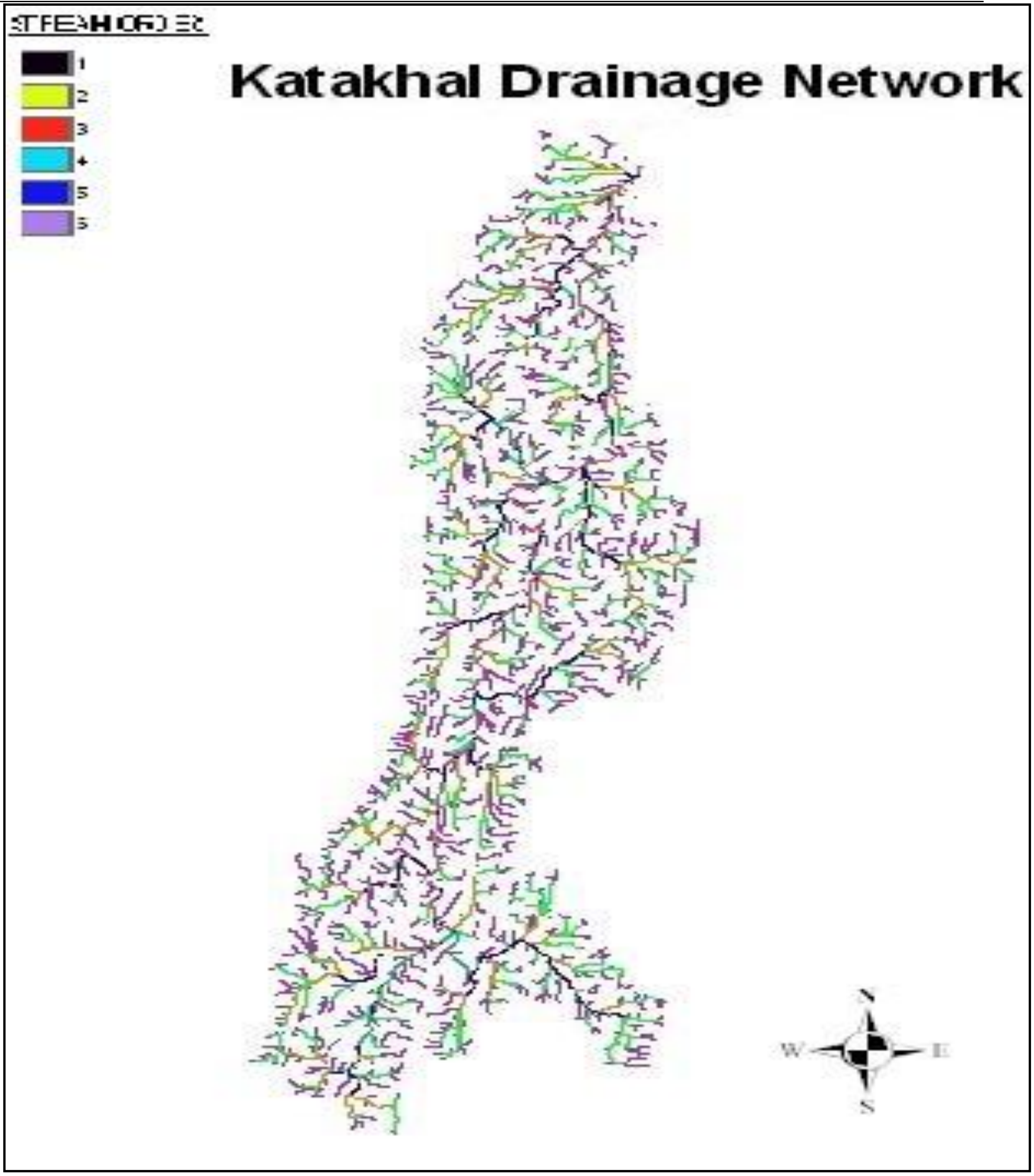


Figure-4.13: Drainage network in Katakhal sub catchment

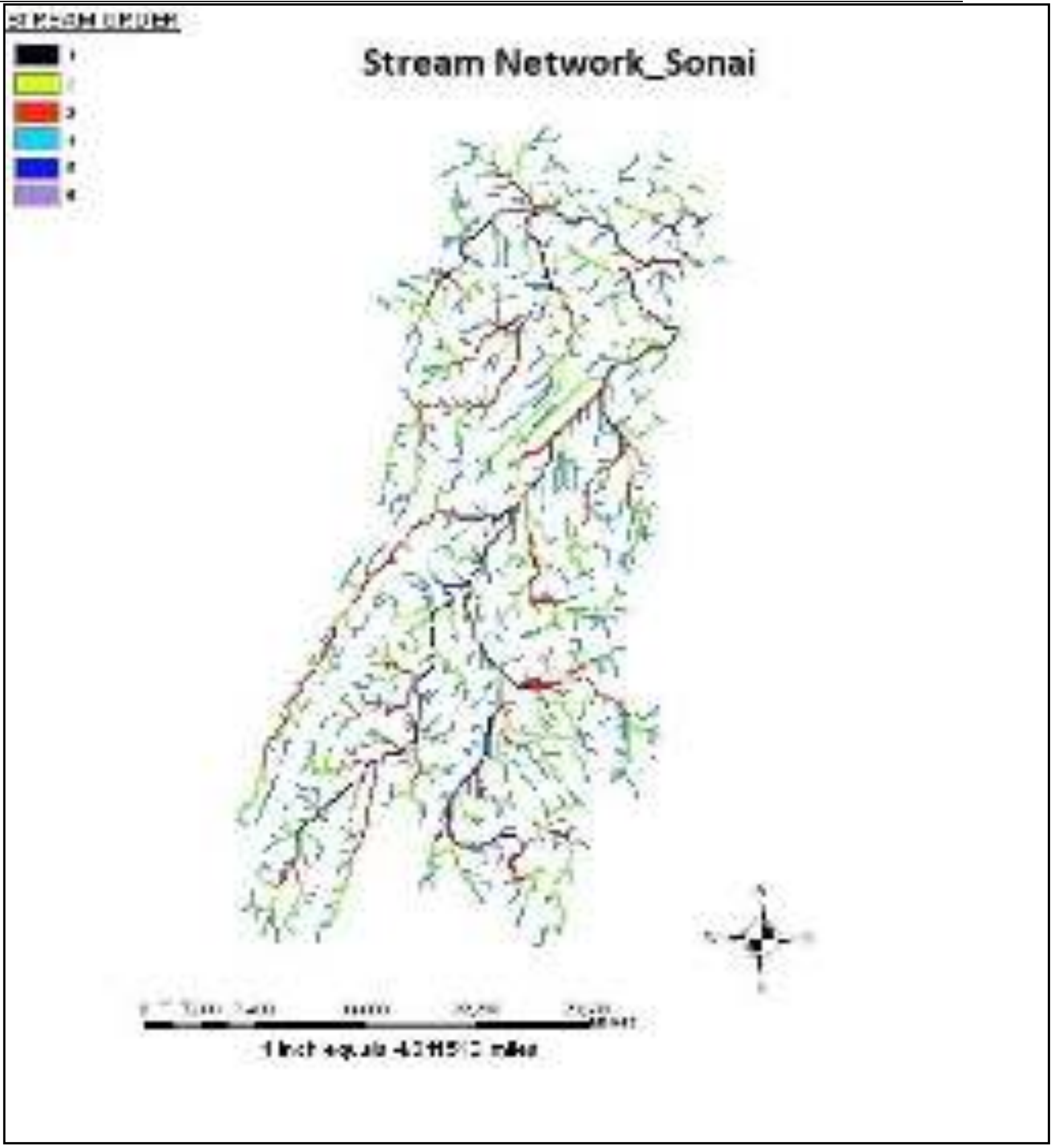


Figure-4.14: Drainage network in Sonai sub catchment

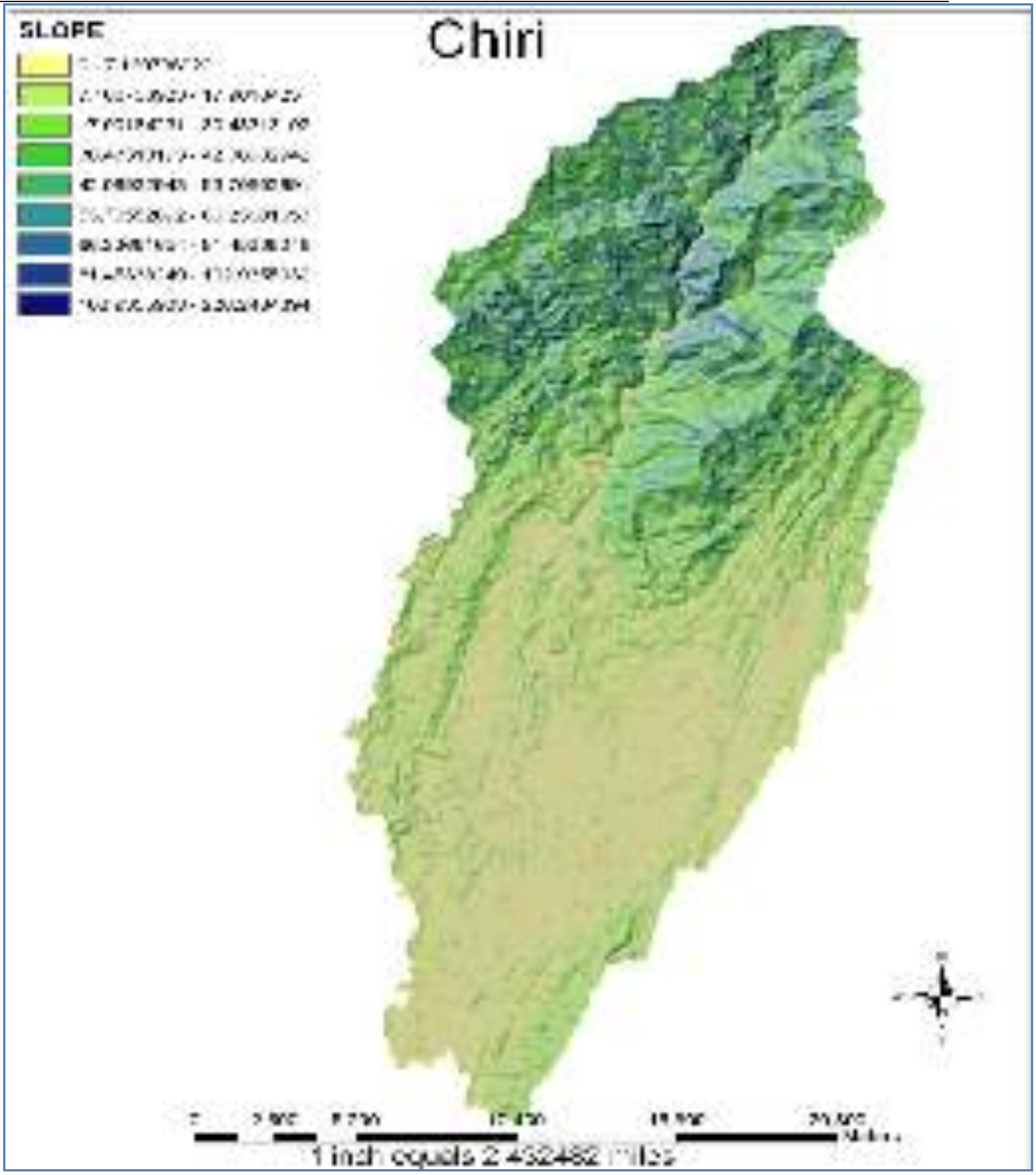


Figure-4.15: Slope map for Chiri sub catchment

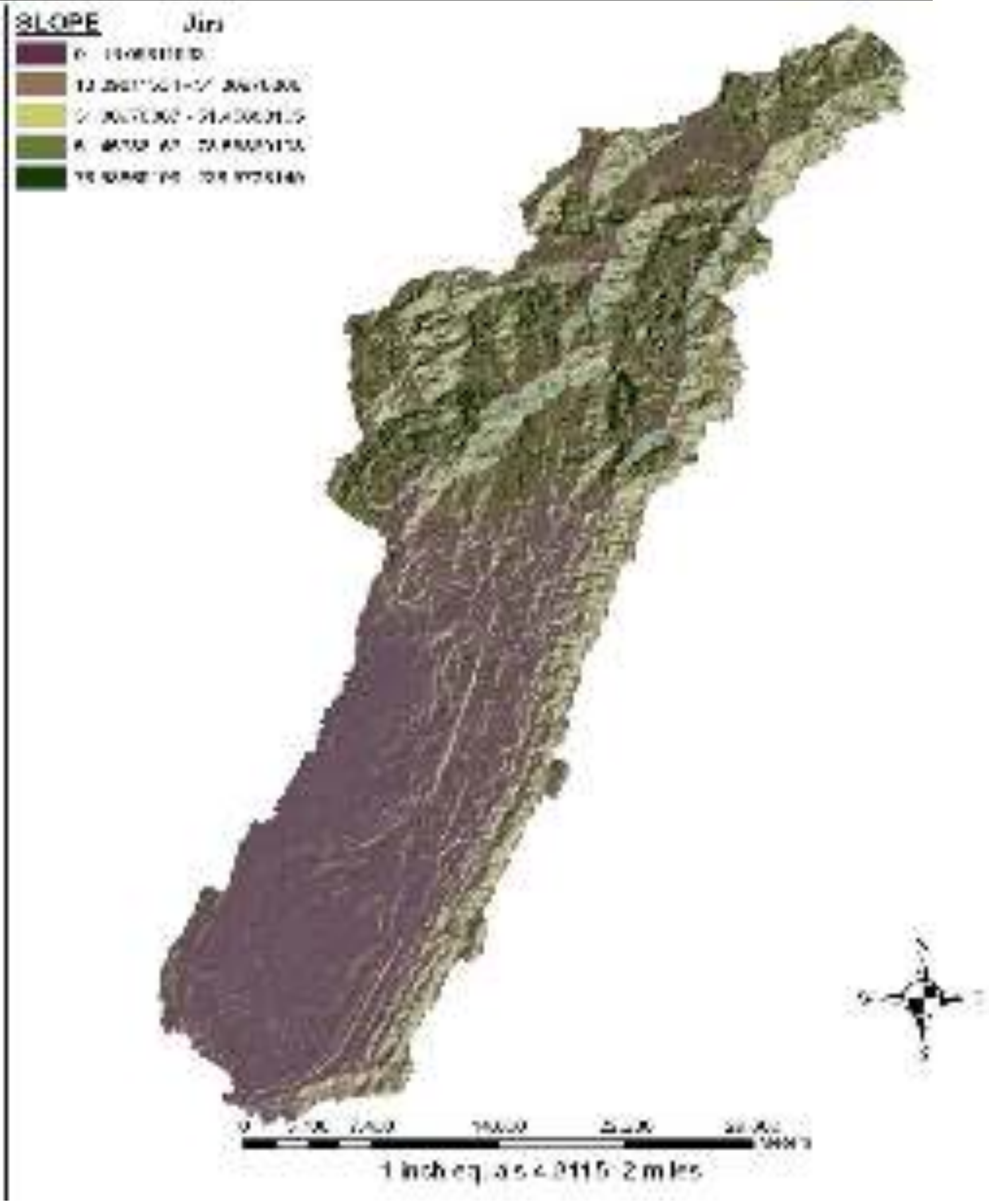


Figure-4.16: Slope map for Jiri sub catchment

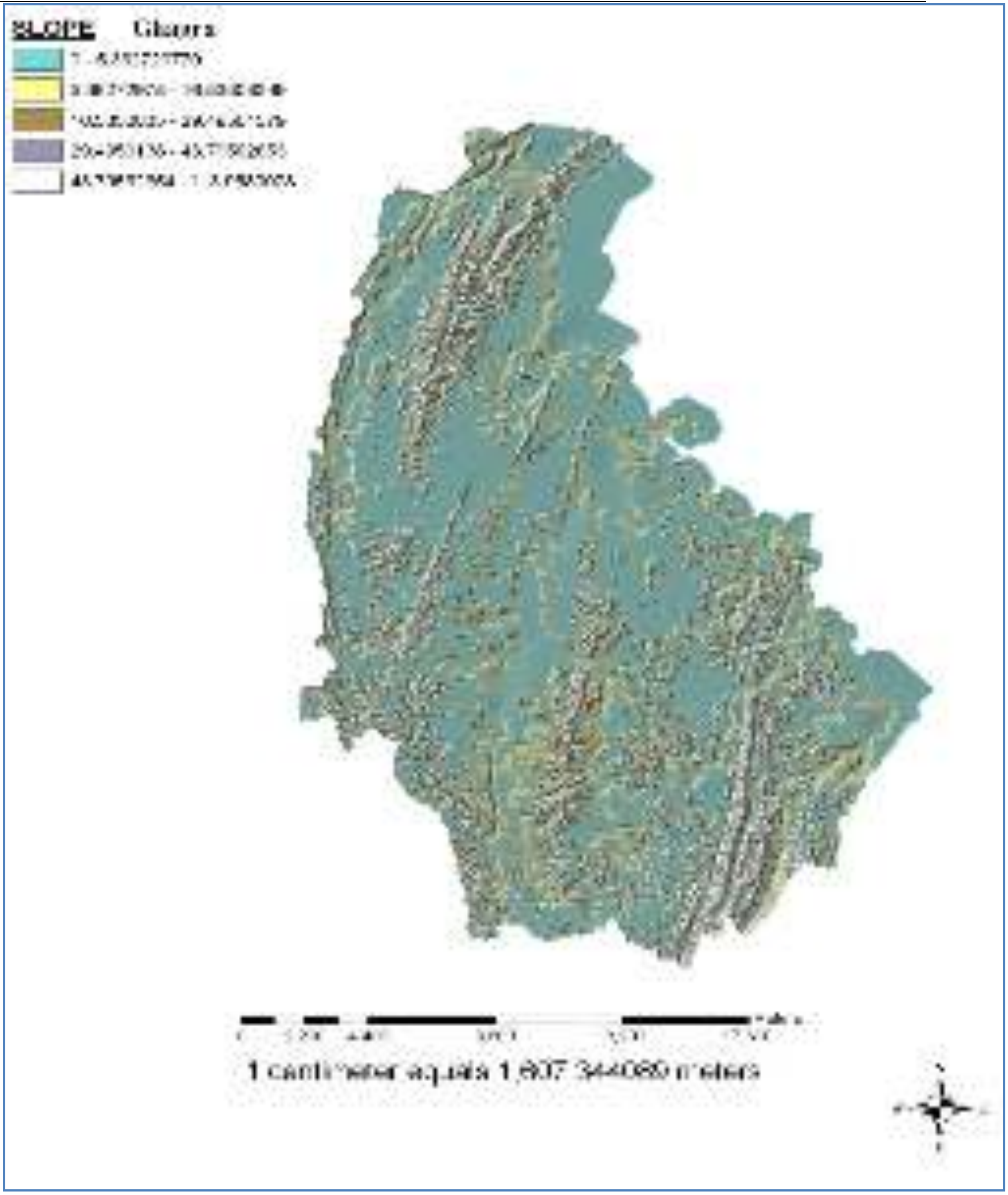


Figure-4.17: Slope map for Ghagra sub catchment

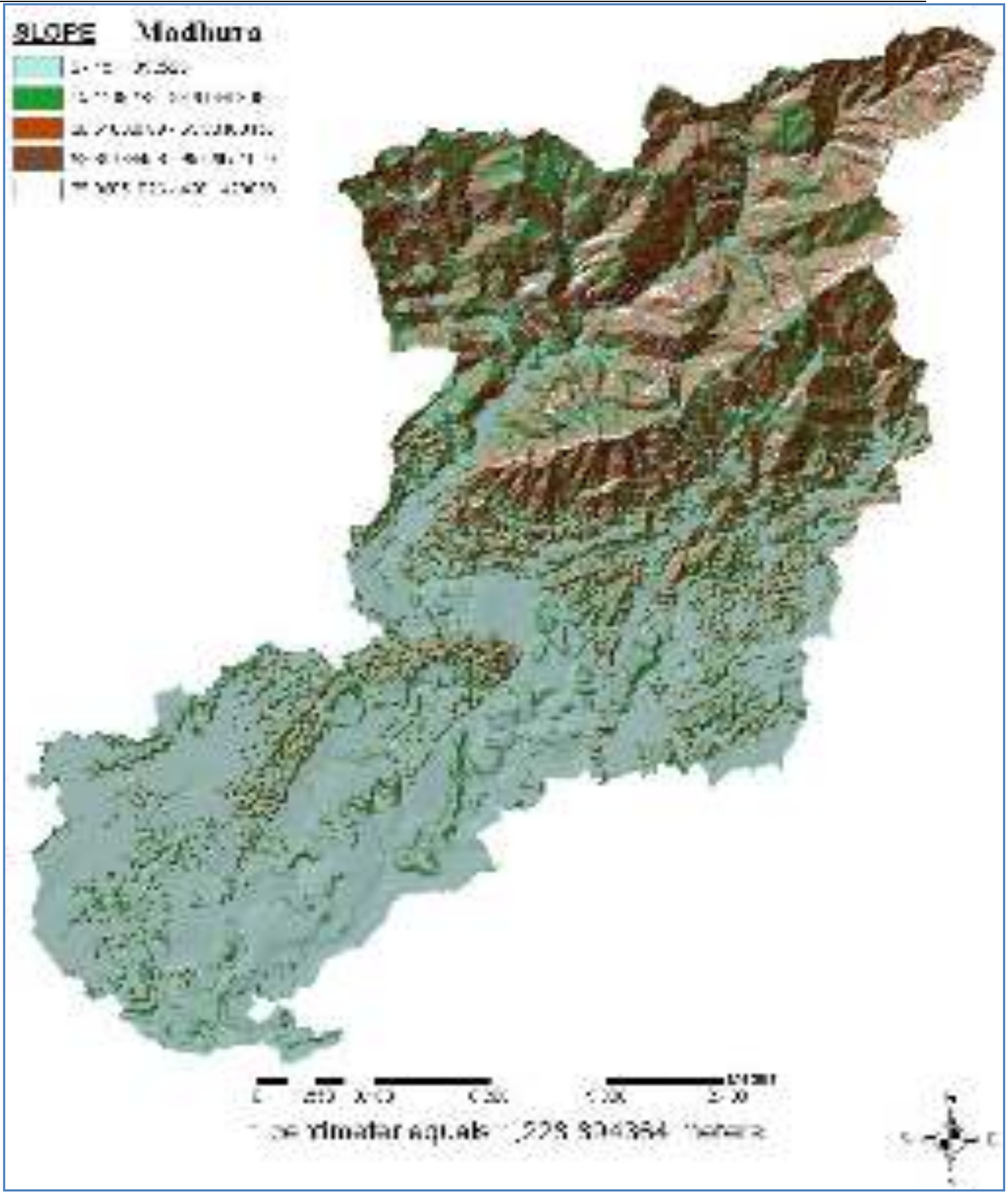


Figure-4.18: Slope map for Madhura sub catchment

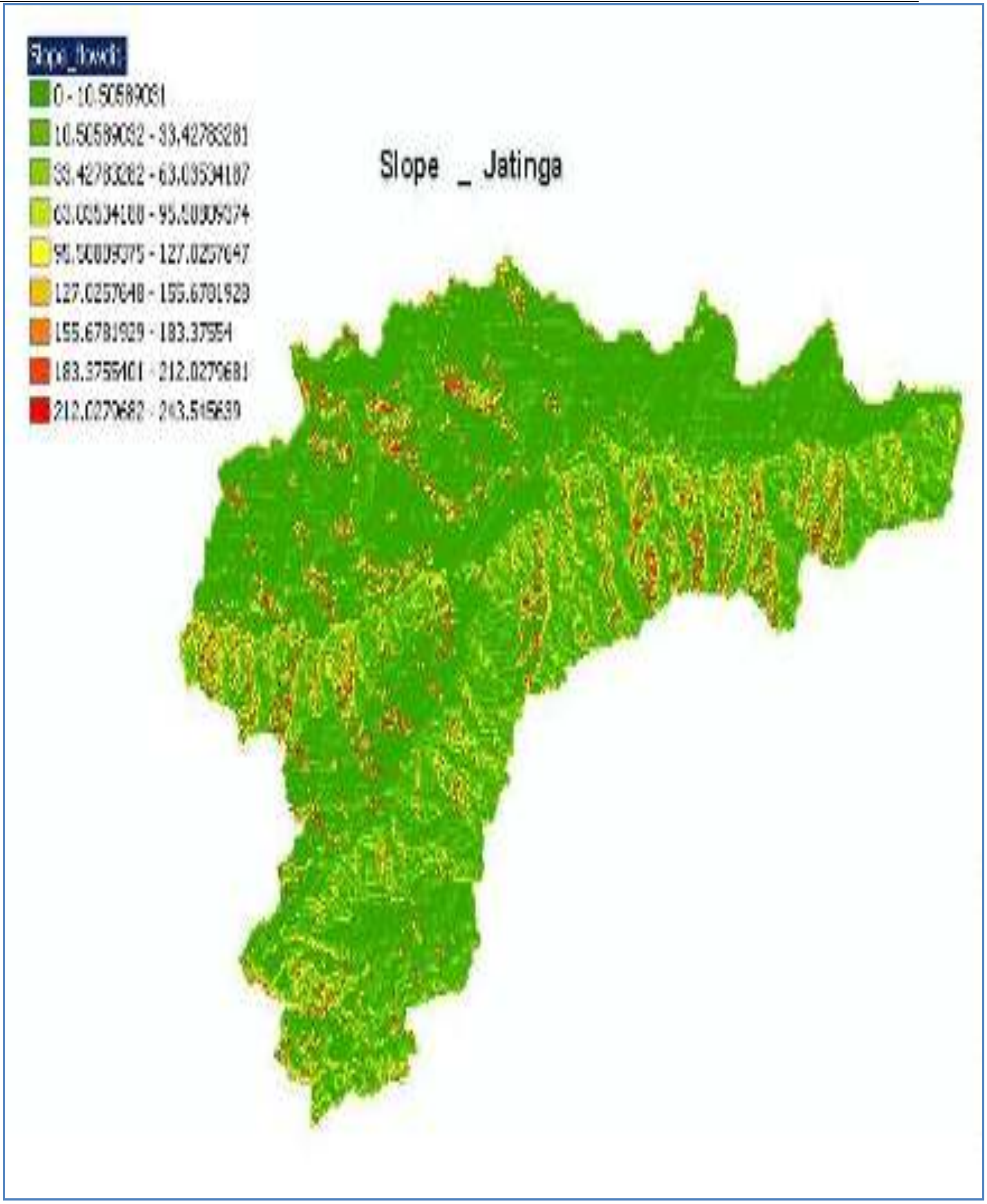


Figure-4.19: Slope map for Jatinga sub catchment

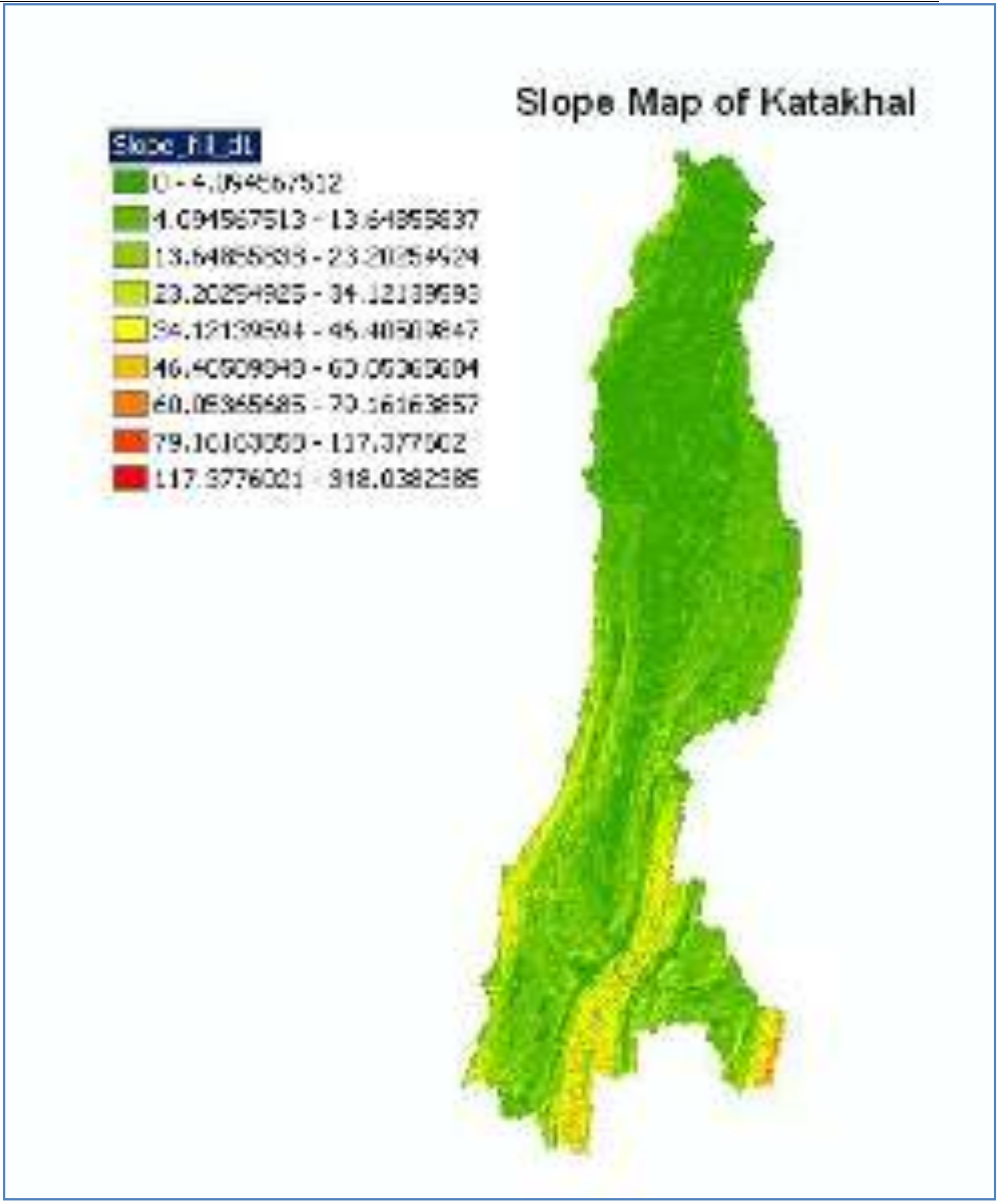


Figure-4.20: Slope map for Katakhal sub catchment

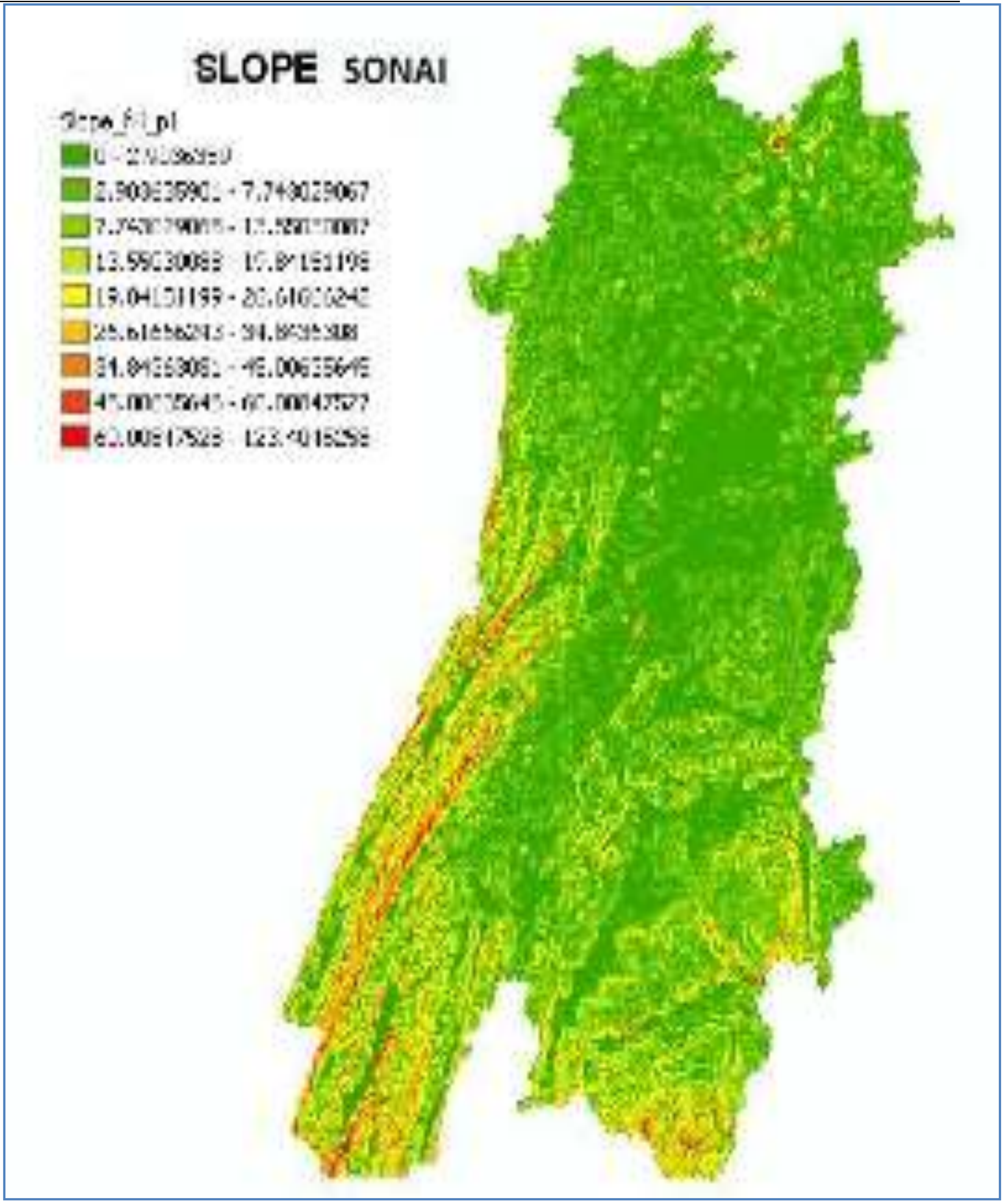


Figure-4.21: Slope map for Sonai sub catchment

Table-4.1: Watershed and Drainage Characteristics of Sub basins in the Study Area

Watersheds	Drainage Characteristics	Stream Order						Watershed Area (km^2)	Average Slope $(\%)$	Main stream length (km)	Watershed perimeter (km)
		1	*2*	*3*	*4*	*5*	*6*				
Madhura	***Total Count***	781	177	42	10	3	1	349.43	0.28	52.61	170.85
	Average stream length (km)	0.422	0.94	2.072	4.769	12.88	14.59				
Ghagra	***Total Count***	506	131	33	7	2	1	409.39	0.09	48.93	157.84
	Average stream length (km)	0.659	1.04	2.487	5.907	9.803	19.784				
Jiri	***Total Count***	*1083*	277	56	9	3	1	*1052.85*	0.22	49.85	152.63
	Average stream length (km)	*0.635*	1.37	2.429	11.69	14.86	48.09				
Chiri	***Total Count***	*569*	124	26	*8*	2	1	438.66	0.26	104.48	275.0
	Average stream length (km)	*0.59*	1.46	3.39	4.36	19.80	11.62				
Katakhal	***Total Count***	1183	282	68	19	4	1	1504.6801	10.64%	129.88	401.00
	Average stream length (km)	0.65	1.45	2.12	10.8	13.62	57.43				
Jatinga	***Total Count***	417	100	25	2	1		371.86	35.085%	55.39	156.00
	Average stream length (km)	0.55	1.03	2.10	4.32	22.93					
Sonai	***Total Count***	614	169	37	08	02	01	488.249	7.798%	95.212	203
	Average stream length (km)	0.60	1.36	3.21	4.11	11.05	15.976				

5.0 Hydrological Modeling: Development of Unit Hydrographs

Hydrologic responses of a watershed are influenced by geomorphologic characteristics of the watershed. Characterization and quantification of such characteristics is useful and essential in the process of evaluating the hydrologic response of a watershed. These characteristics relate to the physical characteristics of the drainage basin and drainage network; physical characteristics of the drainage basin include drainage area, basin shape, ground slope, and centroid (i.e. centre of gravity of the basin). Channel characteristics include channel order, channel length, channel slope, channel profile, and drainage density. Handling and modeling of such spatially varying parameters have become more efficient and accurate with the emergence of advance computing techniques, Geographic Information System (GIS). For deriving UH using GIUH models different watershed characteristics such as stream length, watershed area, slope, etc are essential. Using topographic maps/SRTM/ASTER data and remote sensing data in GIS software like ArcGIS, ERDAS imagine, ILWISS, etc Digital Elevation Model (DEM) can be developed and analyzed. With DEM as an input to quantify the watershed characteristics slope map, stream map, etc may be obtained. Watershed characteristics for the sub basins in the study areathat were estimated by using GIS supported techniquesis given in table-4.1. DEM, Stream networks and the slope maps for the watersheds in the study area are also presented in the earlier sections. Using DEM flow direction and flow accumulation maps for the watersheds are developed. With the drainage network map as input and using Strahler's stream ordering law the drainage network for the watersheds are ordered applying GIS stream ordering tool. On the basis of the ordered drainage network, areas drained and stream lengths for different stream orders are obtained. Horton's geomorphologic parameters (Horton, 1945) R_A, R_B and R_L for the watershed are estimated graphically by plotting average areas drained, stream numbers and average stream length respectively against the stream orders. Absolute slope value for the best fit line is taken to compute the ratios. Graphical representations showing best fit line is used for computing R_A, R_B and R_L for the watersheds.

The best fit lines for Madhura and Ghagra watersheds are shown in Figures. Estimated geomorphologic parameters for all watersheds are given in the Table-4.1. Estimated watersheds mean slope and main stream length values are used in equation (5.1) to obtain velocity factor for the watersheds respectively. The velocity parameter estimated for Madhura and Ghagra watersheds are listed in the Table-5.2. The listed parameters are used to develop triangular based 1hr UHs for the watersheds applying GIUH techniques.

The GIUH model given by equations (5.1), (5.2) and (5.3) are used to estimate peak discharge, time to peak and time base of the IUH for the watersheds in the study area.

$$V = 0.8562 L^{0.23} S^{0.385} \quad (5.1)$$

$$q_p = 1.31 R_L^{0.43} (V / L_\Omega) \quad (5.2)$$

$$t_p = 0.44 (L_\Omega / V)(R_B / R_A)^{0.55} (R_L)^{-0.38} \quad (5.3)$$

$$t_b = 2 / q_p \quad (5.4)$$

Here, $q_p =$ peak flow in units of inverse hours (h^{-1}); $t_p =$ time to peak in hours (h); $V =$ dynamic parameter velocity (m/s); $L_\Omega =$ length of the highest order stream in the watershed (km); and R_L, R_B and $R_A =$ Horton's length ratio, bifurcation ratio and area ratio respectively. To develop IUH for the watersheds dynamic parameter velocity estimated for the watersheds and listed in Tables are used in equations (5.2) and (5.3) obtaining q_p, t_p and t_b values for the watersheds.To develop UH for the watersheds the subbasins are segmented into a number subwatersheds and IUH for these subwatersheds are computed applying GIUH technique. The sub water IUHs are lagged to develop 1-hr UH for the sub watersheds. The UHs routed to the main watershed outlet using kinematic wave technique and superimposed obtaining IUH for the main watershed.Detailed description of unit hydrograph computation for two watersheds, Madhura and Ghagra watersheds are listed.IUH ordinates for the watersheds at an interval of

$0.1h$ are computed and lagged applying S-Curve technique to derive 1hr UH for the watersheds. 1-hr UH estimated for the watersheds using GIUH technique are shown in the figures and tables presented in the next pages.

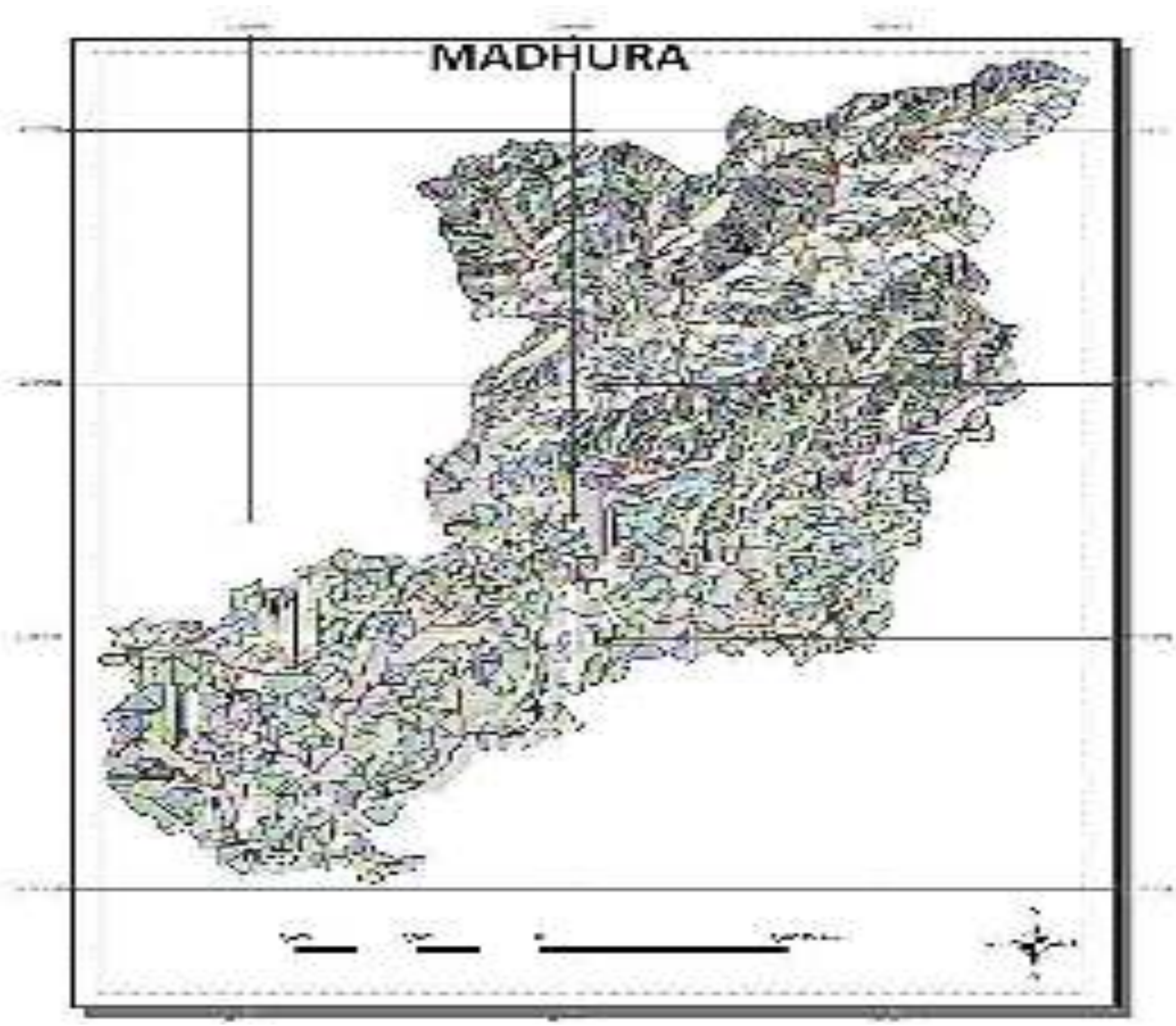


Figure-5.1: 1st order watersheds for Madhura

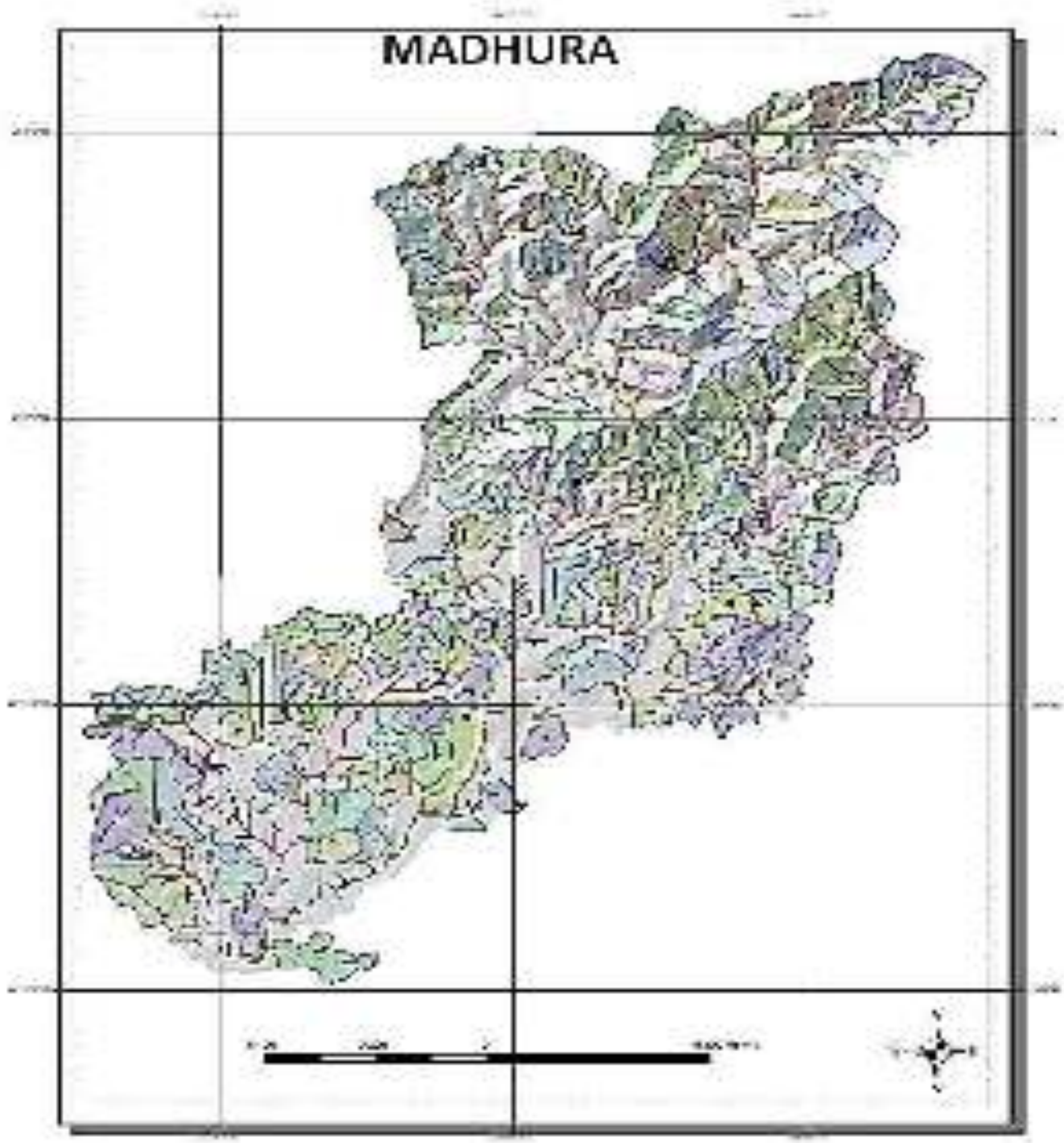


Figure-5.2: 2nd Order sub-watersheds for Madhura.

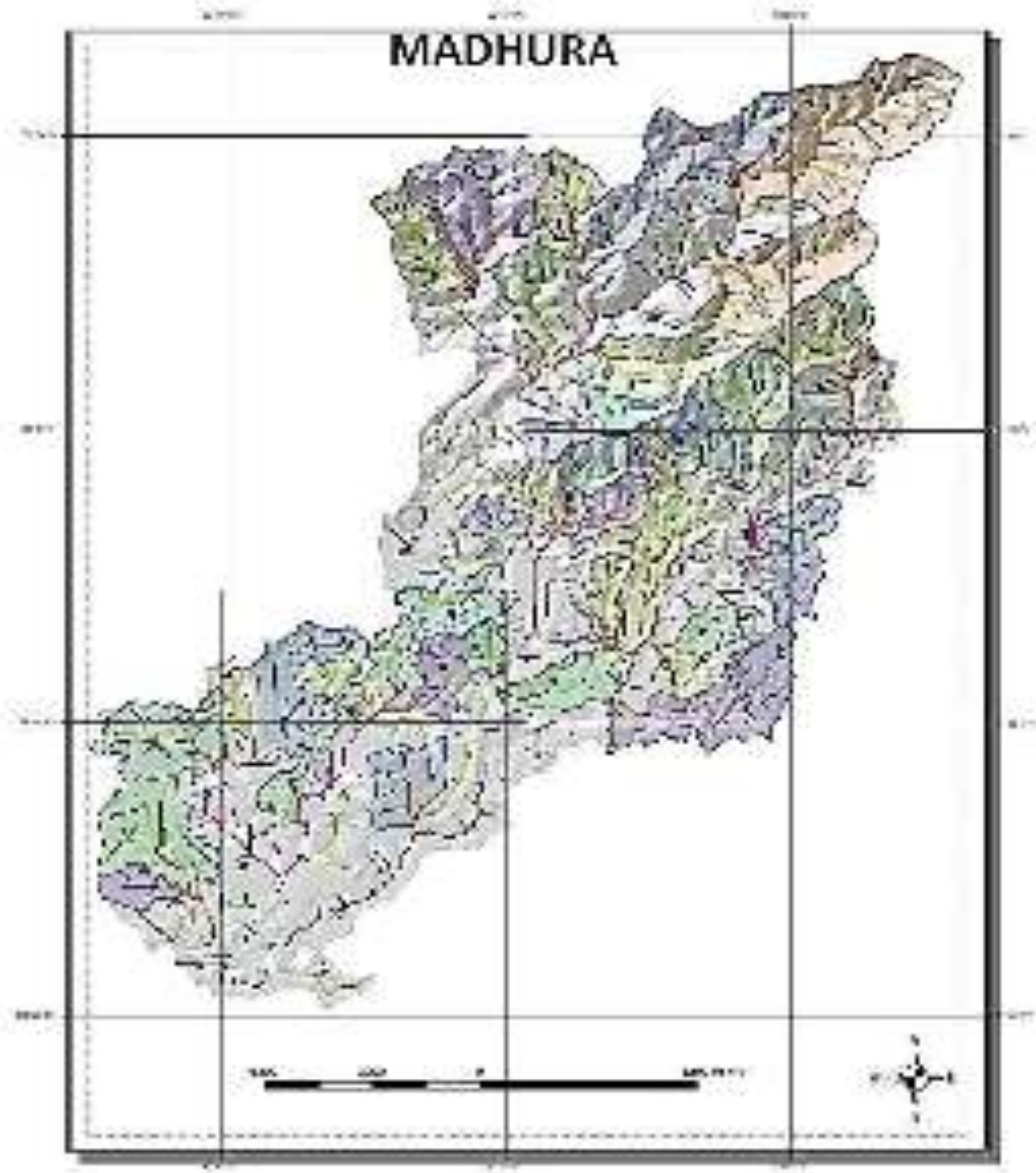


Figure-5.3: 2nd Order sub-watersheds for Madhura.

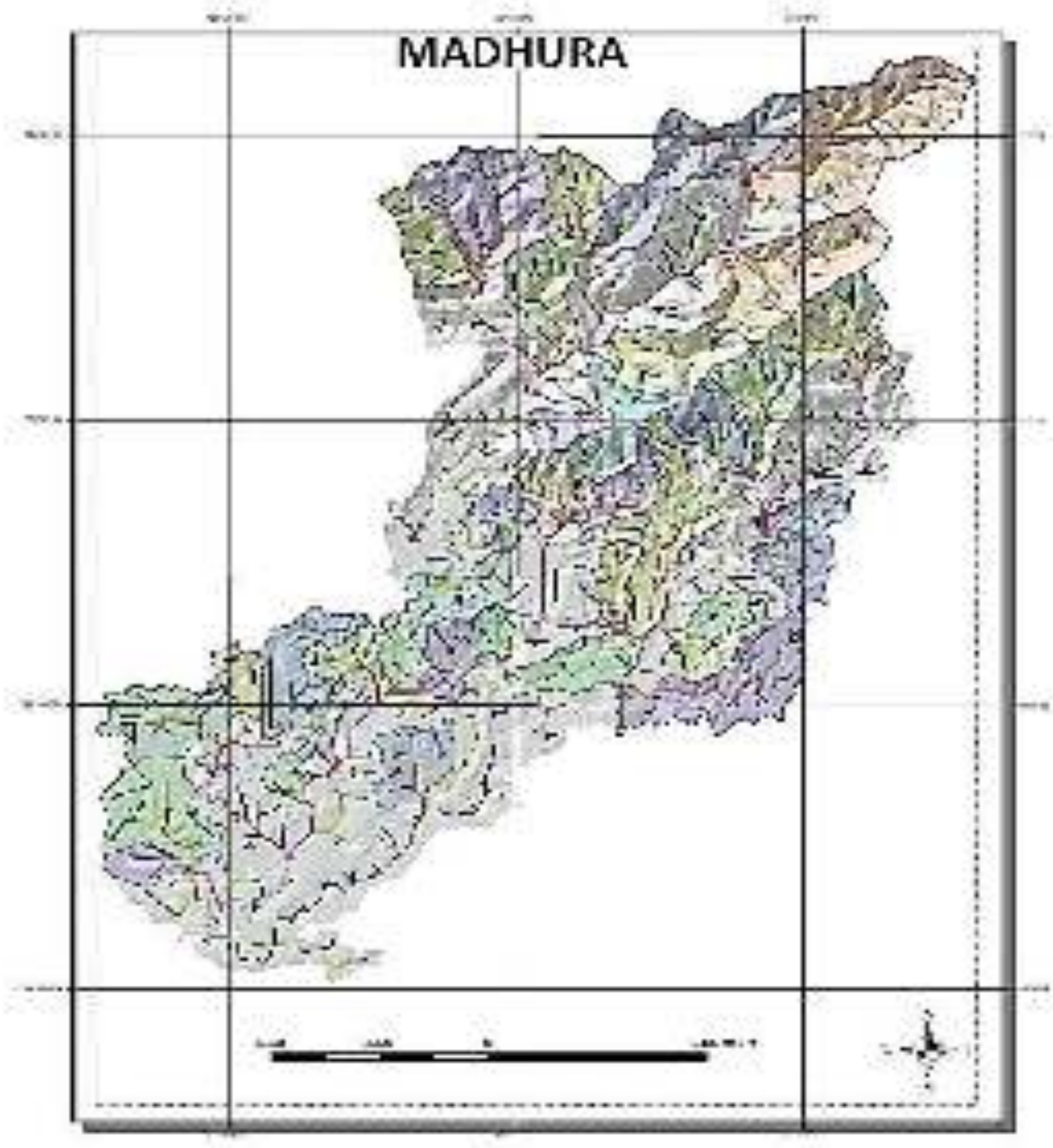


Figure-5.4: 3rd Order sub-watersheds for Madhura

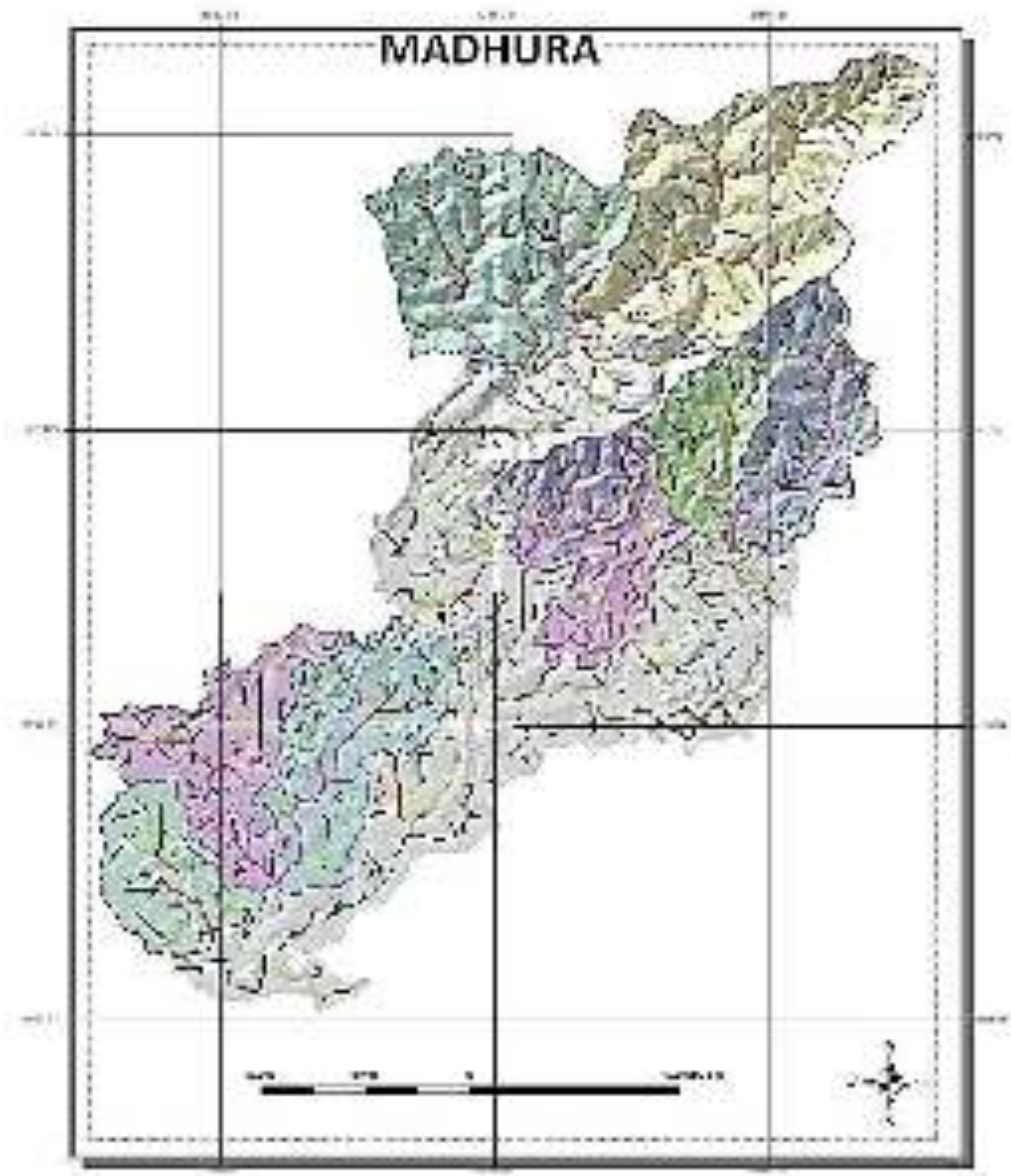


Figure-5.5: 4th Order sub-watersheds for Madhura.

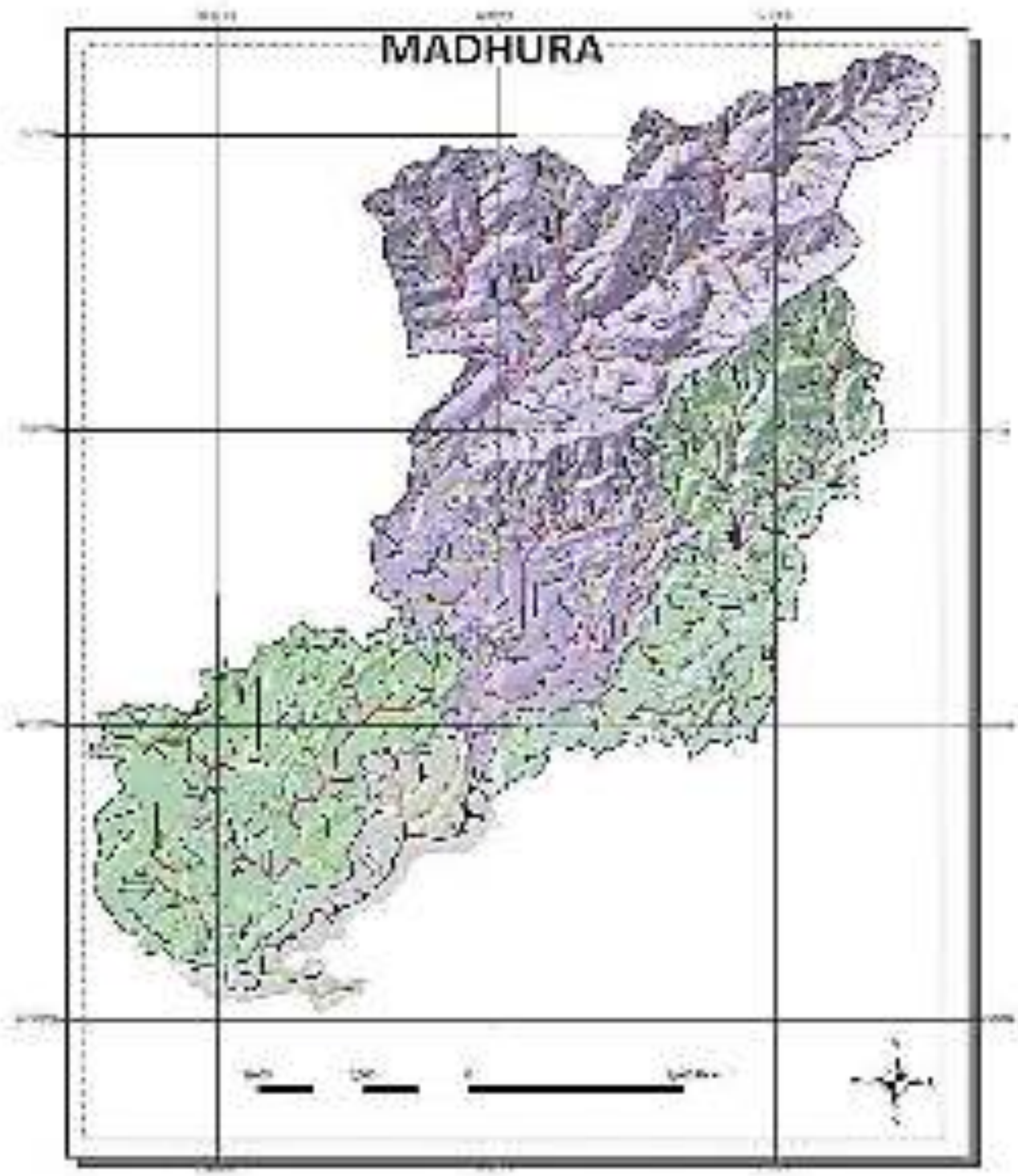


Figure-5.6: 5th Order sub-watersheds for Madhura.

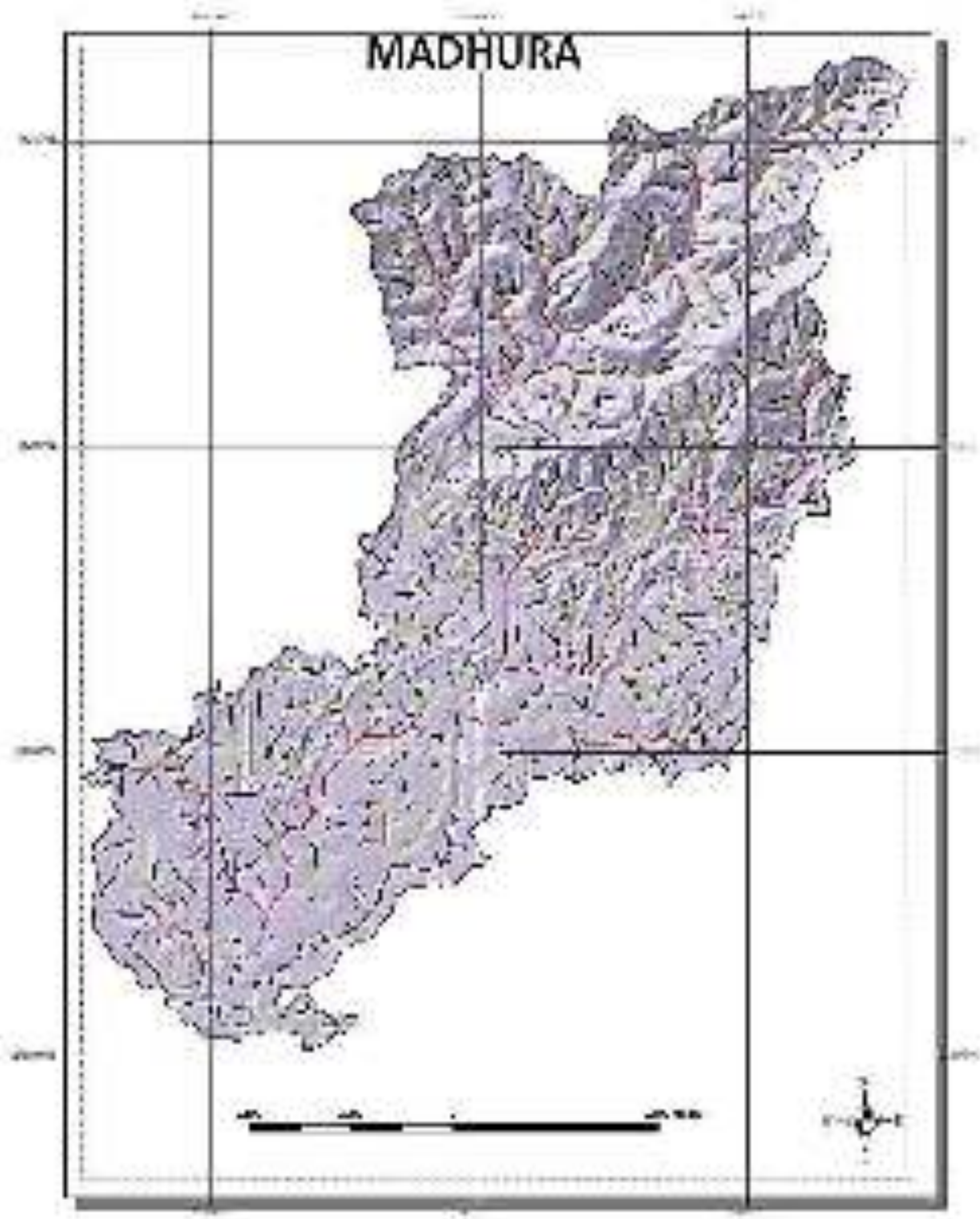


Figure-5.7: Madhura watershed (6th Order).

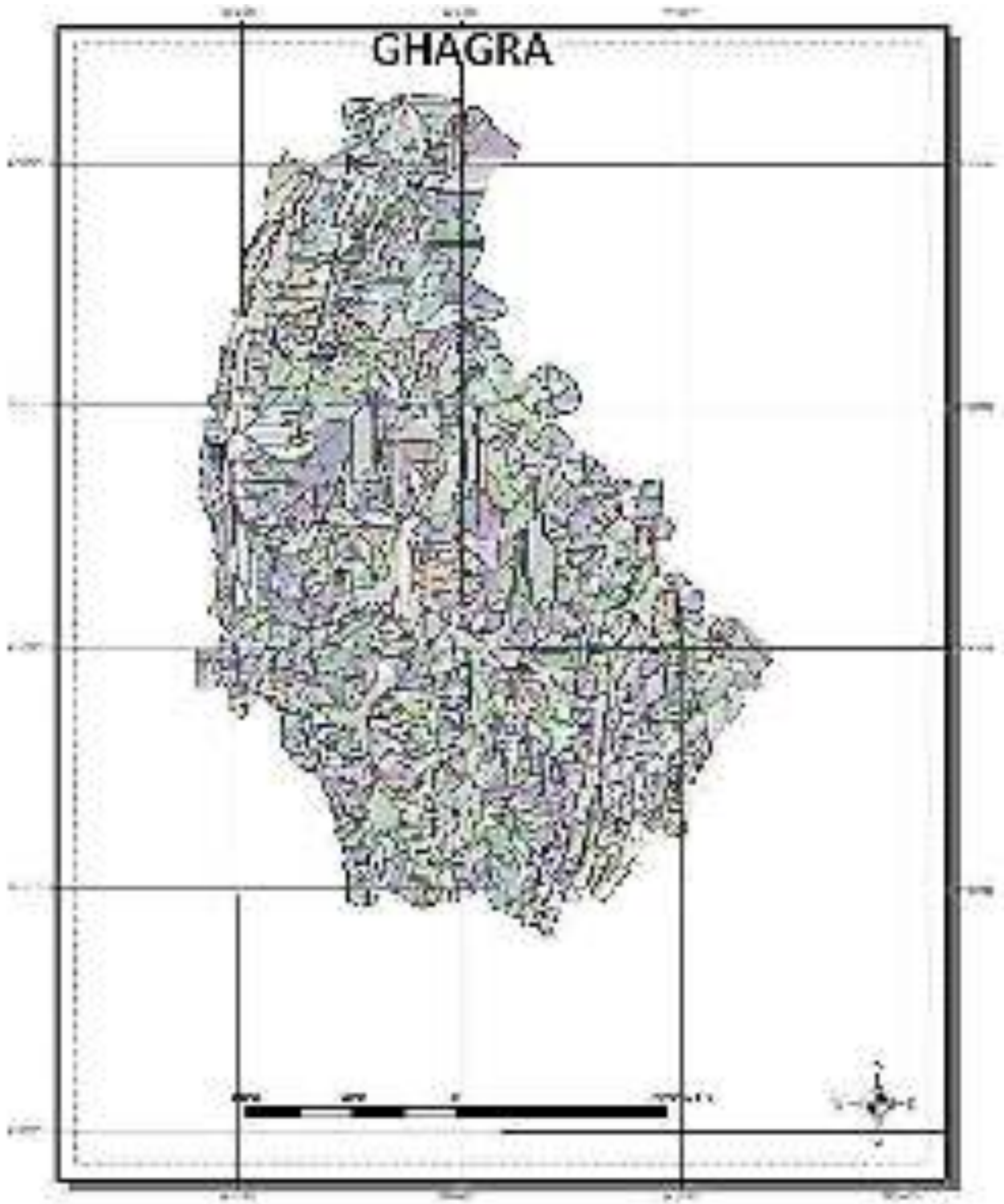


Figure-5.8: 1st Order sub-watersheds for Ghagra.

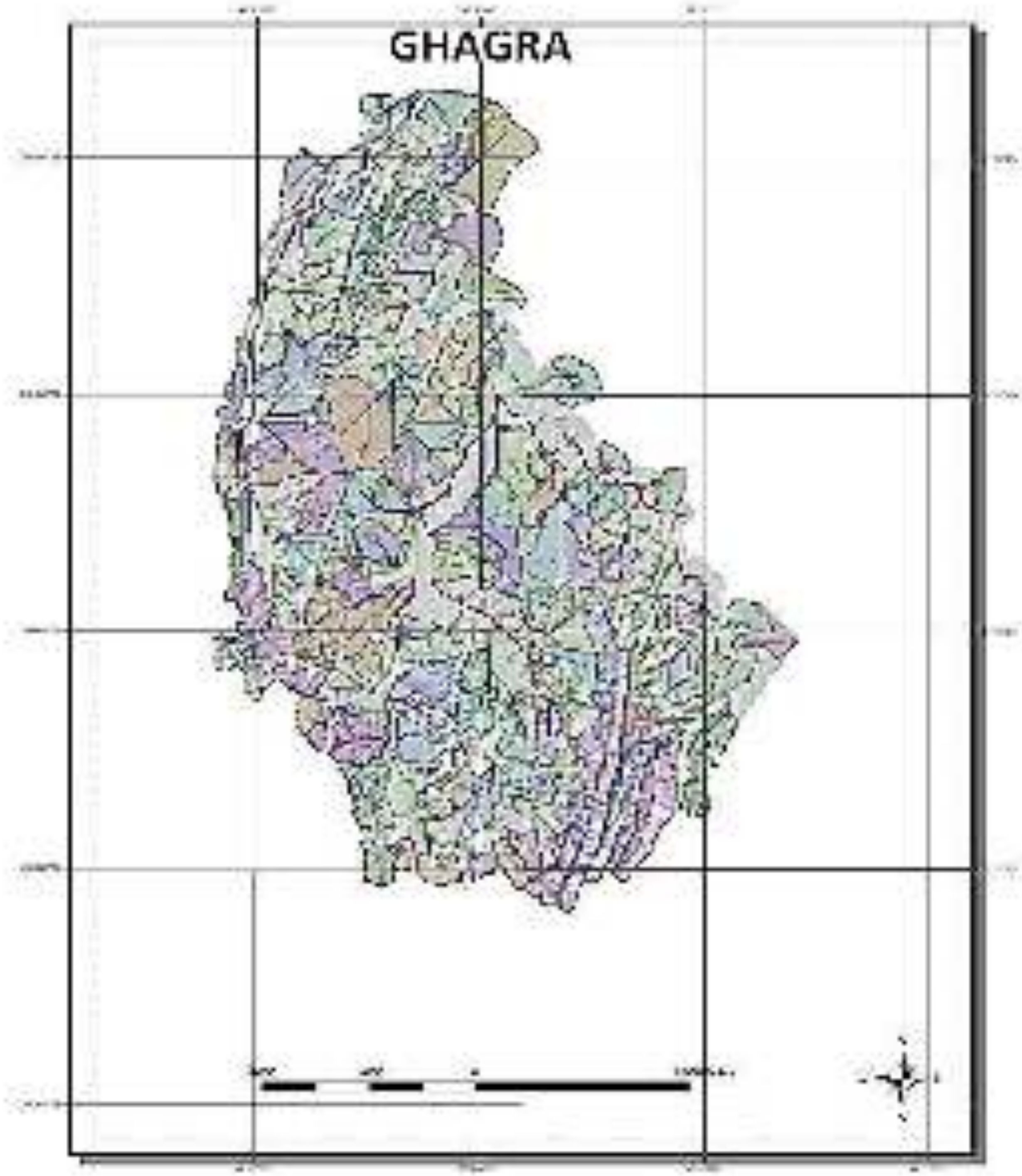


Figure-5.9: 2nd order sub-watersheds for Ghagra.

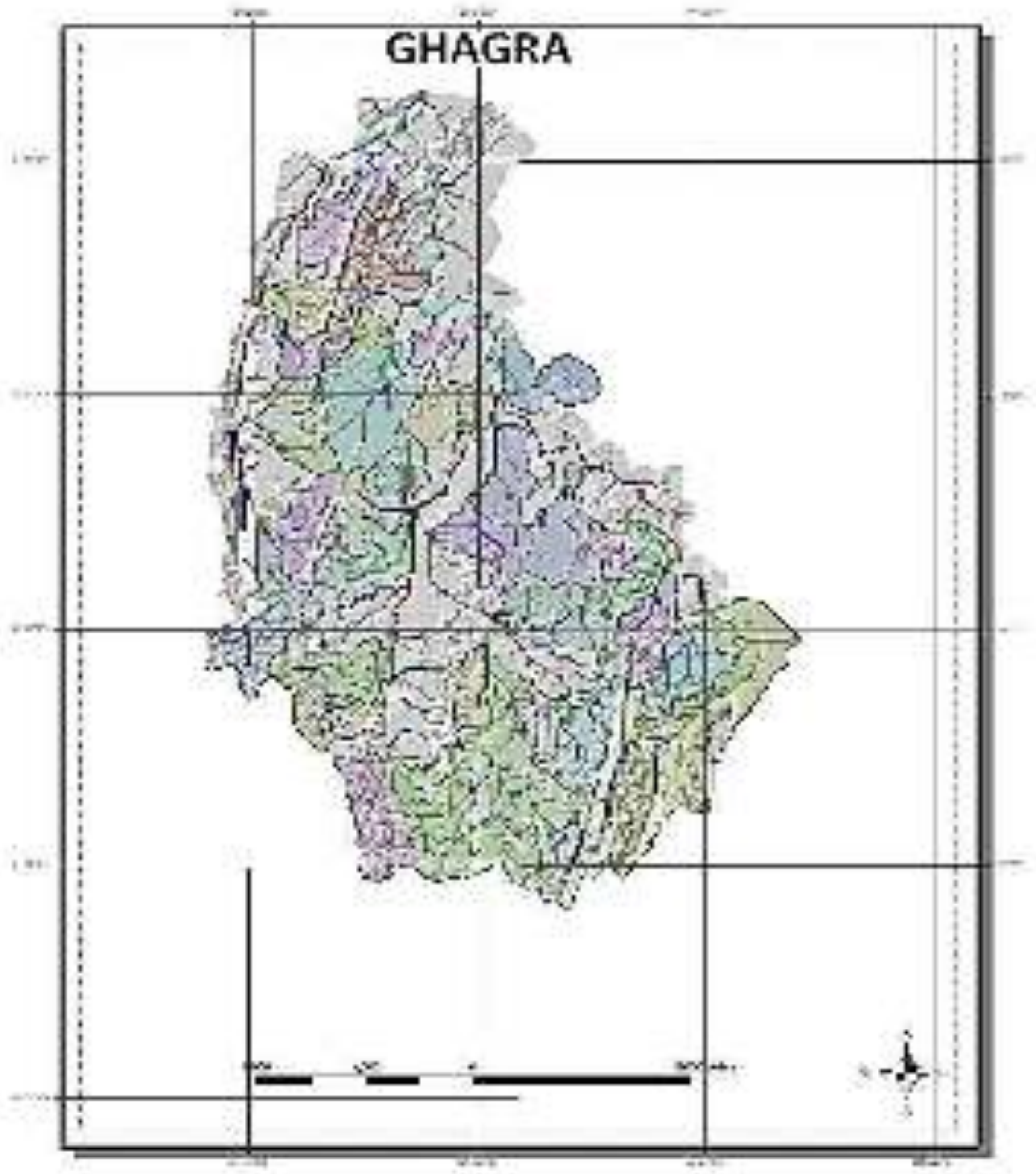


Figure-5.10: 3rd Order sub-watersheds for Ghagra.

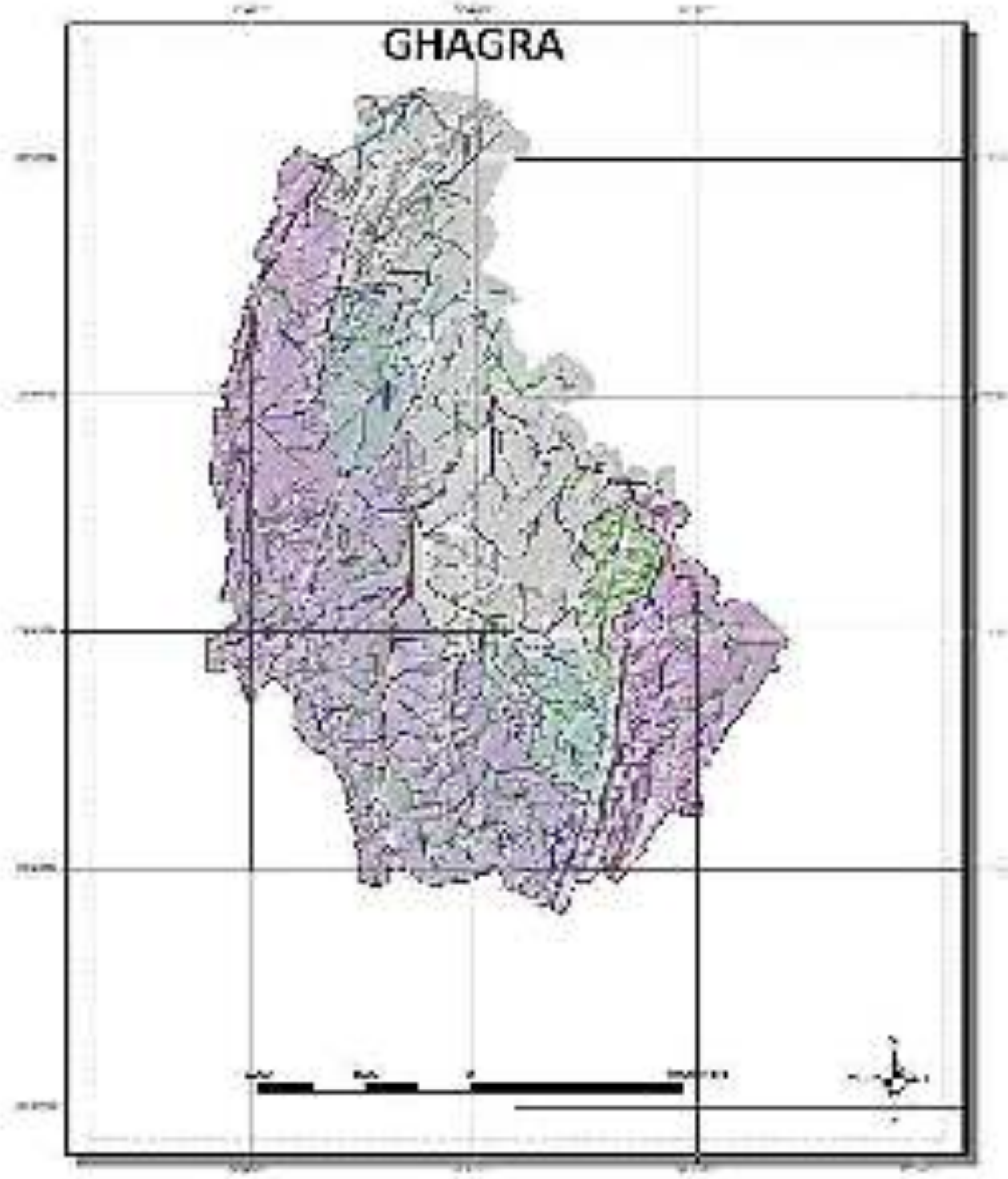


Figure-5.11: 4th Order sub-watersheds for Ghagra.

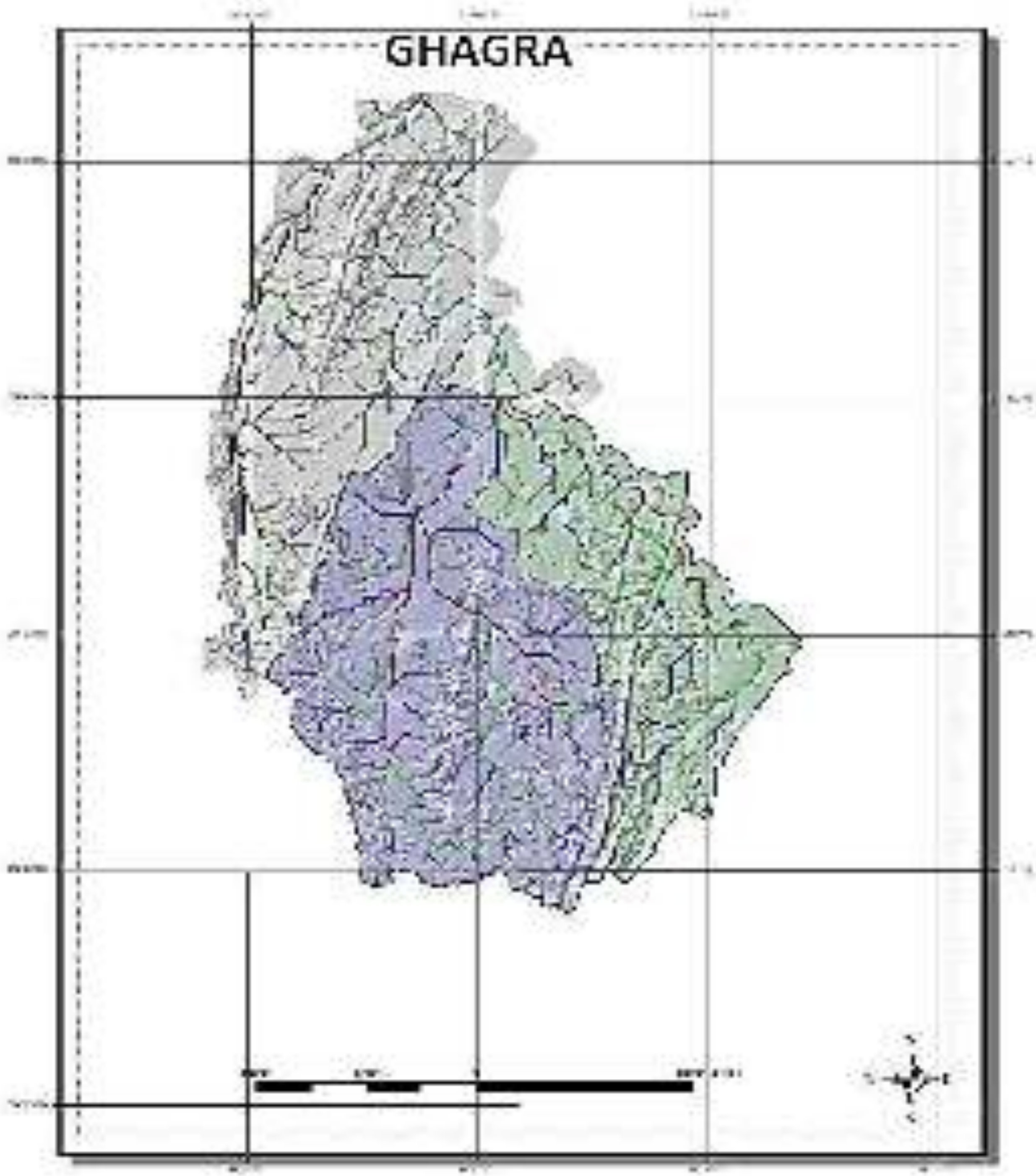


Figure-5.12: 5th order sub-watersheds for Ghagra.

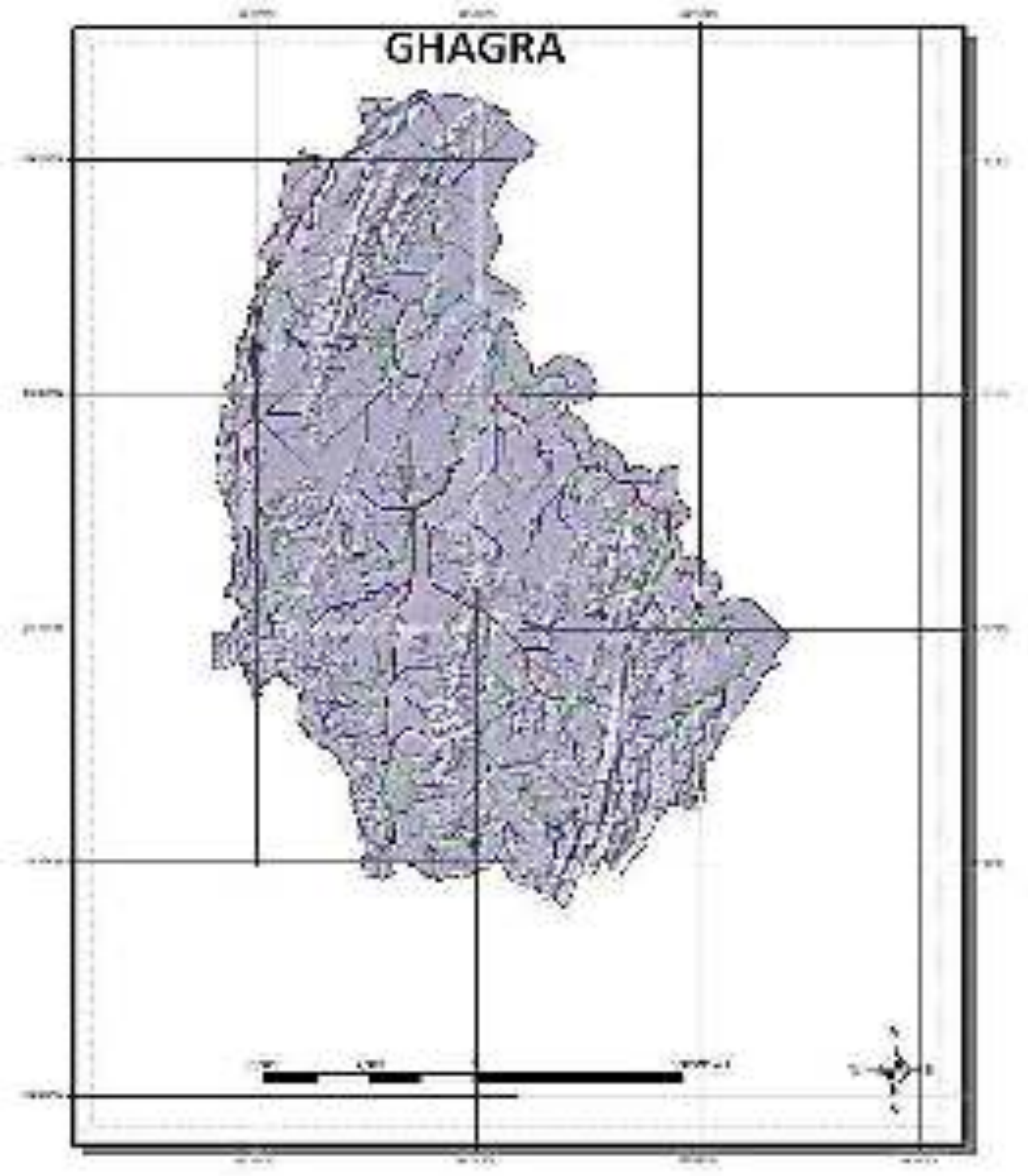


Figure-5.13: Ghagra watershed (6th order).

The Subwatersheds selected for Madhura for development of IUH are indicated in the figure given below:

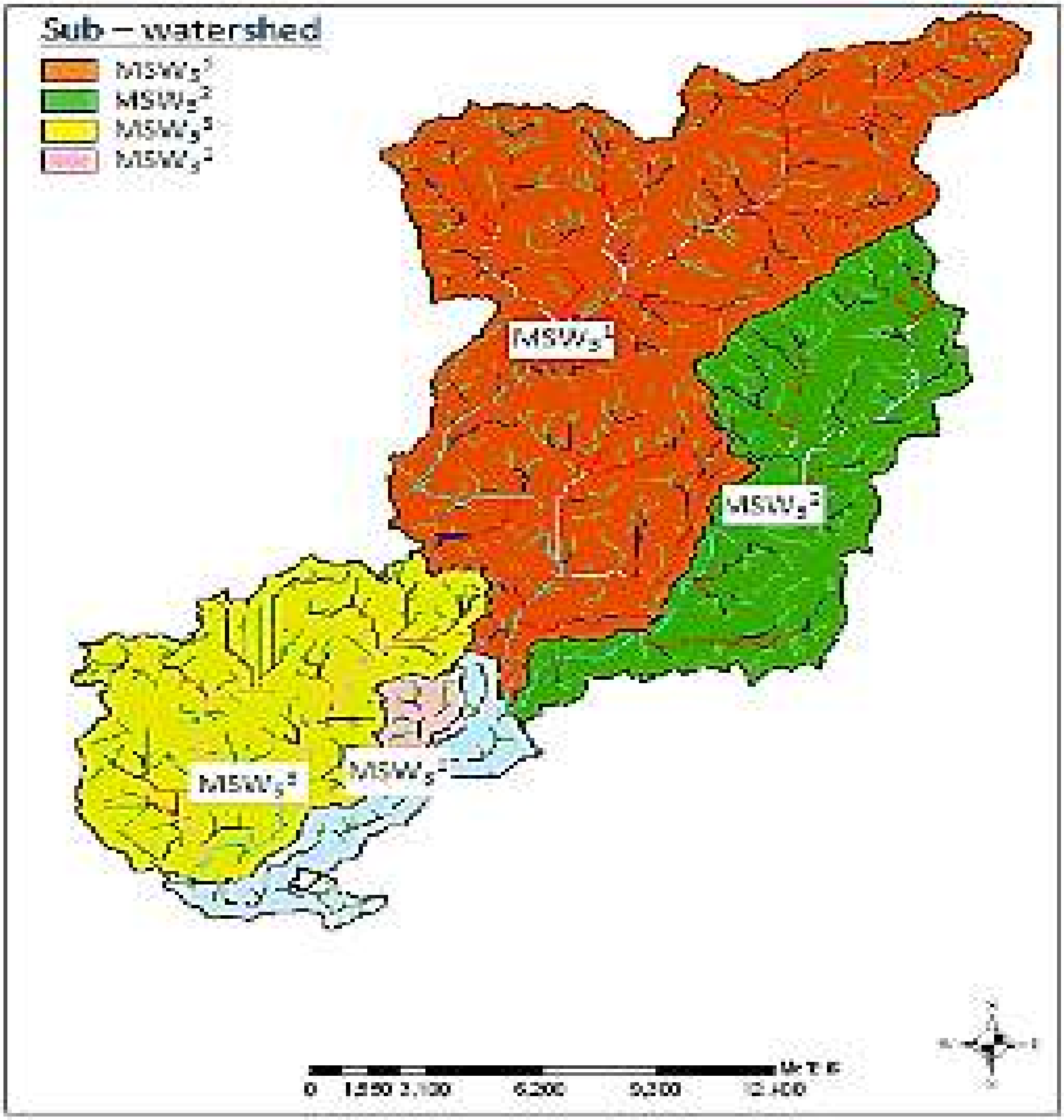


Figure-5.14: Selected sub-watersheds for Madhura.

Subwatersheds in Ghagra selected for developing IUH are as given in the figure given below:

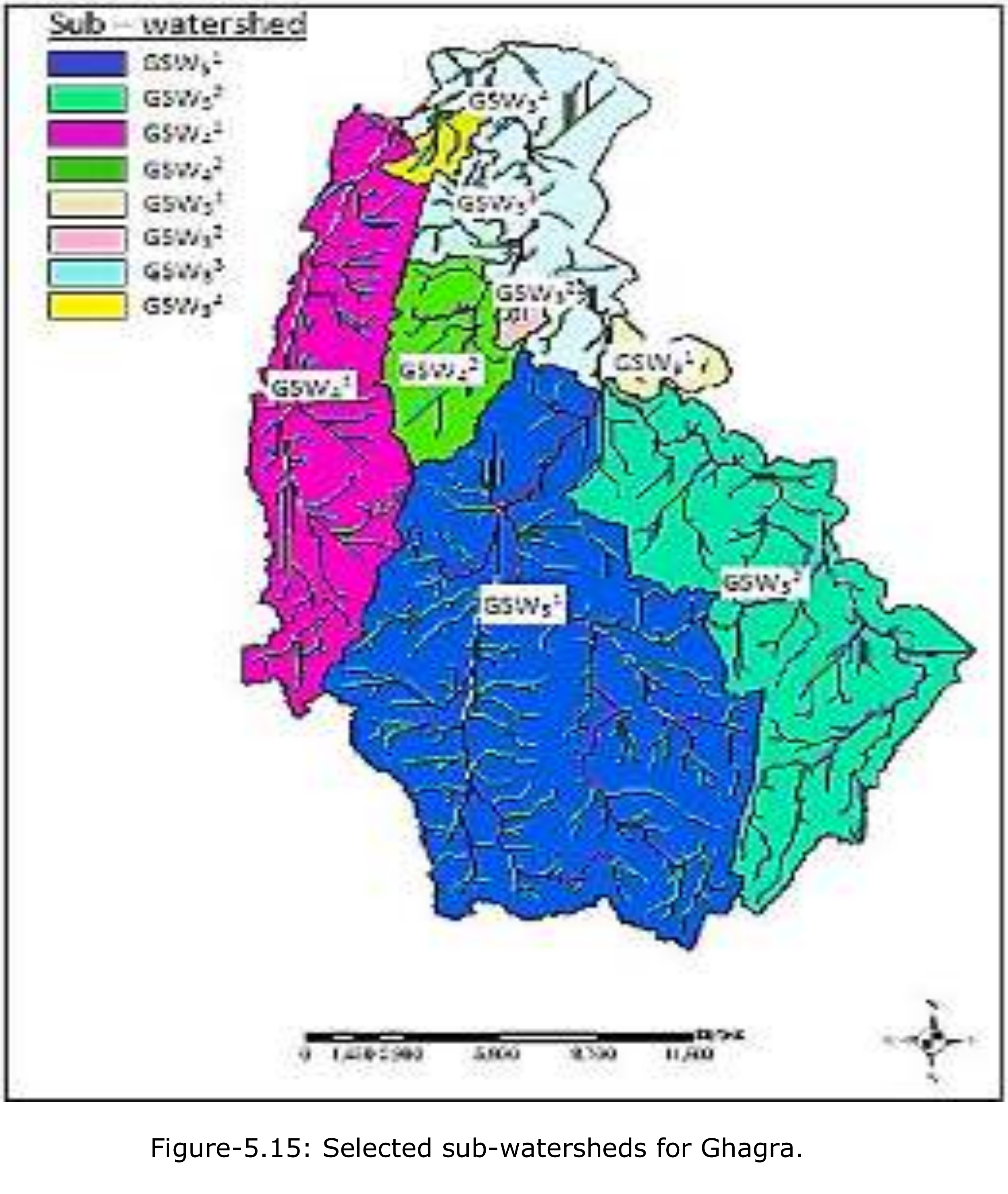


Figure-5.15: Selected sub-watersheds for Ghagra.

Applying conversion tool the raster file of ordered stream network, area drained are converted into vector file and extracted in Microsoft Office Excel worksheet. Using the extracted data sub-watersheds average stream length, stream numbers, average area drained by different orders of stream are obtained. Horton's geomorphologic parameters R_A, R_B and R_L for the sub-watersheds are estimated graphically by plotting the estimated average areas drained, stream numbers and average stream length respectively against the stream orders. Absolute slope values for the best fit line are taken to compute the ratios. Graphical representations showing best fit lines used for computing R_A, R_B and R_L for respective sub-watersheds are shown in Figures-516 through 5.27.

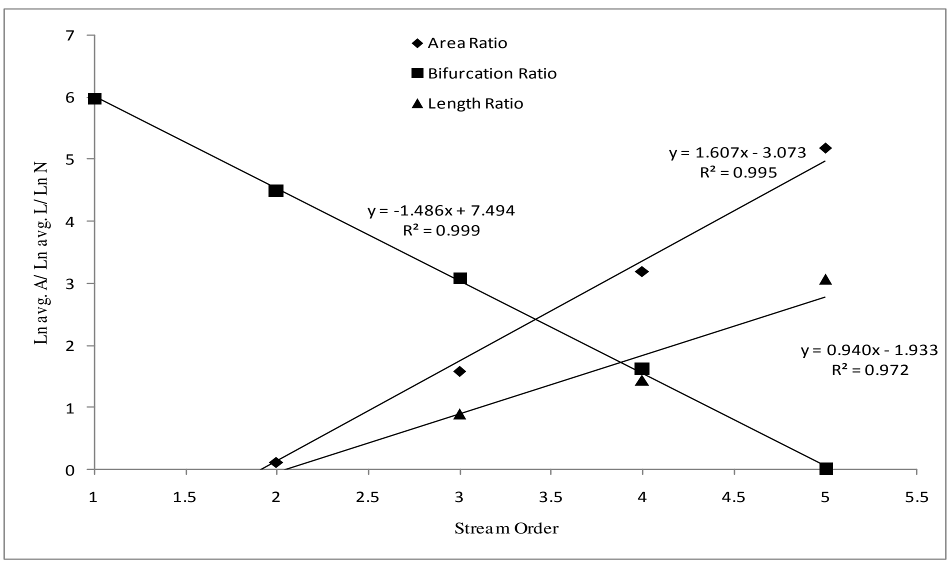


Figure 516: Estimation of ratios R_A, R_B and R_L for MSW_5^1.

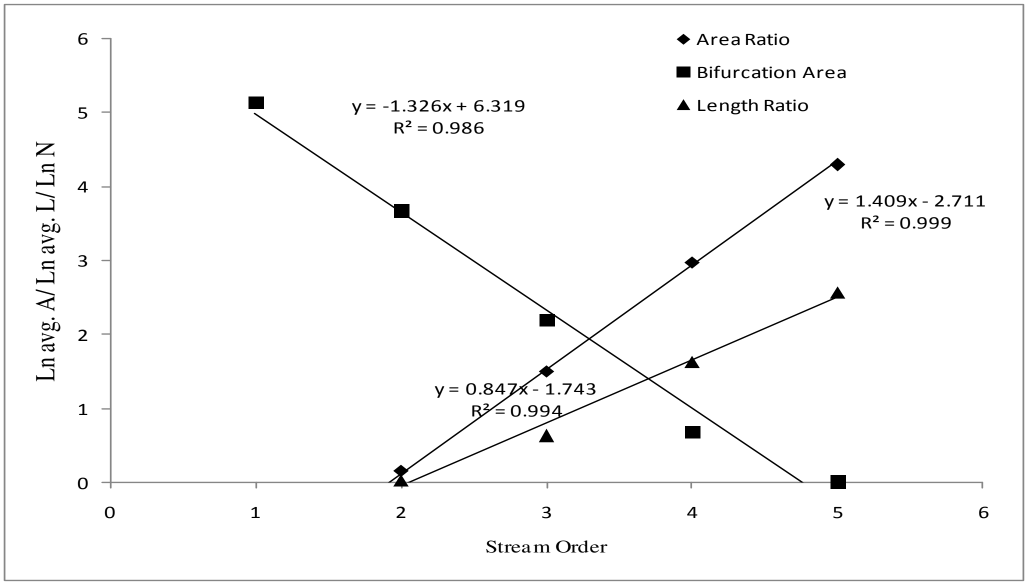


Figure 5.17: Estimation of ratios R_A, R_B and R_L for MSW_5^2.

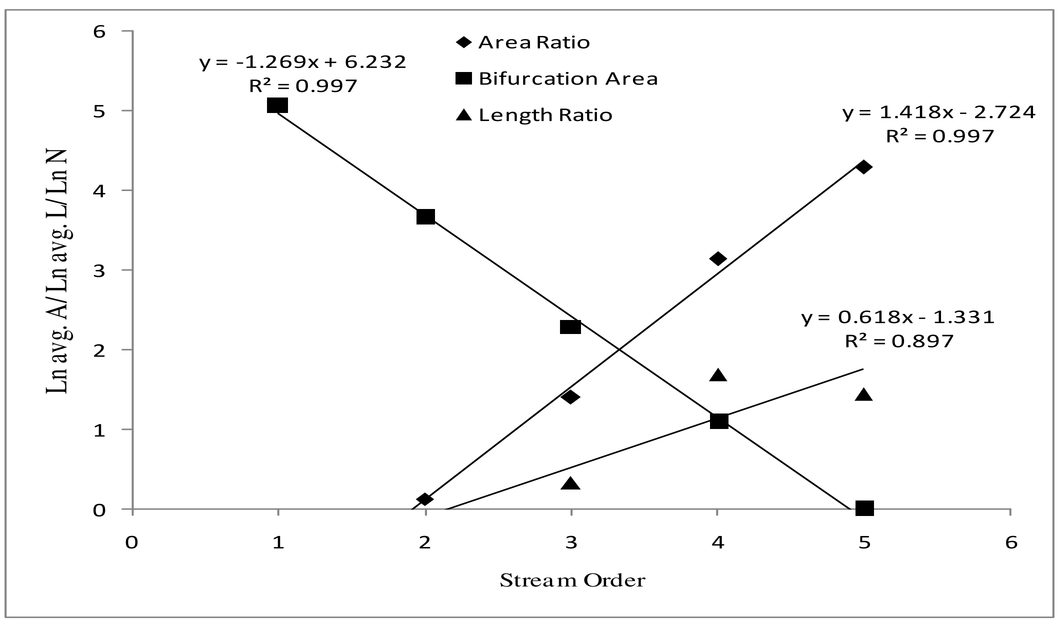


Figure 5.18: Estimation of ratios R_A, R_B and R_L for MSW_5^3.

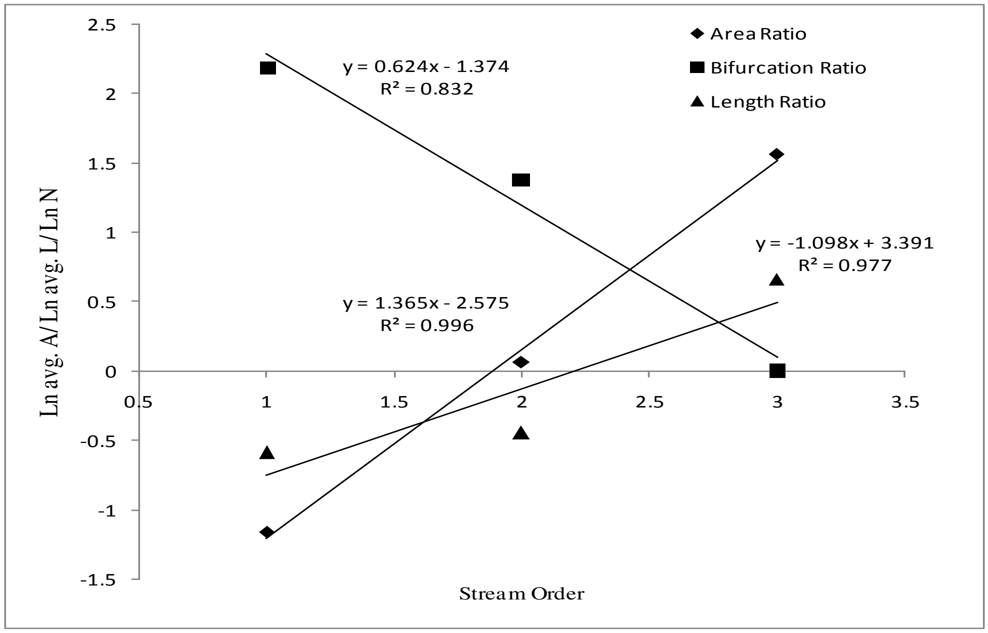


Figure 5.19: Estimation of ratios R_A, R_B and R_L for MSW_3^1.

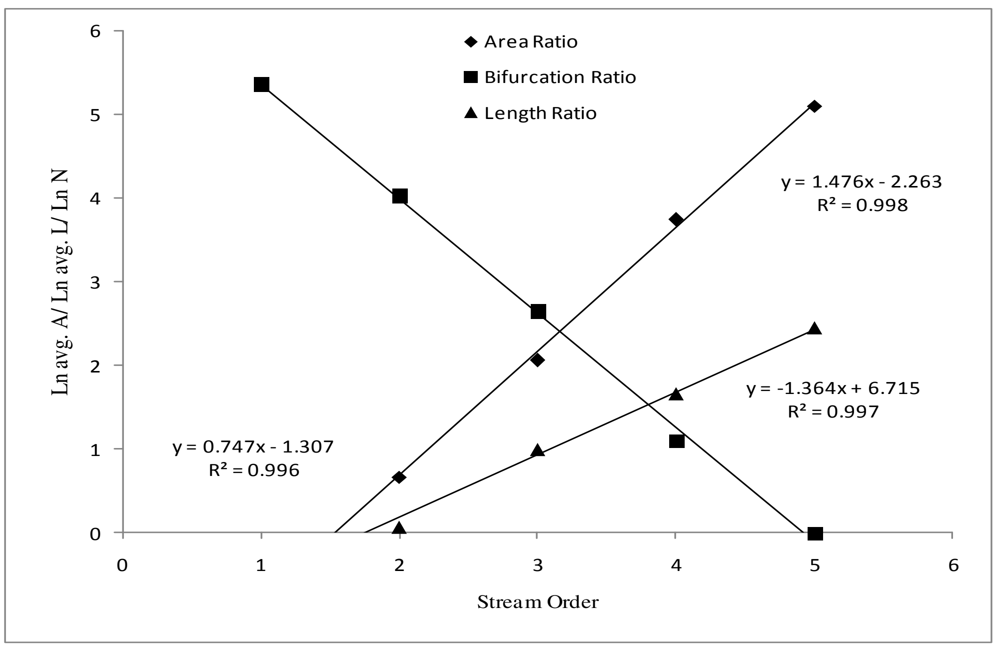


Figure 5.20: Estimation of ratios R_A, R_B and R_L for GSW_5^1.

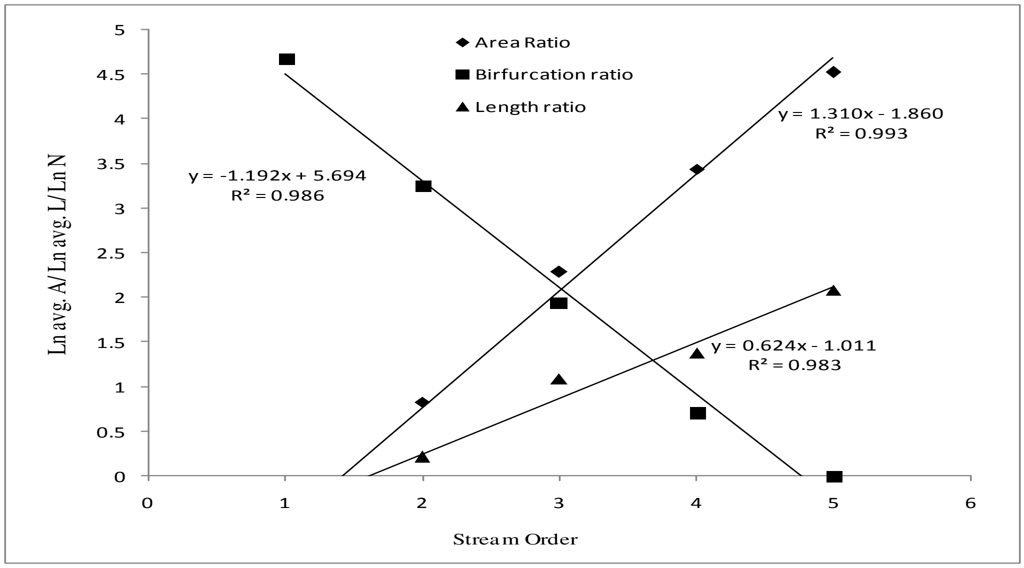


Figure 5.21: Estimation of ratios R_A, R_B and R_L for GSW_5^2.

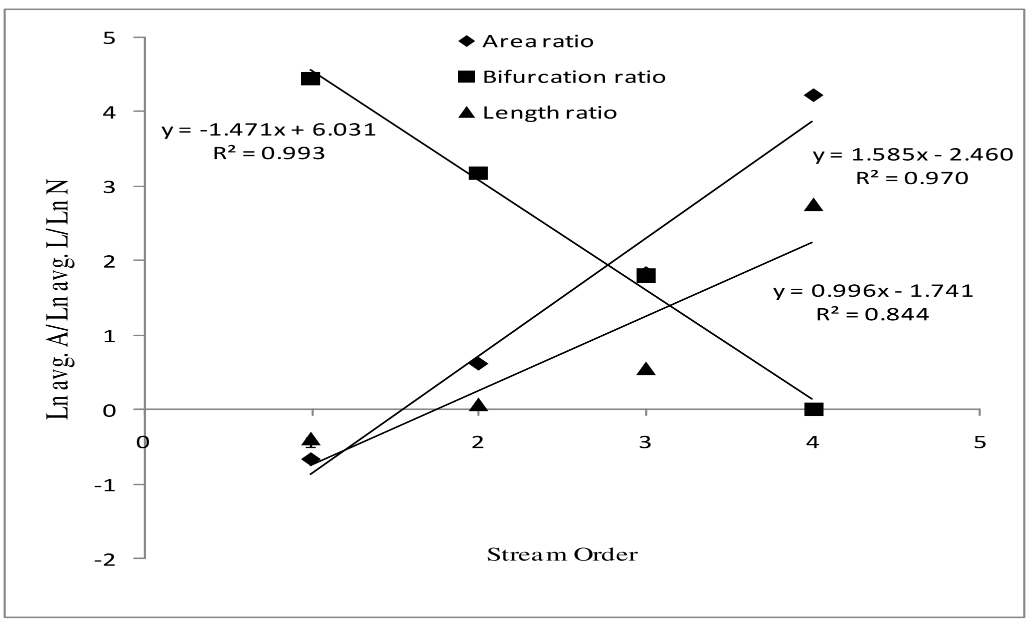


Figure 5.22: Estimation of ratios R_A, R_B and R_L for GSW_4^1.

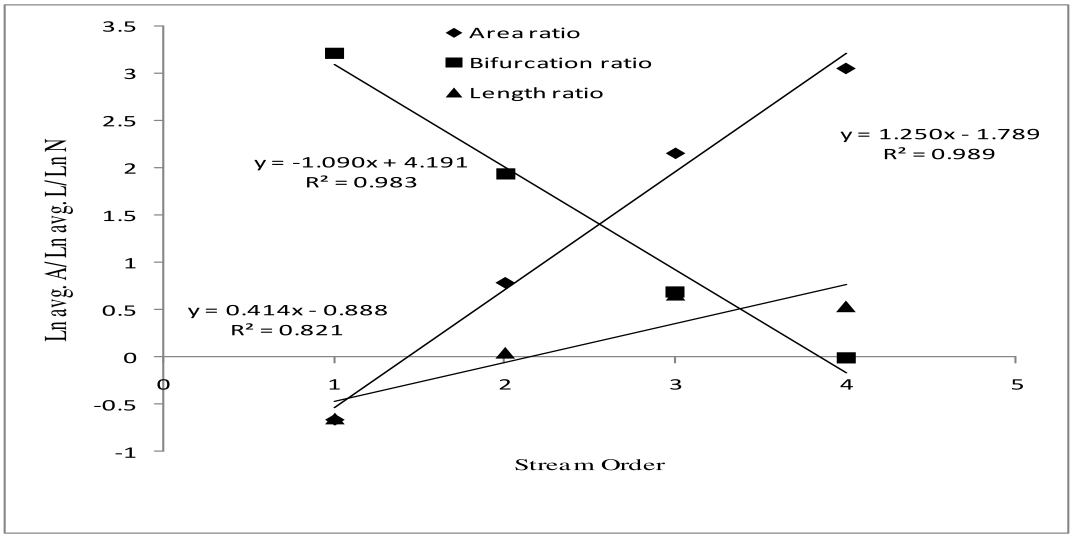


Figure 5.23: Estimation of ratios R_A, R_B and R_L for GSW_4^2.

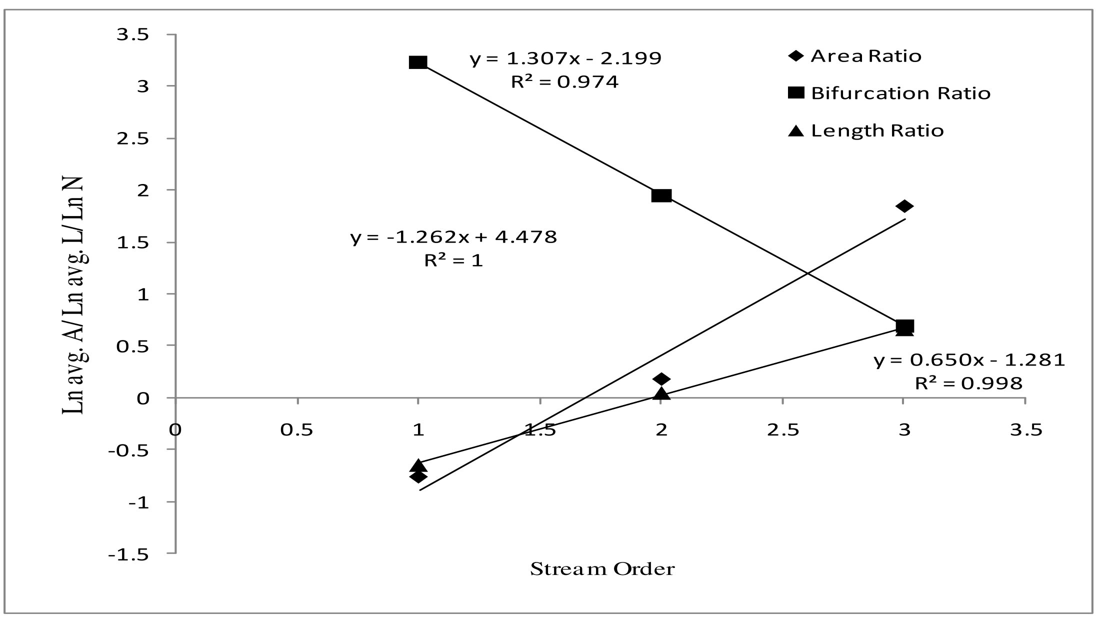


Figure 5.24: Estimation of ratios R_A, R_B and R_L for GSW_3^1.

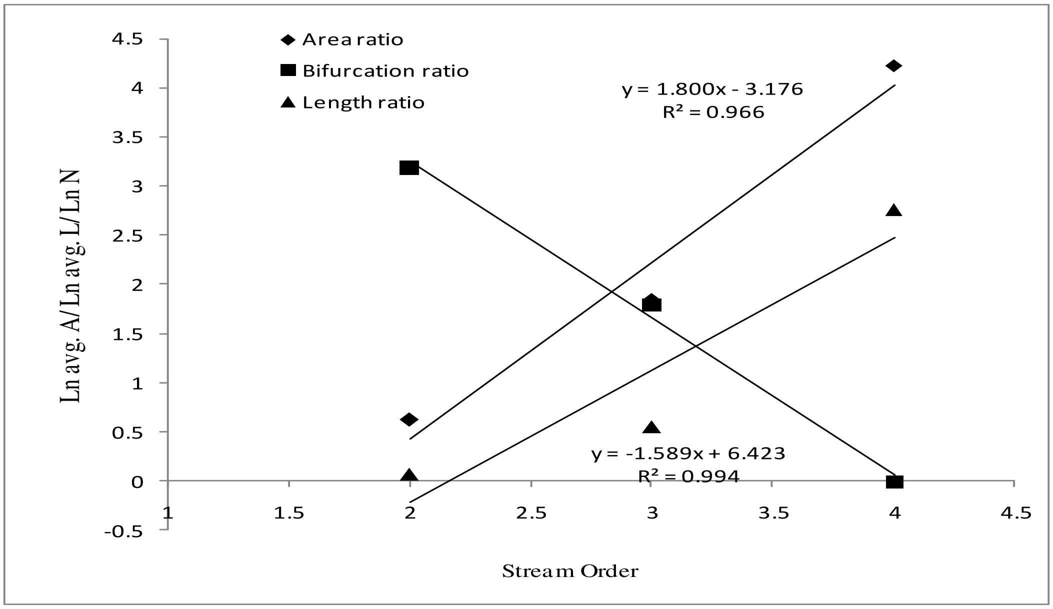


Figure 5.25: Estimation of ratios R_A, R_B and R_L for GSW_3^2.

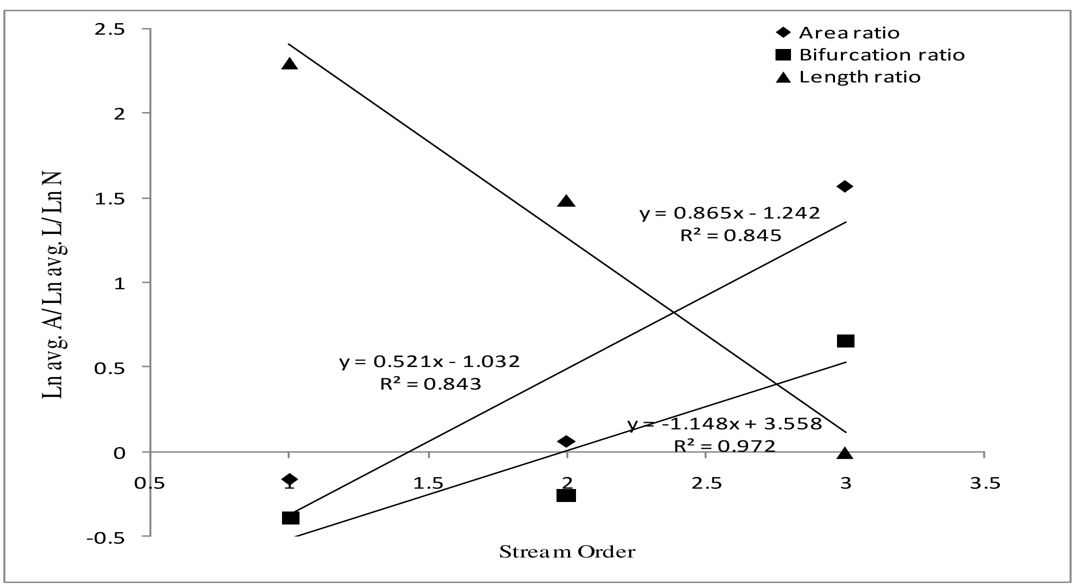


Figure 5.26: Estimation of ratios R_A, R_B and R_L for GSW_3^3.

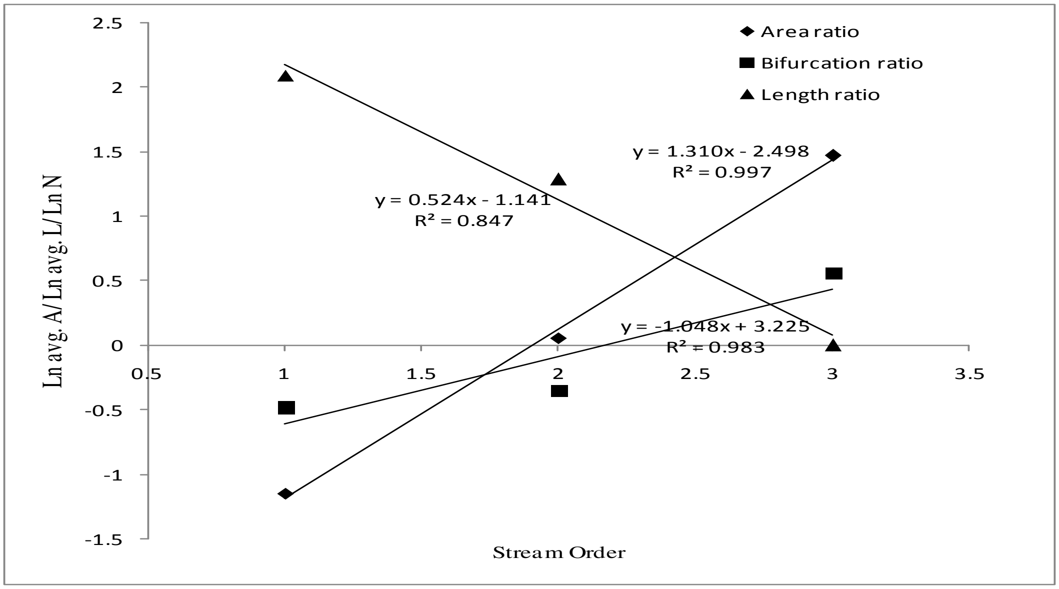


Figure 5.27: Estimation of ratios R_A, R_B and R_L for GSW_3^4.

Table 5.1: Geomorphologic characteristics of sub watersheds of Ghagra and Madhura

Sub-watersheds	Area Ratio (R_A)	Length Ratio (R_L)	Bifur cation Ratio (R_B)	Main stream length (L) (km)	Highest Order Stream Length (L_Ω) (km)	Area (A) (km^2)	Average slope (S) (m/m)	Velocity (V) (m/s)
MSW_5^1	4.98	2.56	4.15	38.02	21.39	170.07	0.39	6.74
MSW_5^2	4.09	2.33	3.77	24.83	13.01	73.14	0.27	5.33
MSW_5^3	4.13	1.86	3.56	17.31	4.23	72.78	0.09	3.26
MSW_3^1	3.92	1.87	2.99	7.18	1.94	4.80	0.08	2.54
GSW_5^1	4.38	2.11	3.91	26.15	11.57	163.74	0.09	3.51
GSW_5^2	3.71	1.87	3.29	28.58	8.04	92.17	0.11	3.88
GSW_4^1	4.88	2.71	4.35	23.50	15.88	68.08	0.1	3.57
GSW_4^2	3.49	1.5	3.00	6.89	2.00	21.26	0.08	2.47
GSW_3^1	3.69	1.62	3.11	4.67	2.11	6.33	0.02	1.22
GSW_3^2	3.19	1.56	3.00	3.65	0.80	1.94	0.07	1.97
GSW_3^3	3.69	1.74	3.11	5.88	2.01	7.62	0.02	1.25
GSW_3^4	3.58	1.81	3.21	3.68	1.01	4.56	0.11	2.42

Table-5.2: Morphological parameters for the subcatchments

Watershed	**Hydraulic flow length (m)**	**Slope**	**V(m/s)**	**L omega(km)**	**Ra**	**Rb**	**Rl**
GHAGRA	48930	0.098	4.19	19.784	3.90	3.64	2.022
MADHURA	52609	0.28	6.39	14.589	4.305	3.826	2.125
CHIRI	49881	0.23	5.85	11.645	3.815	3.504	1.906
JIRI	103240	0.29	7.56	48.09	4.56	4.21	2.44
KATAKHAL	129880	0.11	5.49	57.43	4.35	4.1	2.406
JATINGA	55390	0.35	7.04	22.93	4.01	4.9	3.089
SONAI	95212	0.07	4.29	15.976	3.5	3.8	1.9251

Table 5.3: 1hr UH ordinates for MSW_5^3.

Time (Hours)	**GIUH ordinate**	**GIUH lagged**	**SUM/2**	**S-curve addition**	**S-curve ordinate**	**lagged by 10x0.1 hr**	**1hr UH ordinate**

0	0		0		0		0
0.1	66.60425	0	33.302125	0	33.30213		3.3302125
0.2	133.2085	66.60425	99.906375	33.302125	133.2085		13.32085
0.3	199.81275	133.2085	166.510625	133.2085	299.7191		29.971913
0.4	266.417	199.81275	233.114875	299.719125	532.834		53.2834
0.5	242.2	266.417	254.3085	532.834	787.1425		78.71425
0.6	217.98	242.2	230.09	787.1425	1017.233		101.72325
0.7	193.76	217.98	205.87	1017.2325	1223.103		122.31025
0.8	169.54	193.76	181.65	1223.1025	1404.753		140.47525
0.9	145.32	169.54	157.43	1404.7525	1562.183		156.21825
1	121.1	145.32	133.21	1562.1825	1695.393	0	169.53925
1.1	96.88	121.1	108.99	1695.3925	1804.383	33.302125	177.10804
1.2	72.66	96.88	84.77	1804.3825	1889.153	133.2085	175.5944
1.3	48.44	72.66	60.55	1889.1525	1949.703	299.719125	164.99834
1.4	24.22	48.44	36.33	1949.7025	1986.033	532.834	145.31985
1.5	0	24.22	12.11	1986.0325	1998.143	787.1425	121.1
1.6		0	0	1998.1425	1998.143	1017.2325	98.091
1.7				1998.1425	1998.143	1223.1025	77.504
1.8				1998.1425	1998.143	1404.7525	59.339
1.9				1998.1425	1998.143	1562.1825	43.596
2				1998.1425	1998.143	1695.3925	30.275
2.1				1998.1425	1998.143	1804.3825	19.376
2.2				1998.1425	1998.143	1889.1525	10.899
2.3				1998.1425	1998.143	1949.7025	4.844
2.4				1998.1425	1998.143	1986.0325	1.211
2.5				1998.1425	1998.143	1998.1425	0
2.6				1998.1425	1998.143	1998.1425	

Table5.4: 1hr UH ordinates for GSW_5^1 .

Time (Hours)	**GIUH ordinate**	**GIUH lagged**	**SUM/2**	**S-curve addition**	**S-curve ordinate**	**lagged by 10x0.1 hr**	**1hr UH ordinate**

0	0		0		0		0
0.1	24.969	0	12.4845	0	12.4845		1.24845
0.2	49.938	24.969	37.4535	12.4845	49.938		4.9938
0.3	74.907	49.938	62.4225	49.938	112.3605		11.23605
0.4	99.876	74.907	87.3915	112.3605	199.752		19.9752
0.5	124.845	99.876	112.3605	199.752	312.1125		31.21125
0.6	149.814	124.845	137.3295	312.1125	449.442		44.9442
0.7	174.783	149.814	162.2985	449.442	611.7405		61.17405
0.8	199.752	174.783	187.2675	611.7405	799.008		79.9008
0.9	224.721	199.752	212.2365	799.008	1011.245		101.1245
1	249.69	224.721	237.2055	1011.245	1248.45	0	124.845
1.1	240.067	249.69	244.8785	1248.45	1493.329	12.4845	148.0844
1.2	230.464	240.067	235.2655	1493.329	1728.594	49.938	167.8656
1.3	220.861	230.464	225.6625	1728.594	1954.257	112.3605	184.1896
1.4	211.258	220.861	216.0595	1954.257	2170.316	199.752	197.0564
1.5	201.655	211.258	206.4565	2170.316	2376.773	312.1125	206.466
1.6	192.052	201.655	196.8535	2376.773	2573.626	449.442	212.4184
1.7	182.449	192.052	187.2505	2573.626	2760.877	611.7405	214.9136
1.8	172.846	182.449	177.6475	2760.877	2938.524	799.008	213.9516
1.9	163.243	172.846	168.0445	2938.524	3106.569	1011.245	209.5324
2	153.64	163.243	158.4415	3106.569	3265.01	1248.45	201.656
2.1	144.037	153.64	148.8385	3265.01	3413.849	1493.329	192.052
2.2	134.434	144.037	139.2355	3413.849	3553.084	1728.594	182.449
2.3	124.831	134.434	129.6325	3553.084	3682.717	1954.257	172.846
2.4	115.228	124.831	120.0295	3682.717	3802.746	2170.316	163.243
2.5	105.625	115.228	110.4265	3802.746	3913.173	2376.773	153.64
2.6	96.022	105.625	100.8235	3913.173	4013.996	2573.626	144.037
2.7	86.419	96.022	91.2205	4013.996	4105.217	2760.877	134.434
2.8	76.816	86.419	81.6175	4105.217	4186.834	2938.524	124.831
2.9	67.213	76.816	72.0145	4186.834	4258.849	3106.569	115.228
3	57.61	67.213	62.4115	4258.849	4321.26	3265.01	105.625
3.1	48.007	57.61	52.8085	4321.26	4374.069	3413.849	96.022
3.2	38.404	48.007	43.2055	4374.069	4417.274	3553.084	86.419
3.3	28.801	38.404	33.6025	4417.274	4450.877	3682.717	76.816
3.4	19.198	28.801	23.9995	4450.877	4474.876	3802.746	67.213
3.5	9.595	19.198	14.3965	4474.876	4489.273	3913.173	57.61
3.6	0	9.595	4.7975	4489.273	4494.07	4013.996	48.0074
3.7		0	0	4494.07	4494.07	4105.217	38.88535
3.8				4494.07	4494.07	4186.834	30.7236
3.9				4494.07	4494.07	4258.849	23.52215
4				4494.07	4494.07	4321.26	17.281

4.1				4494.07	4494.07	4374.069	12.00015
4.2				4494.07	4494.07	4417.274	7.6796
4.3				4494.07	4494.07	4450.877	4.31935
4.4				4494.07	4494.07	4474.876	1.9194
4.5				4494.07	4494.07	4489.273	0.47975
4.6				4494.07	4494.07	4494.07	0

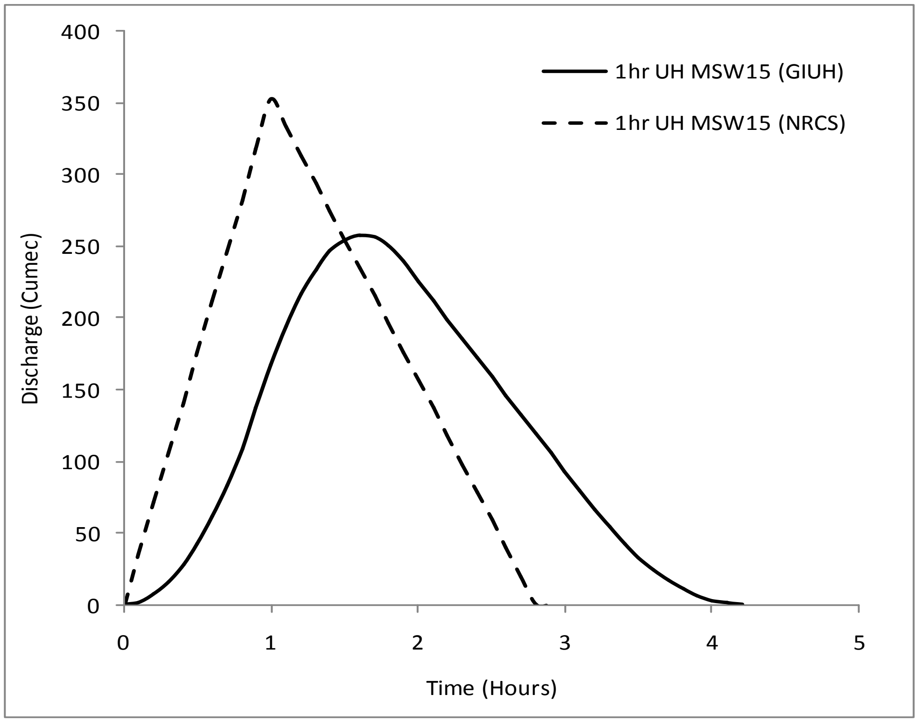


Figure 5.28: 1hr UH for Madhura sub-watershed MSW_5^1 .

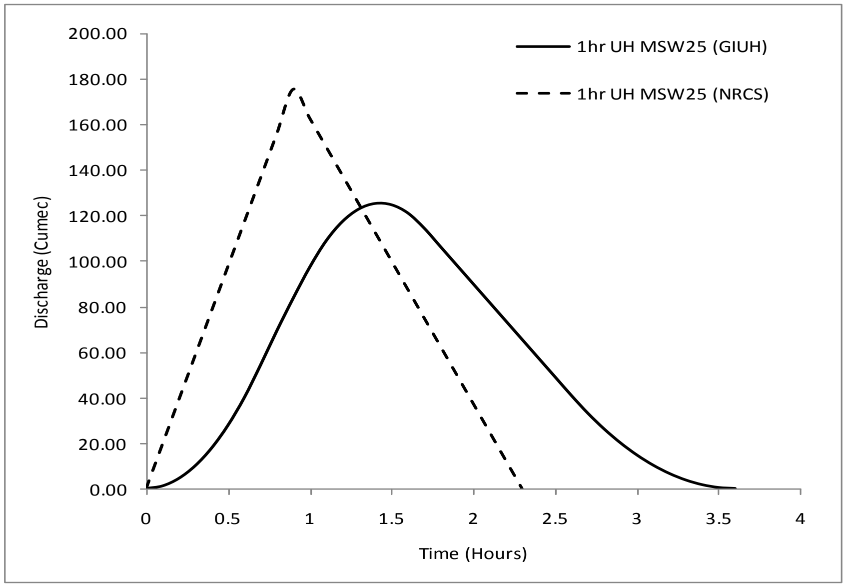


Figure 5.29: 1hr UH for Madhura sub-watershed MSW_5^2 .

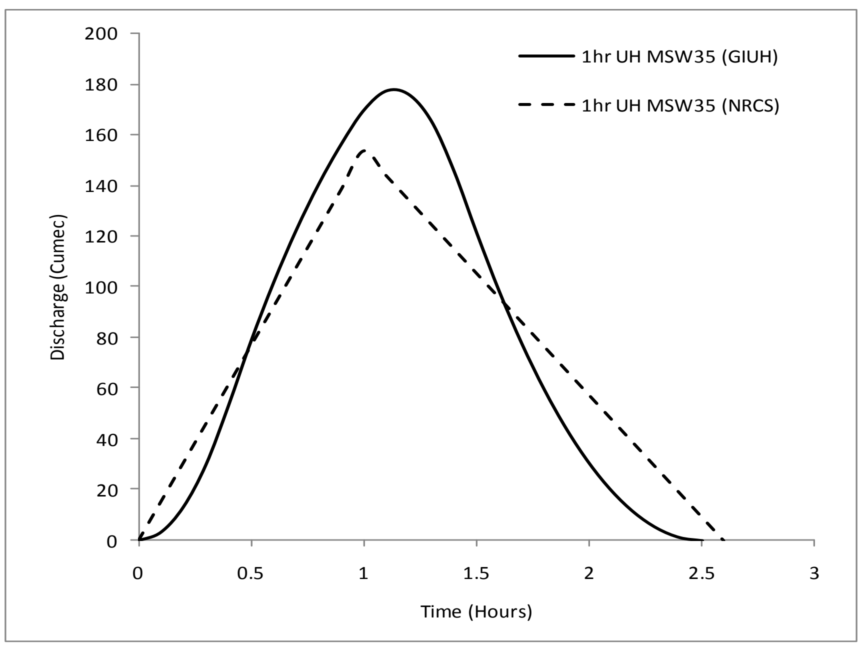


Figure 5.30: 1hr UH for Madhura sub-watershed MSW_5^3 .

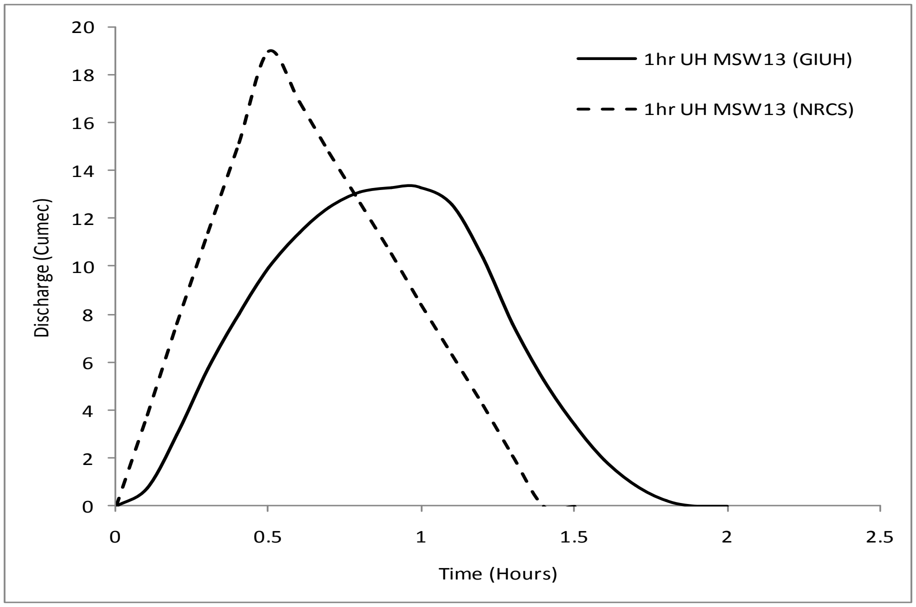


Figure 5.31: 1hr UH for Madhura sub-watershed MSW_3^1.

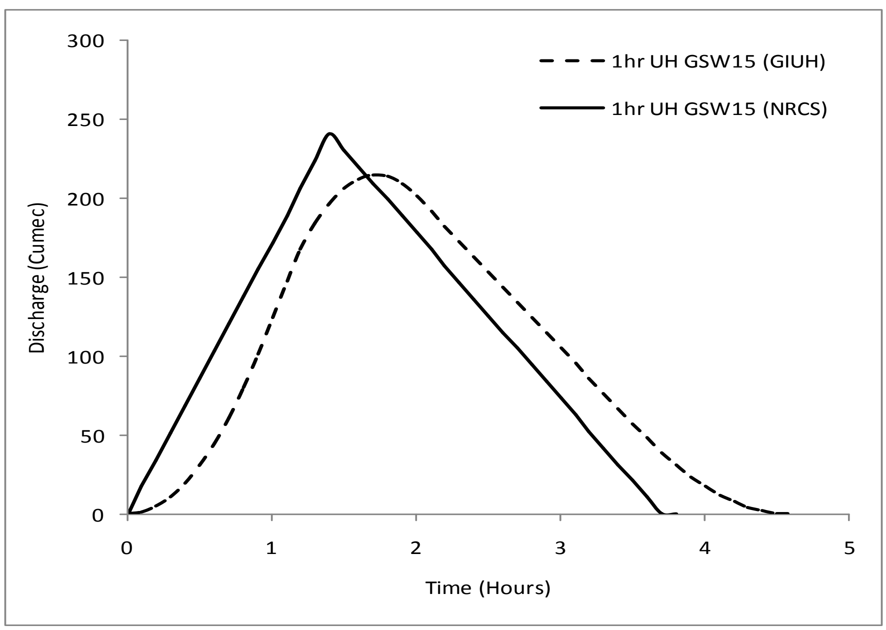


Figure 5.32: 1hr UH for Ghagra sub-watershed GSW_5^1.

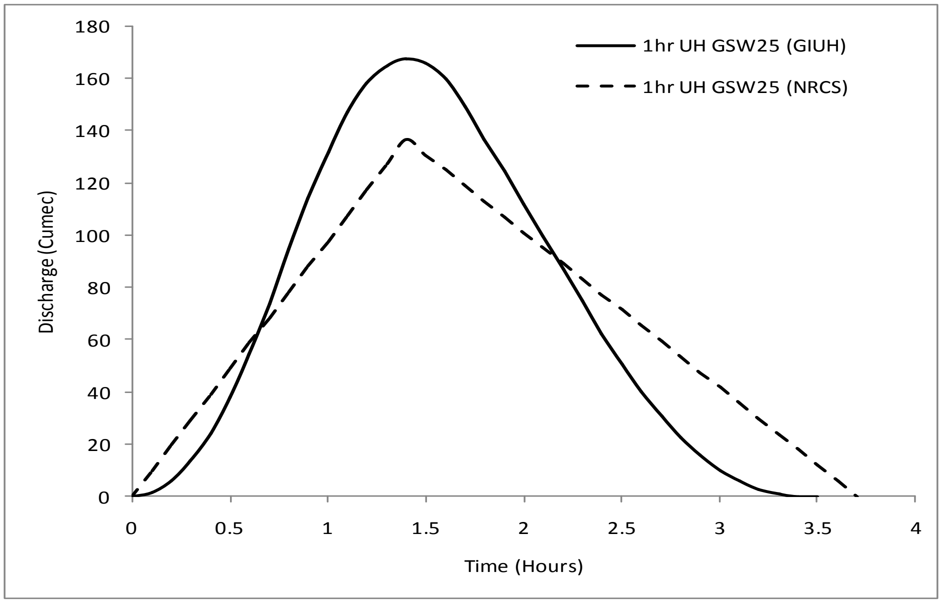


Figure 5.33: 1hr UH for Ghagra sub-watershed GSW_5^2.

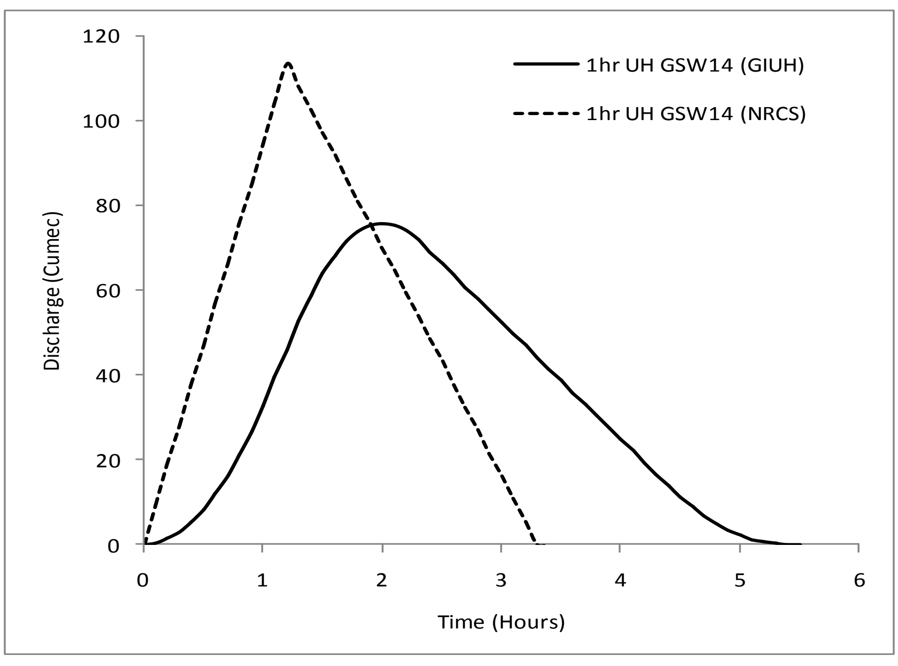


Figure 5.34: 1hr UH for Ghagra sub-watershed GSW_4^1.

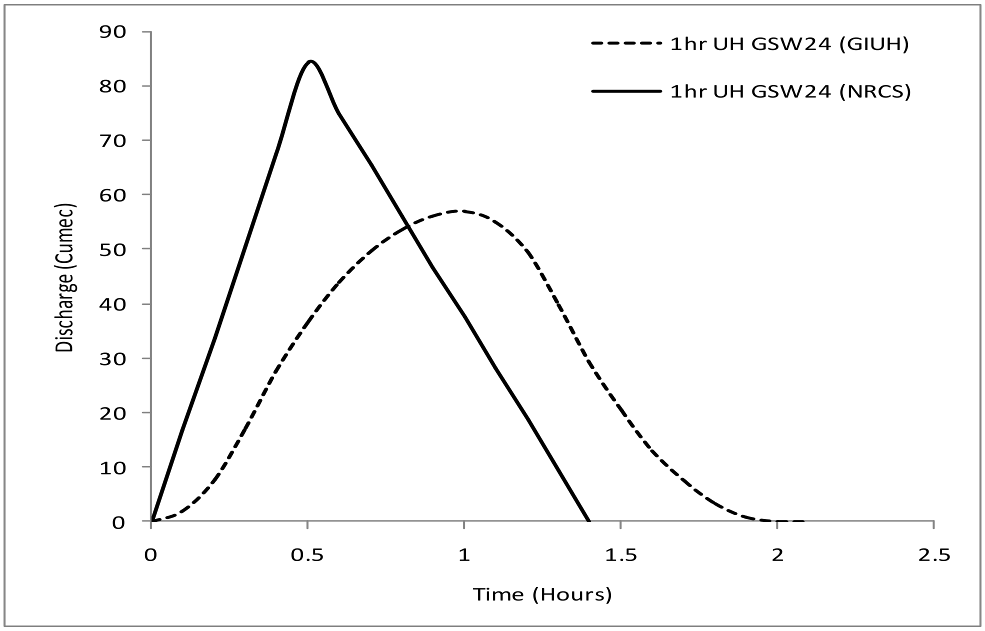


Figure 5.35: 1hr UH for Ghagra sub-watershed GSW_4^2.

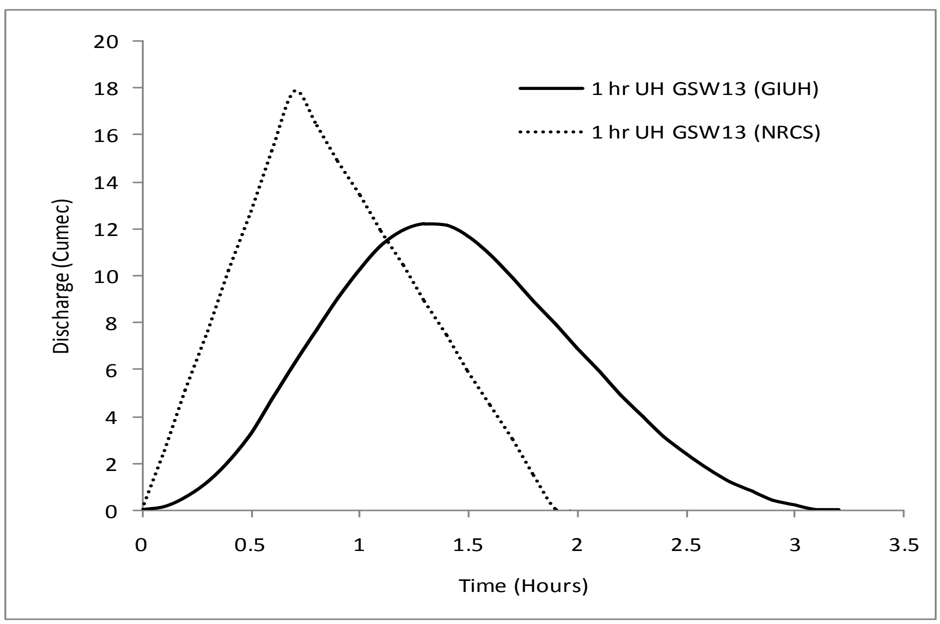


Figure 5.36: 1hr UH for Ghagra sub-watershed GSW_3^1.

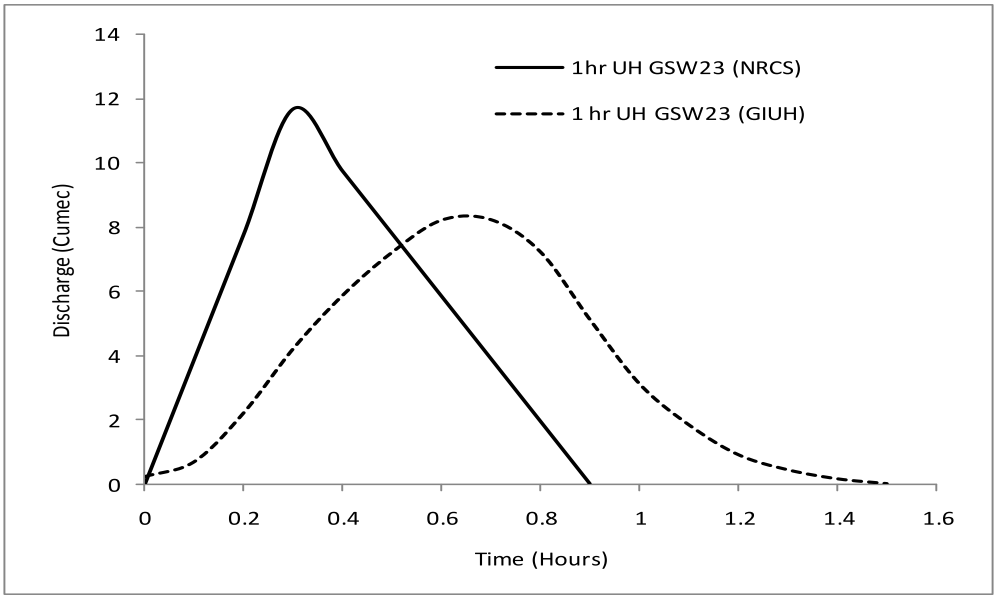


Figure 5.37: 1hr UH for Ghagra sub-watershed GSW_3^2.

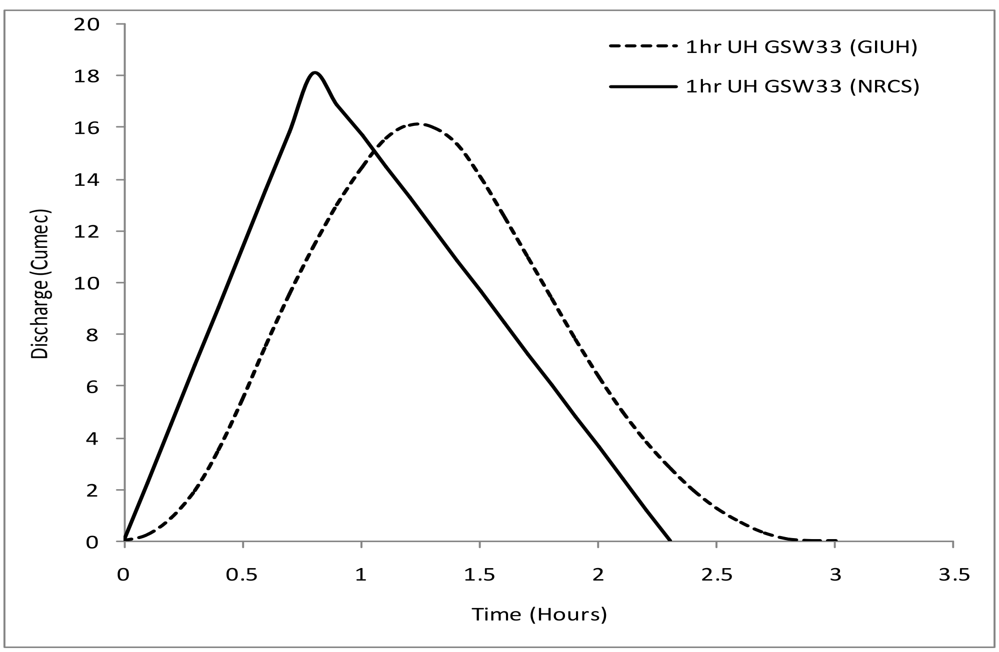


Figure 5.38: 1hr UH for Ghagra sub-watershed GSW_3^3.

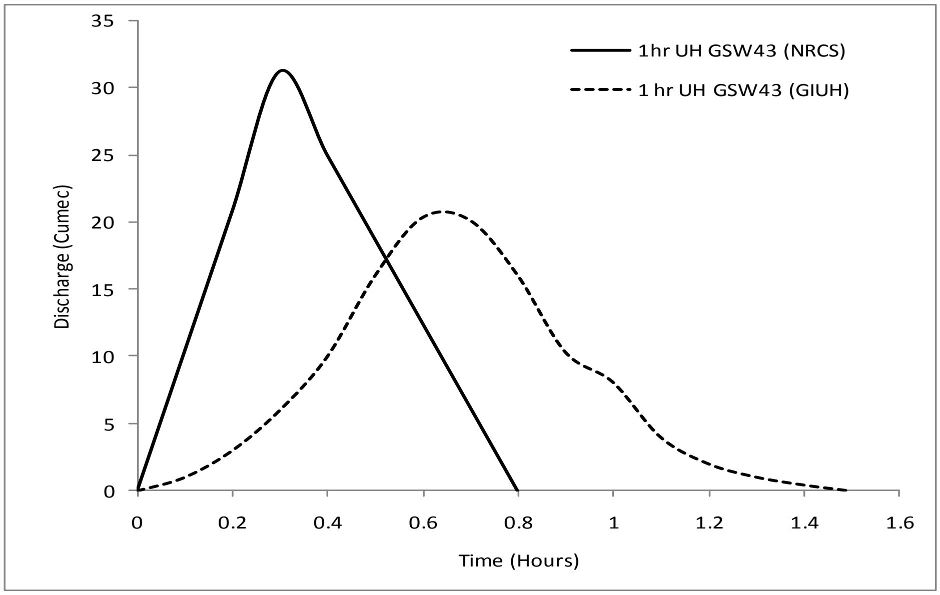


Figure 5.39: 1hr UH for Ghagra sub-watershed GSW_3^4.

Table -5.5: Unit Hydrograph characteristics for the sub-watersheds.

Watersheds	**Time to peak** (t_p) (hrs)		**Peak discharge** (Q_p) (m^3/s)		**Base time** (t_b) (hrs)	
	GIUH	**NRCS**	**GIUH**	**NRCS**	**GIUH**	**NRCS**
MSW_5^1	1.6	1.0	257.78	352.68	4.1	2.8
MSW_5^2	1.4	0.9	125.20	175.28	3.6	2.3
MSW_5^3	1.1	1.0	177.11	153.37	2.5	2.6
MSW_3^1	1.0	0.5	13.32	19.00	1.9	1.5
GSW_5^1	1.7	1.4	214.91	241.08	4.6	3.7
GSW_5^2	1.4	1.4	167.53	136.93	3.5	3.6
GSW_4^1	2.0	1.2	75.81	113.33	5.5	3.4
GSW_4^2	1.0	0.5	56.89	84.30	2.1	1.4
GSW_3^1	1.3	0.7	12.23	17.87	3.2	2.0

GSW_3^2	0.5	0.3	8.23	11.70	1.5	0.9
GSW_3^3	1.2	0.8	16.09	18.11	3.0	2.3
GSW_3^4	0.5	0.4	20.33	24.95	1.5	0.8

5.1 Routing sub-watershed UHs

Sub-watershed UHs derived using GIUH and NRCS techniques are routed by using nonlinear kinematic wave model to the respective main watershed outlet and superimposed with local flows to develop UH for the watersheds. Values for the parameters α and β required for using nonlinear kinematic model are estimated using flow area and corresponding discharge data series for a section. On the basis of maximum top width $(W_{\max})$ and maximum flow depth $(Y_{\max})$ and assuming a parabolic channel section a set of values for the flow area, A_i and corresponding discharge, Q_i are computed. Observed maximum top width and maximum depth for the sub-watershed channel sections in the study sub-watersheds are listed in Table 5.6. Manning's roughness coefficients, n for the reaches are determined using field information, available soil maps and topographic maps etc. n values selected for different channel sections is also given in Table 5.6. Derived values for A_i , and Q_i for a section are used to estimate routing parameters α and β by applying simple nonlinear regression technique. Reach length and estimated routing parameters α and β are listed in Table 5.7.

Table 5.6 : Channel characteristics and parameters.

Sub-watersheds	Manning Roughness Coefficient (n)	Average channel Slope (S_o) (m/m)	Maximum top Width $(W_{\max})$ (m)	Maximum depth $(Y_{\max})$ (m)

MSW_5^1	0.034	0.337	86.50	4.30
MSW_5^2	0.034	0.273	36.10	6.10
MSW_5^3	0.030	0.095	59.50	8.55
MSW_3^1	0.020	0.084	20.56	3.1
GSW_5^1	0.034	0.380	48.40	5.51
GSW_5^2	0.034	0.350	48.38	5.00
GSW_4^1	0.034	0.400	30.20	7.40
GSW_4^2	0.020	0.254	27.50	4.00
GSW_3^1	0.020	0.080	5.60	1.53
GSW_3^2	0.020	0.071	5.10	1.01
GSW_3^3	0.020	0.074	18.60	4.14
GSW_3^4	0.020	0.062	14.30	3.61

Table-5.7: Routing parameters for sub-watersheds.

watersheds	parameters		Reach length $(\Delta x)(km)$
	(α)	(β)	
MSW_5^1	0.280	0.750	14.589
MSW_5^2	0.280	0.750	14.589
MSW_5^3	0.321	0.750	0.929
MSW_3^1	0.246	0.750	11.191
GSW_5^1	0.230	0.750	19.784
GSW_5^2	0.232	0.750	19.784
GSW_4^1	0.189	0.750	0.023

GSW_4^2	0.164	0.750	12.794
GSW_3^1	0.097	0.750	17.692
GSW_3^2	0.250	0.750	13.611
GSW_3^3	0.242	0.750	11.227
GSW_3^4	.0255	0.750	1.245

Using values for the routing parameter, α and β for a reach length, (Δx) the sub-watershed UHs are routed to the respective main outlet. To estimate Q_{t+1}^{j+1} initial value for the variable is required, in the present case initial estimate for Q_{t+1}^{j+1} is taken as the estimated value for Q_t^{j+1}, the value of the variable in the previous time step. The resulted UHs are then superimposed to derive the respective UH for the watersheds. Figures 5.40 and Figures 5.41 shows the derived 1hr UH for Madhura and Ghagra watersheds using GIUH and NRCS techniques. Morphological parameters for all sub basins are listed in the table 5.8:

Table-5.8: Morphological parameters and IUH Characteristics of subbasins

	Hydraulic flow length (m)	Slope	V (m/s)	L_ω (km)	R_A	R_B	R_L	t_p(hrs)	q_p (-hrs)	q_p (Cumec)	A (Sq. km)	t_b (hrs)	t_b (triangular based)
GHAGRA	48930.00	0.10	4.20	19.78	3.90	3.64	2.02	1.53	0.38	427.64	409.39	5.32	4.08
MADHURA	52609.00	0.28	6.39	14.59	4.31	3.83	2.13	0.71	0.79	858.44	389.43	2.52	1.89
CHIRI	49881.00	0.23	5.85	11.65	3.82	3.50	1.91	0.65	0.87	1057.39	438.12	2.30	1.75
JIRI	103240.00	0.29	7.56	48.09	4.56	4.21	2.44	1.91	0.30	884.39	1052.85	6.61	5.09
KATAKHAL	129880.00	0.11	5.49	57.43	4.35	4.10	2.41	3.19	0.18	763.60	1504.68	10.95	8.52
JATINGA	55390.00	0.35	7.05	22.93	4.01	4.90	3.09	1.04	0.65	675.50	371.86	3.06	2.78
SONAI	95212.00	0.07	4.30	15.98	3.50	3.80	1.93	1.33	0.47	633.14	488.25	4.28	3.56

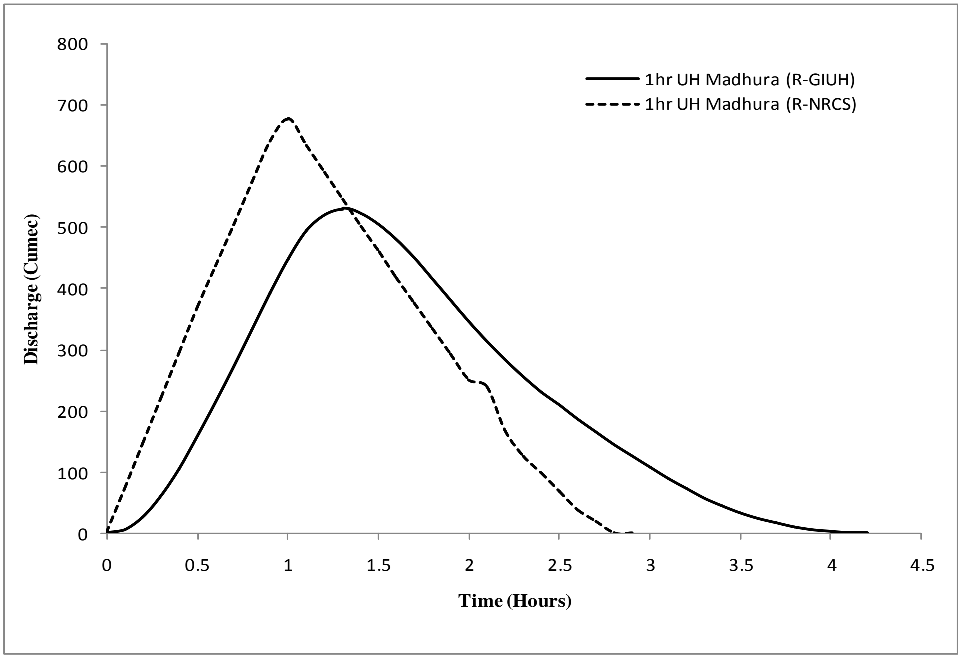


Figure -5.40: 1hr UH for Machura watershed.

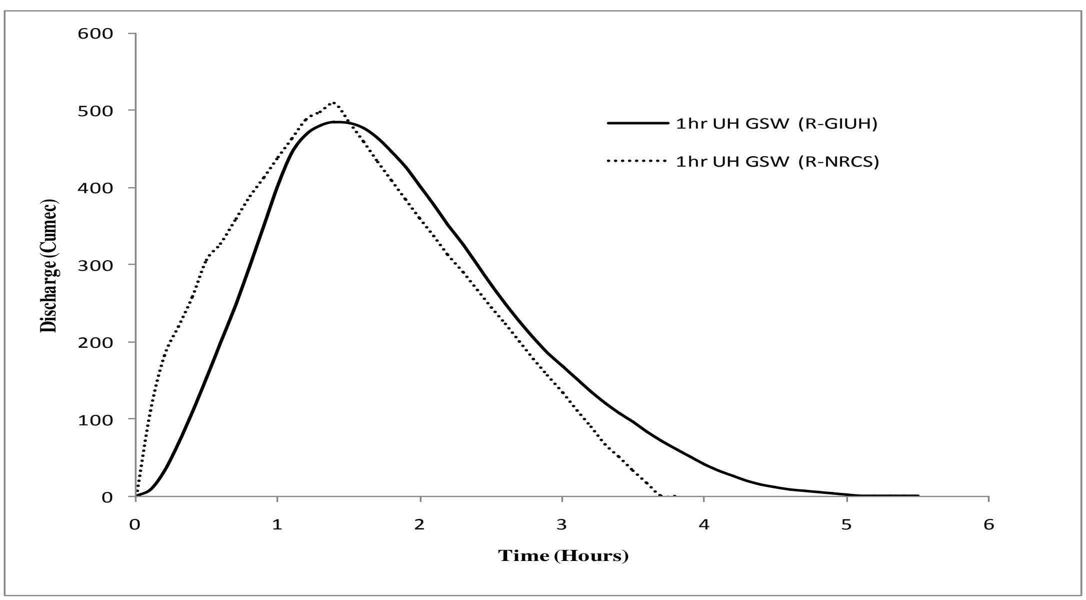


Figure -5.41: 1hr UH for Ghagra watershed

Table5.9: 1hr UH ordinates for Chiri subbasin.

Time (Hours)	GIUH ordinate	GIUH lagged	SUM/2	S-curve addition	S-curve ordinate	lagged by 10x0.1 hr	1hr UH ordinate
0	0.00		0.00		0.00		0.00
0.1	151.06	0.00	75.53	0.00	75.53		7.55
0.2	302.11	151.06	226.58	75.53	302.11		30.21
0.3	453.17	302.11	377.64	302.11	679.75		67.98
0.4	604.22	453.17	528.70	679.75	1208.45		120.84
0.5	755.28	604.22	679.75	1208.45	1888.20		188.82
0.6	906.33	755.28	830.81	1888.20	2719.00		271.90
0.7	1057.39	906.33	981.86	2719.00	3700.87		370.09
0.8	991.36	1057.39	1024.38	3700.87	4725.24		472.52
0.9	925.28	991.36	958.32	4725.24	5683.56		568.36
1	859.20	925.28	892.24	5683.56	6575.80	0.00	657.58
1.1	793.12	859.20	826.16	6575.80	7401.96	75.53	732.64
1.2	727.04	793.12	760.08	7401.96	8162.04	302.11	785.99
1.3	660.96	727.04	694.00	8162.04	8856.04	679.75	817.63
1.4	594.88	660.96	627.92	8856.04	9483.96	1208.45	827.55
1.5	528.80	594.88	561.84	9483.96	10045.80	1888.20	815.76
1.6	462.72	528.80	495.76	10045.80	10541.56	2719.00	782.26
1.7	396.64	462.72	429.68	10541.56	10971.24	3700.87	727.04
1.8	330.56	396.64	363.60	10971.24	11334.84	4725.24	660.96
1.9	264.48	330.56	297.52	11334.84	11632.36	5683.56	594.88
2	198.40	264.48	231.44	11632.36	11863.80	6575.80	528.80
2.1	132.32	198.40	165.36	11863.80	12029.16	7401.96	462.72

2.2	66.24	132.32	99.28	12029.16	12128.44	8162.04	396.64
2.3	0.16	66.24	33.20	12128.44	12161.64	8856.04	330.56
2.4		0.16	0.08	12161.64	12161.72	9483.96	267.78
2.5				12161.72	12161.72	10045.80	211.59
2.6				12161.72	12161.72	10541.56	162.02
2.7				12161.72	12161.72	10971.24	119.05
2.8				12161.72	12161.72	11334.84	82.69
2.9				12161.72	12161.72	11632.36	52.94
3				12161.72	12161.72	11863.80	29.79
3.1				12161.72	12161.72	12029.16	13.26
3.2				12161.72	12161.72	12128.44	3.33
3.3				12161.72	12161.72	12161.64	0.01
3.4				12161.72	12161.72	12161.72	0.00

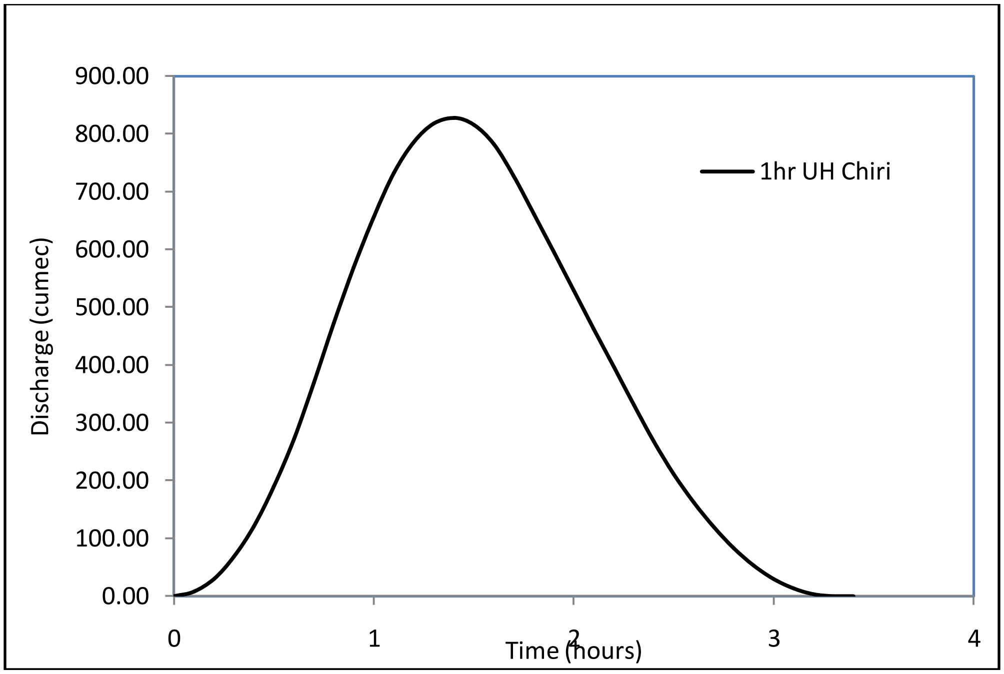


Figure: 5.42:1hr UH ordinates for Chiri subbasin

Table-5.10: 1hr UH ordinates for Jiri subbasin.

Time (Hours)	**GIUH ordinate**	**GIUH lagged**	**SUM/2**	**S-curve addition**	**S-curve ordinate**	**lagged by 10x0.1 hr**	**1hr UH ordinate**
0	0.00		0.00		0.00		0.00
0.1	46.55	0.00	23.27	0.00	23.27		2.33
0.2	93.09	46.55	69.82	23.27	93.09		9.31
0.3	139.64	93.09	116.37	93.09	209.46		20.95
0.4	186.19	139.64	162.91	209.46	372.37		37.24
0.5	232.73	186.19	209.46	372.37	581.83		58.18
0.6	279.28	232.73	256.01	581.83	837.84		83.78

0.7	325.83	279.28	302.55	837.84	1140.39		114.04
0.8	372.37	325.83	349.10	1140.39	1489.49		148.95
0.9	418.92	372.37	395.65	1489.49	1885.14		188.51
1	465.47	418.92	442.19	1885.14	2327.33	0.00	232.73
1.1	512.01	465.47	488.74	2327.33	2816.07	23.27	279.28
1.2	558.56	512.01	535.29	2816.07	3351.36	93.09	325.83
1.3	605.11	558.56	581.83	3351.36	3933.19	209.46	372.37
1.4	651.65	605.11	628.38	3933.19	4561.57	372.37	418.92
1.5	698.20	651.65	674.93	4561.57	5236.50	581.83	465.47
1.6	744.75	698.20	721.47	5236.50	5957.97	837.84	512.01
1.7	791.29	744.75	768.02	5957.97	6725.99	1140.39	558.56
1.8	837.84	791.29	814.57	6725.99	7540.55	1489.49	605.11
1.9	884.39	837.84	861.11	7540.55	8401.67	1885.14	651.65
2	864.80	884.39	874.59	8401.67	9276.26	2327.33	694.89
2.1	845.99	864.80	855.40	9276.26	10131.66	2816.07	731.56
2.2	827.18	845.99	836.59	10131.66	10968.24	3351.36	761.69
2.3	808.37	827.18	817.78	10968.24	11786.02	3933.19	785.28
2.4	789.56	808.37	798.97	11786.02	12584.98	4561.57	802.34
2.5	770.75	789.56	780.16	12584.98	13365.14	5236.50	812.86
2.6	751.94	770.75	761.35	13365.14	14126.48	5957.97	816.85
2.7	733.13	751.94	742.54	14126.48	14869.02	6725.99	814.30
2.8	714.32	733.13	723.73	14869.02	15592.74	7540.55	805.22
2.9	695.51	714.32	704.92	15592.74	16297.66	8401.67	789.60
3	676.70	695.51	686.11	16297.66	16983.76	9276.26	770.75

3.1	657.89	676.70	667.30	16983.76	17651.06	10131.66	751.94
3.2	639.08	657.89	648.49	17651.06	18299.54	10968.24	733.13
3.3	620.27	639.08	629.68	18299.54	18929.22	11786.02	714.32
3.4	601.46	620.27	610.87	18929.22	19540.08	12584.98	695.51
3.5	582.65	601.46	592.06	19540.08	20132.14	13365.14	676.70
3.6	563.84	582.65	573.25	20132.14	20705.38	14126.48	657.89
3.7	545.03	563.84	554.44	20705.38	21259.82	14869.02	639.08
3.8	526.22	545.03	535.63	21259.82	21795.44	15592.74	620.27
3.9	507.41	526.22	516.82	21795.44	22312.26	16297.66	601.46
4	488.60	507.41	498.01	22312.26	22810.26	16983.76	582.65
4.1	469.79	488.60	479.20	22810.26	23289.46	17651.06	563.84
4.2	450.98	469.79	460.39	23289.46	23749.84	18299.54	545.03
4.3	432.17	450.98	441.58	23749.84	24191.42	18929.22	526.22
4.4	413.36	432.17	422.77	24191.42	24614.18	19540.08	507.41
4.5	394.55	413.36	403.96	24614.18	25018.14	20132.14	488.60
4.6	375.74	394.55	385.15	25018.14	25403.28	20705.38	469.79
4.7	356.93	375.74	366.34	25403.28	25769.62	21259.82	450.98
4.8	338.12	356.93	347.53	25769.62	26117.14	21795.44	432.17
4.9	319.31	338.12	328.72	26117.14	26445.86	22312.26	413.36
5	300.50	319.31	309.91	26445.86	26755.76	22810.26	394.55
5.1	281.69	300.50	291.10	26755.76	27046.86	23289.46	375.74
5.2	262.88	281.69	272.29	27046.86	27319.14	23749.84	356.93
5.3	244.07	262.88	253.48	27319.14	27572.62	24191.42	338.12
5.4	225.26	244.07	234.67	27572.62	27807.28	24614.18	319.31

5.5	206.45	225.26	215.86	27807.28	28023.14	25018.14	300.50
5.6	187.64	206.45	197.05	28023.14	28220.18	25403.28	281.69
5.7	168.83	187.64	178.24	28220.18	28398.42	25769.62	262.88
5.8	150.02	168.83	159.43	28398.42	28557.84	26117.14	244.07
5.9	131.21	150.02	140.62	28557.84	28698.46	26445.86	225.26
6	112.40	131.21	121.81	28698.46	28820.26	26755.76	206.45
6.1	93.59	112.40	103.00	28820.26	28923.26	27046.86	187.64
6.2	74.78	93.59	84.19	28923.26	29007.44	27319.14	168.83
6.3	55.97	74.78	65.38	29007.44	29072.82	27572.62	150.02
6.4	37.16	55.97	46.57	29072.82	29119.38	27807.28	131.21
6.5	18.35	37.16	27.76	29119.38	29147.14	28023.14	112.40
6.6	0.00	18.35	9.18	29147.14	29156.31	28220.18	93.61
6.7		0.00	0.00	29156.31	29156.31	28398.42	75.79
6.8				29156.31	29156.31	28557.84	59.85
6.9				29156.31	29156.31	28698.46	45.79
7				29156.31	29156.31	28820.26	33.61
7.1				29156.31	29156.31	28923.26	23.31
7.2				29156.31	29156.31	29007.44	14.89
7.3				29156.31	29156.31	29072.82	8.35
7.4				29156.31	29156.31	29119.38	3.69
7.5				29156.31	29156.31	29147.14	0.92
7.6				29156.31	29156.31	29156.31	0.00

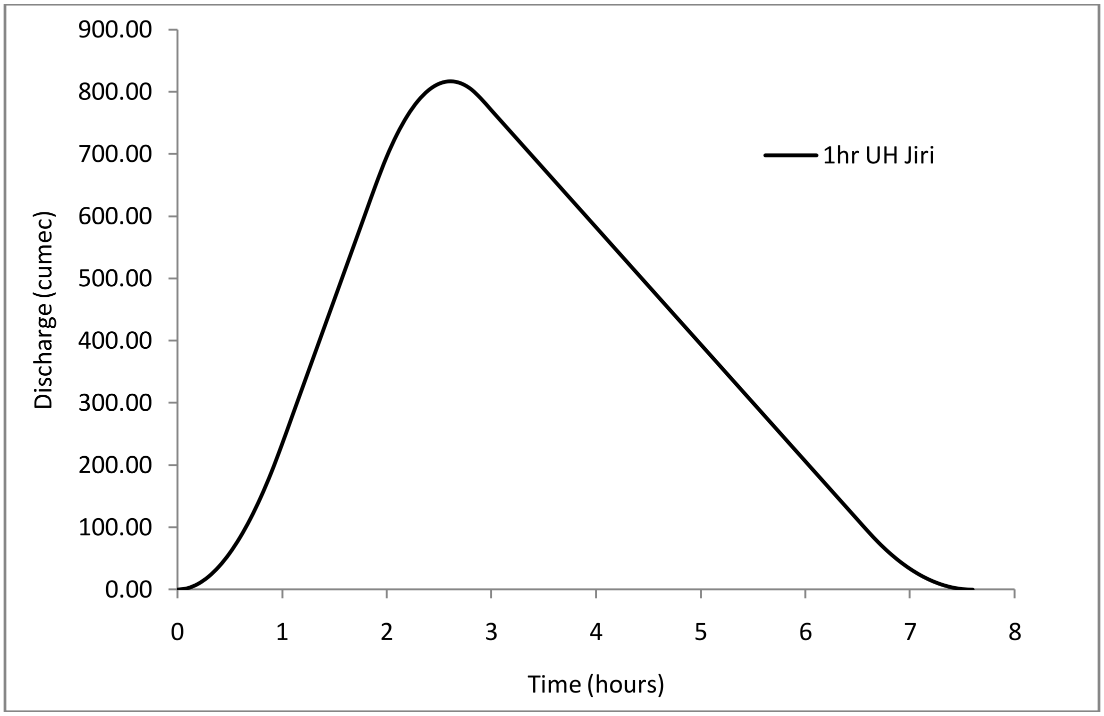


Figure-5.431hr UH ordinates for Jiri subbasin

Table:5.11 1hr UH ordinates for Jatinga subbasin.

Time (Hours)	GIUH ordinate	GIUH lagged	SUM/2	S-curve addition	S-curve ordinate	lagged by 10x0.1 hr	1hr UH ordinate
0	0.00		0.00		0.00		0.00
0.1	46.55	0.00	23.27	0.00	23.27		2.33
0.2	93.09	46.55	69.82	23.27	93.09		9.31
0.3	139.64	93.09	116.37	93.09	209.46		20.95
0.4	186.19	139.64	162.91	209.46	372.37		37.24
0.5	232.73	186.19	209.46	372.37	581.83		58.18

0.6	279.28	232.73	256.01	581.83	837.84		83.78
0.7	325.83	279.28	302.55	837.84	1140.39		114.04
0.8	372.37	325.83	349.10	1140.39	1489.49		148.95
0.9	418.92	372.37	395.65	1489.49	1885.14		188.51
1	465.47	418.92	442.19	1885.14	2327.33	0.00	232.73
1.1	512.01	465.47	488.74	2327.33	2816.07	23.27	279.28
1.2	558.56	512.01	535.29	2816.07	3351.36	93.09	325.83
1.3	605.11	558.56	581.83	3351.36	3933.19	209.46	372.37
1.4	651.65	605.11	628.38	3933.19	4561.57	372.37	418.92
1.5	698.20	651.65	674.93	4561.57	5236.50	581.83	465.47
1.6	744.75	698.20	721.47	5236.50	5957.97	837.84	512.01
1.7	791.29	744.75	768.02	5957.97	6725.99	1140.39	558.56
1.8	837.84	791.29	814.57	6725.99	7540.55	1489.49	605.11
1.9	884.39	837.84	861.11	7540.55	8401.67	1885.14	651.65
2	864.80	884.39	874.59	8401.67	9276.26	2327.33	694.89
2.1	845.99	864.80	855.40	9276.26	10131.66	2816.07	731.56
2.2	827.18	845.99	836.59	10131.66	10968.24	3351.36	761.69
2.3	808.37	827.18	817.78	10968.24	11786.02	3933.19	785.28
2.4	789.56	808.37	798.97	11786.02	12584.98	4561.57	802.34
2.5	770.75	789.56	780.16	12584.98	13365.14	5236.50	812.86
2.6	751.94	770.75	761.35	13365.14	14126.48	5957.97	816.85
2.7	733.13	751.94	742.54	14126.48	14869.02	6725.99	814.30
2.8	714.32	733.13	723.73	14869.02	15592.74	7540.55	805.22
2.9	695.51	714.32	704.92	15592.74	16297.66	8401.67	789.60

3	676.70	695.51	686.11	16297.66	16983.76	9276.26	770.75
3.1	657.89	676.70	667.30	16983.76	17651.06	10131.66	751.94
3.2	639.08	657.89	648.49	17651.06	18299.54	10968.24	733.13
3.3	620.27	639.08	629.68	18299.54	18929.22	11786.02	714.32
3.4	601.46	620.27	610.87	18929.22	19540.08	12584.98	695.51
3.5	582.65	601.46	592.06	19540.08	20132.14	13365.14	676.70
3.6	563.84	582.65	573.25	20132.14	20705.38	14126.48	657.89
3.7	545.03	563.84	554.44	20705.38	21259.82	14869.02	639.08
3.8	526.22	545.03	535.63	21259.82	21795.44	15592.74	620.27
3.9	507.41	526.22	516.82	21795.44	22312.26	16297.66	601.46
4	488.60	507.41	498.01	22312.26	22810.26	16983.76	582.65
4.1	469.79	488.60	479.20	22810.26	23289.46	17651.06	563.84
4.2	450.98	469.79	460.39	23289.46	23749.84	18299.54	545.03
4.3	432.17	450.98	441.58	23749.84	24191.42	18929.22	526.22
4.4	413.36	432.17	422.77	24191.42	24614.18	19540.08	507.41
4.5	394.55	413.36	403.96	24614.18	25018.14	20132.14	488.60
4.6	375.74	394.55	385.15	25018.14	25403.28	20705.38	469.79
4.7	356.93	375.74	366.34	25403.28	25769.62	21259.82	450.98
4.8	338.12	356.93	347.53	25769.62	26117.14	21795.44	432.17
4.9	319.31	338.12	328.72	26117.14	26445.86	22312.26	413.36
5	300.50	319.31	309.91	26445.86	26755.76	22810.26	394.55
5.1	281.69	300.50	291.10	26755.76	27046.86	23289.46	375.74
5.2	262.88	281.69	272.29	27046.86	27319.14	23749.84	356.93
5.3	244.07	262.88	253.48	27319.14	27572.62	24191.42	338.12

5.4	225.26	244.07	234.67	27572.62	27807.28	24614.18	319.31
5.5	206.45	225.26	215.86	27807.28	28023.14	25018.14	300.50
5.6	187.64	206.45	197.05	28023.14	28220.18	25403.28	281.69
5.7	168.83	187.64	178.24	28220.18	28398.42	25769.62	262.88
5.8	150.02	168.83	159.43	28398.42	28557.84	26117.14	244.07
5.9	131.21	150.02	140.62	28557.84	28698.46	26445.86	225.26
6	112.40	131.21	121.81	28698.46	28820.26	26755.76	206.45
6.1	93.59	112.40	103.00	28820.26	28923.26	27046.86	187.64
6.2	74.78	93.59	84.19	28923.26	29007.44	27319.14	168.83
6.3	55.97	74.78	65.38	29007.44	29072.82	27572.62	150.02
6.4	37.16	55.97	46.57	29072.82	29119.38	27807.28	131.21
6.5	18.35	37.16	27.76	29119.38	29147.14	28023.14	112.40
6.6	0.00	18.35	9.18	29147.14	29156.31	28220.18	93.61
6.7		0.00	0.00	29156.31	29156.31	28398.42	75.79
6.8				29156.31	29156.31	28557.84	59.85
6.9				29156.31	29156.31	28698.46	45.79
7				29156.31	29156.31	28820.26	33.61
7.1				29156.31	29156.31	28923.26	23.31
7.2				29156.31	29156.31	29007.44	14.89
7.3				29156.31	29156.31	29072.82	8.35
7.4				29156.31	29156.31	29119.38	3.69
7.5				29156.31	29156.31	29147.14	0.92
7.6				29156.31	29156.31	29156.31	0.00

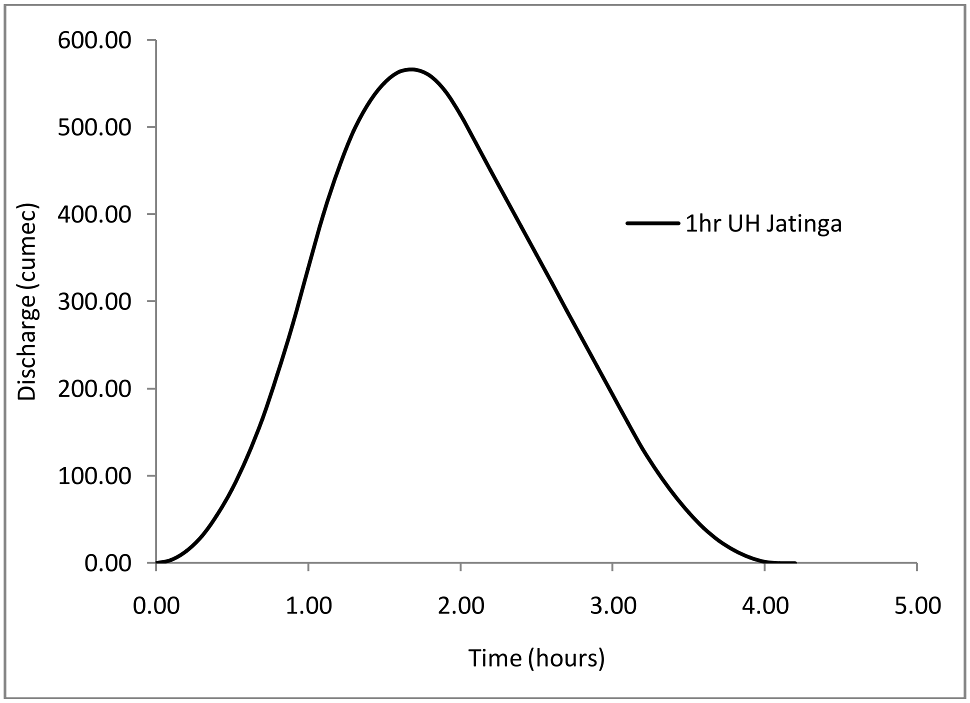


Figure: 5.44 1hr UH ordinates for Jhatinga subbasin

Table:5.12: 1hr UH ordinates for Sonai subbasin.

Time (Hours)	GIUH ordinate	GIUH lagged	SUM/2	S-curve addition	S-curve ordinate	lagged by 10x0.1 hr	1hrUH ordinate
0.00	0.00		0.00		0.00		0.00
0.10	48.70	0.00	24.35	0.00	24.35		2.44
0.20	97.41	48.70	73.05	24.35	97.41		9.74
0.30	146.11	97.41	121.76	97.41	219.16		21.92
0.40	194.81	146.11	170.46	219.16	389.62		38.96
0.50	243.51	194.81	219.16	389.62	608.79		60.88
0.60	292.22	243.51	267.87	608.79	876.65		87.67
0.70	340.92	292.22	316.57	876.65	1193.22		119.32

0.80	389.62	340.92	365.27	1193.22	1558.49		155.85
0.90	438.33	389.62	413.97	1558.49	1972.47		197.25
1.00	487.03	438.33	462.68	1972.47	2435.15	0.00	243.51
1.10	535.73	487.03	511.38	2435.15	2946.53	24.35	292.22
1.20	584.43	535.73	560.08	2946.53	3506.61	97.41	340.92
1.30	633.14	584.43	608.79	3506.61	4115.40	219.16	389.62
1.40	612.10	633.14	622.62	4115.40	4738.01	389.62	434.84
1.50	591.00	612.10	601.55	4738.01	5339.56	608.79	473.08
1.60	569.90	591.00	580.45	5339.56	5920.01	876.65	504.34
1.70	548.80	569.90	559.35	5920.01	6479.36	1193.22	528.61
1.80	527.70	548.80	538.25	6479.36	7017.61	1558.49	545.91
1.90	506.60	527.70	517.15	7017.61	7534.76	1972.47	556.23
2.00	485.50	506.60	496.05	7534.76	8030.81	2435.15	559.57
2.10	464.40	485.50	474.95	8030.81	8505.76	2946.53	555.92
2.20	443.30	464.40	453.85	8505.76	8959.61	3506.61	545.30
2.30	422.20	443.30	432.75	8959.61	9392.36	4115.40	527.70
2.40	401.10	422.20	411.65	9392.36	9804.01	4738.01	506.60
2.50	380.00	401.10	390.55	9804.01	10194.56	5339.56	485.50
2.60	358.90	380.00	369.45	10194.56	10564.01	5920.01	464.40
2.70	337.80	358.90	348.35	10564.01	10912.36	6479.36	443.30
2.80	316.70	337.80	327.25	10912.36	11239.61	7017.61	422.20
2.90	295.60	316.70	306.15	11239.61	11545.76	7534.76	401.10
3.00	274.50	295.60	285.05	11545.76	11830.81	8030.81	380.00
3.10	253.40	274.50	263.95	11830.81	12094.76	8505.76	358.90

3.20	232.30	253.40	242.85	12094.76	12337.61	8959.61	337.80
3.30	211.20	232.30	221.75	12337.61	12559.36	9392.36	316.70
3.40	190.10	211.20	200.65	12559.36	12760.01	9804.01	295.60
3.50	169.00	190.10	179.55	12760.01	12939.56	10194.56	274.50
3.60	147.90	169.00	158.45	12939.56	13098.01	10564.01	253.40
3.70	126.80	147.90	137.35	13098.01	13235.36	10912.36	232.30
3.80	105.70	126.80	116.25	13235.36	13351.61	11239.61	211.20
3.90	84.60	105.70	95.15	13351.61	13446.76	11545.76	190.10
4.00	63.50	84.60	74.05	13446.76	13520.81	11830.81	169.00
4.10	42.40	63.50	52.95	13520.81	13573.76	12094.76	147.90
4.20	21.30	42.40	31.85	13573.76	13605.61	12337.61	126.80
4.30	0.20	21.30	10.75	13605.61	13616.36	12559.36	105.70
4.40	0.00	0.20	0.10	13616.36	13616.46	12760.01	85.64
4.50		0.00	0.00	13616.46	13616.46	12939.56	67.69
4.60				13616.46	13616.46	13098.01	51.84
4.70				13616.46	13616.46	13235.36	38.11
4.80				13616.46	13616.46	13351.61	26.48
4.90				13616.46	13616.46	13446.76	16.97
5.00				13616.46	13616.46	13520.81	9.56
5.10				13616.46	13616.46	13573.76	4.27
5.20				13616.46	13616.46	13605.61	1.09
5.30				13616.46	13616.46	13616.36	0.01
5.40				13616.46	13616.46	13616.46	0.00

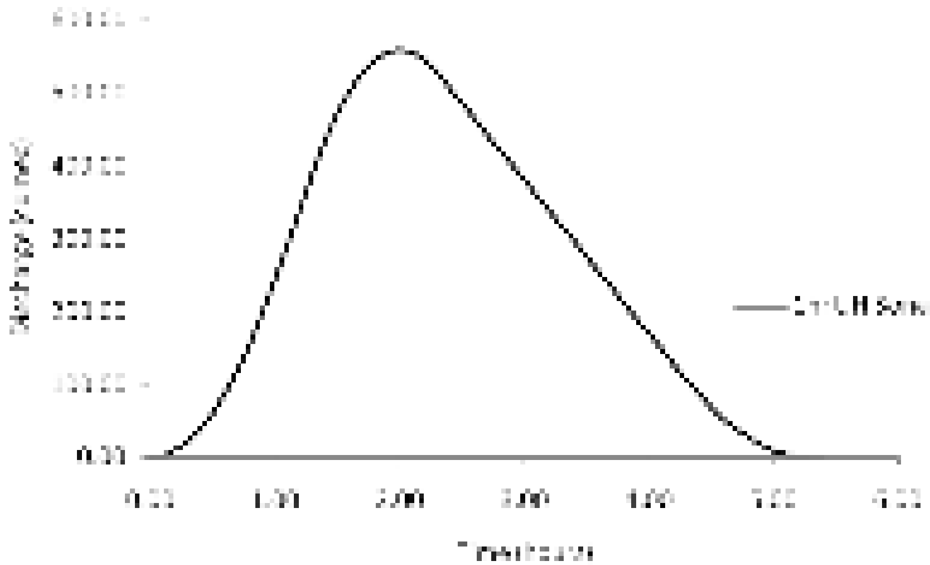


Figure 5.45: 1hr UH ordinates for Sonai Subbasin

Table 5.13: 1hr UH ordinates for Katakhal subbasin.

Time (Hours)	GIUH ordinate	GIUH lagged	SUM/2	S-curve addition	S-curve ordinate	lagged by 10x0.1 hr	1hr UH ordinate
0	0.00		0.00		0.00		0.00
0.1	23.86	0.00	11.93	0.00	11.93		1.19
0.2	47.72	23.86	35.79	11.93	47.72		4.77
0.3	71.59	47.72	59.66	47.72	107.38		10.74
0.4	95.45	71.59	83.52	107.38	190.90		19.09
0.5	119.31	95.45	107.38	190.90	298.28		29.83
0.6	143.17	119.31	131.24	298.28	429.52		42.95
0.7	167.04	143.17	155.11	429.52	584.63		58.46
0.8	190.90	167.04	178.97	584.63	763.60		76.36

0.9	214.76	190.90	202.83	763.60	966.43		96.64
1	238.62	214.76	226.69	966.43	1193.12	0.00	119.31
1.1	262.49	238.62	250.56	1193.12	1443.67	11.93	143.17
1.2	286.35	262.49	274.42	1443.67	1718.09	47.72	167.04
1.3	310.21	286.35	298.28	1718.09	2016.37	107.38	190.90
1.4	334.07	310.21	322.14	2016.37	2338.51	190.90	214.76
1.5	357.94	334.07	346.00	2338.51	2684.52	298.28	238.62
1.6	381.80	357.94	369.87	2684.52	3054.39	429.52	262.49
1.7	405.66	381.80	393.73	3054.39	3448.11	584.63	286.35
1.8	429.52	405.66	417.59	3448.11	3865.71	763.60	310.21
1.9	453.39	429.52	441.45	3865.71	4307.16	966.43	334.07
2	477.25	453.39	465.32	4307.16	4772.48	1193.12	357.94
2.1	501.11	477.25	489.18	4772.48	5261.66	1443.67	381.80
2.2	524.97	501.11	513.04	5261.66	5774.70	1718.09	405.66
2.3	548.83	524.97	536.90	5774.70	6311.60	2016.37	429.52
2.4	572.70	548.83	560.77	6311.60	6872.37	2338.51	453.39
2.5	596.56	572.70	584.63	6872.37	7457.00	2684.52	477.25
2.6	620.42	596.56	608.49	7457.00	8065.49	3054.39	501.11
2.7	644.28	620.42	632.35	8065.49	8697.84	3448.11	524.97
2.8	668.15	644.28	656.22	8697.84	9354.05	3865.71	548.83
2.9	692.01	668.15	680.08	9354.05	10034.13	4307.16	572.70
3	715.87	692.01	703.94	10034.13	10738.07	4772.48	596.56
3.1	739.73	715.87	727.80	10738.07	11465.88	5261.66	620.42
3.2	763.60	739.73	751.67	11465.88	12217.54	5774.70	644.28

3.3	752.77	763.60	758.18	12217.54	12975.73	6311.60	666.41
3.4	742.86	752.77	747.81	12975.73	13723.54	6872.37	685.12
3.5	732.94	742.86	737.90	13723.54	14461.44	7457.00	700.44
3.6	723.02	732.94	727.98	14461.44	15189.42	8065.49	712.39
3.7	713.11	723.02	718.07	15189.42	15907.49	8697.84	720.96
3.8	703.19	713.11	708.15	15907.49	16615.64	9354.05	726.16
3.9	693.28	703.19	698.23	16615.64	17313.87	10034.13	727.97
4	683.36	693.28	688.32	17313.87	18002.19	10738.07	726.41
4.1	673.44	683.36	678.40	18002.19	18680.59	11465.88	721.47
4.2	663.53	673.44	668.49	18680.59	19349.08	12217.54	713.15
4.3	653.61	663.53	658.57	19349.08	20007.65	12975.73	703.19
4.4	643.70	653.61	648.65	20007.65	20656.30	13723.54	693.28
4.5	633.78	643.70	638.74	20656.30	21295.04	14461.44	683.36
4.6	623.86	633.78	628.82	21295.04	21923.86	15189.42	673.44
4.7	613.95	623.86	618.91	21923.86	22542.77	15907.49	663.53
4.8	604.03	613.95	608.99	22542.77	23151.76	16615.64	653.61
4.9	594.12	604.03	599.07	23151.76	23750.83	17313.87	643.70
5	584.20	594.12	589.16	23750.83	24339.99	18002.19	633.78
5.1	574.28	584.20	579.24	24339.99	24919.23	18680.59	623.86
5.2	564.37	574.28	569.33	24919.23	25488.56	19349.08	613.95
5.3	554.45	564.37	559.41	25488.56	26047.97	20007.65	604.03
5.4	544.54	554.45	549.49	26047.97	26597.46	20656.30	594.12
5.5	534.62	544.54	539.58	26597.46	27137.04	21295.04	584.20
5.6	524.70	534.62	529.66	27137.04	27666.70	21923.86	574.28

5.7	514.79	524.70	519.75	27666.70	28186.45	22542.77	564.37
5.8	504.87	514.79	509.83	28186.45	28696.28	23151.76	554.45
5.9	494.96	504.87	499.91	28696.28	29196.19	23750.83	544.54
6	485.04	494.96	490.00	29196.19	29686.19	24339.99	534.62
6.1	475.12	485.04	480.08	29686.19	30166.27	24919.23	524.70
6.2	465.21	475.12	470.17	30166.27	30636.44	25488.56	514.79
6.3	455.29	465.21	460.25	30636.44	31096.69	26047.97	504.87
6.4	445.38	455.29	450.33	31096.69	31547.02	26597.46	494.96
6.5	435.46	445.38	440.42	31547.02	31987.44	27137.04	485.04
6.6	425.54	435.46	430.50	31987.44	32417.94	27666.70	475.12
6.7	415.63	425.54	420.59	32417.94	32838.53	28186.45	465.21
6.8	405.71	415.63	410.67	32838.53	33249.20	28696.28	455.29
6.9	395.80	405.71	400.75	33249.20	33649.95	29196.19	445.38
7	385.88	395.80	390.84	33649.95	34040.79	29686.19	435.46
7.1	375.96	385.88	380.92	34040.79	34421.71	30166.27	425.54
7.2	366.05	375.96	371.01	34421.71	34792.72	30636.44	415.63
7.3	356.13	366.05	361.09	34792.72	35153.81	31096.69	405.71
7.4	346.22	356.13	351.17	35153.81	35504.98	31547.02	395.80
7.5	336.30	346.22	341.26	35504.98	35846.24	31987.44	385.88
7.6	326.38	336.30	331.34	35846.24	36177.58	32417.94	375.96
7.7	316.47	326.38	321.43	36177.58	36499.01	32838.53	366.05
7.8	306.55	316.47	311.51	36499.01	36810.52	33249.20	356.13
7.9	296.64	306.55	301.59	36810.52	37112.11	33649.95	346.22
8	286.72	296.64	291.68	37112.11	37403.79	34040.79	336.30

8.1	276.80	286.72	281.76	37403.79	37685.55	34421.71	326.38
8.2	266.89	276.80	271.85	37685.55	37957.40	34792.72	316.47
8.3	256.97	266.89	261.93	37957.40	38219.33	35153.81	306.55
8.4	247.06	256.97	252.01	38219.33	38471.34	35504.98	296.64
8.5	237.14	247.06	242.10	38471.34	38713.44	35846.24	286.72
8.6	227.22	237.14	232.18	38713.44	38945.62	36177.58	276.80
8.7	217.31	227.22	222.27	38945.62	39167.89	36499.01	266.89
8.8	207.39	217.31	212.35	39167.89	39380.24	36810.52	256.97
8.9	197.48	207.39	202.43	39380.24	39582.67	37112.11	247.06
9	187.56	197.48	192.52	39582.67	39775.19	37403.79	237.14
9.1	177.64	187.56	182.60	39775.19	39957.79	37685.55	227.22
9.2	167.73	177.64	172.69	39957.79	40130.48	37957.40	217.31
9.3	157.81	167.73	162.77	40130.48	40293.25	38219.33	207.39
9.4	147.90	157.81	152.85	40293.25	40446.10	38471.34	197.48
9.5	137.98	147.90	142.94	40446.10	40589.04	38713.44	187.56
9.6	128.06	137.98	133.02	40589.04	40722.06	38945.62	177.64
9.7	118.15	128.06	123.11	40722.06	40845.17	39167.89	167.73
9.8	108.23	118.15	113.19	40845.17	40958.36	39380.24	157.81
9.9	98.32	108.23	103.27	40958.36	41061.63	39582.67	147.90
10	88.40	98.32	93.36	41061.63	41154.99	39775.19	137.98
10.1	78.48	88.40	83.44	41154.99	41238.43	39957.79	128.06
10.2	68.57	78.48	73.53	41238.43	41311.96	40130.48	118.15
10.3	58.65	68.57	63.61	41311.96	41375.57	40293.25	108.23
10.4	48.74	58.65	53.69	41375.57	41429.26	40446.10	98.32

10.5	38.82	48.74	43.78	41429.26	41473.04	40589.04	88.40
10.6	28.90	38.82	33.86	41473.04	41506.90	40722.06	78.48
10.7	18.99	28.90	23.95	41506.90	41530.85	40845.17	68.57
10.8	9.07	18.99	14.03	41530.85	41544.88	40958.36	58.65
10.9	0.00	9.07	4.54	41544.88	41549.41	41061.63	48.78
11		0.00	0.00	41549.41	41549.41	41154.99	39.44
11.1				41549.41	41549.41	41238.43	31.10
11.2				41549.41	41549.41	41311.96	23.75
11.3				41549.41	41549.41	41375.57	17.38
11.4				41549.41	41549.41	41429.26	12.02
11.5				41549.41	41549.41	41473.04	7.64
11.6				41549.41	41549.41	41506.90	4.25
11.7				41549.41	41549.41	41530.85	1.86
11.8				41549.41	41549.41	41544.88	0.45
11.9				41549.41	41549.41	41549.41	0.00
12				41549.41	41549.41	41549.41	0.00

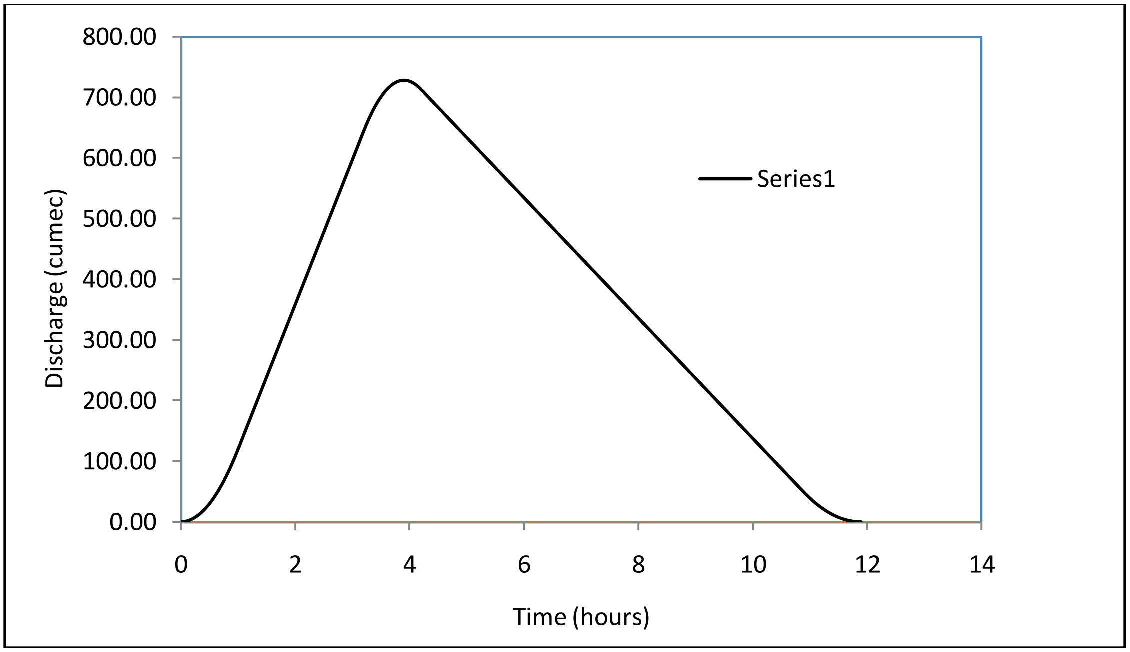


Figure 5.46: 1hr UH ordinates for Katakhal subbasin