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CENTRAL WATER AND POWER RESEARCH STATION

TECHNICAL REPORT NO. 5015
NOVEMBER 2012

MORPHOLOGICAL STUDIES OF RIVER GANDAK USING SATELLITE AND SOI DATA

Dr. I D GUPTA
DIRECTOR

GOVERNMENT OF INDIA

CENTRAL WATER AND POWER RESEARCH STATION

P.O.: KHADAKWASLA RESEARCH STATION, PUNE – 411 024

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EXECUTIVE SUMMARY

MORPHOLOGICAL STUDIES OF RIVER GANDAK USING SATELLITE AND SOI DATA

Alluvial rivers in India as well as all over the world are facing the problems of erosion or deposition depending on the relative magnitude of sediment carried by the streams with respect to the sediment transport capacity. The phenomenon of sediment transport is complex in nature and it is known that sediment transport capacity varies with the power of flow velocity; the exponent ranges between 3 to 5.

Examples in Northern India are known to all of us were used damages have been noticed due to cores of rivers. Such capacity is generally initiated because of the higher sediment transport capacity than the incoming sediment flow. Under such scenario banks are eroded and used damages to the agricultural fields, dwellings, roads, railways and other municipal and industrial establishments take place. A group was formed under the leadership of Ministry of Water Resources, New Delhi and it was decided to study the behaviour of alluvial river in North India. The meeting was held at CWC, New Delhi and it was decided that the studies for river Gandak was carried out at CWPRS, Pune.

Reach of river Gandak from entry by the Indian Territory upto the confluence of river Ganga was selected for the study. It was further clarified that initially the confluence near river Ganga is under the influence of changes in flow and sediment transport. Therefore, it was considered appropriate to consider the stretch of river Gandak near the confluence area of beyond the effect of backwater zone.

Studies have been carried out using the bank line data of river Gandak extracted from Survey of India (SOI) Toposheets for the year(s) available at CWPRS. Further data of bank line was extracted from the Satellite data collected from the then National Remote Sensing Agency (NRSA), Hyderabad. Satellite data were collected at an interval between 4 to 6 years depending on the availability of colorful data. The Satellite data de-coded using the salient features available SOI Toposheets. The study area is covered in more than 15 Toposheets of SOI. The mosaic of the study area showing SOI Toposheets is shown in Figure 1.

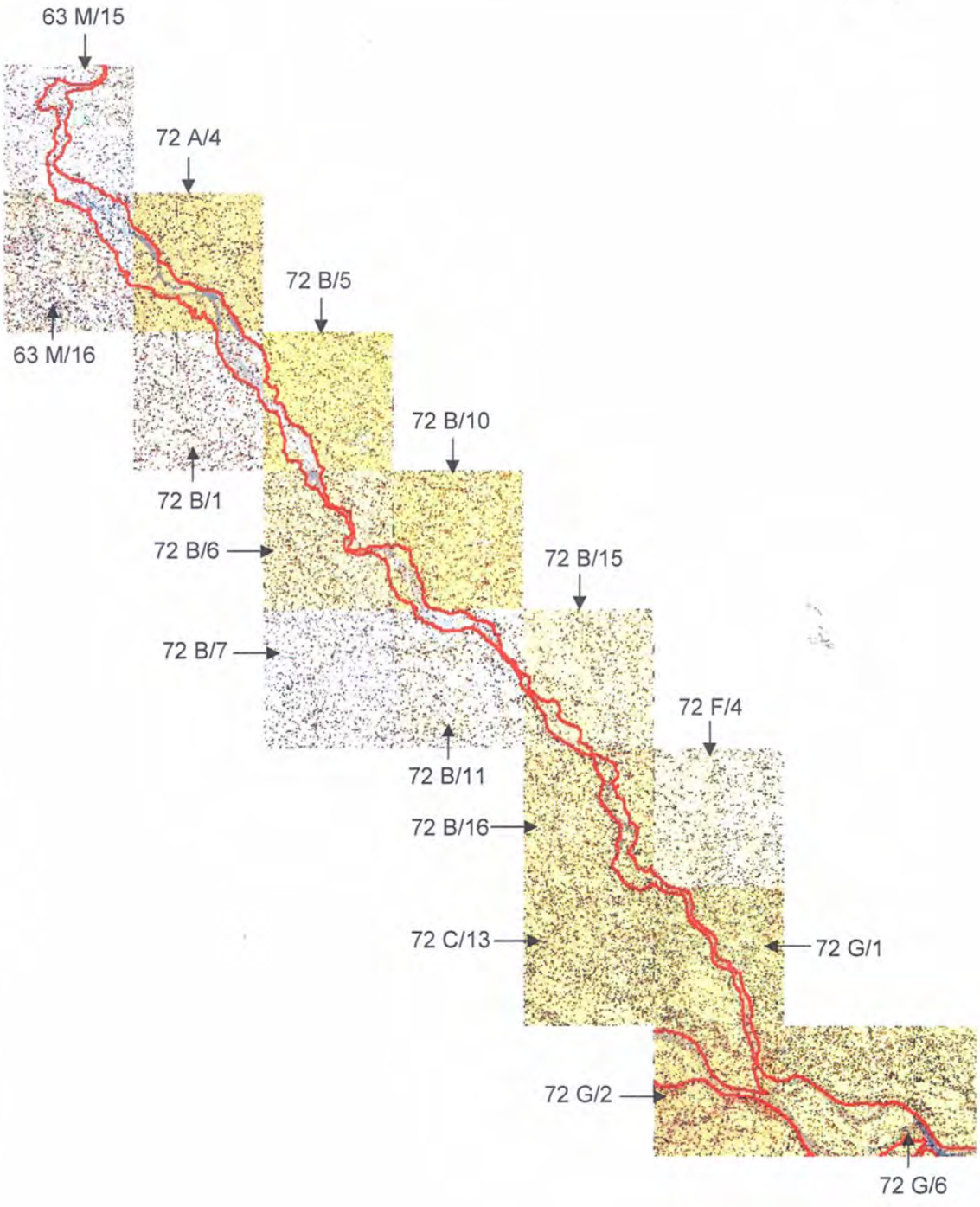

FIGURE 1: BANK LINES OF GANDAK RIVER - TOPOSHEET

In the present studies bank lines were extracted from Satellite data for the years 1988, 1994, 1999 & 2004. These data were extracted using EASIPACE software available in Remote Sensing Laboratory of CWPRS. The bank line data were super imposed on the available year SOI Toposheets to identify likely locations where erosion is taking place. Since the sensor selection for Satellite data is varies LISS II to LISS III locations where measurable changes in bank line was noticed to identify through super imposition. For this purpose the location of SOI Toposheets was selected and transferred to Satellite data using

Geo-reference technology. The changes in bank line have been measured and combined for different stretches in study area. The study area was divided into seven zones having overlap on either or both upstream and downstream sections, depending on the locations of the zone. Review of the analysis indicates that there are 18 locations where erosion is taking place. SOI Toposheets were used for identifying the nearby town where erosion was identified.

Analysis of stream flow and sediment data at Triveni and Dumariaghat has been carried out to review the changes in the pattern of sediment being carried in river Gandak. The results showing the area wise equations of sediment transport between discharge and corresponding sediment flow indicate that the exponent in the attempted relation

$$Q = A\, Q_s^{b}$$

The power is changing from minimum of 0.6946 to a maximum of 1.7311. The attempts were affected by clubbing the data as per the availability of bank lines from Satellite data. The results indicate that there is no major change in the regression coefficient of the sediment transport equation.

The studies carried out indicate that there are 18 locations in the study area where erosion is taking place. Further 10 locations have been identified and observations to identify and confirm the changes in bank line due to deposition.

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INDEX

Table No.	List of Tables	Page

Figure No.	List of Figures	Page

CHAPTER 1

INTRODUCTION

Technical Report No. 5015 **Month: November, 2012**

MORPHOLOGICAL STUDIES OF RIVER GANDAK USING SATELLITE AND SOI DATA

1.0 INTRODUCTION

Alluvial rivers in India as well as in other countries are facing the problem of erosion and deposition. These phenomena occur in the river due to inbalance in sediment transport capacity and inflow of sediment. It is known that erosion is likely to take place when inflow of sediment in the stream is less than the carrying capacity; as against this depositions will take place if sediment inflow is more than transporting capacity of the river. Either of these phenomena are posing difficulties to the planners as well as causing damages to the adjoining area where agricultural fields or towns, available monuments that are likely to be located. Examples are available where the large sectors of agricultural fields have been washed away during the change of course of alluvial rivers.

It is, therefore, necessary to give protection against the erosion to the properties and monuments located on the bank of river. In this direction, an attempt is proposed in river Gandak for identifying erosion areas. A meeting was held by Member (RM), CWC, New Delhi on 26 May 2004. It was decided in the meeting that different rivers where the problem of erosion / deposition is experienced are to be identified. The task was carried out and different rivers were recognized. Study of these rivers was assigned to different organizations like NIH, CWPRS etc. Out of these rivers, it was decided that morphological studies of river Gandak might be carried out by CWPRS.

It was further, decided that bank like data of river Gandak is to be collected from Survey of India toposheets of 1974-76 and bank line of latter years are to be extracted using satellite data. The satellite data are to be collected at an interval ranging from 4 to 6 years, as per the availability of cloud free dates, collected from National Remote Sensing Centre (NRSC), Hyderabad. Accordingly, attempts have been made to collect the SOI toposheets in the first phase. It was decided after review of available toposheets that in lieu of the toposheets for 1974-76, the toposheets as available at CWPRS are to be used. Accordingly, the data on bank like of river Gandak from SOI toposheets and satellite imagery were collected and analyzed. An interim report was submitted to CWC in March 2006. The report was reviewed and observations received in May 2006 were complied in subsequent meeting held in October / December 2006.

Further, comments were communicated. Replies to these comments were incorporated and draft final was submitted to CWC for getting clearance to submit final copies. The clearance was received in October, 2012 with suggestions and additional comments. Attempts have been made to comply these comments by dividing a total of stretch of river Gandak in different zones in order to identify locations on left and right bank where major changes have taken place. In addition, gauge and discharge data at Triveni / Dumariaghat has been collected from CWC, Patna / Lucknow.

This report has been prepared after compliance of comments / observations communicated to CWPRS by CWC.

CHAPTER 2

STUDY AREA

MORPHOLOGICAL STUDIES OF RIVER GANDAK USING SATELLITE AND SOI DATA

2.0 STUDY AREA

Gandaki River or Kali Gandaki, also known as the Narayani in southern Nepal and the Gandak in India, is one of the major rivers of Nepal and a left bank (north bank) tributary of river Ganga in India. Kali Gandaki starts at the north of Tibetan plateau of the Himalayas in the Mustang District of Nepal, near the Tibetan border. The two headwaters of river, Nup Chhu and Shar Chhu meet near the town of Lo Manthang in upper Mustang. These two rivers are also known as "West River" and "East River". These rivers then flow southwest with the name of Mustang Khola. In Kagbeni a major tributary, Kak Khola, flowing from Muktinath, meets Mustang Khola, and since then together this river is called the Kali Gandaki. The course of this river advents southwards through a steep gorge known as the Kali Gandaki Gorge, or Andha Galchi, between the mountains Dhaulagiri (rising up to 8167 m) to the west and Annapurna (8091 m) to the east side. If one measures the depth of a canyon by the difference between the river bed and the heights of the highest peaks on either side, the Gorge is the world`s deepest. The course of the river between the Dhaulagiri and Annapurna massifs is at an elevation between 1300 m and 2600 m. The river is much older than the Himalayas.

The river is joined by Rahught Khola at Galeshwar on the south of the gorge, Myagdi Khola at Beni, Modi Khola near Kushma and Badigaad at Rudrabeni. The river then takes a right-angle turn and runs east. The largest hydroelectric project in Nepal is located along this stretch of the river. A major tributary Trisuli joins Kali Gandaki at Devighat just as the river exits the foothills of the Himalayas into the southern plains of Nepal. Masryanadi is a major tributary of Trisuli. From Devighat, the river flows southwest and is called Narayani or Sapt Gandaki.

The river then meanders back towards the southeast and enters India. The entry point of the river at the Indo-Nepal border is at the convergence of Gandak, near Triveni. Here, the rivers meet with Pachnad and Sonha also sliding into India from Nepal. Pandai River flows into the Indian state of Bihar from Nepal in the eastern end of the Valmiki Sanctuary and finally meets Masan. The river flows across the Gangetic plain of Bihar state and eventually merges with river Ganga near at Hajipur. Before merging with river Ganga, river flows through the districts of Champaran, Sarang and Muzaffarpur. The river has a total catchment area of 46,300 sq. km out of which 7620 sq. km is located in India. The Gandaki river basin is known to contain 1025 glaciers and 338 lakes. The basin also contains 3 of the

world's 14 highest mountains over 8,000m. After the entry in India at Triveni, river flows for an extended length of 300 km out of total length of 630 km and then joins Ganga.

River Gandak rises in the Great Himalaya Range in Nepal after it flows southwest into India and then turns southeast along the Uttar Pradesh–Bihar state border and across the Indo-Gangetic Plain. Gandak river study reach in India is covered in 15 SOI toposheets.

Photographs of river Gandak in study area are presented in Appendix-I.

CHAPTER 3

TERMS OF REFERENCE/ METHODOLOGY

MORPHOLOGICAL STUDIES OF RIVER GANDAK USING SATELLITE AND SOI DATA

3.0 TERMS OF REFERENCE/ METHODOLOGY

3.1 It was desired by CWC that the following work components be carried out at CWPRS:

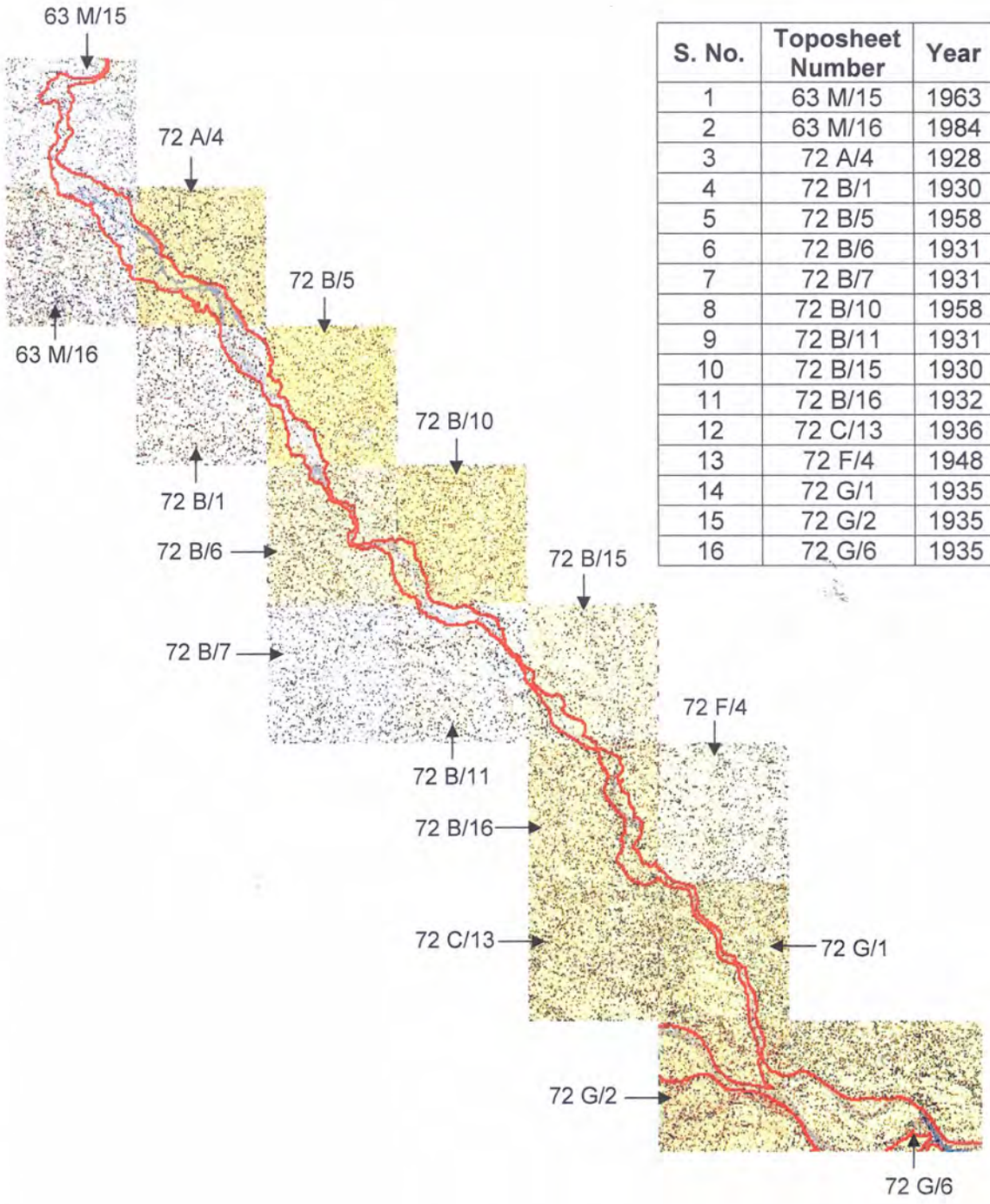
3.1.1 To demarcate pre and post monsoon course of river Gandak for the years 1990, 1994, 1999 and 2003. These courses are to be superimposed on the river course of 1974 -76 toposheets from Survey of India.

3.1.2 To study and identify shifting of course, critical locations and rate of shifting

3.1.3 The SOI Toposheets available at CWPRS were reviewed and the position was communicated to CWC. Accordingly, available toposheets were used for preparing the reference line for comparison.

The available cloud free data from NRSA were reviewed and necessary changes were made in the data used for comparison. Thus, in place of 1990, the data of 1988 was used and in place of 2003, data for 2004 were considered in the studies.

3.2 As indicated above, the reach of river Gandak is covered in 15 toposheets. Out of these toposheets, 63M14 and 63M05 were not available at CWPRS as well as SOI office at Dehradun. The reach as could be delineated from SOI toposheets was identified and bank lines were marked as shown in Figure 3.1. These vectors were used later on for the purpose of superimposition.



S. No.	Toposheet Number	Year	Scale
1	63 M/15	1963	One cm : 500 m
2	63 M/16	1984	
3	72 A/4	1928	One inch : One mile
4	72 B/1	1930	
5	72 B/5	1958	
6	72 B/6	1931	
7	72 B/7	1931	
8	72 B/10	1958	
9	72 B/11	1931	
10	72 B/15	1930	
11	72 B/16	1932	
12	72 C/13	1936	
13	72 F/4	1948	
14	72 G/1	1935	
15	72 G/2	1935	
16	72 G/6	1935	

FIGURE 3.1: BANK LINES OF GANDAK RIVER - TOPOSHEET

3.3 Request was filed with then M/s NRSA, Hyderabad to inform the dates on which cloud free data over the entire river reach are available. Accordingly, the data of the study reach were collected as given in Table 3.1.

TABLE 3.1: DETAILS OF SATELLITE DATA USED

Sl. No.	Satellite	Sensor	Path/Row	Date of Pass	Toposheet
1	IRS-P6	LISS-III	103/52	31.10.2004	SOI-72A 4
2	IRS-P6	LISS-III	103/53	31.10.2004	SOI-72B 6
3	IRS-P6	LISS-III	104/53	29.11.2004	SOI-72B 16
4	IRS-P6	LISS-III	103/52	31.10.2004	–
5	IRS-P6	LISS-III	103/53	31.10.2004	–
6	IRS-P6	LISS-III	104/53	29.11.2004	–
7	IRS-1D	LISS-III	103/52	17.11.1999	
8	IRS-1D	LISS-III	103/53	17.11.1999	–
9	IRS-1D	LISS-III	104/53	14.11.1999	–
10	IRS-1D	LISS-III	105/54	11.11.1999	–
11	IRS-1B	LISS-II	23/48	27.11.1994	–
12	IRS-1B	LISS-II	23/48	27.11.1994	–
13	IRS-1B	LISS-II	23/49	27.11.1994	–
14	IRS-1B	LISS-II	22/49	22.02.1995	
15	IRS-1B	LISS-II	22/49	22.02.1995	
16	IRS-1B	LISS-II	22/49	22.02.1995	
17	IRS-1B	LISS-II	21/50	12.10.1994	–
18	IRS-1A	LISS-II	23/48	16.10.1988	–
19	IRS-1A	LISS-II	23/48	19.03.1989	
20	IRS-1A	LISS-II	23/49	16.10.1988	
21	IRS-1A	LISS-II	23/49	21.12.1988	
22	IRS-1A	LISS-II	22/49	07.12.1989	
23	IRS-1A	LISS-II	22/49	15.10.1988	–
24	IRS-1A	LISS-II	22/49	15.10.1988	–
25	IRS-1A	LISS-II	21/50	14.10.1988	–

3.4 As per the decisions taken in the meeting with CWC, the bank line data for a period of 16 years from 1988 -1989 to 2004 - 2005 were collected at an interval of about 4 to 6 years. Broadly, the data were collected for the following years:

- 1988 -1989
- 1994 -1995
- 1999 -2000
- 2004 -2005

3.5 The satellite data received from NRSA was geo-coded using the information available in SOI toposheets. The bank lines were marked on satellite data of each year and the vectors were saved using the utility available in EASIPACE software at CWPRS.

3.6 The bank line vectors thus obtained were superimposed in different pairs of the 5 year period bank lines. The changes in the bank lines thus became clear on superimposition. These are identified as likely areas that may require attention for damages during the floods.

CHAPTER 4

ANALYSIS, RESULTS AND DISCUSSIONS

MORPHOLOGICAL STUDIES OF RIVER GANDAK USING SATELLITE AND SOI DATA

4.0 ANALYSIS, RESULTS AND DISCUSSIONS

4.1 The first stage of the work was completed by delineating the bank line from the available toposheets of SOI. Thereafter the information from SOI toposheet was used for geocoding the satellite data received from NRSA. The bank lines of satellite data were delineated on each year. The bank lines for 1988, 1994, 1999 and 2004 are shown in Figures 4.1 to 4.4 respectively.

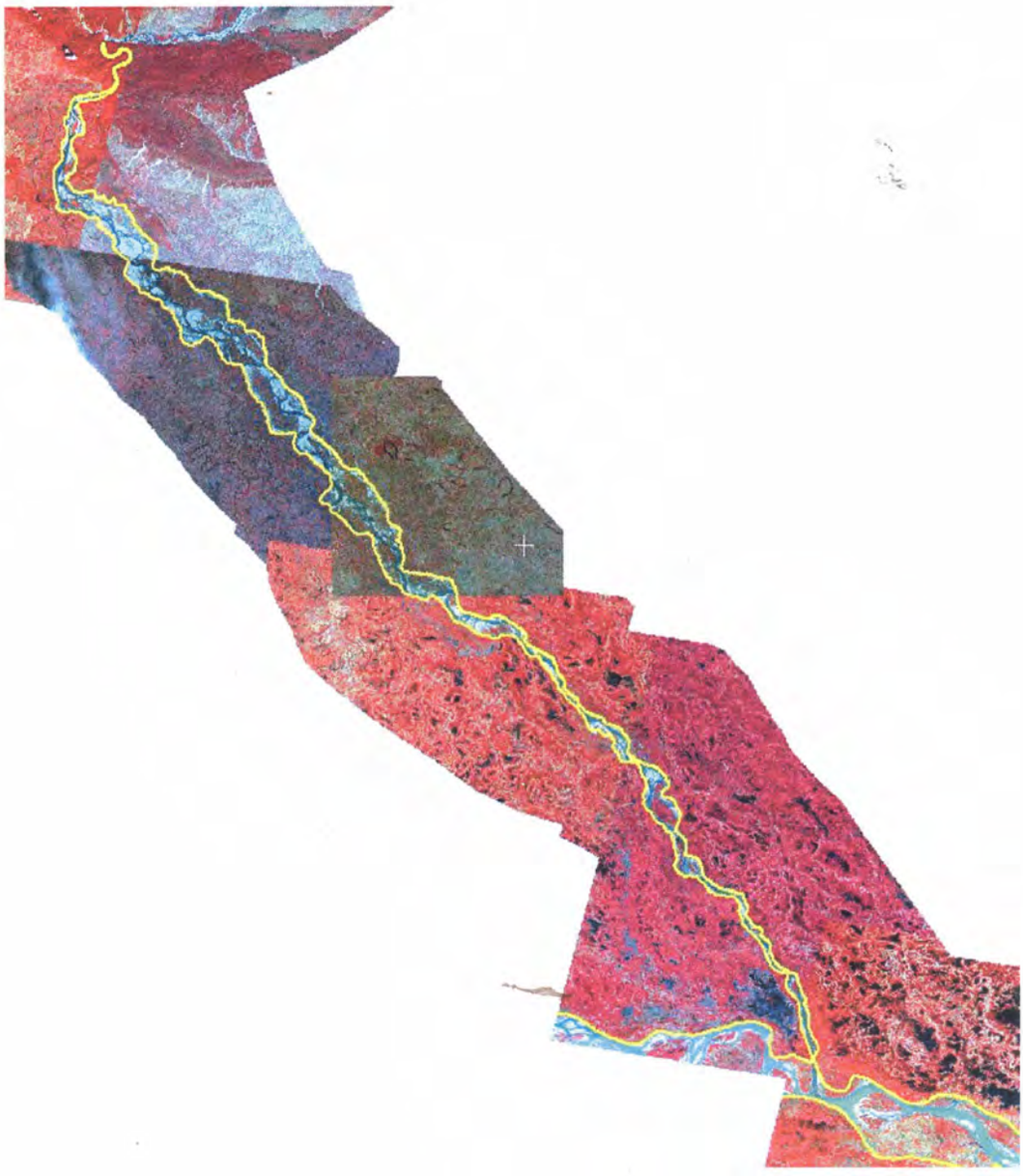


FIGURE 4.1: BANK LINES OF GANDAK RIVER – 1988

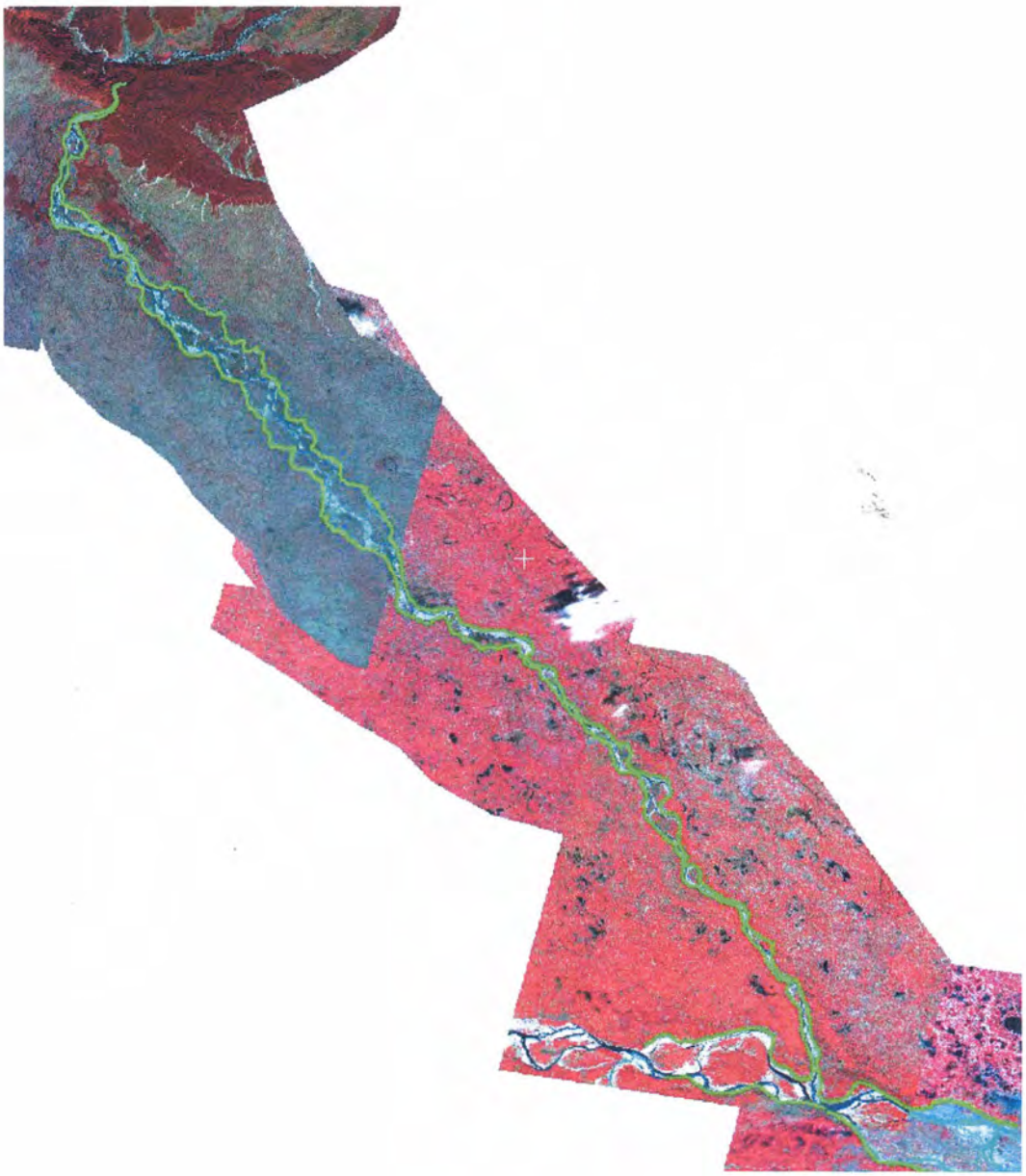


FIGURE 4.2: BANK LINES OF GANDAK RIVER – 1994

FIGURE 4.3: BANK LINES OF GANDAK RIVER – 1999

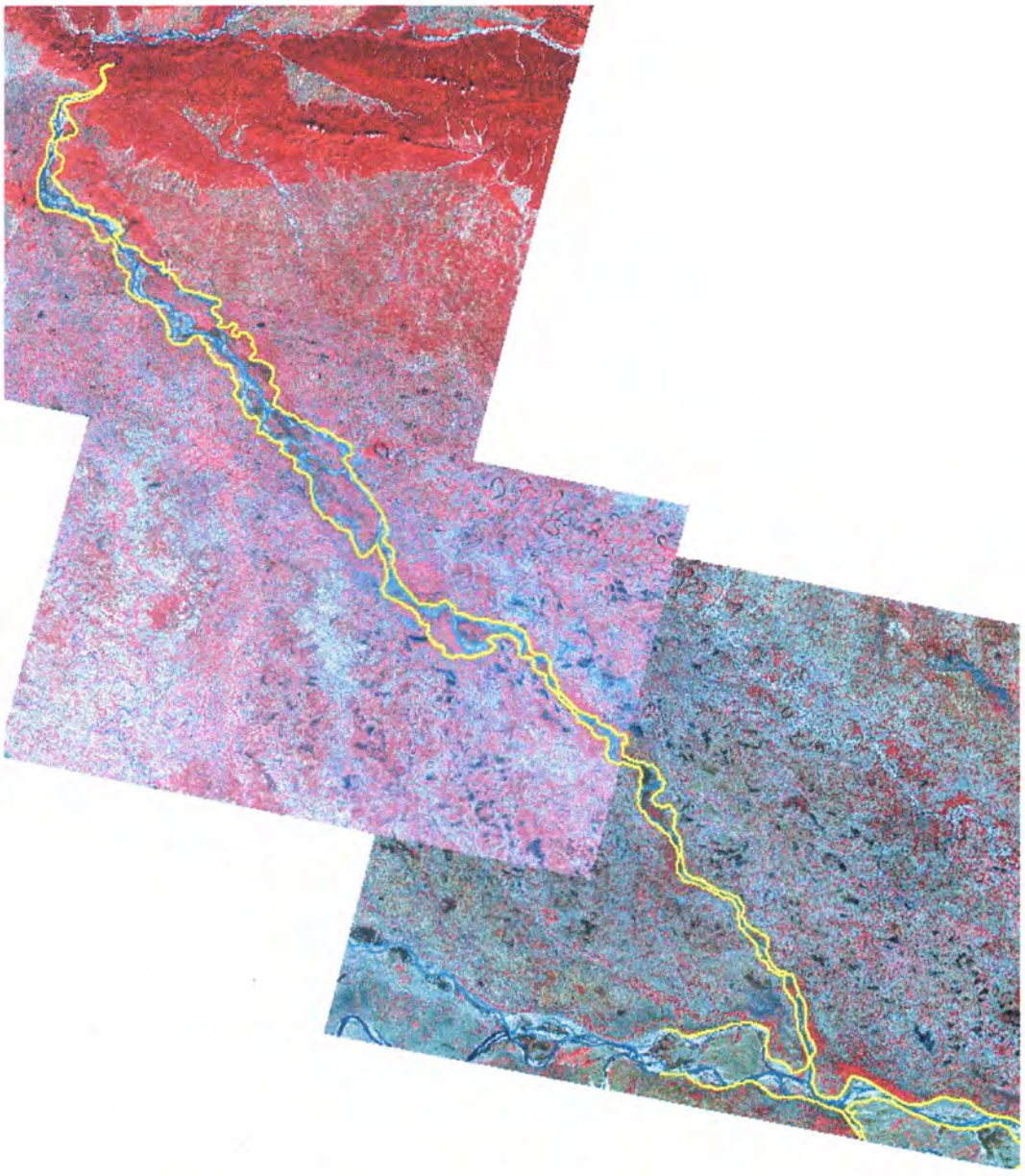


FIGURE 4.4: BANK LINES OF GANDAK RIVER – 2004

4.2 In order to identify the changes in the bank lines, two years' bank lines were superimposed in the following manner:

Sl. No.	Source	Comparison with bank line for the year	Figure No.
1	Toposheet	1988	4.5
2		1994	4.6
3		1999	4.7
4		2004	4.8
. 5	Toposheet	1988, 1994, 1999, 2004	4.9

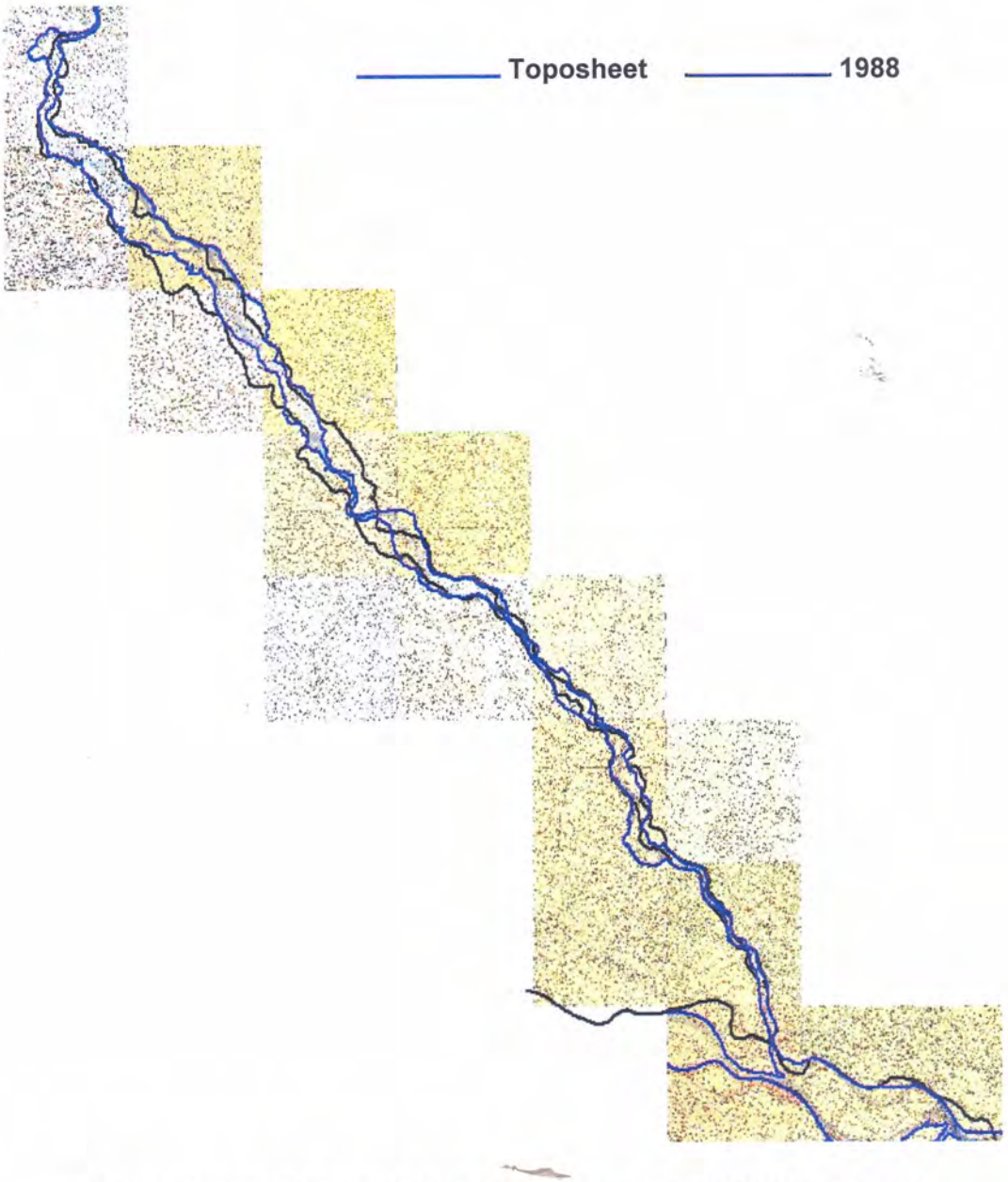


FIGURE 4.5: SUPERIMPOSED BANK LINES – TOPOSHEET & 1988

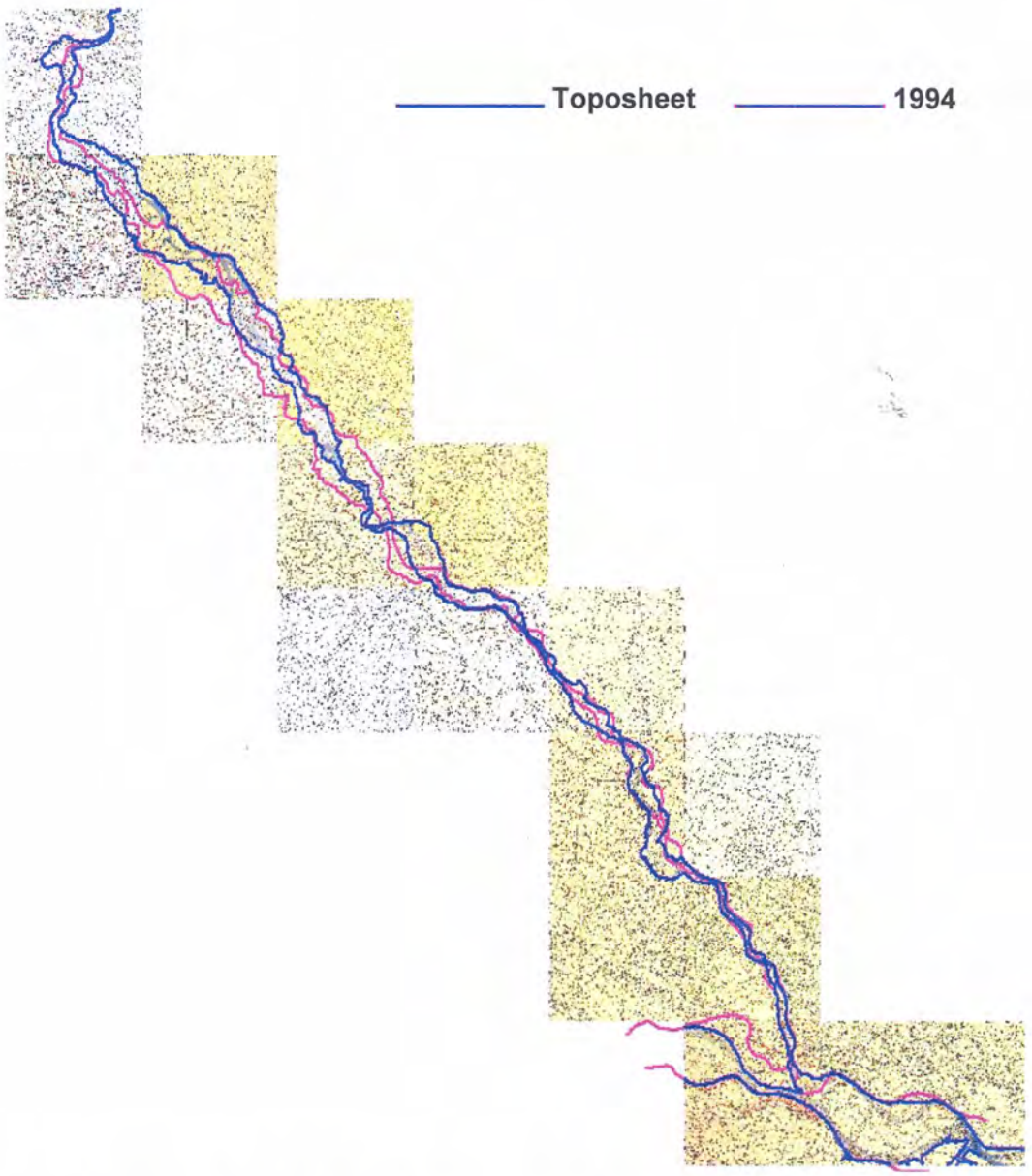


FIGURE 4.6: SUPERIMPOSED BANK LINES – TOPOSHEET & 1994

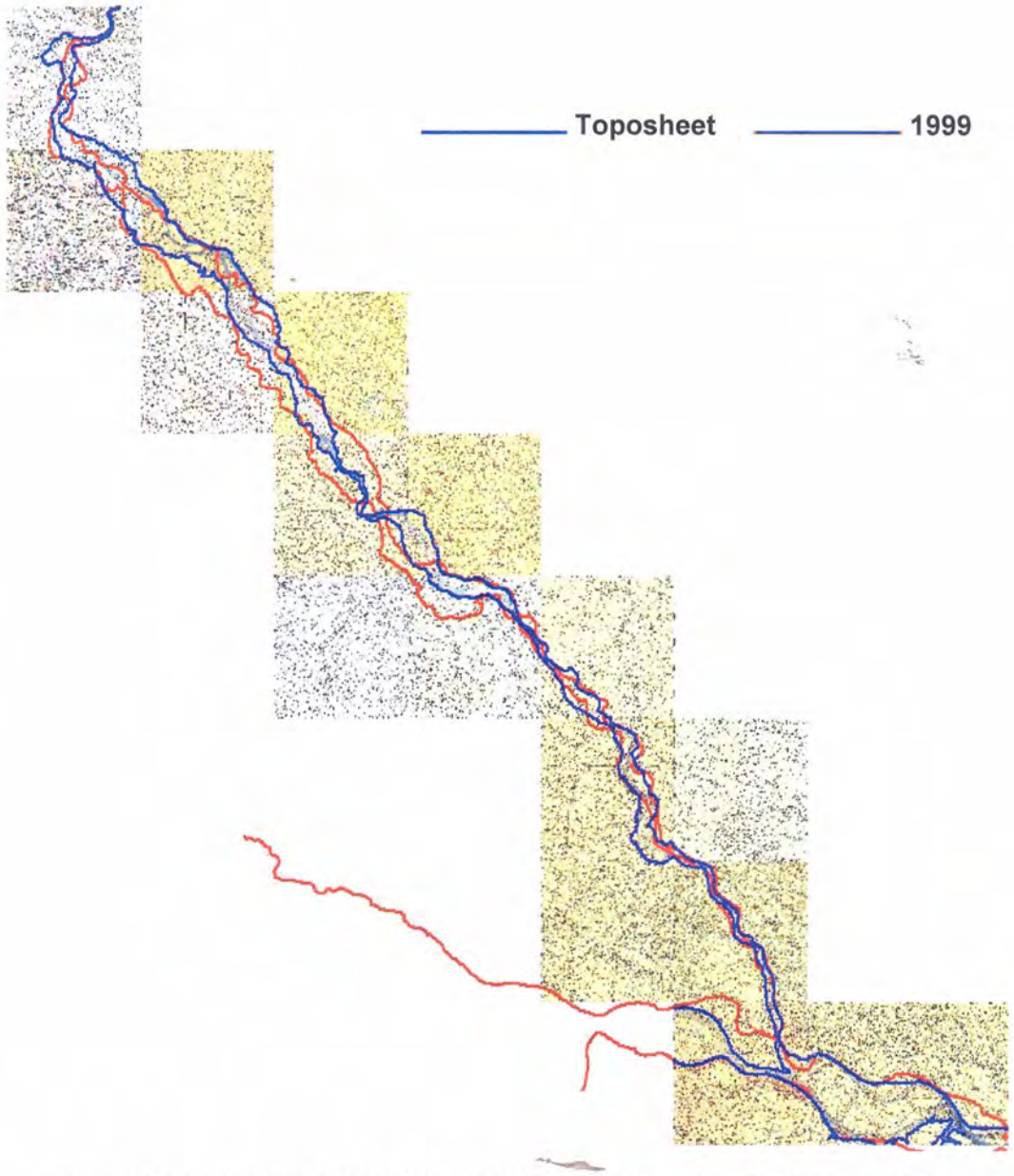


FIGURE 4.7: SUPERIMPOSED BANK LINES – TOPOSHEET & 1999

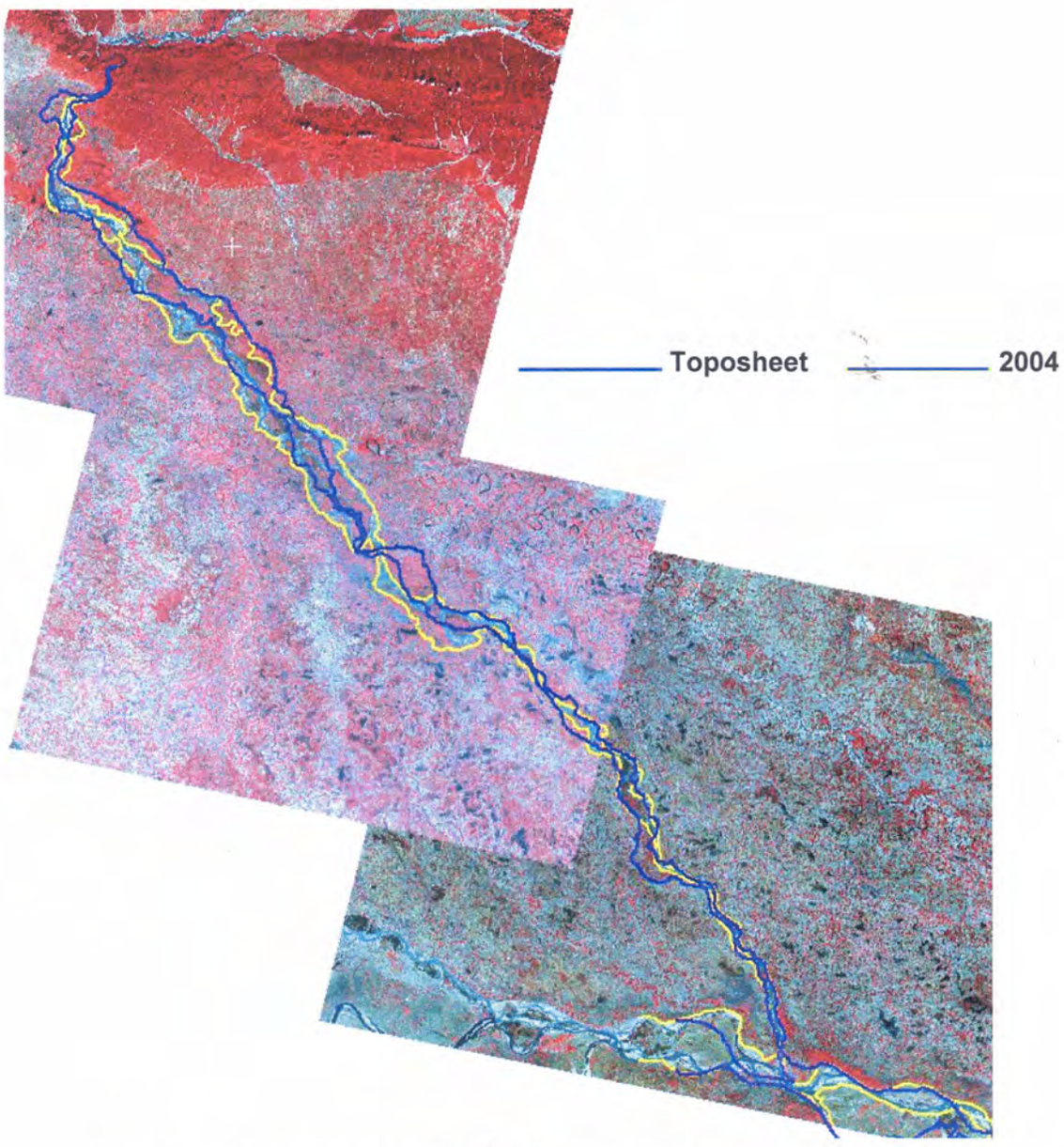


FIGURE 4.8: SUPERIMPOSED BANK LINES – TOPOSHEET & 2004

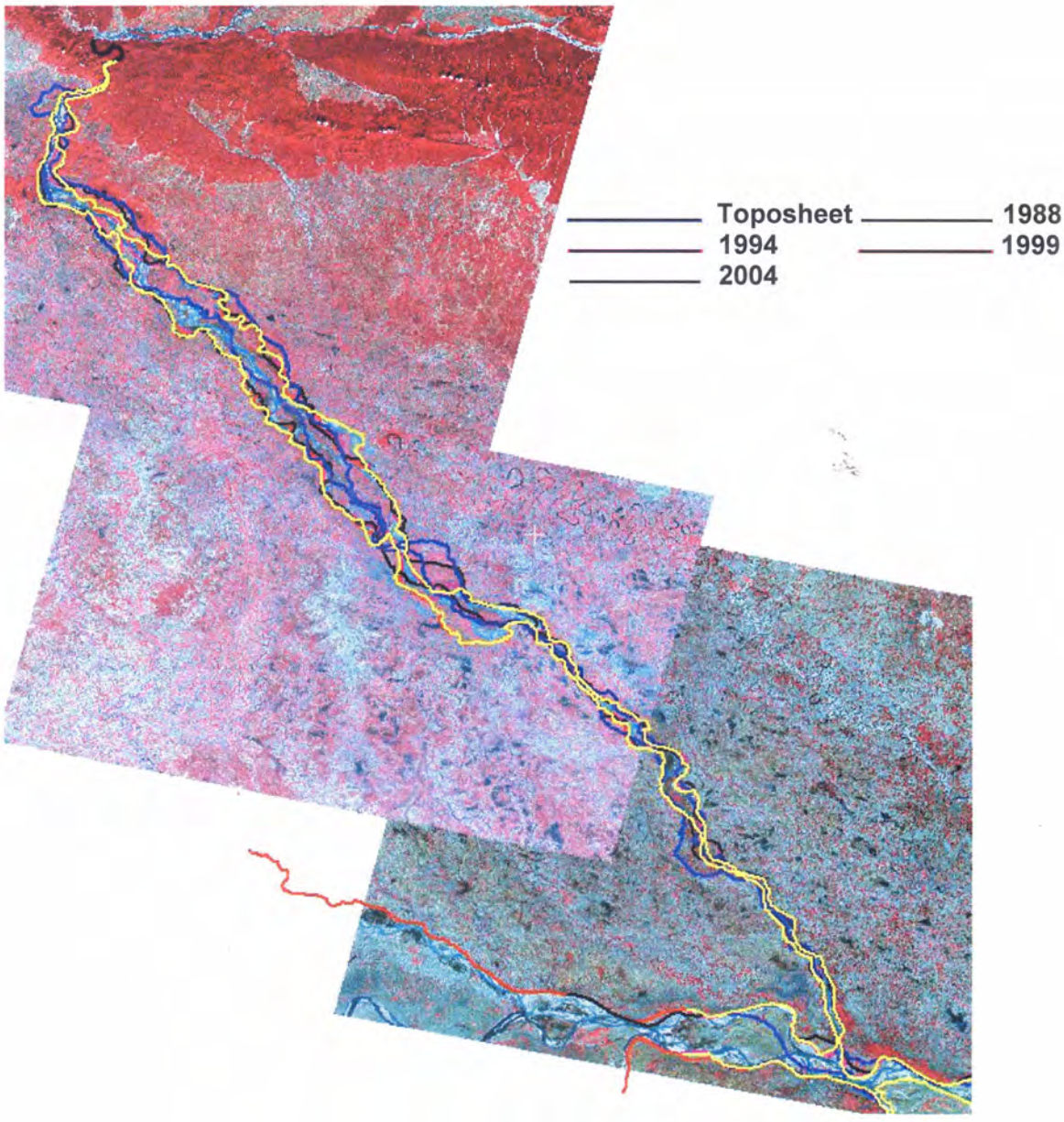


FIGURE 4.9: SUPERIMPOSED BANK LINES TOPOSHEET, 1988, 1994, 1999 & 2004

4.3 The review of the bank lines as identified above indicates that

i) The stretch of river considered in the studies can be divided in three broad regions as :

I Hilly region near origin

II Intermediate region as the river enters plain area and

III Outfall of river Gandak in river Ganga

ii) There are no major changes in bank lines from the SOI toposheet to 2004 in hilly region.

iii) Similarly, major changes in bank lines were not discernible in the area near confluence of river Gandak with river Ganga.

iv) A comparison of bank lines from toposheets with 1988 satellite data (Figure 4.5) shows that there has been shifting of course of river Gandak in the zones identified as I, II and III. It can be seen that both the banks are shifted downwards in zone I and widening of channel can be seen in zone II. As against this, the shifting of both banks leading to formation of meander can be noticed near region III. A shifting of left bank of river Ganga on upstream of confluence can be seen at the confluence of river Gandak.

v) A comparison of bank lines of toposheets and 1994 (Figure 4.6) shows that the changes taken place between toposheet and 1988 have tried to readjust between 1988-1994 at certain places. The overall picture shows no significant change in the bank lines of 1988 and 1994 with respect to bank lines in toposheets.

vi) A comparison of bank lines of toposheet and 1999 is presented in Figure 4.7. The general trend of change in the bank line with respect to toposheet is similar to the change noticed during 1994. The bank line of 1999 in the region II appears to shift towards left as compared to its position noticed in toposheet. The course of river Gandak shows narrowing of river width at the end of region III.

vii) A superimposition of bank line is obtained from toposheet and 2004 satellite data is presented in Figure 4.8.

viii) A comparison of bank lines presented in Figures 4.5 and 4.8 further shows that the river is trying to gain the position as present in the year 1988. Some transitions could be noticed in the region II and III. Some changes at the confluence of river Gandak with river Ganga are likely to have taken place, since the bank lines of river Ganga as obtained in 1988 and 2004 indicate changes.

4.4 A comparison of all the five bank lines viz. toposheet, 1988, 1994, 1999 and 2004 is presented in Figure 4.9. It can be seen that there is shifting in left bank of river Gandak between the bank lines of toposheet and 2004 in the hilly region. Similar changes in bank lines are also noticed between toposheet and 2004 in the intermediate zone. The bank lines from the toposheet to 2004 in the last stretch of river Gandak before confluence with river Ganga appear to be by and large at the same location.

4.5 A meeting was held at CWC, New Delhi in November/December 2006 wherein the draft report was discussed and comments/observations were communicated. Further studies

have been carried out at CWPRS for compliance of observations/comments of the Committee Members.

The total stretch of river Gandak under study has been divided in 7 different zones. The reach covers area of river Gandak downstream of origin in hilly area upto the confluence with River Ganga near Hajipur. The boundaries of these zones are shown in Figure 4.10 and coordinates of diagonal are presented in Table 4.1. The care has been taken to provide overlap of down stream zone B for the first zone on upstream side A. Similarly overlaps of interim zones from B to F have been provided for both upstream and downstream zones. The last zone G has overlap only on the upstream Zone F.

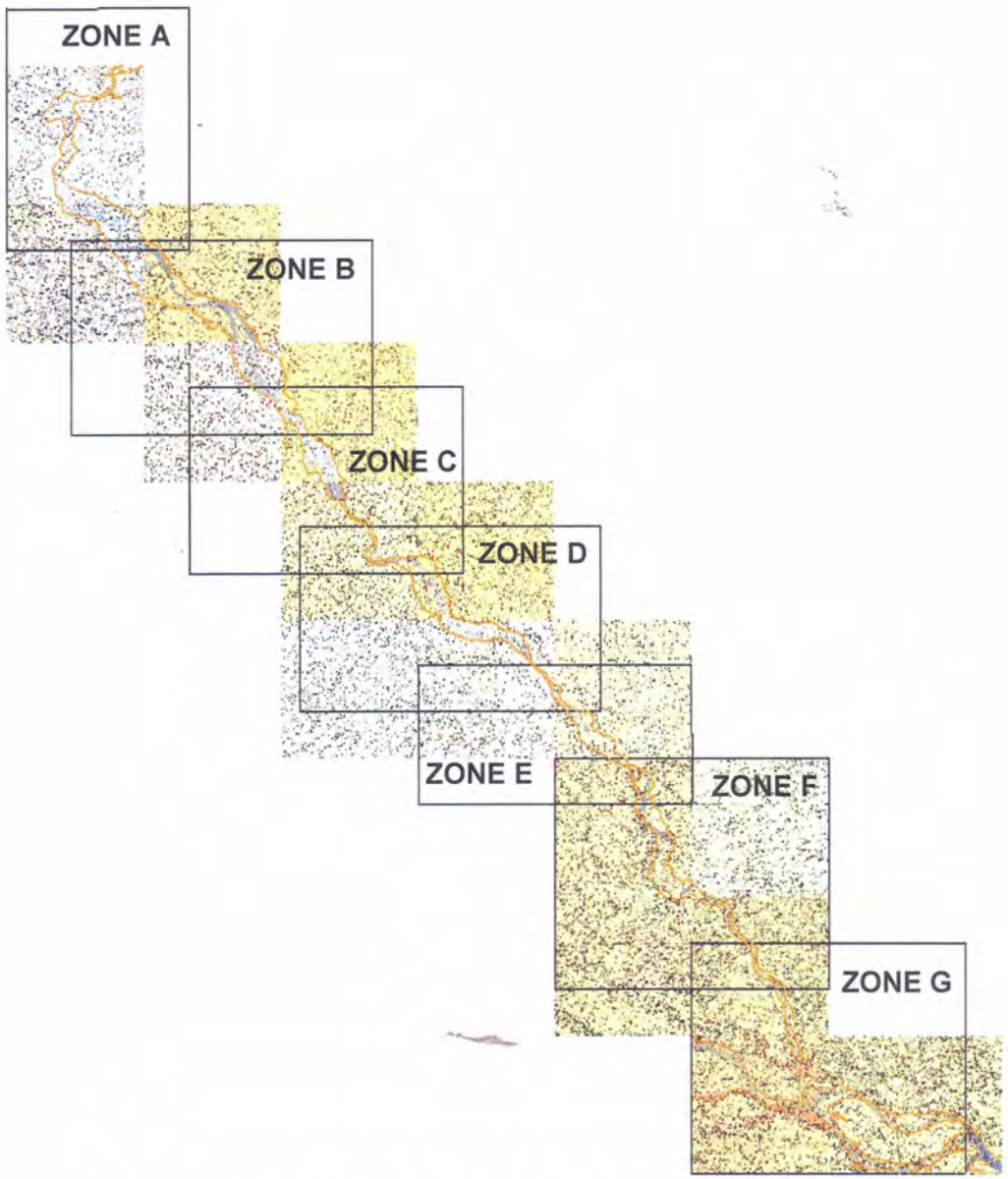


FIGURE 4.10: ZONING OF RIVER GANDAK

TABLE 4.1: ZONE CO-ORDINATES

S. No.	ZONE	X (Top Left Corner)				Y (Bottom Right Corner)			
		Longitude		Latitude		Longitude		Latitude	
		D	M	D	M	D	M	D	M
1	A	83	45	27	36	84	5	27	10
2	B	83	52	27	11	84	25	26	50
3	C	84	5	26	55	84	35	26	35
4	D	84	17	26	40	84	50	26	20
5	E	84	30	26	25	85	0	26	10
6	F	84	45	26	15	85	15	25	50
7	G	85	0	25	55	85	30	25	30

A comparison of bank lines of river Gandak during 1988, 1994, 1999 and 2004 has been made with bank lines of river Gandak as prevailed during the year in which Survey of India toposheet was available. Comparisons of bank lines for Zone A are shown in Figure 4.11. Figure contains sub part a, b, c and d showing the comparison of bank lines for the year 1998, 1994, 1999 and 2004 respectively. A review has been taken for identifying the erosion/deposition of area on left and right bank of river Gandak within each zone. The delineation of locations on bank lines of left and right bank has been done for identification of changes and rate of change of bank line with reference to the toposheet. Computations have further been continued for each of the year and these changes have been vectorially added upto year 2004. In order to achieve these, reference points were identified on bank line of toposheet. These are denominated in the form of determination is given as

XYI

where,
X = Zone name A to G
Y = Bank line of river either left (L) or right (R)
I = Serial number of location ranking from 1, 2, 3 etc.

Thus, in Figure 4.11 changes on right bank in zone A have been identified as AR1, AR2 to AR4 whereas changes in left bank have been identified as AL1, AL2 to AL6. The coordinates of the reference points have been identified and presented in Table AR for right

bank and AL for left bank. The length of segments between reference points has been measured by using EASIPACE software utility available at CWPRS.

Similarly, the work has been continued and corresponding changes in the bank line for zones B to G are presented. The details of Tables and Figures for each zone are given below:

Item No.	Zone No.	Figure No showing changes for Bank line (s)	Figure No showing nearby town/ villages for each zone	Table showing coordinates of Reference Points		Table showing Rate of change in Bank lines	
				Right Bank	Left Bank	Right Bank	Left Bank
1	A	4.11	4.18	4AR	4AL	4.2	4.3
2	B	4.12	4.19	4BR	4BL	4.4	4.5
3	C	4.13	4.20	4CR	4CL	4.6	4.7
4	D	4.14	4.21	4DR	4DL	4.8	4.9
5	E	4.15	4.22	4ER	4EL	4.10	4.11
6	F	4.16	4.23	4FR	4FL	4.12	4.13
7	G	4.17	4.24	4GR	4GL	4.14	4.15

The data in Table 4ZR and 4ZL (Z refers to zone from A to G) has been further utilized to find out rate of change in bank line of right and left bank separately. The lengths have been measured with respect to toposheets and the changes in length of segment are presented in Table 4ZR are for right bank and Table 4ZL for left bank. Positive sign is assigned if there is erosion with respect to toposheet and negative sign is assigned for deposition with respect to toposheets. These changes have been measured with respect to toposheets for 1998 and subsequently between the year for 1994, 1999 and 2004. Rate of change in bank line has also been determined and added vectorially to derive cumulative rate of change in bank line.

In order to identify the locations like AR1, AR2 etc where changes in bank line have taken place, attempts were made to identify towns/villages in the vicinity using available toposheets. The changes of locations in each left and right bank are shown in Figure 4.18 to 4.24 for zone A to G respectively. These are marked on bank line data of 1988 for all the zones.

TABLE 4AR: COMPARISON OF TOPOSHEET RIGHT BANK LINE IN ZONE A

RIGHT BANK															
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
AR1	1988	-	83	56	43.2	27	28	6.2	83	56	49.5	27	28	6.2	173.97
	1994	-							83	56	49.5	27	28	6.2	173.97
	1999	-							83	56	49.5	27	28	6.1	175.89
	2004	-							83	56	49.4	27	28	6.2	176.17
AR2	1988	-	83	49	2.8	27	24	45.8	83	51	42.8	27	24	45.8	4438.85
	1994	-							83	51	41.6	27	24	45.8	4404.35
	1999	-							83	51	41.1	27	24	45.8	4392.50
	2004	-							83	51	41.1	27	24	45.8	4392.50
AR3	1988	+	83	51	13.4	27	20	17.3	83	50	55	27	20	17.4	512.62
	1994	+							83	50	53.3	27	20	17.4	559.74
	1999	+							83	50	51.8	27	20	17.2	595.73
	2004	+							83	50	47.4	27	20	17.3	719.07
AR4	1988	+	83	51	11.1	27	14	59.4	83	50	30.7	27	14	59.4	1114.89
	1994	+							83	49	57.4	27	14	59.4	2034.17
	1999	+							83	49	58	27	14	59.4	2014.57
	2004	+							83	49	58	27	14	59.4	2014.57

TABLE 4AL: COMPARISON OF TOPOSHEET LEFT BANK LINE IN ZONE A

LEFT BANK															
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
AL1	1988	+	83	53	4.2	27	25	53.6	83	53	4.2	27	25	44	299.39
	1994	+							83	53	4.2	27	25	45.7	245.38
	1999	+							83	53	4.2	27	25	43.9	309.10
	2004	+							83	53	4.2	27	25	39.4	442.38
AL2	1988	+	83	52	19	27	22	45.5	83	53	26.7	27	22	45.5	1881.56
	1994	+							83	53	35.6	27	22	45.5	2123.42
	1999	+							83	53	55.8	27	22	45.5	2691.90
	2004	+							83	53	56	27	22	45.5	2685.46
AL3	1988	-	83	52	49	27	20	50	83	51	55.8	27	20	50	1476.82
	1994	-							83	51	33.8	27	20	50	2087.30
	1999	-							83	51	37.4	27	20	50	1984.06
	2004	-							83	52	49.6	27	20	50	1977.97
AL4	1988	+	83	51	6.8	27	18	26	83	52	21	27	18	26	2068.84
	1994	+							83	50	57	27	18	26	273.19
	1999	+							83	52	16.7	27	18	26	1932.65
	2004	+							83	52	13.2	27	18	26	1834.86
AL5	1988	-	83	59	10.5	27	13	32.6	83	58	23	27	13	32.6	1317.12
	1994	-							83	55	54.2	27	13	32.6	5455.80
	1999	-							83	55	28.1	27	13	32.6	6177.73
	2004	-							83	55	35.1	27	13	32.6	6023.17
AL6	1988	-	84	1	21.8	27	10	30.2	84	0	47.2	27	10	30.2	957.93
	1994	-							83	58	52.1	27	10	30.2	4158.11
	1999	-							83	59	13	27	10	30.2	3580.29
	2004	-							83	58	39.9	27	10	29.9	4596.55

TABLE 4BR: COMPARISON OF TOPOSHEET RIGHT BANK LINE IN ZONE B

RIGHT BANK														
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
BR1	1988	-	83	56	8.4	27	10	27.5	83	56	31.5	27	10	27.5	852.46
	1994	-							83	57	59.8	27	10	27.5	3283.69
	1999	-							83	57	59.8	27	10	27.5	3283.69
	2004	-							83	58	7.7	27	10	27.5	3313.37
BR2	1988	+	83	58	22.3	27	7	0.1	83	57	43.1	27	7	0.1	1078.80
	1994	-							83	59	39.7	27	7	0.1	2133.32
	1999	+							83	57	51.2	27	7	0.1	856.76
	2004	-							83	59	41.1	27	7	0.1	1965.93
BR3	1988	+	84	5	4.4	27	3	42.4	84	5	4.4	26	59	25.4	7909.92
	1994	+							84	5	4.4	26	59	56.8	6943.96
	1999	+							84	5	4.4	26	59	32.7	7686.21
	2004	+							84	5	4.4	26	59	23.7	8040.78
BR4	1988	+	84	9	43.3	26	59	23.9	84	7	31.5	26	59	23.9	3634.48
	1994	+							84	7	38.5	26	59	23.9	3440.32
	1999	+							84	7	34.3	26	59	23.9	3554.98
	2004	+							84	7	44.4	26	59	23.9	3308.24
BR5	1988	+	84	14	24.1	26	52	59.8	84	12	29.9	26	52	59.8	3152.74
	1994	+							84	12	40.7	26	52	59.8	2855.83
	1999	+							84	12	10.3	26	52	59.8	3694.72
	2004	+							84	11	31	26	52	59.8	4826.88

TABLE 4.12: RATE OF CHANGE OF RIGHT BANK LINE OF RIVER GANDAK IN ZONE F

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
FR1	1988	1932	+	818.23	14.61	14.61
	1994		+	948.90	21.78	36.39
	1999		+	1033.56	16.93	53.32
	2004		+	1036.41	0.57	53.89

TABLE 4.13: RATE OF CHANGE OF LEFT BANK LINE OF RIVER GANDAK IN ZONE F

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
FL1	1988	1932	+	1565.17	27.95	27.95
	1994		+	1512.68	-8.75	19.20
	1999		+	1565.17	10.50	29.70
	2004		+	1590.01	4.97	34.67
FL3	1988	1932	+	267.14	4.77	4.77
	1994		+	1446.90	196.63	201.40
	1999		+	1541.68	18.96	220.35
	2004		+	1560.81	3.83	224.18
FL5	1988	1932	-	952.22	17.00	17.00
	1994		+	745.14	-34.51	-17.51
	1999		+	745.14	0.00	-17.51
	2004		-	1036.41	58.25	40.74

TABLE 4BL: COMPARISON OF TOPOSHEET LEFT BANK LINE IN ZONE B

LEFT BANK														
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
BL1	1988	-	84	10	21.4	27	3	15.3	84	8	51.4	27	3	15.3	2479.09
	1994	-							84	8	24.1	27	3	15.3	3231.31
	1999	-							84	8	27	27	3	15.3	3153.17
	2004	-							83	58	31.1	27	3	15.3	4580.76
BL2	1988	-	84	14	55.5	26	57	58.4	84	12	57.6	26	57	58.4	3254.06
	1994	-							84	12	34.5	26	57	58.4	3888.52
	1999	-							84	12	25.8	26	57	58.4	4181.59
	2004	-							84	12	25.8	26	57	58.4	4181.59
BL3	1988	+	84	16	31.9	26	52	59.8	84	17	1	26	52	59.8	811.30
	1994	-							84	15	27.7	26	52	59.8	1764.55
	1999	-							84	15	29.3	26	52	59.8	1720.69
	2004	-							84	12	25.8	26	52	59.8	4181.59

TABLE 4CR: COMPARISON OF TOPOSHEET RIGHT BANK LINE IN ZONE C

RIGHT BANK														
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
CR1	1988	+	84	16	50.9	26	50	5.8	84	13	25.8	26	50	5.8	5661.45
	1994	+							84	13	26.3	26	50	5.8	5647.70
	1999	+							84	13	27.2	26	50	5.8	5624.56
	2004	+							84	13	12	26	50	5.8	6044.68
CR2	1988	+	84	21	53.1	26	41	54.8	84	19	50.3	26	41	54.8	3396.70
	1994	+							84	19	30.9	26	41	54.8	3933.06
	1999	+							84	19	39.1	26	41	54.8	3704.95
	2004	+							84	19	19.9	26	41	54.8	4235.89

TABLE 4CL: COMPARISON OF TOPOSHEET LEFT BANK LINE IN ZONE C

LEFT BANK														
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
CL1	1988	-	84	20	27.4	26	48	3.9	84	19	56.9	26	48	3.9	844.28
	1994	+							84	20	46.9	26	48	3.9	537.55
	1999	-							84	20	3.9	26	48	3.9	650.68
	2004	+							84	23	14.3	26	48	3.9	4607.94
CL2	1988	+	84	22	24.6	26	41	54.4	84	25	53.9	26	41	54.4	5785.92
	1994	+							84	25	51.9	26	41	54.4	5731.58
	1999	+							84	25	54.7	26	41	54.4	5806.40
	2004	+							84	25	54.7	26	41	54.4	5806.40

TABLE 4DR: COMPARISON OF TOPOSHEET RIGHT BANK LINE IN ZONE D

RIGHT BANK														
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
DR1	1988								84	27	46.7	26	35	55.4	
	1994								84	25	6.7	26	38	5.8	
	1999								84	24	22.1	26	37	36.2	
	2004								84	24	25.7	26	36	25.2	
DR2	1988	+	84	29	42.8	26	32	33.2	84	27	41.9	26	32	33.3	3349.34
	1994	+							84	29	42.8	26	32	33.3	4360.99
	1999	+							84	29	42.8	26	32	33.3	4609.20
	2004	+							84	26	40.3	26	32	33.2	5055.21
DR3	1988	-	84	34	29.6	26	28	18.8	84	35	17.6	26	28	18.8	1331.02
	1994	-							84	35	25.3	26	28	18.8	1544.58
	1999	+							84	31	5.7	26	28	18.8	5644.95
	2004	+							84	31	21.1	26	28	18.8	5219.89
DR4	1988	-	84	34	29.6	26	28	18.8	84	34	29.6	26	28	46.7	861.11
	1994	-							84	34	29.6	26	28	30	344.63
	1999	+							84	34	29.6	26	25	30.2	5191.51
	2004	+							84	34	29.6	26	25	33.9	5079.31
DR5	1988	+	84	43	37	26	24	7.5	84	43	10.6	26	24	7.5	731.37
	1994	+							84	42	57.5	26	24	7.5	1093.80
	1999	+							84	42	46.8	26	24	7.5	1390.76
	2004	+							84	42	46.8	26	24	7.5	1390.76

TABLE 4DL: COMPARISON OF TOPOSHEET LEFT BANK LINE IN ZONE D

LEFT BANK															
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
DL1	1988	+	84	42	46.8	26	25	1.7	84	44	2.3	26	25	1.7	2099.92
	1994	+							84	42	46.8	26	25	1.7	2335.42
	1999	+							84	44	19.1	26	25	1.7	2565.12
	2004	+							84	44	19.1	26	25	1.7	2565.12

TABLE 4ER: COMPARISON OF TOPOSHEET RIGHT BANK LINE IN ZONE E

RIGHT BANK															
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
ER1	1988	+	84	44	43.2	26	22	36	84	44	23.3	26	22	36	554.15
	1994	+							84	44	18.7	26	22	36	685.59
	1999	+							84	44	11.5	26	22	36	881.53
	2004	+							84	44	2.5	26	22	36	1139.94
ER2	1988	-	84	47	41.5	26	17	12.4	84	49	3.4	26	17	12.4	2271.95
	1994	-							84	49	33.6	26	17	12.4	3102.01
	1999	-							84	48	46.5	26	17	12.4	1803.38
	2004	-							84	48	52.1	26	17	12.4	1961.72
ER3	1988	+	84	52	38.2	26	14	14.7	84	51	8.8	26	14	14.7	2482.97
	1994	+							84	50	46.9	26	14	14.7	3086.81
	1999	+							84	50	30.9	26	14	14.7	3533.44
	2004	+							84	50	31.5	26	14	14.7	3518.44

TABLE 4EL: COMPARISON OF TOPOSHEET LEFT BANK LINE IN ZONE E

LEFT BANK															
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
EL1	1988	-	84	45	43.4	26	22	25	84	45	12.6	26	22	25	854.81
	1994	-							84	45	3	26	22	25	1120.13
	1999	-							84	45	9.7	26	22	25	934.13
	2004	-							84	45	9.7	26	22	25	934.13
EL2	1988	-	84	48	47.5	26	19	50.1	84	47	0.5	26	19	50.1	2968.49
	1994	-							84	46	53.7	26	19	50.1	3155.62
	1999	-							84	47	1.3	26	19	50.1	2945.62
	2004	-							84	47	1.3	26	19	50.1	2945.62
EL3	1988	+	84	55	26.6	26	11	31.8	84	56	23.7	26	11	31.8	1581.94
	1994	+							84	56	29.1	26	11	31.8	1732.42
	1999	+							84	56	26.1	26	11	31.8	1649.35
	2004	+							84	56	26.1	26	11	31.8	1649.35

TABLE 4FR: COMPARISON OF TOPOSHEET RIGHT BANK LINE IN ZONE F

RIGHT BANK														
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
FR1	1988	+	85	6	5.2	25	54	46.1	85	5	35.8	25	54	46.1	818.23
	1994	+							85	5	31.2	25	54	46.1	948.90
	1999	+							85	5	28.1	25	54	46.1	1033.56
	2004	+							85	5	28.4	25	54	46.1	1036.41

TABLE 4FL: COMPARISON OF TOPOSHEET LEFT BANK LINE IN ZONE F

LEFT BANK														
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
FL1	1988	+	84	56	37.1	26	8	23.7	84	57	33.4	26	8	23.7	1565.17
	1994	+							84	57	31.6	26	8	23.7	1512.68
	1999	+							84	57	33.5	26	8	23.7	1565.17
	2004	+							84	57	33.5	26	8	23.7	1590.01
FL2	1988		84	57	6.8	26	3	50.4	84	57	6.8	26	3	50.4	
	1994								84	57	41.7	26	4	36.4	
	1999								84	57	33.9	26	4	32.7	
	2004								84	57	37.9	26	4	32.7	
FL3	1988	+	84	56	59.3	26	3	39.6	84	57	9	26	3	39.6	267.14
	1994	+							84	57	51.4	26	3	39.6	1446.90
	1999	+							84	57	54.8	26	3	39.6	1541.68
	2004	+							84	57	54.8	26	3	39.6	1560.81
FL4	1988		84	57	10.3	26	3	28	84	57	10.3	26	3	28	
	1994								84	57	45.1	26	3	4.4	
	1999								84	57	47.6	26	2	55.6	
	2004								84	57	45.5	26	3	4.1	
FL5	1988	-	85	6	51	25	54	46	85	6	16.7	25	54	46	952.22
	1994	+							85	7	17.7	25	54	46	745.14
	1999	+							85	7	17.7	25	54	46	745.14
	2004	-							85	5	28.4	25	54	46	1036.41

TABLE 4GR: COMPARISON OF TOPOSHEET RIGHT BANK LINE IN ZONE G

RIGHT BANK														
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
GR1	1988	-	85	6	46	25	52	12.2	85	6	59.3	25	52	12.2	367.88
	1994	-							85	7	9.3	25	52	12.2	646.33
	1999	+							85	6	39.2	25	52	12.2	192.72
	2004	-							85	7	7.4	25	52	12.2	602.88
GR2	1988	+	85	9	57.9	25	48	38.7	85	9	22.4	25	48	38.7	987.40
	1994	+							85	9	24.7	25	48	38.7	924.03
	1999	+							85	9	29.2	25	48	38.7	802.62
	2004	+							85	9	29	25	48	38.7	810.70

TABLE 4GL: COMPARISON OF TOPOSHEET LEFT BANK LINE IN ZONE G

LEFT BANK														
Legend	Year	Sign	From (Toposheet)						To						Change in m
			Longitude			Latitude			Longitude			Latitude			
			D	M	S	D	M	S	D	M	S	D	M	S	
GL1	1988	-	85	8	47.2	25	51	41.5	85	8	4.8	25	51	41.5	1182.76
	1994	-							85	7	56.4	25	51	41.5	1433.00
	1999	-							85	7	56.4	25	51	41.5	1433.00
	2004	-							85	7	56.4	25	51	41.5	1433.00
GL2	1988	+	85	10	27.8	25	48	38.7	85	10	35.4	25	48	38.7	210.83
	1994	+							85	10	35.4	25	48	38.7	210.83
	1999	+							85	10	35.4	25	48	38.7	210.83
	2004	+							85	10	35.4	25	48	38.7	210.83

TABLE 4.2: RATE OF CHANGE OF RIGHT BANK LINE OF RIVER GANDAK IN ZONE A

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
AR1	1988	1963	-	173.97	6.96	6.96
	1994		-	173.97	0.00	6.96
	1999		-	175.89	0.38	7.34
	2004		-	176.17	0.06	7.40
AR2	1988	1963	-	4438.85	177.55	177.55
	1994		-	4404.35	-5.75	171.80
	1999		-	4392.50	-2.37	169.43
	2004		-	4392.50	0.00	169.43
AR3	1988	1963	+	512.62	20.50	20.50
	1994		+	559.74	7.85	28.36
	1999		+	595.73	7.20	35.56
	2004		+	719.07	24.67	60.22
AR4	1988	1963	+	1114.89	44.60	44.60
	1994		+	2034.17	153.21	197.81
	1999		+	2014.57	-3.92	193.89
	2004		+	2014.57	0.00	193.89

TABLE 4.3: RATE OF CHANGE OF LEFT BANK LINE OF RIVER GANDAK IN ZONE A

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
AL1	1988	1963	+	299.39	11.98	11.98
	1994		+	245.38	-9.00	2.97
	1999		+	309.10	12.74	15.72
	2004		+	442.38	26.66	42.37
AL2	1988	1963	+	1881.56	75.26	75.26
	1994		+	2123.42	40.31	115.57
	1999		+	2691.90	113.70	229.27
	2004		+	2685.46	-1.29	227.98
AL3	1988	1963	-	1476.82	59.07	59.07
	1994		-	2087.30	101.75	160.82
	1999		-	1984.06	-20.65	140.17
	2004		-	1977.97	-1.22	138.95
AL4	1988	1963	+	2068.84	82.75	82.75
	1994		+	273.19	-299.28	-216.52
	1999		+	1932.65	331.89	115.37
	2004		+	1834.86	-19.56	95.81
AL5	1988	1984	-	1317.12	329.28	329.28
	1994		-	5455.80	689.78	1019.06
	1999		-	6177.73	144.39	1163.45
	2004		-	6023.17	-30.91	1132.53
AL6	1988	1984	-	957.93	239.48	239.48
	1994		-	4158.11	533.36	772.85
	1999		-	3580.29	-115.56	657.28
	2004		-	4596.55	203.25	860.53

TABLE 4.4: RATE OF CHANGE OF RIGHT BANK LINE OF RIVER GANDAK IN ZONE B

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
BR1	1988	1984	-	852.46	213.12	213.12
	1994		-	3283.69	405.21	618.32
	1999		-	3283.69	0.00	618.32
	2004		-	3313.37	5.94	624.26
BR2	1988	1928	+	1078.80	17.98	17.98
	1994		-	2133.32	175.75	193.73
	1999		+	856.76	-255.31	-61.58
	2004		-	1965.93	221.83	160.26
BR3	1988	1928	+	7909.92	131.83	131.83
	1994		+	6943.96	-160.99	-29.16
	1999		+	7686.21	148.45	119.29
	2004		+	8040.78	70.91	190.20
BR4	1988	1930	+	3634.48	62.66	62.66
	1994		+	3440.32	-32.36	30.30
	1999		+	3554.98	22.93	53.24
	2004		+	3308.24	-49.35	3.89
BR5	1988	1930	+	3152.74	54.36	54.36
	1994		+	2855.83	-49.49	4.87
	1999		+	3694.72	167.78	172.65
	2004		+	4826.88	226.43	399.08

TABLE 4.5: RATE OF CHANGE OF LEFT BANK LINE OF RIVER GANDAK IN ZONE B

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
BL1	1988	1928	-	2479.09	41.32	41.32
	1994		-	3231.31	125.37	166.69
	1999		-	3153.17	-15.63	151.06
	2004		-	4580.76	285.52	436.58
BL2	1988	1930	-	3254.06	56.10	56.10
	1994		-	3888.52	105.74	161.85
	1999		-	4181.59	58.61	220.46
	2004		-	4181.59	0.00	220.46
BL3	1988	1958	+	811.30	27.04	27.04
	1994		-	1764.55	158.88	185.92
	1999		-	1720.69	-8.77	177.15
	2004		-	4181.59	492.18	669.33

TABLE 4.6: RATE OF CHANGE OF RIGHT BANK LINE OF RIVER GANDAK IN ZONE C

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
CR1	1988	1931	+	5661.45	99.32	99.32
	1994		+	5647.70	-2.29	97.03
	1999		+	5624.56	-4.63	92.40
	2004		+	6044.68	84.02	176.43
CR2	1988	1931	+	3396.70	59.59	59.59
	1994		+	3933.06	89.39	148.98
	1999		+	3704.95	-45.62	103.36
	2004		+	4235.89	106.19	209.55

TABLE 4.7: RATE OF CHANGE OF LEFT BANK LINE OF RIVER GANDAK IN ZONE C

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
CL1	1988	1931	-	844.28	14.81	14.81
	1994		+	537.55	-51.12	-36.31
	1999		-	650.68	22.63	-13.68
	2004		+	4607.94	791.45	777.77
CL2	1988	1931	+	5785.92	101.51	101.51
	1994		+	5731.58	-9.06	92.45
	1999		+	5806.40	14.96	107.41
	2004		+	5806.40	0.00	107.41

TABLE 4.8: RATE OF CHANGE OF RIGHT BANK LINE OF RIVER GANDAK IN ZONE D

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
DR2	1988	1931	+	3349.34	58.76	58.76
	1994		+	4360.99	168.61	227.37
	1999		+	4609.20	49.64	277.01
	2004		+	5055.21	89.20	366.21
DR3	1988	1931	-	1331.02	23.35	23.35
	1994		-	1544.58	35.59	58.94
	1999		+	5644.95	820.07	879.02
	2004		+	5219.89	-85.01	794.01
DR4	1988	1931	-	861.11	15.11	15.11
	1994		-	344.63	-86.08	-70.97
	1999		+	5191.51	969.38	898.40
	2004		+	5079.31	-22.44	875.96
DR5	1988	1931	+	731.37	12.83	12.83
	1994		+	1093.80	60.41	73.24
	1999		+	1390.76	59.39	132.63
	2004		+	1390.76	0.00	132.63

TABLE 4.9: RATE OF CHANGE OF LEFT BANK LINE OF RIVER GANDAK IN ZONE D

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
DL1	1988	1931	+	2099.92	36.84	36.84
	1994		+	2335.42	39.25	76.09
	1999		+	2565.12	45.94	122.03
	2004		+	2565.12	0.00	122.03

TABLE 4.10: RATE OF CHANGE OF RIGHT BANK LINE OF RIVER GANDAK IN ZONE E

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
ER1	1988	1931	+	554.15	9.72	9.72
	1994		+	685.59	21.91	31.63
	1999		+	881.53	39.19	70.82
	2004		+	1139.94	51.68	122.50
ER2	1988	1930	-	2271.95	39.17	39.17
	1994		-	3102.01	138.34	177.51
	1999		-	1803.38	-259.73	-82.21
	2004		-	1961.72	31.67	-50.54
ER3	1988	1932	+	2482.97	44.34	44.34
	1994		+	3086.81	100.64	144.98
	1999		+	3533.44	89.33	234.30
	2004		+	3518.44	-3.00	231.30

TABLE 4.11: RATE OF CHANGE OF LEFT BANK LINE OF RIVER GANDAK IN ZONE E

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
EL1	1988	1930	-	854.81	14.74	14.74
	1994		-	1120.13	44.22	58.96
	1999		-	934.13	-37.20	21.76
	2004		-	934.13	0.00	21.76
EL2	1988	1930	-	2968.49	51.18	51.18
	1994		-	3155.62	31.19	82.37
	1999		-	2945.62	-42.00	40.37
	2004		-	2945.62	0.00	40.37
EL3	1988	1932	+	1581.94	28.25	28.25
	1994		+	1732.42	25.08	53.33
	1999		+	1649.35	-16.61	36.71
	2004		+	1649.35	0.00	36.71

TABLE 4.14: RATE OF CHANGE OF RIGHT BANK LINE OF RIVER GANDAK IN ZONE G

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
GR1	1988	1935	-	367.88	6.94	6.94
	1994		-	646.33	46.41	53.35
	1999		+	192.72	-90.72	-37.37
	2004		-	602.88	82.03	44.66
GR2	1988	1935	+	987.40	18.63	18.63
	1994		+	924.03	-10.56	8.07
	1999		+	802.62	-24.28	-16.21
	2004		+	810.70	1.62	-14.60

TABLE 4.15: RATE OF CHANGE OF LEFT BANK LINE OF RIVER GANDAK IN ZONE G

Legend	Year	Toposheet Year	Sign	Change in m	Rate of change in Bank Lines (m/yr)	
					Individual	Cumulative
GL1	1988	1935	-	1182.76	22.32	22.32
	1994		-	1433.00	41.71	64.02
	1999		-	1433.00	0.00	64.02
	2004		-	1433.00	0.00	64.02
GL2	1988	1935	+	210.83	3.98	3.98
	1994		+	210.83	0.00	3.98
	1999		+	210.83	0.00	3.98
	2004		+	210.83	0.00	3.98

4.6 The observations on changes in bank line in each of the zones A to G are given below:

Zone A – Right Bank: Review of Table 4.2 indicates that there are four locations where major changes have taken place with respect to bank lines of toposheet (1963). These are identified as AR1 to AR4. It can be seen that the changes that have taken place at AR1 near Trivenighat have remained practically same. Thus, it can be considered that the bank is not showing any major change from 1994 to 2004.

At location AR2 near Nansahi Jangal the trend is similar to the trend observed for AR1. The bank is nearing stable state.

At location AR3 opposite Bettiah RF the changes in bank line from 1963 to 2004 via 1988, 1994 and 1999 shows an increasing trend. This leads to the likely location of bank erosion.

The trend of change in bank line at AR4 is similar to the trend observed at AR3. However, the rate of change is tending to be zero between 1999 and 2004.

Zone A - Left Bank: From Table 4.3, at location AL1 opposite Nansahi Jangal the left bank has undergone changes of the order of 299 m between 1963 and 1988 and the change continued to 442 m in 2004. The rate of change in bank initially goes down from 1963 to 1988/1994 and rises upto 2004.

At location AL2 near Sohgibarwa there is large change in bank line as compared to AL1. The rate of change in bank line shows the overall increasing trend. This location may possibly be considered as location where erosion is taking place.

At location AL3 near Bettiah RF the change in bank line is reversing as compared the change in AL2. The magnitude of change is somewhat lower than the change in bank line at AL2. At this location bank line shows tendency of deposition.

The location AL4 near Basai shows the trend similar to the AL2 direction. The magnitude is declining from 1988 to 1994 and trying to more towards 1988 position.

The trend of change in bank line is reversed at location AL5 opposite to Bhaisaha as compared to change at AL4 and the bank is showing similar trend to location AL3. At this location maximum change of about 6000 m was noticed between 1994 and 1999/2004.

The change in bank line at AL6 below the Bagaha has similar trend to the change in bank line observed at AL5. The magnitude of change in bank line is fluctuating from 1988 to 2004. The overall trend of cumulative rate of bank line follows the trend of change in bank line.

Zone B – Right Bank: In Zone B there are five locations on right bank and three locations on left bank that show change in bank line. Out of the five locations, on right bank deposition is observed at first location and trend of erosion is shown at the last three locations. The second location shows the fluctuating trend of erosion and deposition.

At location BR1 there is deposition from 1984 to 2004. Initially there is a change of about 850 m upto 1988 which rises to about 3200 m by 1994 and 1999 and further, increases to 3300 m in 2004. Thus it can be seen that the right bank has started to change from 1988 to 1999 and is becoming practically stable upto 2004.

At location BR2 the change is alternating in nature i.e. deposition and erosion are noticed in alternative years. The similar trend is noticed in individual and cumulative rate of change in bank line.

At other three locations viz. BR3, BR4 and BR5 the trend of erosion is observed. The magnitude of change is maximum in BR3 near Madhubani PO with a value of about 8000 m between 1928 and 2004. The overall change in bank line is reducing from BR3 to BR5. The reach between BR3 to BR5 needs to be kept under observations for possible erosion/ deposition.

Zone B – Left Bank: In Zone B along left bank the trend of deposition is observed. The maximum change in bank line has occurred at BL1 near Ratwal of about 4500 m from 1928 to 2004. Similar order of magnitude of change in bank line is observed at location BL2 near Nawalpur. Howerver, the change in bank line between 1958 and 2004 is of the order of 4100 m at location BL3 near Jogapatti. It can be observed that overall there has been deposition along the left bank of Zone B.

Zone C – Right Bank and Left Bank: There are two locations each along right bank and left bank where changes in bank line were noticed. There is tendency of erosion along right bank. Along left bank the change is alternative in nature at location CL1 near Malahi and trend of erosion is displayed at location CL2 near Nutan Dube. The maximum change in bank line of 6000 m is observed at CR1 and minimum change of bank line of about 530 m is observed near location CL1. The changes in bank line at CR1 appear to reach stability upto

1999. However, increasing trend is displayed between 1999 and 2004. At CR2 the change in bank line is varying between 3300 m to 4200 m.

Zone D – Right Bank: It was noticed towards north west corner of Zone D left bank of toposheet is crossing the right bank of river Gandak from 1988 to 2004. The river was taking an almost 90° turn around DR1. The shape of river has changed around this location and it can be seen that there is a shift in river course towards south east with respect to toposheet at this location.

There are four locations in Zone D on right bank. These are identified as DR2, DR3, DR4 and DR5. A trend of erosion was noticed at DR2 and DR5, where as initially deposition was seen upto 1994 in DR3 and DR4. The pattern had changed from deposition to erosion between 1994 and 1999. This trend had continued upto 2004.

In Zone D minimum change in bank line of about 340 m was noticed at DR4 between 1988 and 1994 and maximum change in bank line of 5600 m was noticed between 1931 and 1999 at location DR3 near Gopalganj. It can be seen that the trend of erosion at DR2 shows an increasing values whereas the erosion noticed at DR5 appears to be stabled by 2004.

Zone D – Left Bank: Along left bank only one location DL1 at Dumaria was noticed during review of bank line from 1991 to 2004. The trend of erosion can be labeled at this location which appears to be stabilized by 2004.

Zone E – Right Bank: Three locations could be identified where change in bank line were noticed. The first and third location viz. ER1 and ER3 indicated possible erosion whereas signs of deposition are likely to be there at location ER2. At location ER1 near Sidhwalia RS the rate of change in bank line shows rising trend whereas at location ER3 near Faizullapur the cutting of bank line appears to reach stable value by 2004. At this location maximum change in bank line of about 3500 m was noticed between 1932 and 1999.

The deposition pattern is likely to be observed at ER2. The change in bank line shows rise from 1930 to 1988 and continued upto 1994. Thereafter, the change is remaining between 1800 m and 1900 m for 1999 and 2004 respectively.

Zone E – Left Bank: Three locations could be identified where measurable change in bank line was noticed. The first two locations viz EL1 opposite Sidhwalia RS and EL2 near Kesariya/ Sundarpur indicated a deposition pattern whereas erosive pattern was displayed at EL3. At all the locations EL1, EL2 and EL3 the change in bank line shows rising trend from 1988 to 1994 which is declining upto 1999 and remain at the same value by 2004.

Zone F – Right Bank: One location viz. FR1 near Manrar and could be identified that shows change in bank line. The trend of erosion is indicated at this location. The change in bank line appears to reach a nearly constant value of about 1000 m by 2004.

Zone F – Left Bank: Three locations could be noticed during the review of change in left bank line of Zone F. Erosive trends nearly reach the stable value by 2004 was noticed at FL1 near Mohabbatpur. A trend of erosion could be seen at FL3. The change in bank line indicates rising trend at location FL3. FL2 and FL4 are the locations of intersection of left bank of toposheet and right bank of satellite data of respective year. The co-ordinates of intersection points are presented in Table 4FL.

Zone G – Right Bank: This is the last zone of the study area, which is near the confluence of river Gandak with wholly river Ganga. The confluence is near Hajipur town. The changes in bank lines are likely to be affected by hydraulic and morphological conditions as well as sequence of water and sediment flow experienced in both the rivers. It is, therefore, considered appropriate to review the changes in bank lines of river Gandak at location sufficiently upstream of the confluence where the above factors are not influencing the flow conditions in river Gandak. Accordingly, the study reach was restricted upstream of confluence of river Ganga. In this reach two locations each on right bank and left bank could be identified. The deposition trend is shown at location GR1 upto 1994 followed by reduction in deposition in 1999 and continuation of deposition further upto 2004. A location GR2 erosive trend could be noticed during comparison of bank line of 1935 to 2004. The change in bank line indicates reducing trend upto 2004.

A trend of deposition was noticed in GL1 near Lalganj and trend of erosion was displayed at GL2 near Gurmia and opposite Mangarpal Naran. In both the cases the respective trend is likely to reach a constant value of 1400 m at GL1 and 200 m at GL2.

4.7 Analysis of Gauge, Discharge and Sediment Data:

4.7.1 It was desired during the meeting that available gauge discharge and sediment data of river Gandak at Triveni and Dumariaghat be collected and analyzed. Accordingly, request was sent to CWC, Patna and following data were made available to CWPRS after approval of the Ministry of Water Resources:

Site	Daily Data	Ten Daily Average Data
	Water level/Gauge (m) and Discharge (m^3/s)	**Discharge (m^3/s) and Sediment (g/l)**
Triveni	1961 to 2008	1988 to March, 1999
Dumariaghat	June, 1997 to March, 2008	---
Remarks	At Triveni site: • The daily water levels of 1987, 1988, 1990 to 1994 and 1996 years were not available. • The daily discharges of 1965 to 1968 and 1996 years were not available.	

Discharge data at Triveni was analyzed and annual maximum and minimum values of discharge and corresponding water level were extracted. These are given in Table 4.16. It can be observed that annual maximum discharge varies from minimum of 1140 cum/s to a maximum 20427 cum/s. Similarly, minimum discharge is varying from a minimum of 11 cum/s to a maximum of 426 cum/s.

Table 4.16: Maximum and minimum values of gauge and discharges at Triveni site

Date	Maximum		Date	Minimum	
	Gauge (m)	Discharge (m^3/s)		Gauge (m)	Discharge (m^3/s)
1	2	3	4	5	6
21.08.1961	112.392	20427.000	21.02.1961	105.000	234.000
19.08.1962	110.712	7853.020	28.02.1962	105.792	426.500
22.08.1963	109.572	10343.470	04.03.1963	105.602	292.310
04.08.1964	110.552	8802.460	11.04.1964	105.682	234.340
29.08.1965	111.142	---	13.03.1965	105.692	279.050
25.08.1966	110.962	---	14.04.1966	105.852	---
11.07.1967	110.492	---	16.12.1967	106.662	---
24.07.1968	111.142	---	03.01.1968	106.692	---
22.08.1969	106.615	4160.040	27.11.1969	103.735	244.880
21.07.1970	108.200	19542.630	15.04.1970	103.305	142.630
09.08.1971	107.700	6409.500	05.02.1971	104.000	171.130
29.07.1972	108.200	12625.790	01.02.1972	103.740	195.040
13.09.1973	108.500	13402.000	26.02.1973	103.500	96.300
06.08.1974	108.480	13902.000	02.03.1974	103.033	97.350
28.07.1975	108.500	12416.510	23.02.1975	102.090	42.780
24.08.1976	107.700	10322.000	09.05.1976	102.050	63.390
14.08.1977	107.400	9452.000	08.03.1977	102.220	67.600
17.06.1978	108.350	10885.000	08.02.1978	101.800	66.000
22.08.1979	107.730	6795.000	31.01.1979	102.080	41.900
07.09.1980	107.500	8700.000	28.04.1980	102.550	61.070
01.08.1981	108.200	8140.000	09.01.1981	102.120	75.050
14.09.1982	107.550	7820.000	28.02.1982	102.390	85.980
18.07.1983	107.300	7322.320	28.02.1983	101.610	15.230
08.09.1984	108.130	11080.000	23.03.1984	102.400	30.010
06.19.1985	106.925	7197.350	04.01.1985	102.800	11.370
15.09.1986	108.960	12700.000	11.02.1986	102.890	22.640
13.08.1987	---	12200.000	14.03.1987	102.630	24.000
16.08.1988	---	6598.000	07.03.1988	---	57.510
30.07.1989	107.400	10500.000	27.02.1989	---	16.330
19.07.1990	---	5617.000	02.03.1990	102.255	24.780
17.08.1991	---	4050.000	18.03.1991	---	24.150
28.08.1992	---	4975.000	06.02.1992	---	25.840
07.09.1993	---	7900.000	04.03.1993	---	16.240
28.07.1994	---	5913.000	15.05.1994	---	12.610
12.07.1995	108.100	7750.000	18.03.1995	---	48.880
	---	---	11.03.1996	103.200	42.310
13.08.1997	107.520	6052.000	17.02.1997	102.930	37.510
22.08.1998	108.810	10220.000	28.03.1998	103.090	80.450
04.07.1999	109.010	12700.000	24.03.1999	103.120	62.440
03.08.2000	108.540	9290.000	04.03.2000	103.770	87.340
01.08.2001	109.450	14950.000	26.03.2001	103.630	130.000
24.07.2002	109.500	15200.000	01.04.2002	103.900	234.000
01.08.2003	109.450	14950.000	18.02.2003	104.000	280.000
12.07.2004	108.080	7858.000	25.03.2004	103.840	208.000
20.08.2005	108.100	7915.000	28.04.2005	103.800	190.000
28.08.2006	107.800	6830.000	04.04.2006	103.990	275.000
07.09.2007	109.100	13250.000	25.12.2007	104.200	388.000
31.05.2008	105.000	1140.000	22.02.2008	103.700	157.000

The data at Dumariaghat from June 1997 to March 2008 were collected by CWPRS. The analysis data has been carried out and results showing minimum and maximum values of water level and discharge at Dumariaghat are presented in Table 4.17.

Table 4.17: Maximum and minimum values of gauge and discharges at Dumariaghat

Date	Maximum		Date	Minimum	
	Gauge (m)	Discharge (m^3/s)		Gauge (m)	Discharge (m^3/s)
1	2	3	4	5	6
16.08.1997	---	6000.000*	09.06.1997	---	283.000
24.08.1998	---	10260.000*	26.03.1998	---	133.000
29.08.1999	---	10000.000*	19.03.1999	---	104.000
05.08.2000	---	9000.000*	14.03.2000	---	85.000*
03.08.2001	---	11500.00*	25.02.2001	---	158.000*
27.07.2002	---	11350.00*	27.03.2002	---	178.000*
03.08.2003	---	9880.000*	12.03.2003	---	50.000*
23.08.2004	---	3780.000*	05.03.2004	---	40.000*
29.08.2005	---	3560.000*	22.03.2005	---	70.000*
30.08.2006	61.920	4310.000	03.04.2006	---	65.000*
10.09.2007	63.140	11400.000	08.03.2007	57.990	87.290
			27.03.2008	57.790	78.000
* Computed discharge					

In addition, analysis of Ten-daily average discharge and sediment data at Triveni site in river Gandak for a period of 12 years from 1988 to March 1999 were supplied. These data have been analyzed and results are presented in Section 4.7.2.

Attempts were being made to collect additional data at Station Lalganj site. However, these data could not be collected due to the difficulties during collection.

4.7.2 The 10-daily average discharge and sediment load at Triveni site on river Gandak was collected from CWC, Patna. These are reviewed for identification of outliers / exceptionally high or low value of discharge and corresponding sediment. Data for the period from 1988 to 1998 has been analyzed to derive year to year sediment rating curve in the form of discharge (cum/s) versus sediment load (g/l). These are shown in Figure 4.25 to Figure 4.35 respectively.

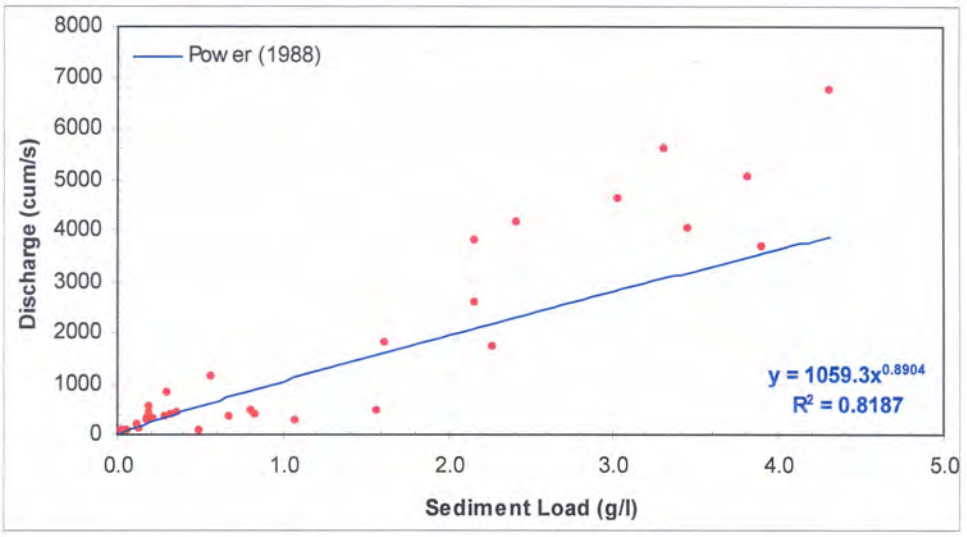


FIGURE 4.25: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI – 1988

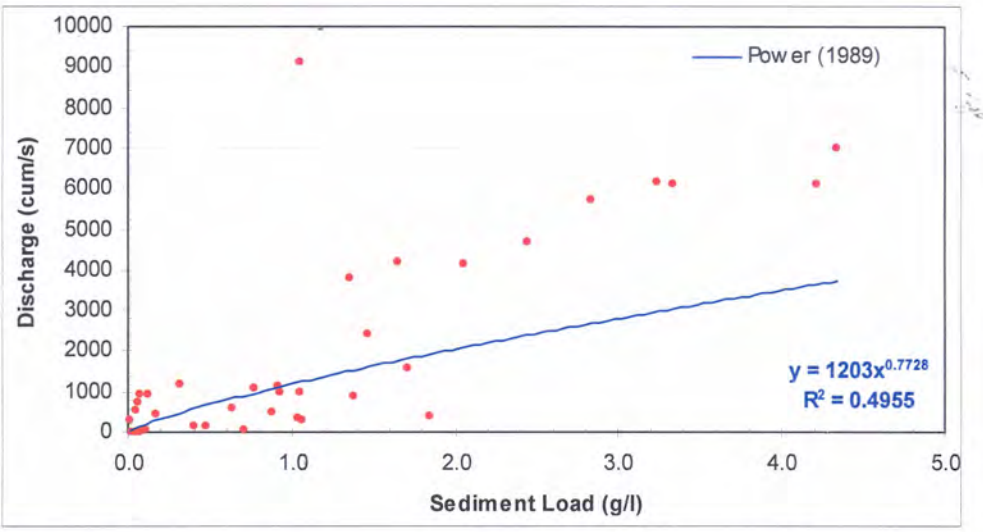


FIGURE 4.26: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI – 1989

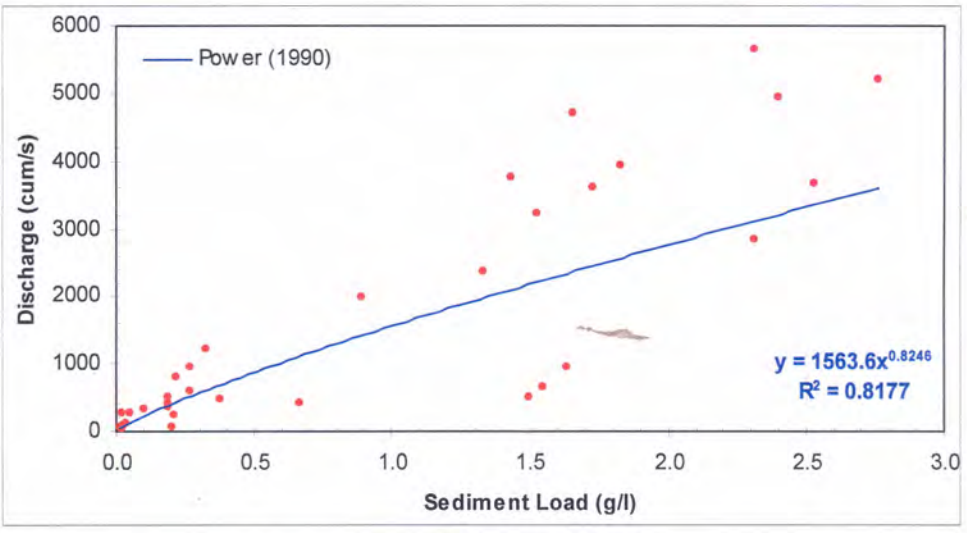


FIGURE 4.27: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI - 1990

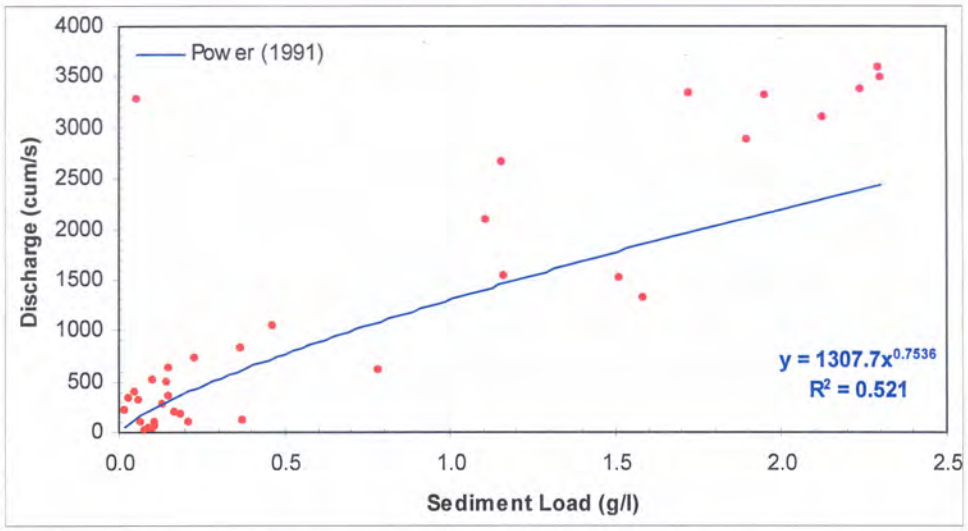


FIGURE 4.28: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI – 1991

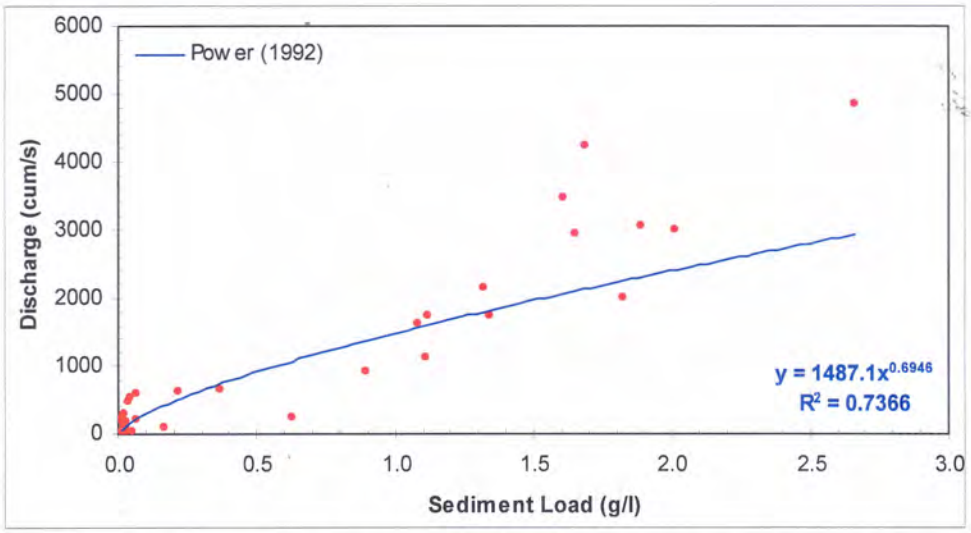


FIGURE 4.29: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI – 1992

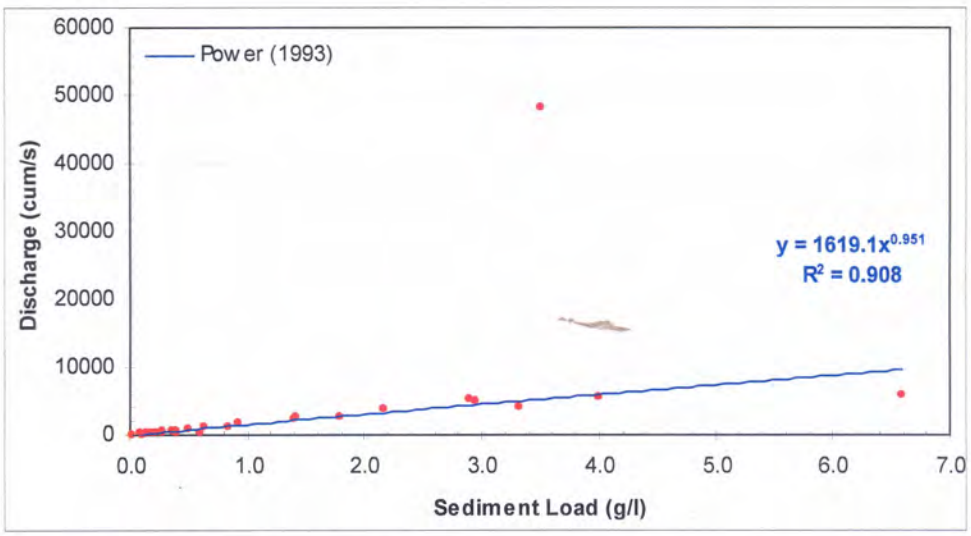


FIGURE 4.30: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI - 1993

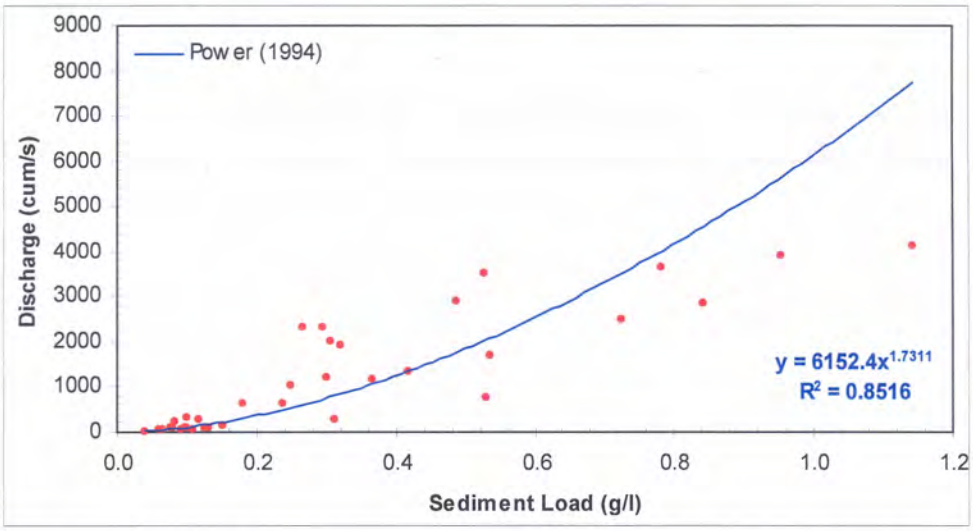


FIGURE 4.31: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI – 1994

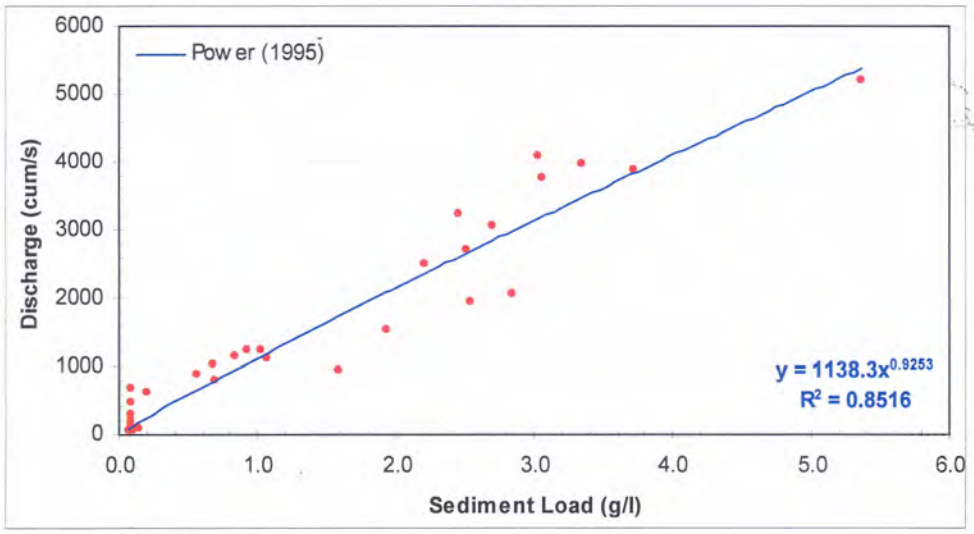


FIGURE 4.32: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI – 1995

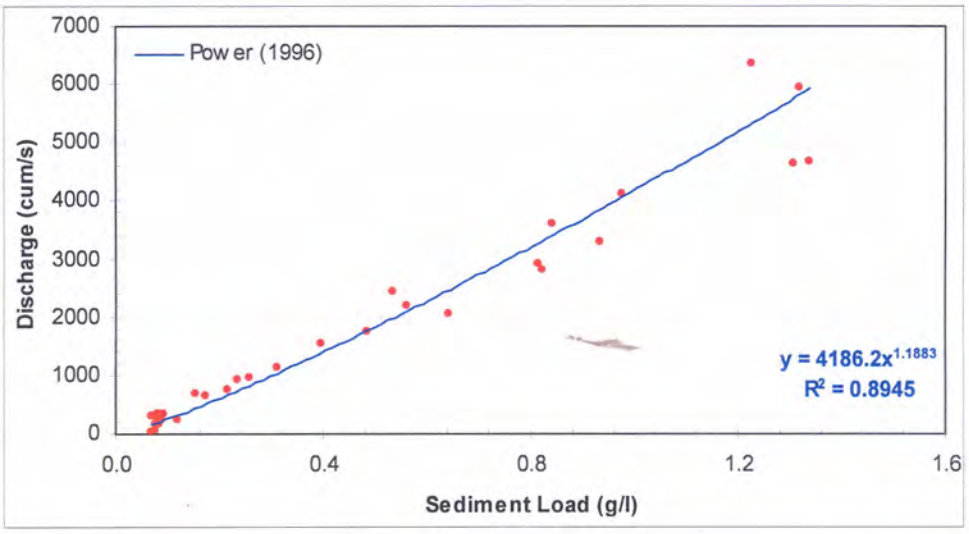


FIGURE 4.33: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI - 1996

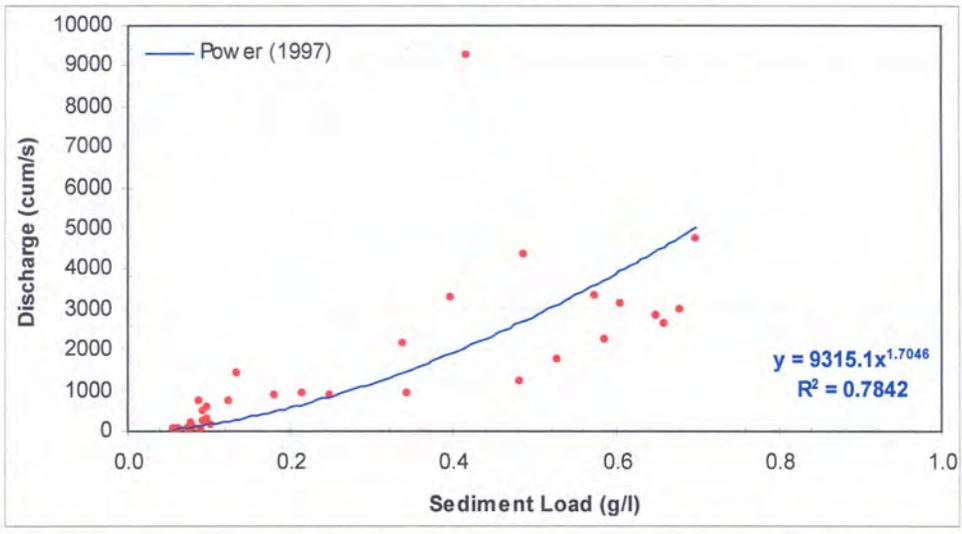


FIGURE 4.34: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI – 1997

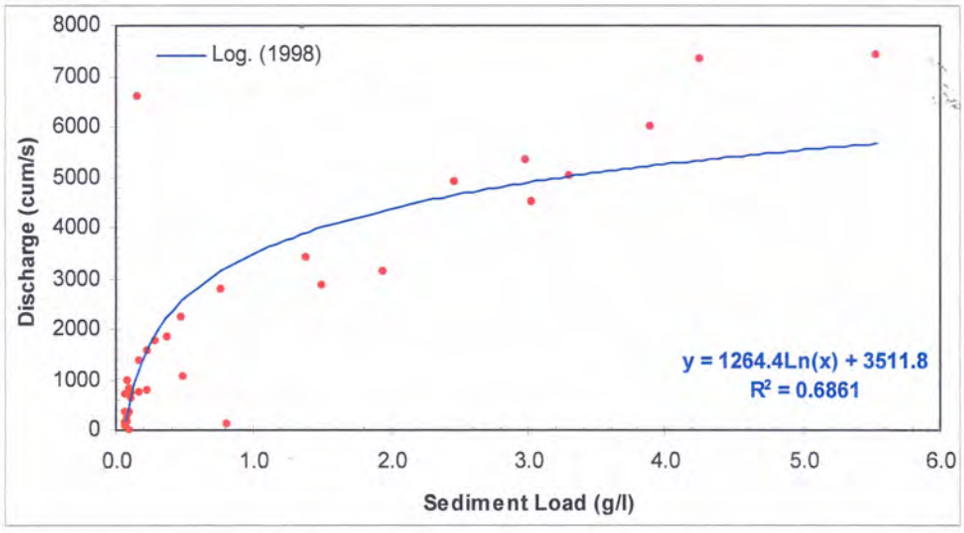


FIGURE 4.35: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI - 1998

It can be observed that except for the year 1998 power relation can be fitted to rating curve. The rating curve equation is in the form of

$$Q = A\, Q_s^{\,b}$$

where

Q = discharge in cum/s

A & b = regression coefficients and

Q_s = sediment in (g/l)

The summary of rating curve equation is given in Table 4.18 below:

TABLE 4.18: SUMMARY OF RATING CURVES RIVER GANDAK AT TRIVENI

Year	Regression Co-efficient		R^2
	A	b	
1988	1059.3	0.8904	0.8187
1989	1203.0	0.7728	0.4955
1990	1563.6	0.8246	0.8177
1991	1307.7	0.7536	0.5210
1992	1487.1	0.6946	0.7366
1993	1619.1	0.9510	0.9080
1994	6152.4	1.7311	0.8516
1995	1138.3	0.9253	0.8516
1996	4186.2	1.1883	0.7842
1997	9315.1	1.7046	0.7842
1998	Q= 1264.4 Ln(x)+3511.8		0.6861

These data were further analyzed to review the possibility of change in fluvial characteristics of river Gandak. The data were clubbed into two groups as 1988 to 1993 and 1994 to 1998. These divisions were made as per the availability of bank line from satellite data. The data were combined in above two groups and attempts were made to derive regression relations. The curves developed along with plots are presented in Figures 4.36 and 4.37.

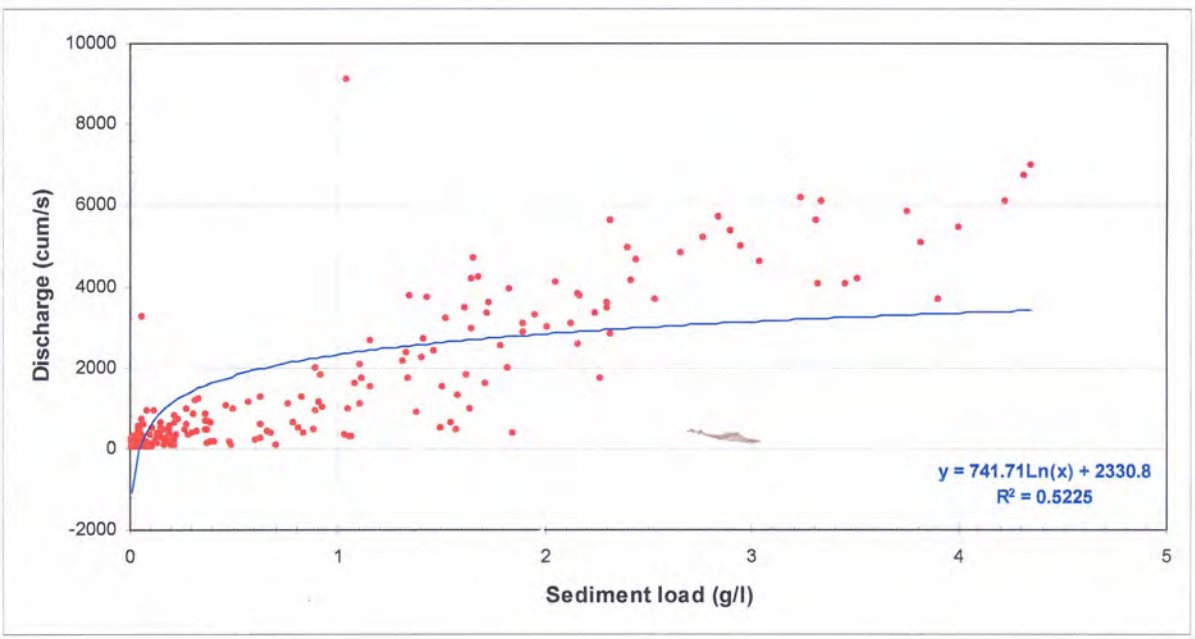


FIGURE 4.36: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI - (1988-1993)

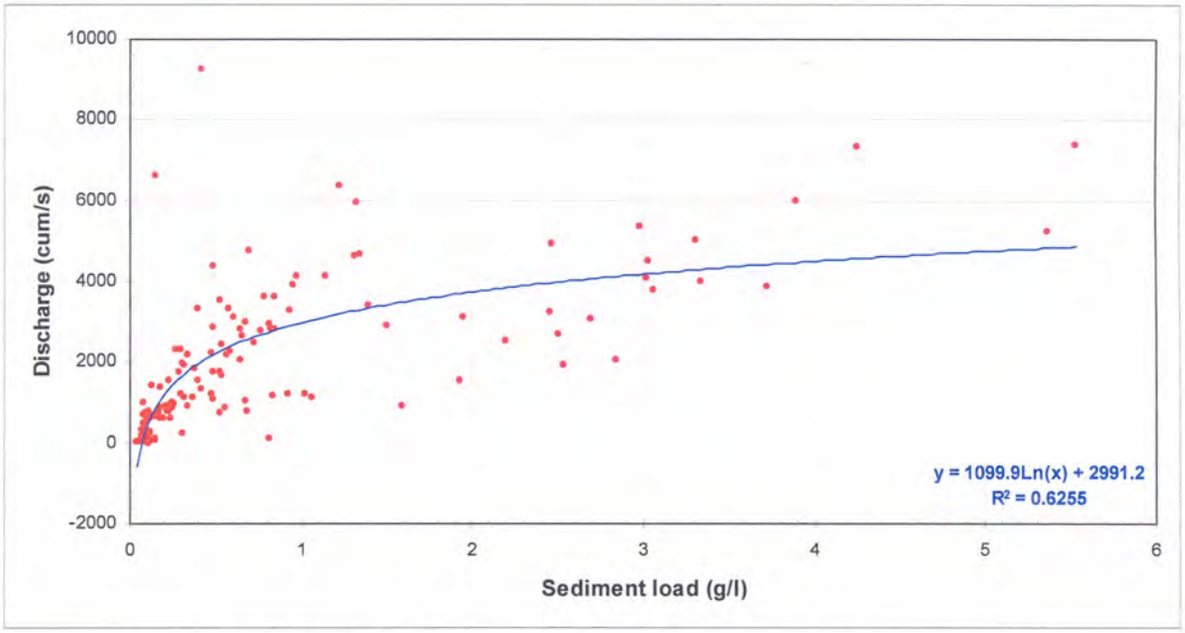


FIGURE 4.37: SEDIMENT RATING CURVE: RIVER GANDAK AT TRIVENI - (1994-1999)

It can be observed from Table 4.18 that except for the year 1998 power relations could be obtained for sediment rating curve. The power is changing from minimum of 0.6946 to a maximum of 1.7311. For the year 1998 logarithmic relation has been derived is as given below:

$$Y = 1264.4 \text{ Ln } (X) + 3511.8$$

It can be observed from the regression relations that the variation in R^2 coefficient for the individual year and group data for 1993 to 1998 is from 0.49 to 0.90 and 0.52 to 0.62 respectively. These variations can be considered as marginal in nature. These can be considered as indicative trend and river Gandak to be nearly stable from the point of view of sediment transport capacity.

4.8 Compliance of the Comments:

4.8.1 The interim report submitted by CWPRS was reviewed and comments were received. The compliances of these comments have been made while preparing the draft report. However, the compliance of the items also is enclosed as Appendix II.

4.8.2 Comments on draft final report were received from CWC. These have been replied and cognisance of comments is taken while preparing final report. However, compliance of comments is also presented as Appendix III.

CHAPTER 5

CONCLUSIONS

MORPHOLOGICAL STUDIES OF RIVER GANDAK USING SATELLITE AND SOI DATA

5.1 CONCLUSIONS

Studies have been carried at CWPRS to identify erosion and deposition area in Gandak river basin. The stretch of river Gandak from entry into Indian Territory near Triveni upto confluence of river with Ganga near Hajipur, opposite Patna, Bihar has been considered. The morphological changes including changes in bank lines have been studied. Bank line data on the above reach of river Gandak have been collected from Survey of India (SOI) toposheets and satellite data collected from NRSC, Hyderabad. The total stretch has been divided into 7 zones identified as A, B, C, D, E, F and G. The details of zones are described in Table 4.1.

Studies have been carried out by extracting the bank line data from SOI toposheets. The bank lines were extracted from satellite data using EASIPACE software available in Remote Sensing Laboratory of CWPRS. Bank line data from cloud free dates in the year 1988, 1994, 1999 and 2004 were extracted and superimposed individually on the bank line of SOI Toposheets (Figures 4.11 to Figure 4.17) in zone wise. It can be concluded from the studies carried out that

1. There are number of places on left and right bank of river Gandak in each of the 7 zones from A to G considered in the studies where changes in bank line could be identified. The changes in bank line are ranging from 174 m upto few kilometers. The details of changes in bank line are given in Tables 4AR to 4GL. An abstract of the results of analysis showing number of locations on each bank line with minimum and maximum change in bank line of right and left bank in each zone are given in Table 5.1A and 5.1B respectively.

Table 5.1A: SUMMARY OF CHANGE IN BANK LINE OF RIVER GANDAK

S. No.	Zone number	Number of location(s) on right bank	Change in right bank line (m)							
			Minimum		Location	Place	Maximum		Location	Place
1	A	4	-	173.97	AR1	Tribeni Ghat	-	4438.85	AR2	Nansahi Jangal
2	B	5	-	852.46	BR1	Bodhi Chappra	+	8040.78	BR3	Madhubani PO
3	C	2	+	3396.70	CR2	Dowath	+	6044.68	CR1	Thakraha
4	D	4	-	344.63	DR4	Gopalganj	+	5644.95	DR3	Gopalganj
5	E	3	+	554.15	ER1	Sidhwalia RS	+	3533.44	ER3	Faizullapur
6	F	1	+	818.23	FR1	Manrar	+	1036.41	FR1	Manrar
7	G	2	+	192.72	GR1	Parasbava	+	987.40	GR2	Mangarpalnaryan

Note: Negative sign indicates deposition and Positive sign shows erosion with reference to bank line prevailing in SOI toposheets

Table 5.1B: SUMMARY OF CHANGE IN BANK LINE OF RIVER GANDAK

S. No.	Zone number	Number of location(s) on left bank	Change in left bank line (m)							
			Minimum		Location	Place	Maximum		Location	Place
1	A	6	+	245.38	AL1	Bhainsalotan	-	6177.73	AL5	Bagaha
2	B	3	+	811.30	BL3	Joga Patti	-	4580.76	BL1	Ratwal
3	C	2	+	537.55	CL1	Malahi	+	5806.40	CL2	Nutan Dube
4	D	1	+	2099.92	DL1	Dumaria	+	2565.12	DL1	Dumaria
5	E	3	-	854.81	EL1	Dumaria Ghat	-	3155.62	EL2	Sunderpur
6	F	5	-	267.14	FL3	Fatehabad	+	1590.01	FL1	Mohabatpur
7	G	2	+	210.83	GL2	Gurmia	-	1433.00	GL1	Lalganj

Note: Negative sign indicates deposition and Positive sign shows erosion with reference to bank line prevailing in SOI toposheets

It can be seen from the above Table 5.1A and 5.1B that

a) There is at least one location in each zone where measurable changes could be noticed with reference to the bank line prevailing in SOI toposheets. Thus, there is minimum of one location on each of left and right bank of river Gandak and a maximum of 5 locations on right bank and 6 locations on left bank of river Gandak.

b) The minimum change in right bank is ranging from lower value of 174 m at AR1 to high value of about 3400 m at location CR2. Further, maximum change in right bank is varying from 987 m at GR2 to 8040 m at location BR3.

c) Similarly, minimum change in left bank in each zone is varying between 210 m at GL2 and about 2100 m at DL1. Further, maximum change in left bank is in the range of 1430 m at GL1 and 6177 m at AL5.

2. The details of changes in the bank line have been discussed in Section 4.6 of the report. This can be summarized to indicate that the six locations i.e. BR3, CR1, DR3, ER3, FR1 and GR2 can be considered as places on right bank where erosion is likely to take place within the range of data considered in the studies. Further, deposition in all the zones is likely to take place at location AR2. Similarly, erosion is noticed at CL2, DL1, FR1 and GL1 and deposition can be seen at AL5, BL1 and EL2.

3. The rate of change in bank line has been estimated for each zone at the location where measurable changes have been noticed (Section 4.6 of the report). These rates have been estimated using the reference bank line of SOI toposheets for the available year (Section 3.2 of Report) and subsequent, bank line extracted from satellite data. Thereafter, rate of change is determined with reference to bank line of previous year to the year extracted from satellite imagery. These rates have been added vectorially. It is noticed that at the three locations i.e. BR2, CL1 and GR5 the river is showing fluctuating trend of deposition followed by erosion and vice-versa at other locations. The details of estimation of rate of change in bank line are presented in Tables 4.2 to 4.15. These have summarized in Table 5.2. A review of Table 5.2 indicates that

a) The minimum rate of change in right bank is ranging from lower value of 4 m/yr at BR4 to high value of 176 m/yr at location CR1. Further, maximum rate of change in right bank is varying from 44 m/yr at GR1 to 876 m/yr at location DR4.

TABLE 5.2: SUMMARY OF RATE OF CHANGE IN BANK LINE OF RIVER GANDAK

Zone	Rate of change in bank lines (m/yr)							
	Right Bank				Left Bank			
	Min	Place	Max	Place	Min	Place	Max	Place
A	7.40	AR1	193.89	AR4	42.37	AL1	1132.53	AL5
B	3.89	BR4	624.26	BR1	220.46	BL2	669.33	BL3
C	176.43	CR1	209.55	CR2	107.41	CL2	777.77	CL1
D	132.63	DR5	875.96	DR4	122.03	DL1	122.03	DL1
E	- 50.54	ER2	231.30	ER3	21.76	EL1	40.37	EL2
F	53.89	FR1	53.89	FR1	34.67	FR1	224.18	FR3
G	- 14.60	GR2	44.66	GR1	3.98	GL2	64.02	GL1

b) Similarly, minimum rate of change in left bank in each zone is varying between 4 m/yr at GL2 and about 220 m/yr at BL2. Further, maximum rate of change in left bank is in the range of 40 m/yr at EL2 and 1132 m/yr at AL5.

4. It is considered pertinent to indicate here that the changes in the bank line that were noticed over the periods from earliest year 1928 upto 2004. It is difficult to identify the cause of results of natural processes like erosion and deposition. Each of these processes is dependent on number of factors, which are varying in space and time; discharge and sediment load can be identified as some of the factors. In addition, the base material of bed and bank also plays a significant role in the process. It is, further, noticed that it is very difficult to identify the exact location of erosion/ deposition over a long period. The prediction made so far, have been either over a short period are for the identified locations. These aspects are equally applicable for stretch of river Gandak included in the studies.

5. It is, therefore, indicated that the year to year bank line changes at the locations identified in 3 above can be considered and necessary protection measures can be provided in the form of spur/ percupines with pitching banks using stones, bricks, concrete blocks or combination of these using wire crates. The wire can be either metallic or synthetic in nature. The hydraulic parameters are, therefore, required to decide the details of protection works as well as other protection to be provided at the identified locations.

5.2 LIMITATIONS OF THE STUDY

The studies for identifying the changes in bank line have been carried out using SOI and Satellite data collected from NRSA, Hyderabad. It was noticed during the study that the SOI Toposheets are not available for the same year. This leads to use of available year Toposheet. Sensor used in Satellite data is varying from LISS II to LISS III, which implies that there is limitation in measuring/ identifying the length, over which changes in bank line are noticed, due to the pixel size of each sensor.

Initially, it was contemplated to study the effect of structure along river Gandak on the changes in bank line. It is pertinent to indicate here that changes in bank line in turn typical in river channels. The river channel position is affected due to the structure like spurs, porcupine, barrage etc. The effect of these structures becomes measurable or prominent after the time period which varies from couple of years to few decades. As such it is very difficult to identify whether the changes in bank line can be attributed solely to the structure or is combined effect on structure and other morphological changes taking place in river due to time and space variations in of flow and sediment load.

The studies have limitations due to the pixel size as indicated above. The availability of discharge and corresponding sediment data on account of concurrency. Further out of these data discharge varies at faster rate than the sediment transport which is relatively slower process. This type of change in behavior with respect of time and space imposes another limitation on the studies.

CHAPTER 6

ACKNOWLEDGEMENT

MORPHOLOGICAL STUDIES OF RIVER GANDAK USING SATELLITE AND SOI DATA

6.0 ACKNOWLEDGEMENT

Studies have been carried out at CWPRS at the request of CWC, New Delhi. The co-operation of the officers from Morphological Directorate as well as Field Circle from Patna and Lucknow of CWC is acknowledged with thanks. The studies were carried out in by Shri V G Bhave Joint Director, River and Reservoir Systems Modeling (R&RSM) Group of CWPRS. Dr. I. D. Gupta was Director, CWPRS and Shri S. Govindan was Additional Director during conduct of studies. The studies were initially supervised by S/Shri P. B. Deolalikar and P K Khare Joint Directors (Retired) CWPRS. Efforts taken by Shri M.K. Pawar, Chief Research Officer in procurement and analysis of satellite data are appreciated. Major assistance is given by Shri C. Srishailam, Research Officer in analysis of bank line data, compilation of the results, analysis of satellite and bank line data, preparation of maps etc have been of great help in conduct of the studies and preparation of the report. In addition, support and cooperation received from officers of Remote Sensing Laboratory of CWPRS are also acknowledged. The staff members of SWH and Physics Division have provided excellent assistance/cooperation in conduct of the studies and preparation of the report.

APPENDICES

APPENDIX – I

PHOTOGRAPHS OF RIVER GANDAK IN STUDY REACH

Gandak river in study reach displays braided channels in certain places (Photo 1). These are situated at different locations in the states of Uttar Pradesh and Bihar. Further, river Gandak flows at certain locations along the border of Uttar Pradesh and Bihar. Protection measures in the form of embankments and spurs are provided along the length. The embankments require careful maintenance and it is known that these are prone to failure in absence of maintenance (Photo 2). Spurs are provided at number of locations in study reach. Protection with crates from brick/stone is provided. These also need maintenance and state of some spurs is shown in Photos 3 and 4.

PHOTO 1: BRAIDED CHANNELS IN RIVER GANDAK

PHOTO 2: BREACH IN EMBANKMENT OF RIVER GANDAK

PHOTO 3: SERIES OF DAMAGED SPURS ON RIVER GANDAK

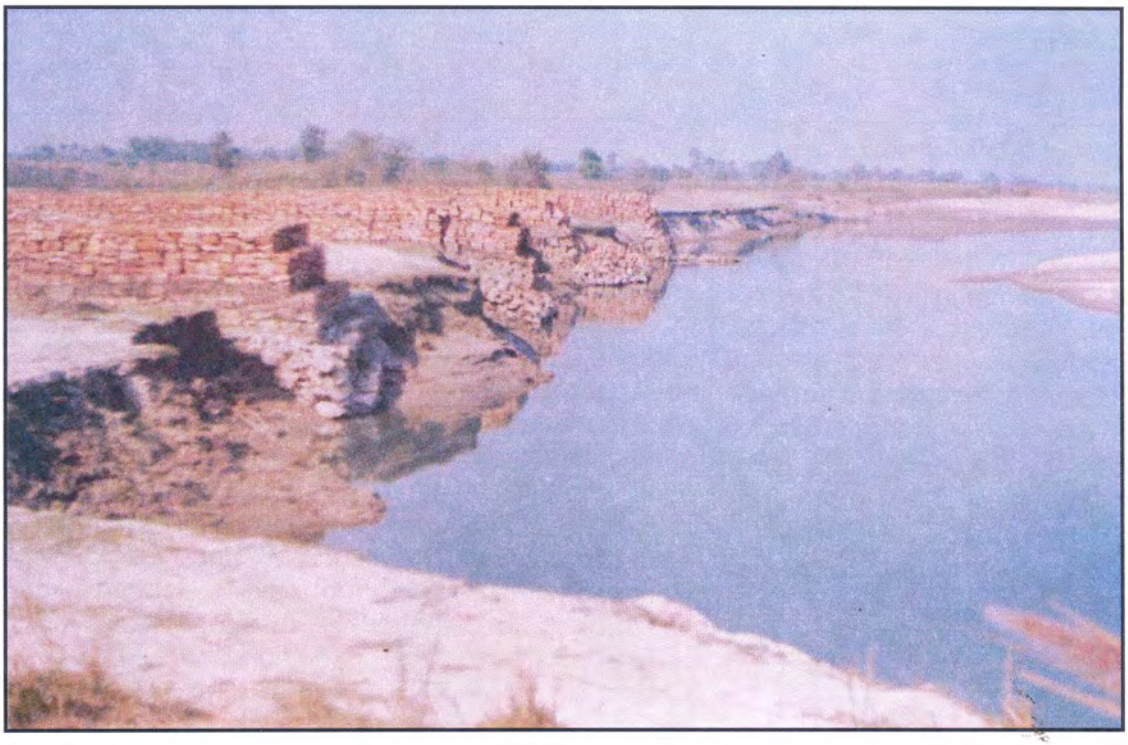


PHOTO 4: DAMAGED SPURS WITH STONE PITCHING

APPENDIX – II

S. No.	Observations	Compliance
1.	The bank line migration parameters of river Gandak presented in the reports are of general nature. Quantitative information may be provided in detail with respect to space and time using the satellite data. Study of aggradation and degradation in different reaches of the river (erosion/deposition patterns) identification of stable and unstable reaches along the river considering the usefulness of the study in solving the flood problems namely due to inundation, erosion of banks, and changes of course of river. Appraisal of plan form morphological changes/ including causes of aggradation/ degradation and its variation/changes in plan form of river Gandak may be included. The problem of river instability and consequent bank erosion (present and future trends) if any along the river is also to be discussed in the report for river Gandak.	Total stretch of river Gandak under study is divided in to seven zones. Comparison of bank lines from SOI Toposheets and satellite data is carried out to quantity the changes. Details of analysis are presented in section 4.6 of the report.
2.	Possible generation of cross-section, reduced level and top width with respect to space and time using satellite data could be done and compared with the hydrographical data.	Studies have been carried out to quantity change in bank line, that would lead to change in width of river. Details are given in section 4.6 of report.
3.	As per the terms of reference (TOR), the objective of the study included the performance evaluation of major flood control structures executed so far, as well as their effect on river morphology. This study aspect has to be included discussing also the adverse effects/ desired benefits of the flood control structures/ protection works like flood embankments, anti erosion works like spurs, revetments, bank pitching, bed bars etc undertaken.	This aspect would require special study with fine grid satellite data. Further, this may be duplication of efforts put in by Gandak High Level Committee.
4.	To give better perception of river and its linkage with its tributaries and Master River, drainage system of the rivers, its tributaries and it's association with the master river system may be shown in the introduction part of the report. Index map should also be provided highlighting the location of different flood control/river training structures.	Complied
5.	Identified zones A-I may be shown on larger scale to the extent possible to enhance the visual understanding	Complied and details presented in section 4.5 and Figures 4.11 to 4.17.
6.	Water spread area during flood season and also water spread area during lean period may be discussed in the report in detail with the help	Attempts are made to study channel migration through changes in bank line, water

	of figure including about the channel migration/ palio channels, longitudinal slope/cross sectional slope etc. at vulnerable points.	spread area proposed to be studied would require availability of satellite data of cloud free dates and on smaller resolution. It is difficult to get cloud free data during flood period as sky remains overcast in such situation due to occurrence of rainfall.
7.	Trend of switch over of thalweg from one side to the other side of the river and development of new fluvial form indicators may be studied to identify severity during floods.	Complied and added in report
8.	Prioritization of channel improvement zones and general trend of longitudinal bed profile changes of the river Gandak may also be discussed.	Erosion areas have been identified. Priority can be decided by the implementing agency through discussions with design agency, funding organization and research organization conducting the study.
9.	Study may also be carried out to achieve implementation of hydrodynamic flow simulation modeling for macro level stream bed changes due to any channel modifications.	This is beyond scope of study and would need studies on 2-D/ 3-D model required. Additional data, funds and time frame would be required.
10.	CWPRS is also requested to take up preparation of a comprehensive report, reviewing earlier report and inclusion of subsequent hydrodynamic parameters of which the present report through remote sensing would be a part. It could be on the lines of CWC/MoWR guidelines published in April 1991	This can be taken up after finalization of current report. Other reports can be decided through mutual discussions with concerned institutions.

APPENDIX – III

S. No.	Observations	Compliance
1.	Report may be organized chapter-wise. Executive Summary may be included as a part of Final Report. A separate chapter on Conclusions with point wise deliberations followed by Limitations in the study e.g. (a) non-availability of Toposheets for the required period (1974-76), (b) practical problems in evaluation of performance of hydraulic structures, (c) major morphological problems with reasons not including these in the report etc.; may be included in the report.	Report is organized chapter wise and section on limitations is added
2.	Refer Table.13, at S.No.6, location of Maximum Change in Left bank lines is FL1 (not FR1) and location of Minimum Change in Left bank lines is FL3 (not FR3). At S.No.7, sign of minimum change in Left bank lines is + (not -) and sign of maximum change in Left bank lines is – (not +).	Complied
3.	The magnitude of river shift in terms of yearly rate as well as direction of shifting especially at critical locations may be elaborated. The map of each zone showing backline shifting with the location points (in terms of chaingage, place-name, latitude, longitude) is essential for making these details more comprehensive as well as self explanatory.	Place name is added in the Figures 4.18 to 4.24 as desired
4.	The Table of Content with page numbers, List of Tables, Figures, Symbols, etc. may be provided in the report. All colored figures are required to be produced on A3 size paper.	Complied

Central Water and Power Research Station (CWPRS), Pune,

has grown from a humble beginning dealing with twin problems of irrigation and drainage in 1916 to an institution of international standing over the last EIGHT decades. CWPRS is one of the very few institutions of its kind in the world concerned with the entire life cycle of water, from its occurrence to its joining the ocean and dealing with the various uses of water on one hand and water-related disasters on the other. The global scenario of water use today is centered around sustainable development and associated environmental issues. The responsibility of CWPRS is to find and provide technical solutions to various problems associated with projects on water resources, energy and water-borne transport including coastal and harbour engineering. As the Regional Laboratory of ESCAP since 1971, CWPRS has offered its services to a number of projects in the neighbourhood as well as countries in the Middle East and Africa. The activities of CWPRS encompass the studies undertaken in the following major disciplines :

- Hydrology and Water Resources Analysis
- River Engineering
- Reservoir and Appurtenant Structures
- Coastal and Offshore Engineering
- Ship Hydrodynamics
- Hydraulic Machinery
- Earth Sciences
- Mathematical Modelling
- Foundations and Structures
- Instrumentation and Control Engineering

With the capabilities of the Research Station, developed through multilateral and bilateral aid programmes, in-house developments, governmental support and the expertise gained during the course of last 8 decades, CWPRS is well equipped to meet the challenges ahead and contribute in the nation building endeavours.

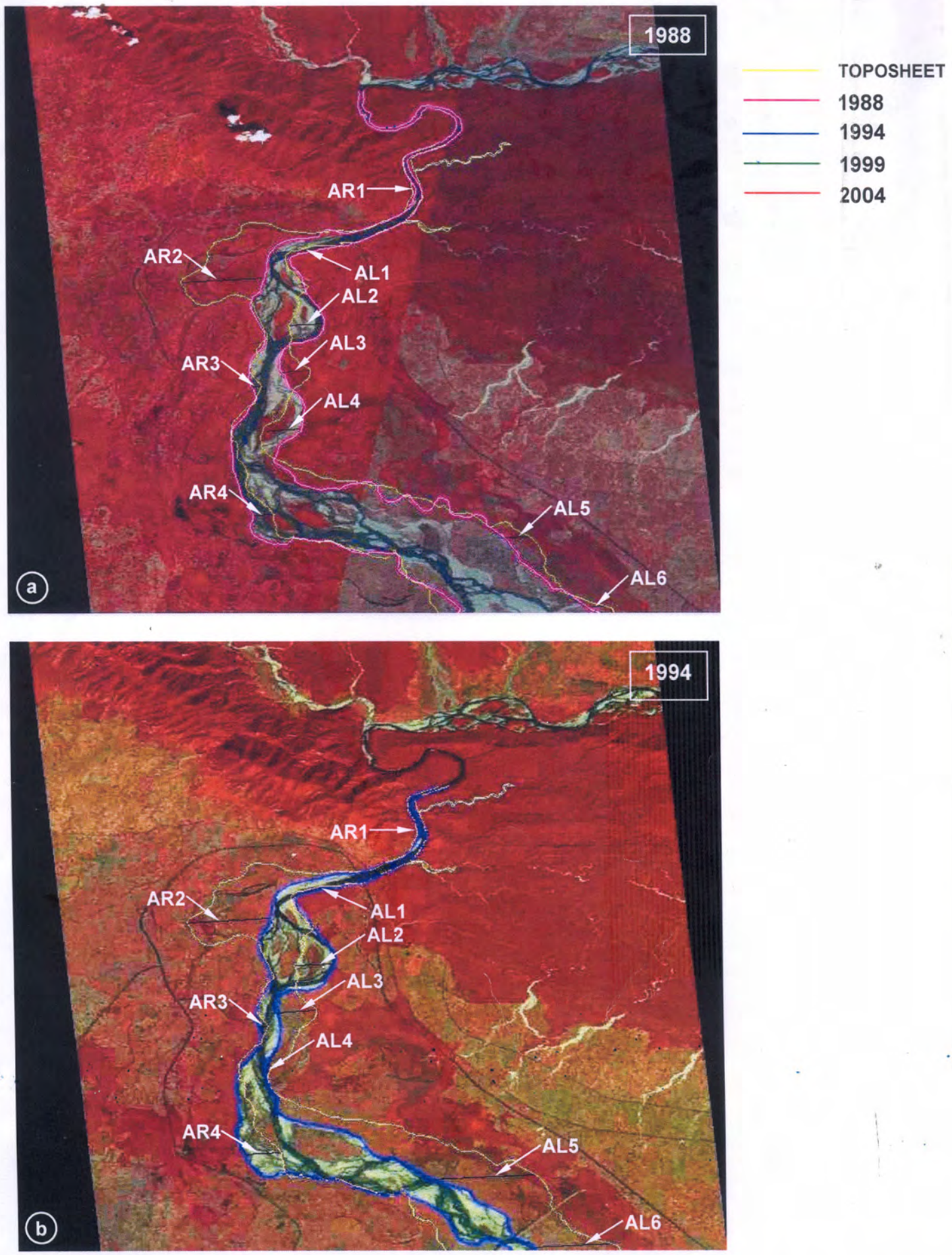
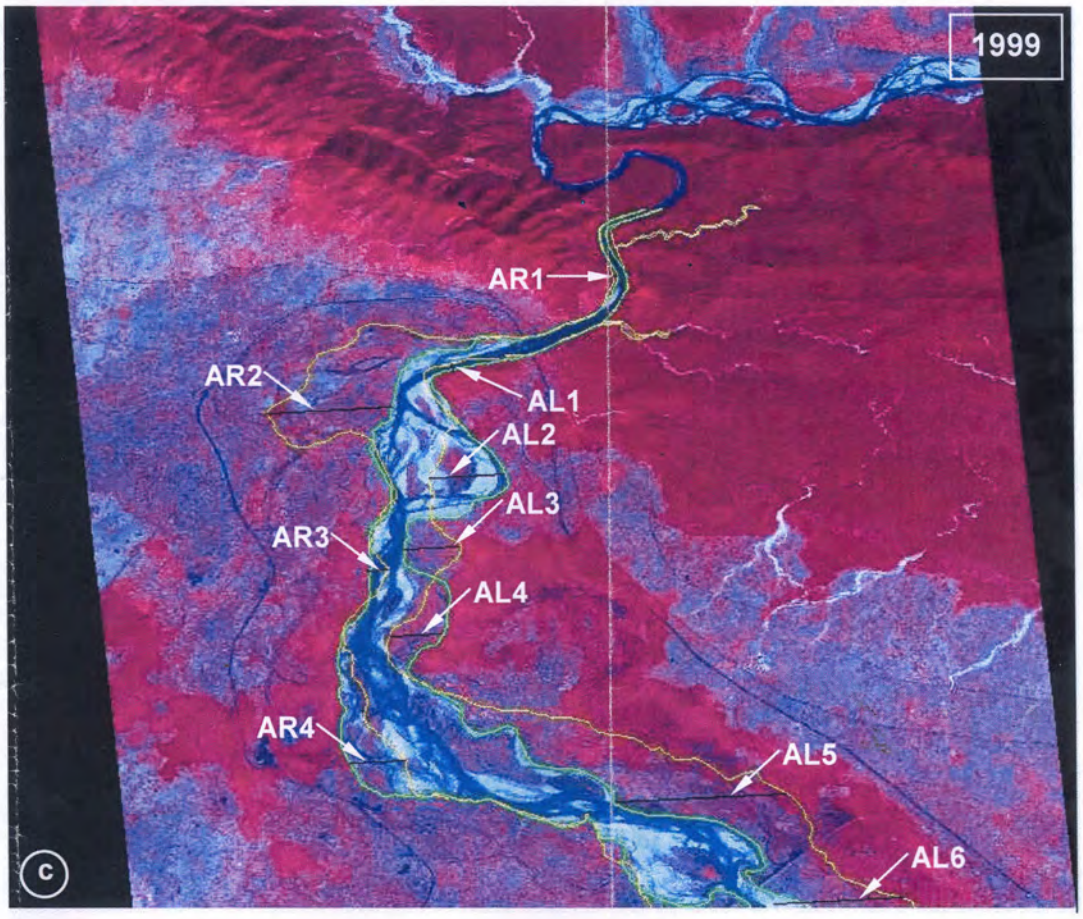
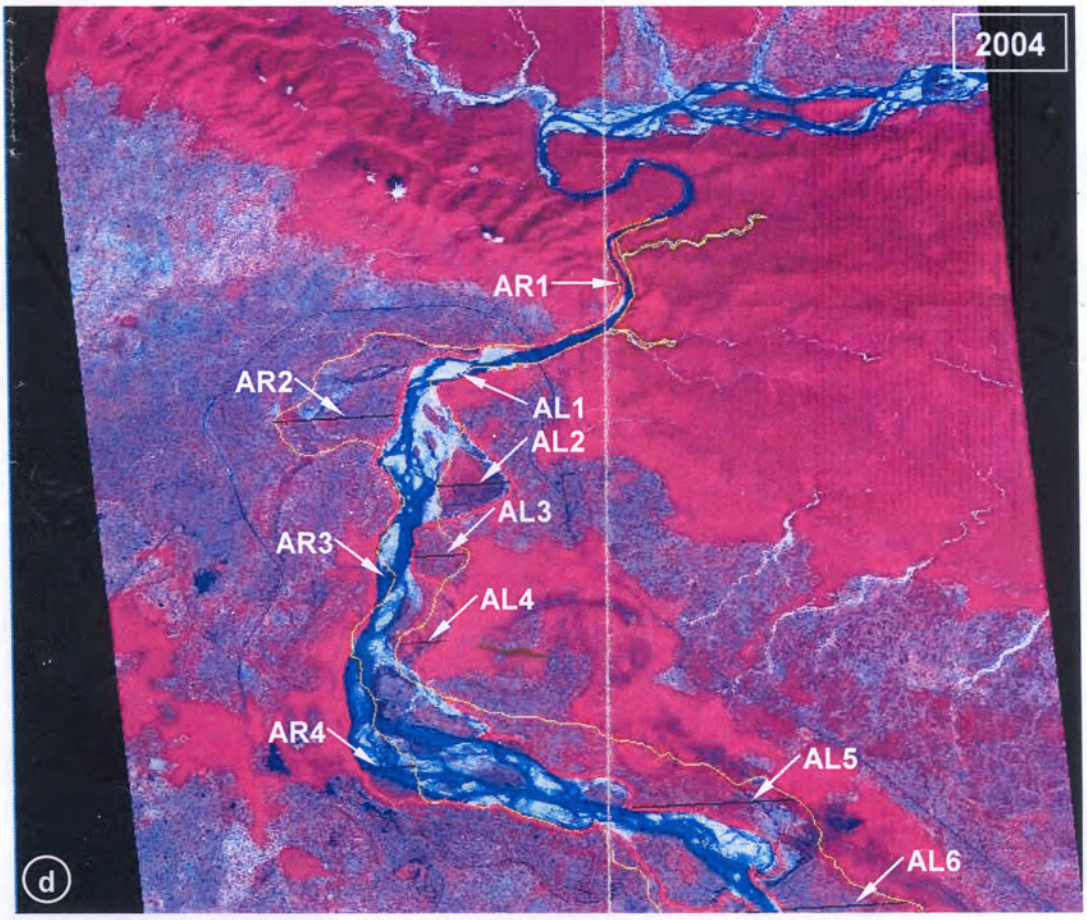


FIGURE 4.11: CHANGES IN BANK LINES OF RIVE

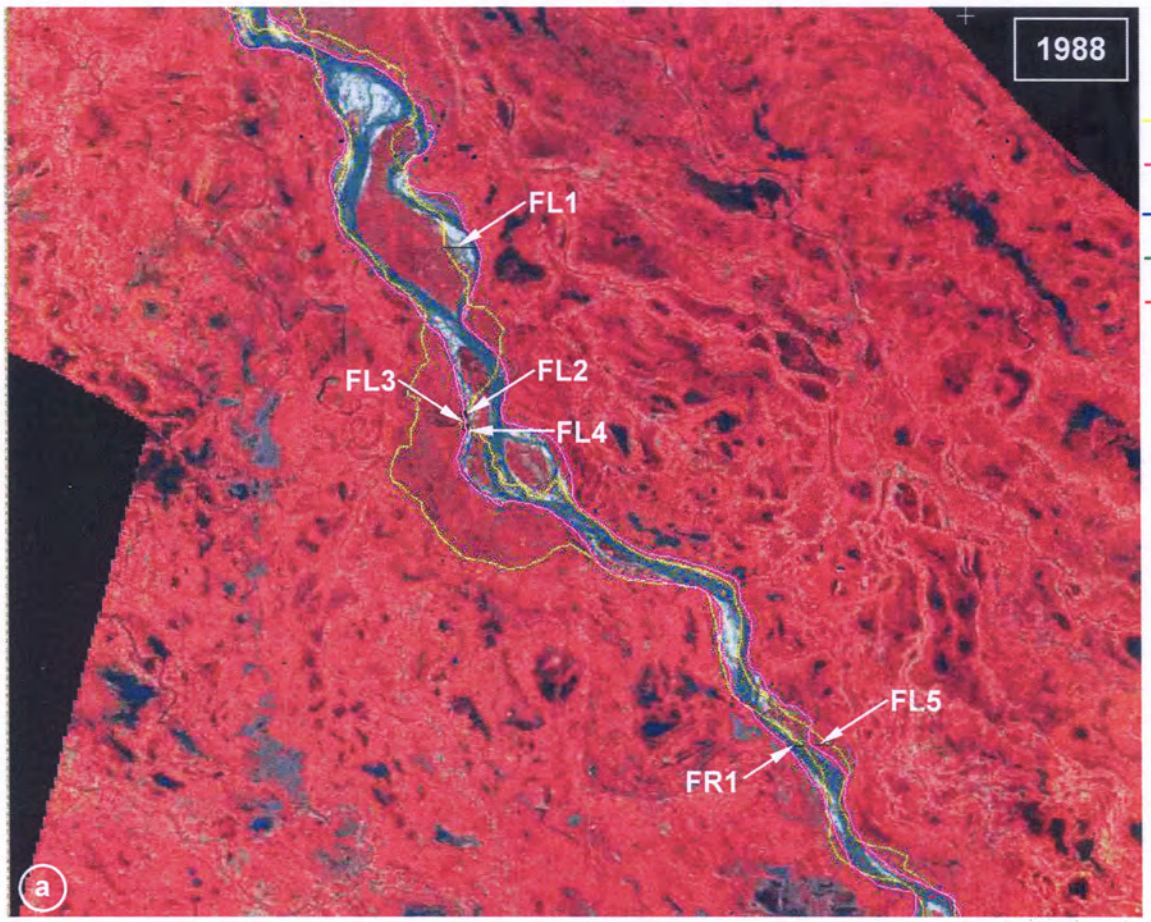
TOPOSHEET
1988
1994
1999
2004





BANK LINES OF RIVER GANDAK FOR ZONE A

22B



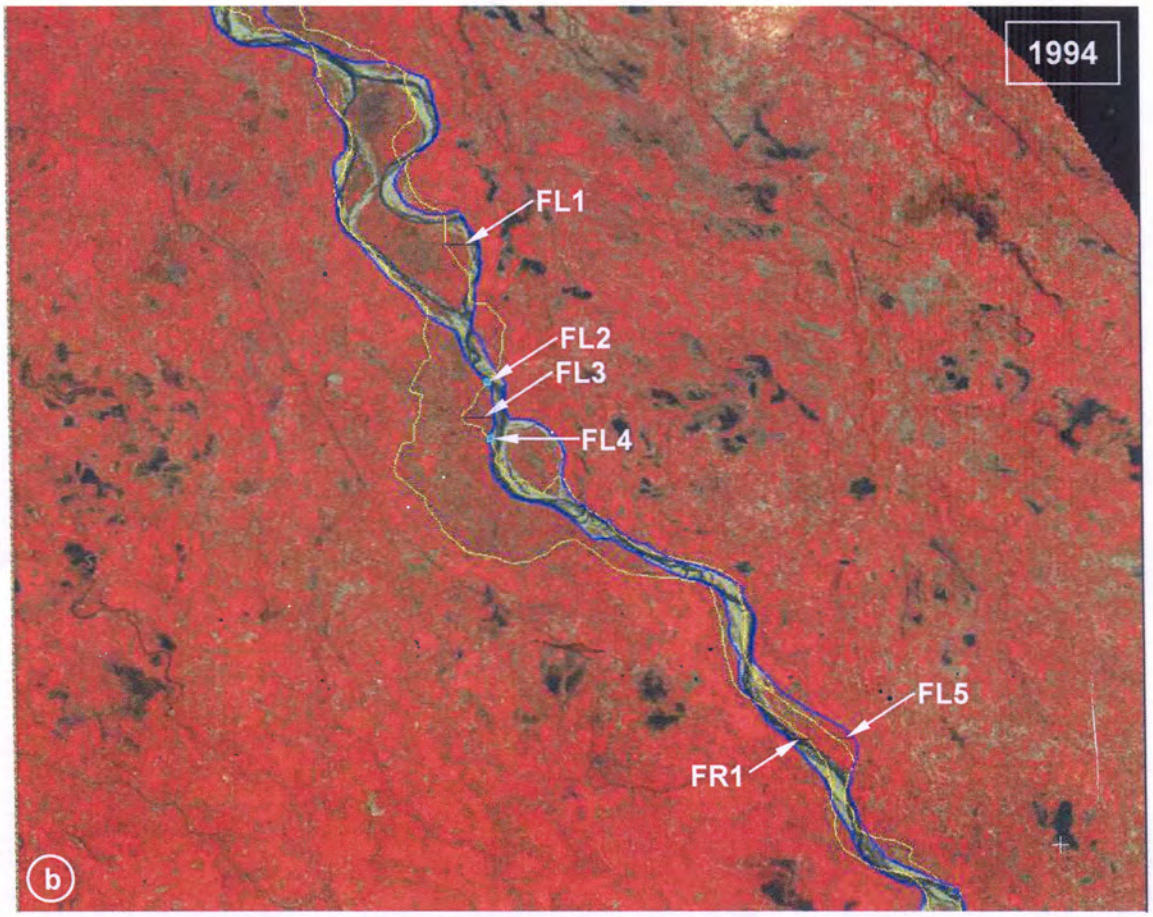
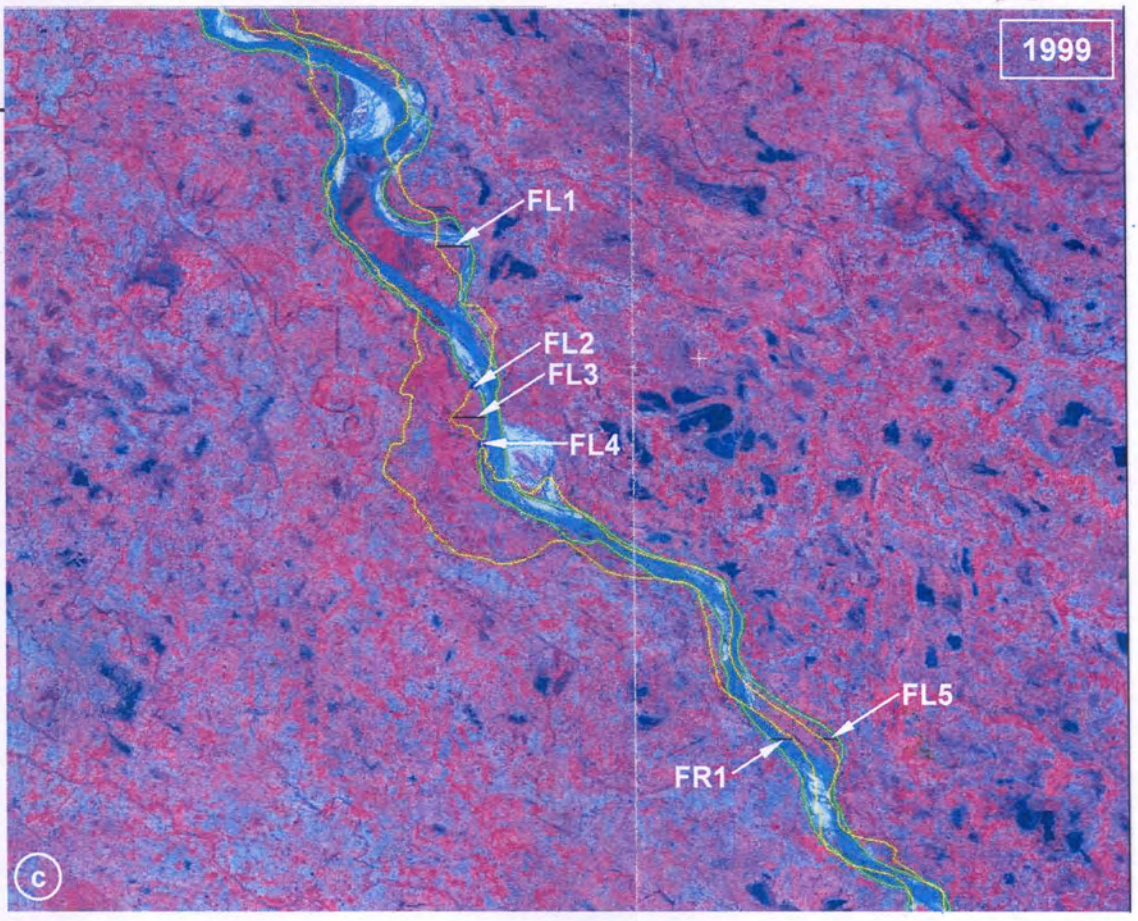
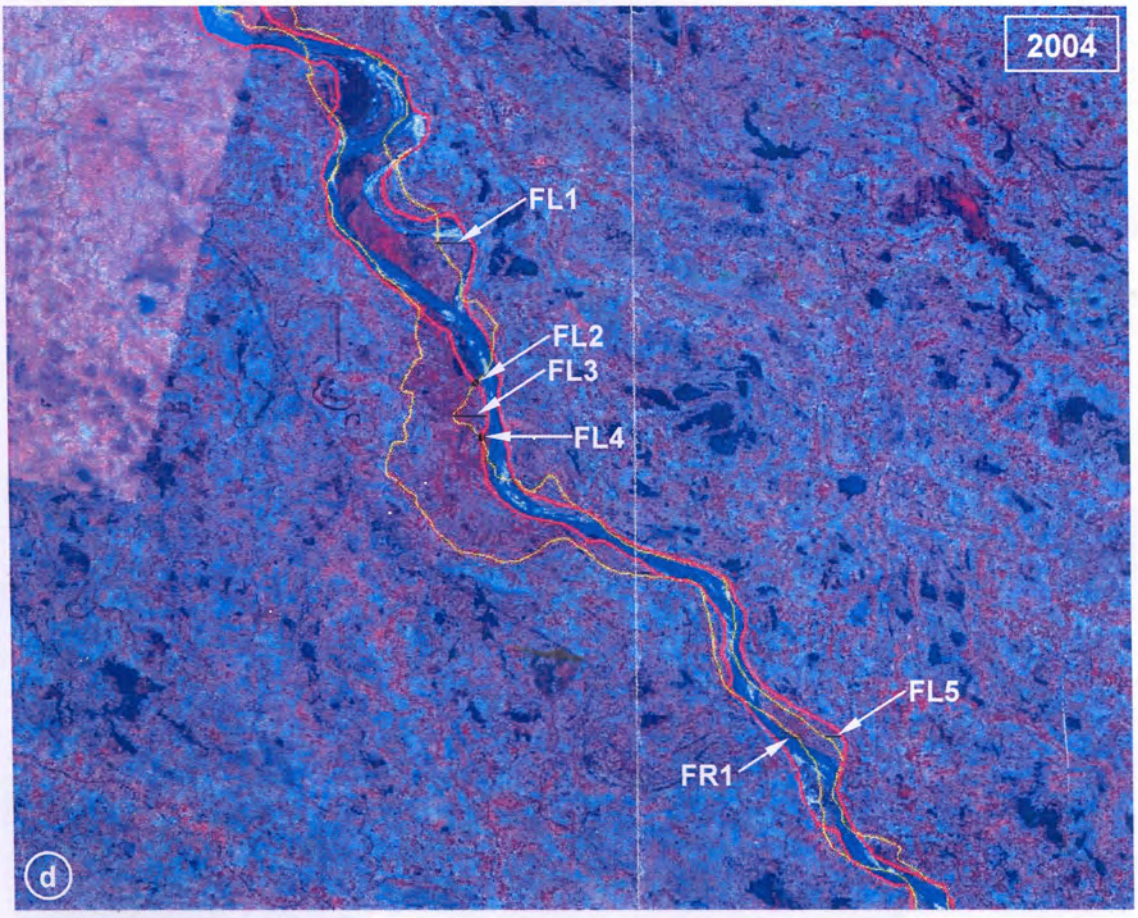


FIGURE 4.16: CHANGES IN BANK LINES OF

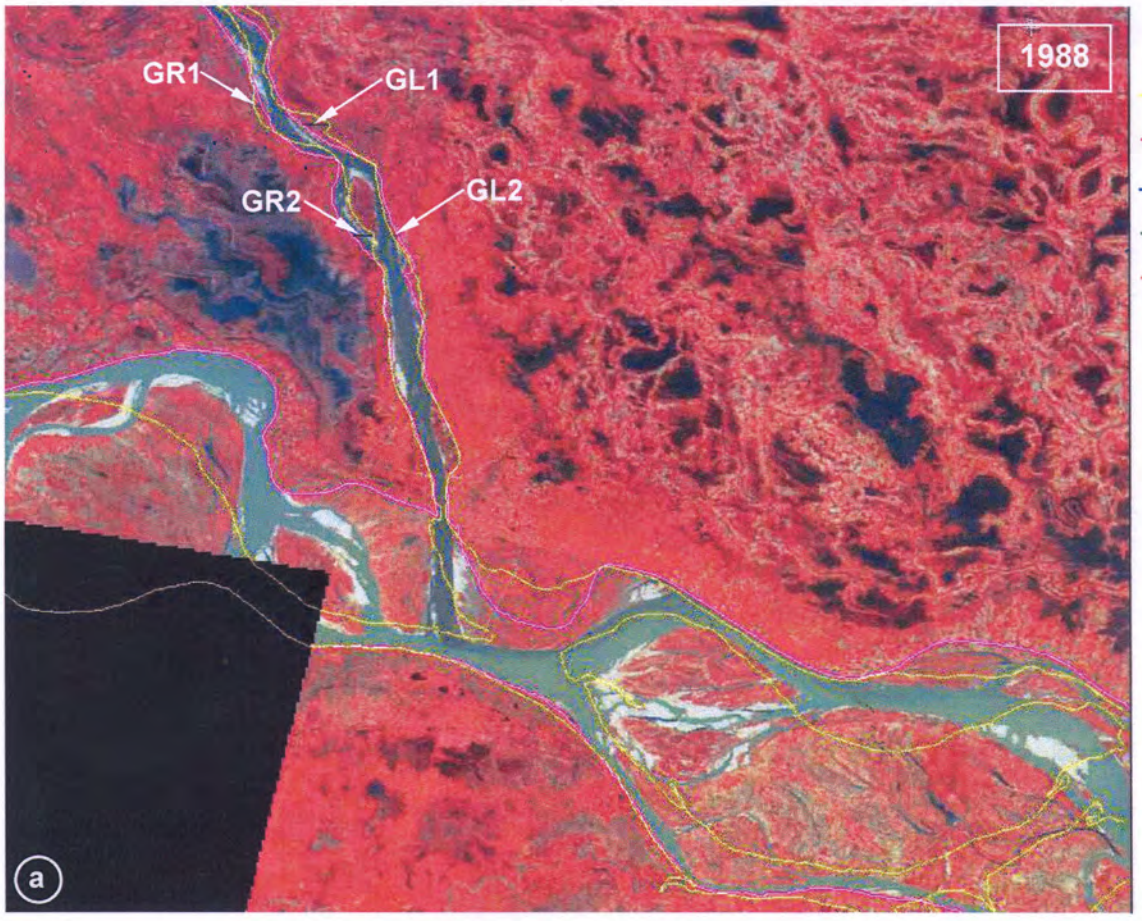
TOPOSHEET
1988
1994
1999
2004





BANK LINES OF RIVER GANDAK FOR ZONE F

27B



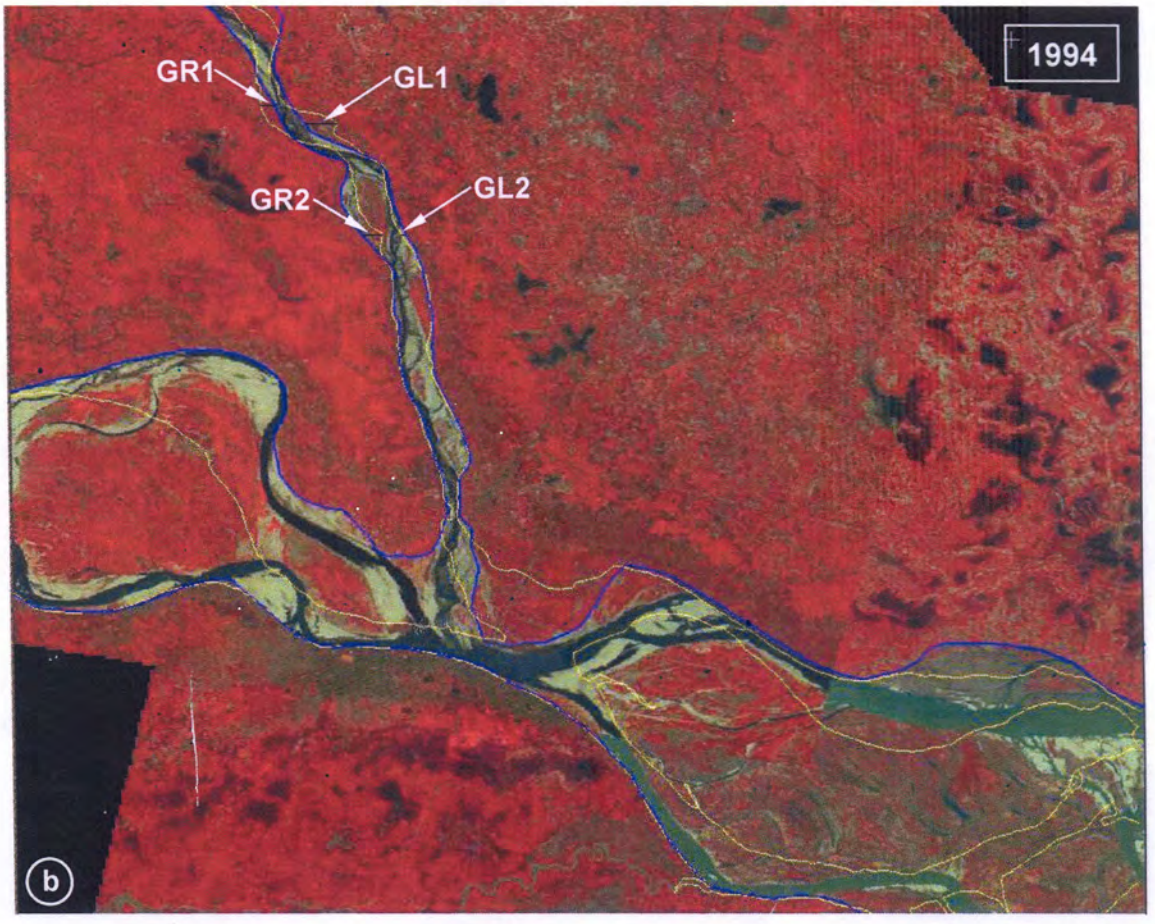
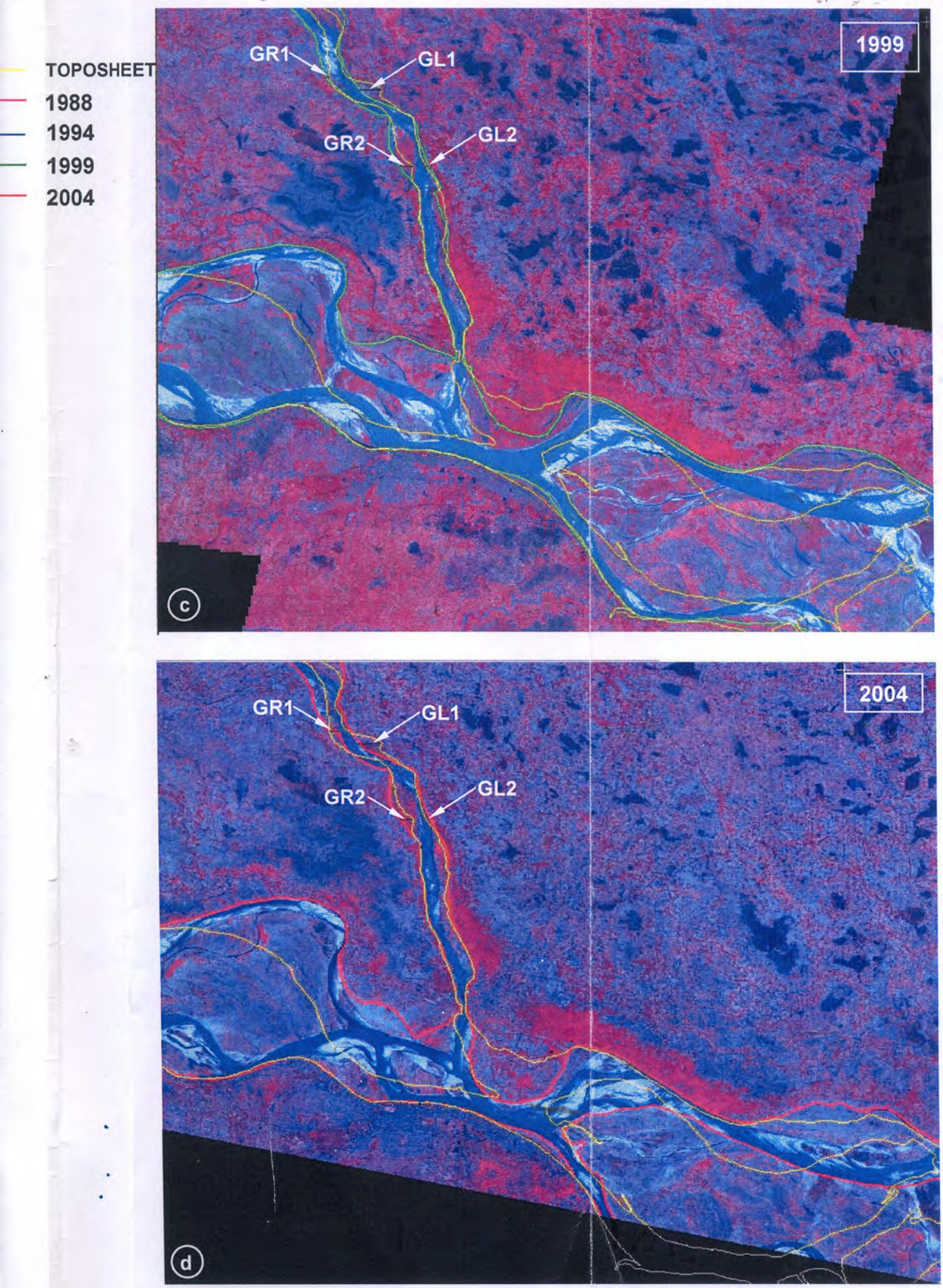


FIGURE 4.17: CHANGES IN BANK LINES



ANK LINES OF RIVER GANDAK FOR ZONE G

28B

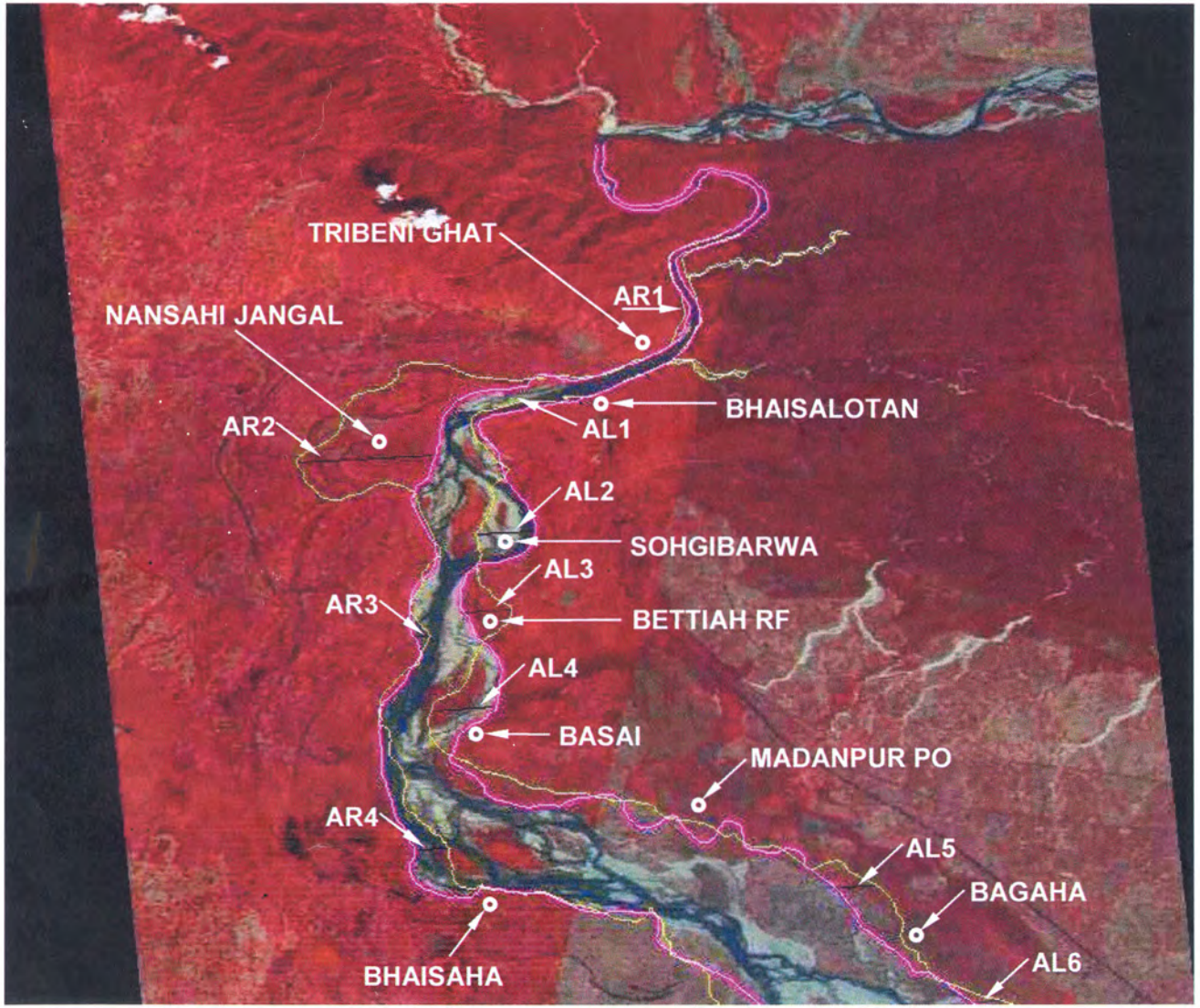


FIGURE 4.18: LOCATIONS OF TOWNS/ VILLAGES – ZONE A

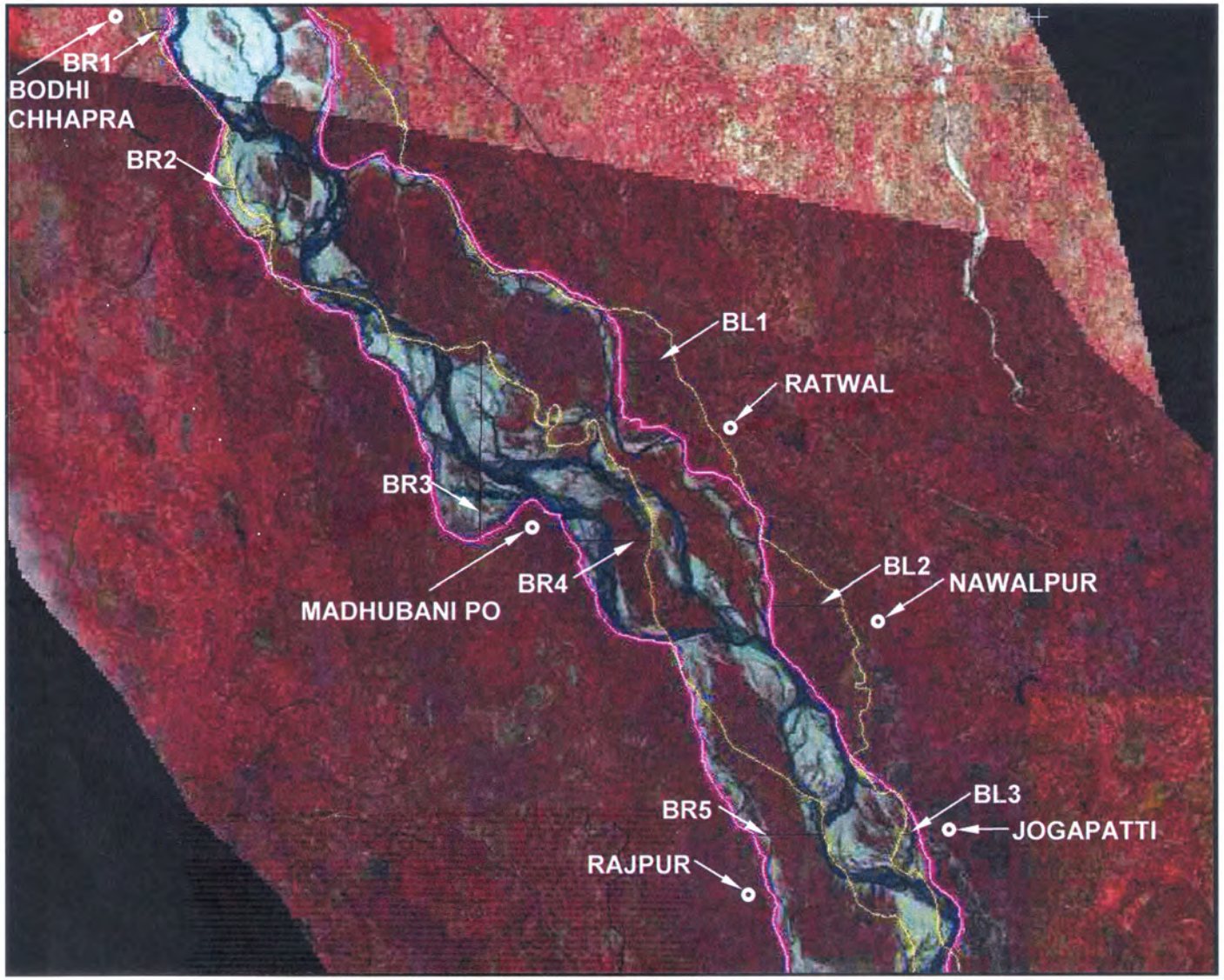


FIGURE 4.19: LOCATIONS OF TOWNS/ VILLAGES – ZONE B

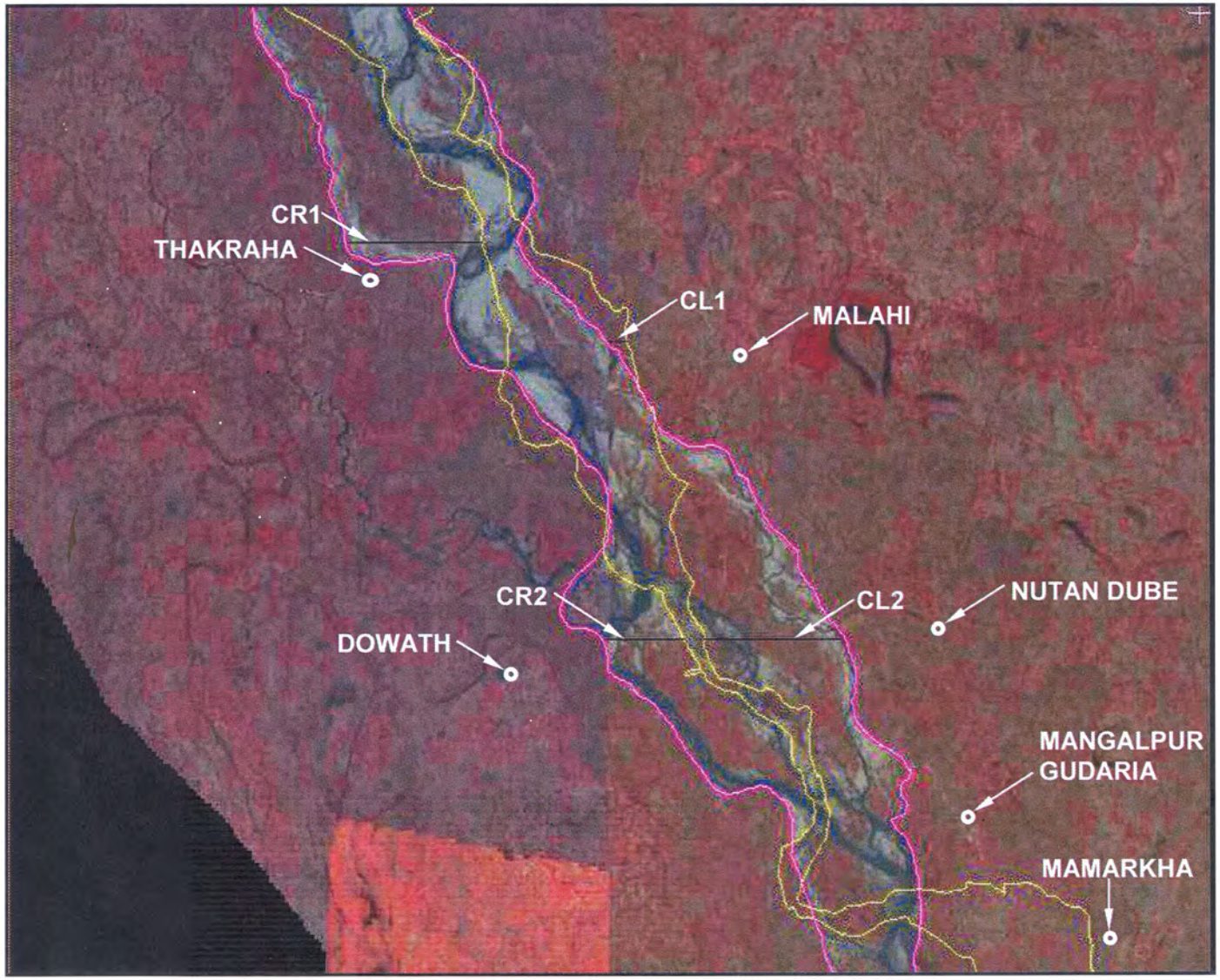


FIGURE 4.20: LOCATIONS OF TOWNS/ VILLAGES – ZONE C

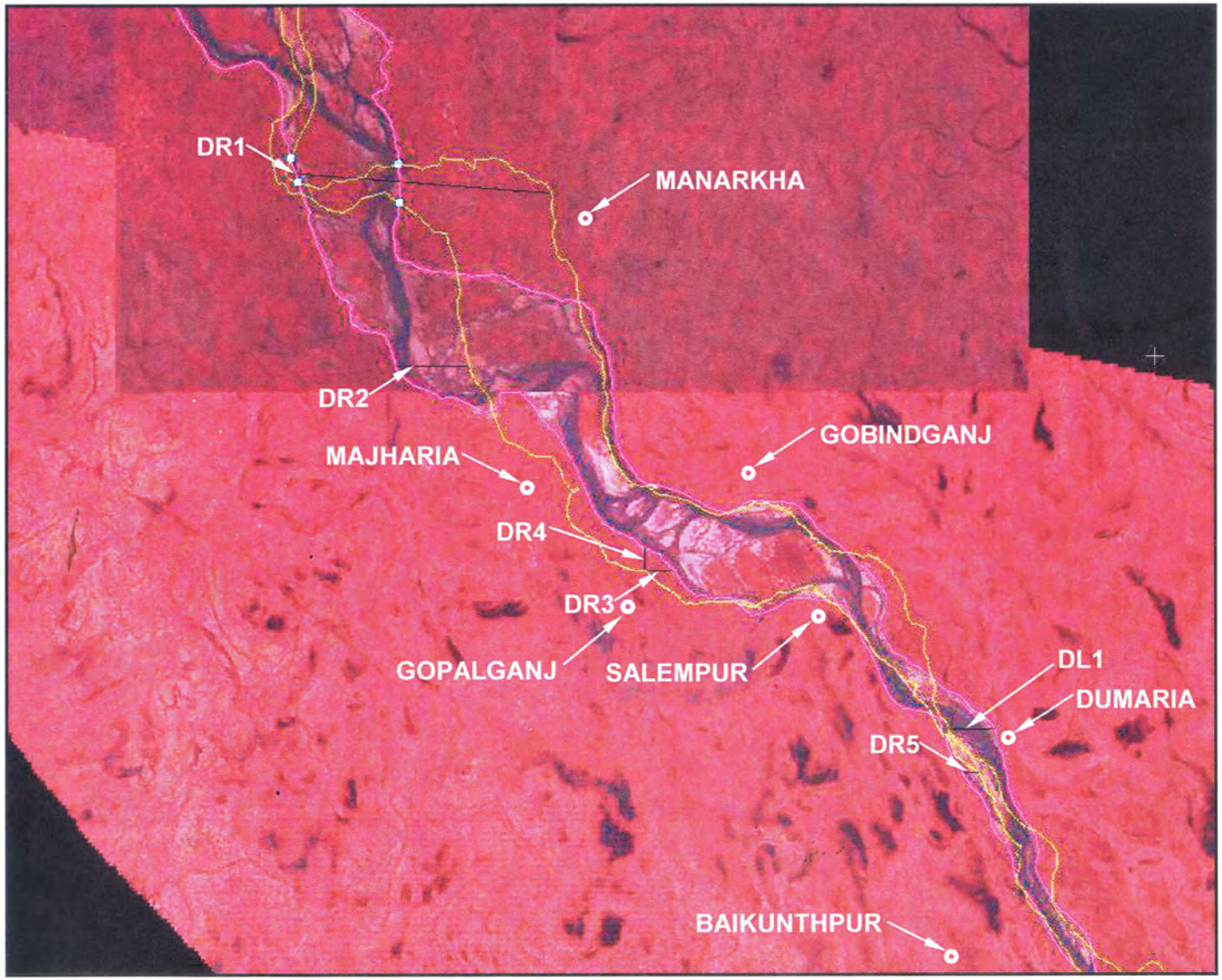


FIGURE 4.21: LOCATIONS OF TOWNS/ VILLAGES – ZONE D

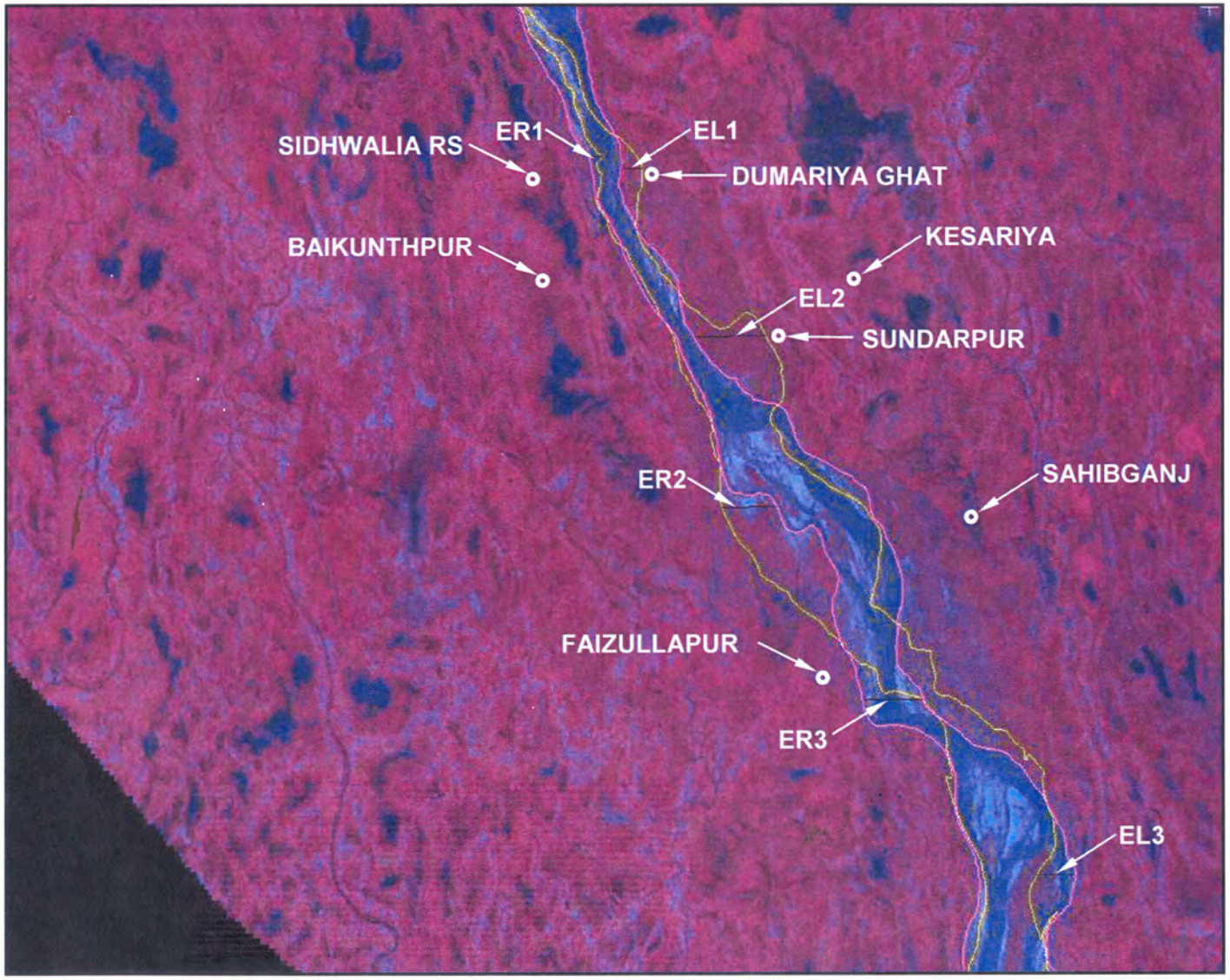


FIGURE 4.22: LOCATIONS OF TOWNS/ VILLAGES – ZONE E

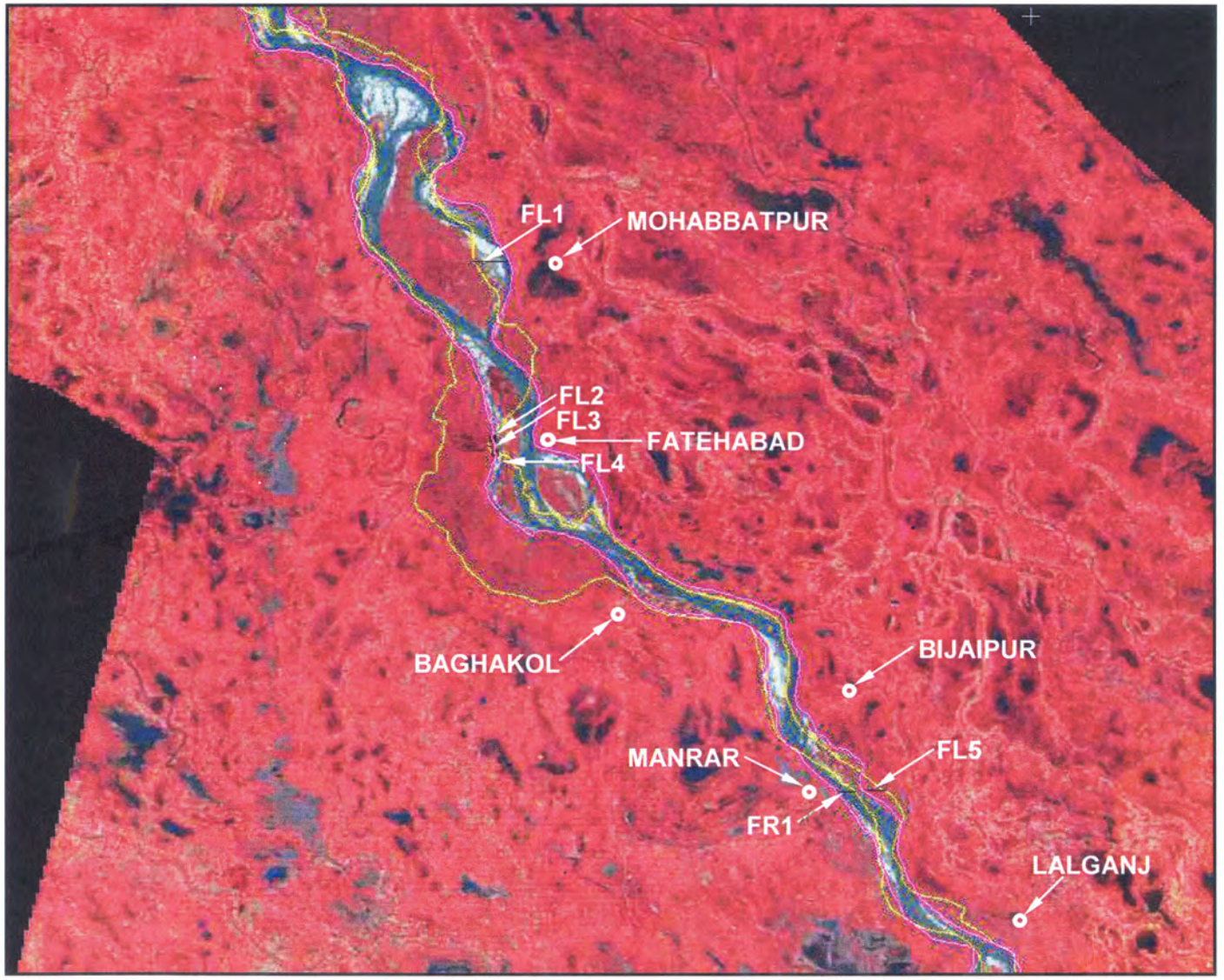


FIGURE 4.23: LOCATIONS OF TOWNS/ VILLAGES – ZONE F

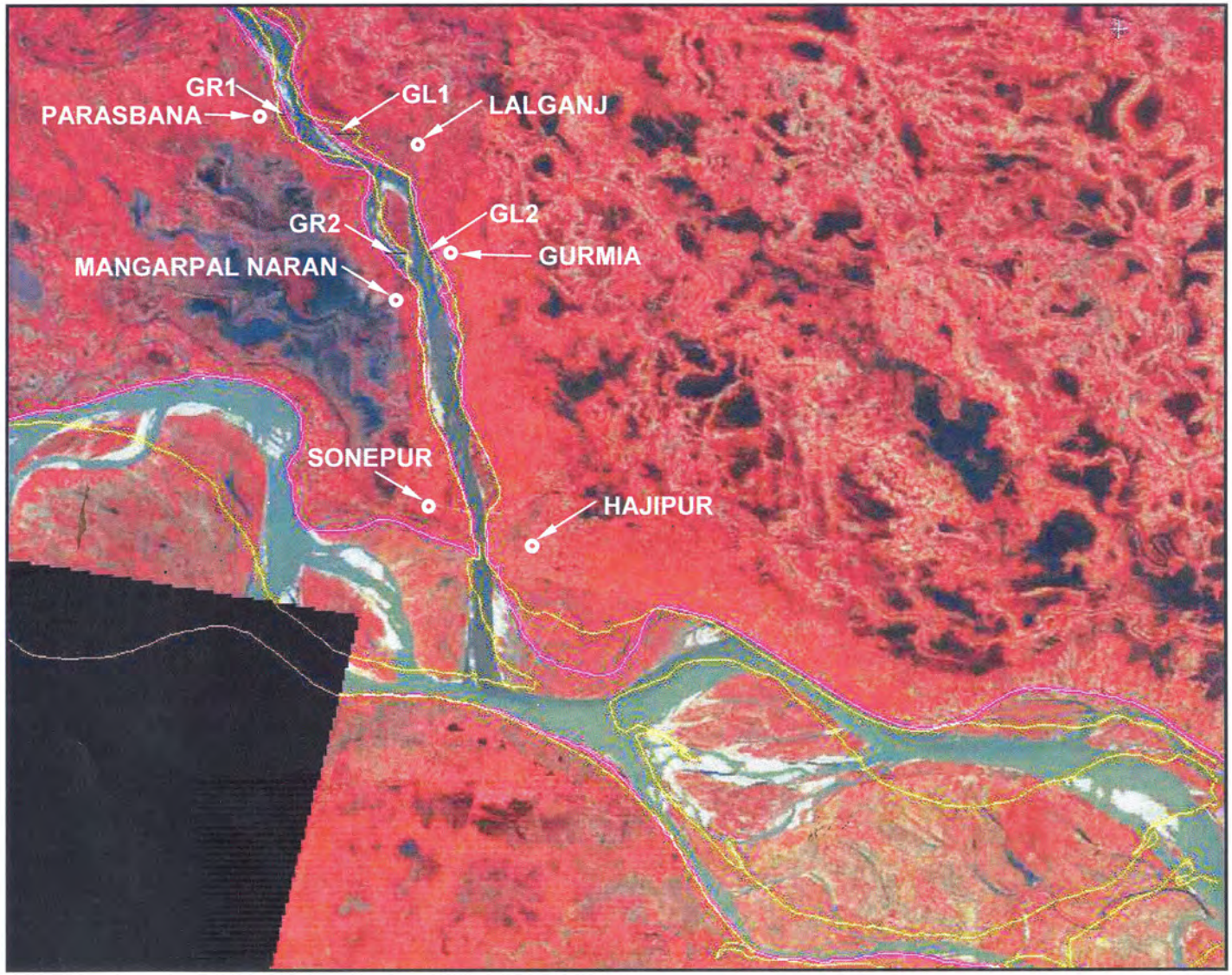
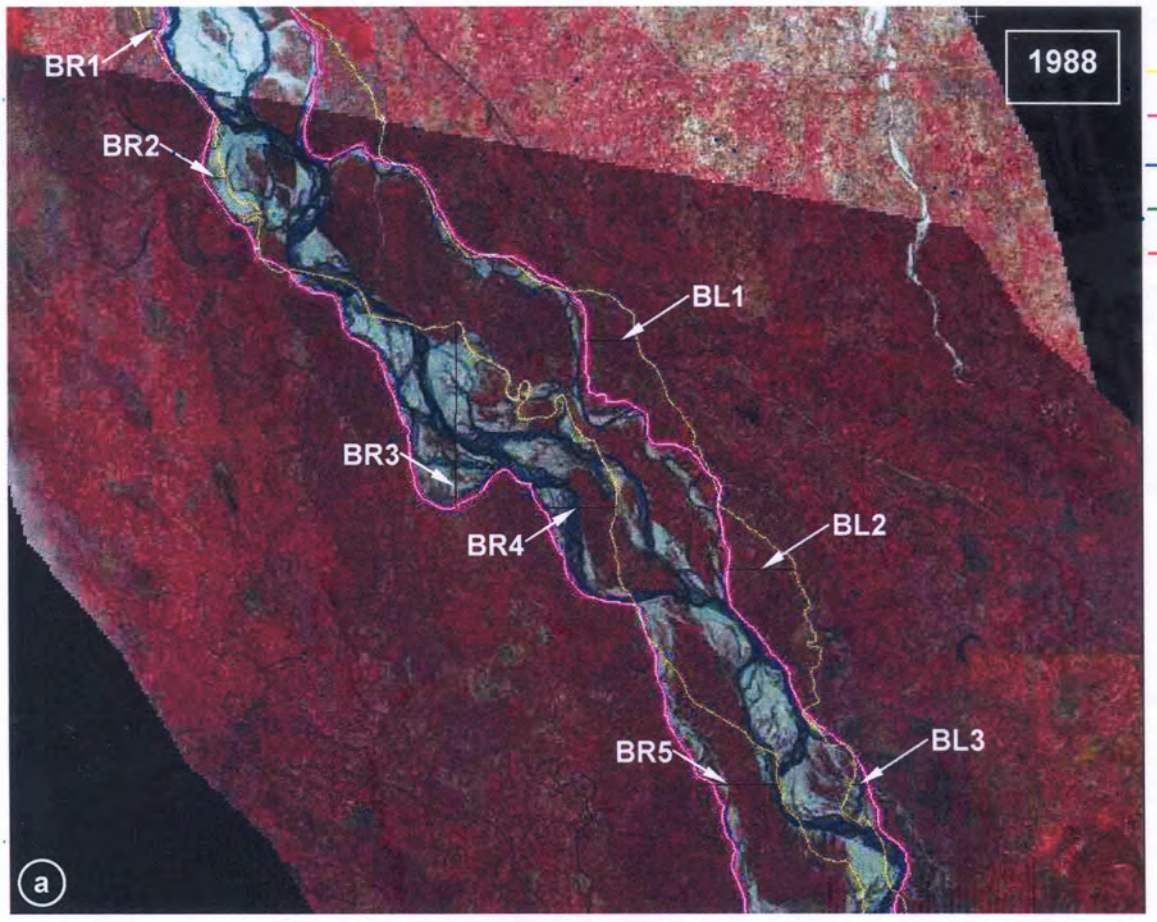


FIGURE 4.24: LOCATIONS OF TOWNS / VILLAGES – ZONE G



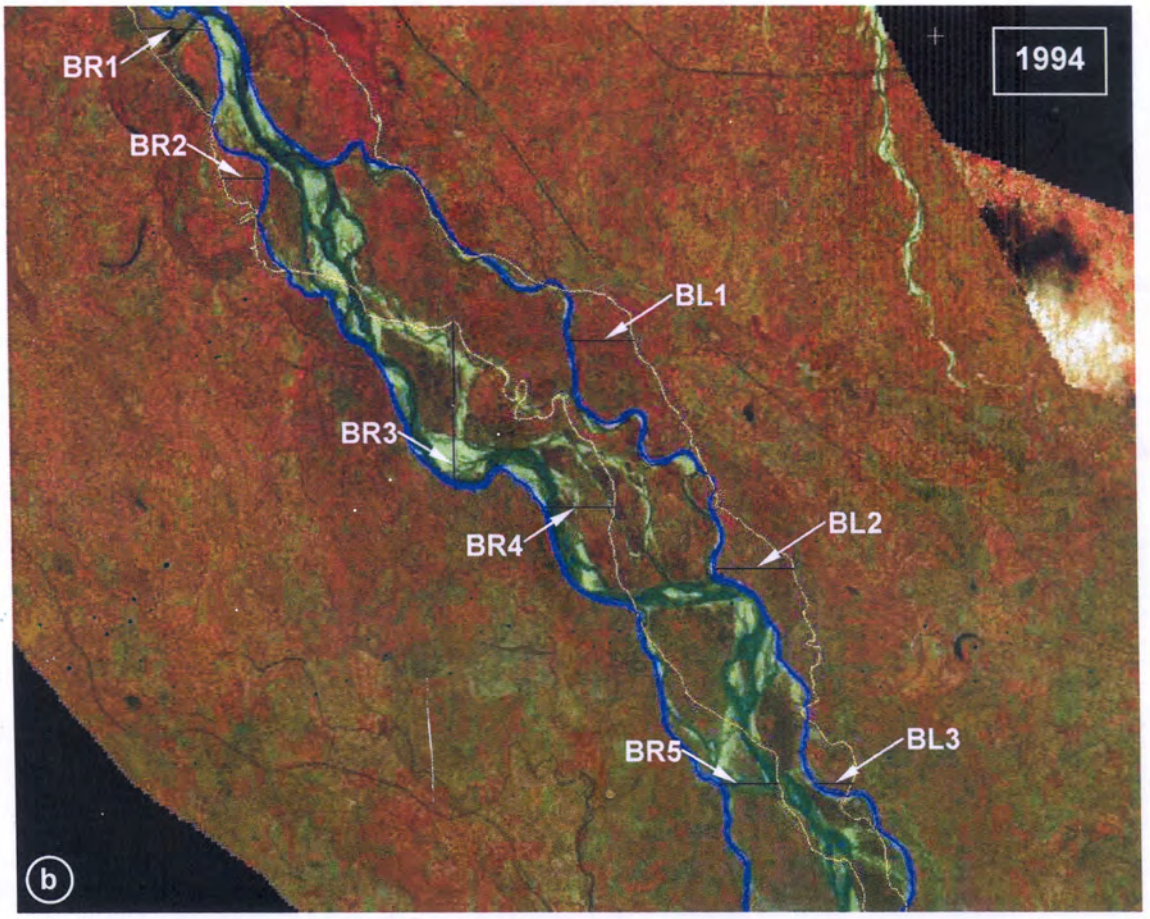
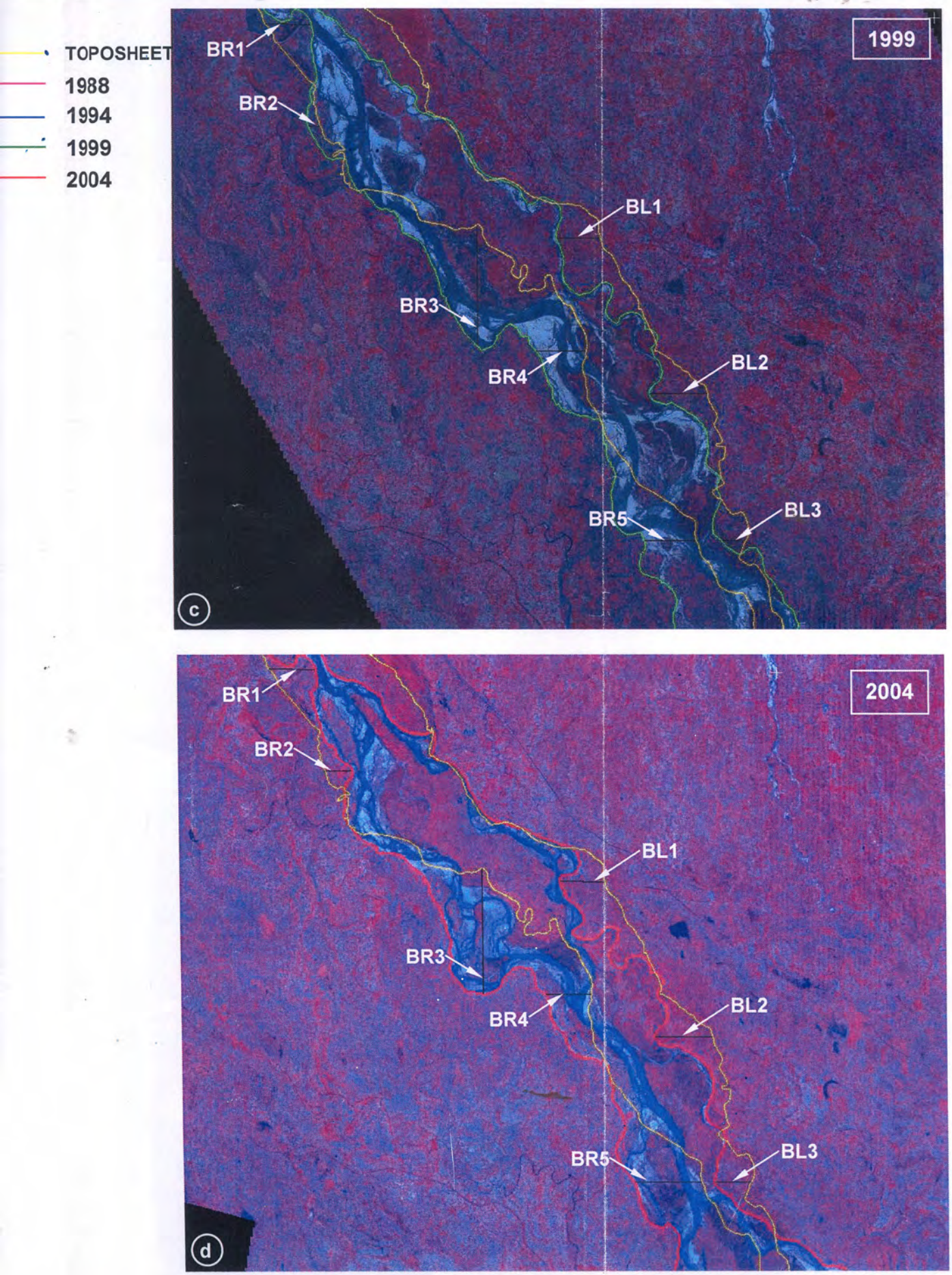


FIGURE 4.12: CHANGES IN BANK LINES



BANK LINES OF RIVER GANDAK FOR ZONE B

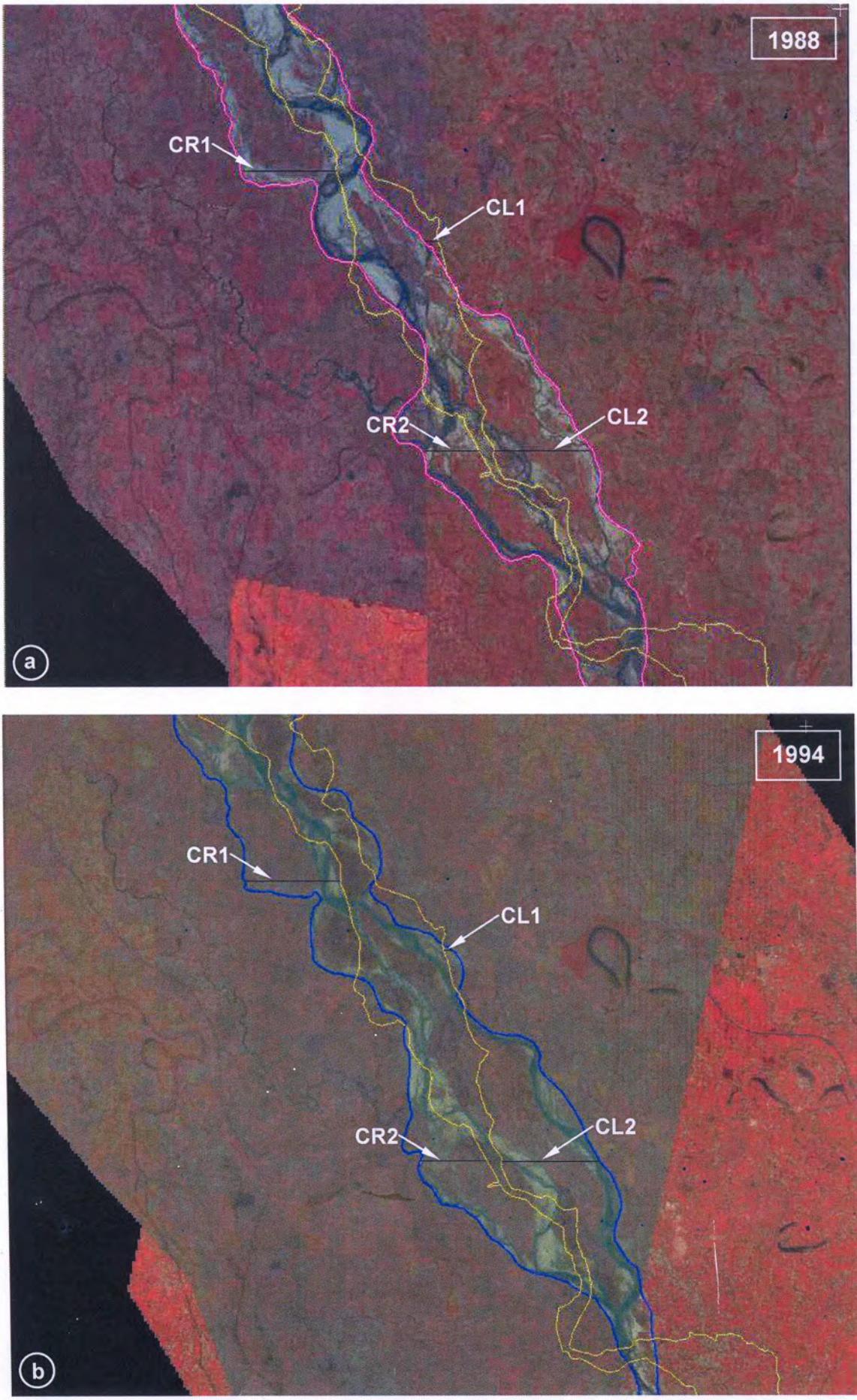
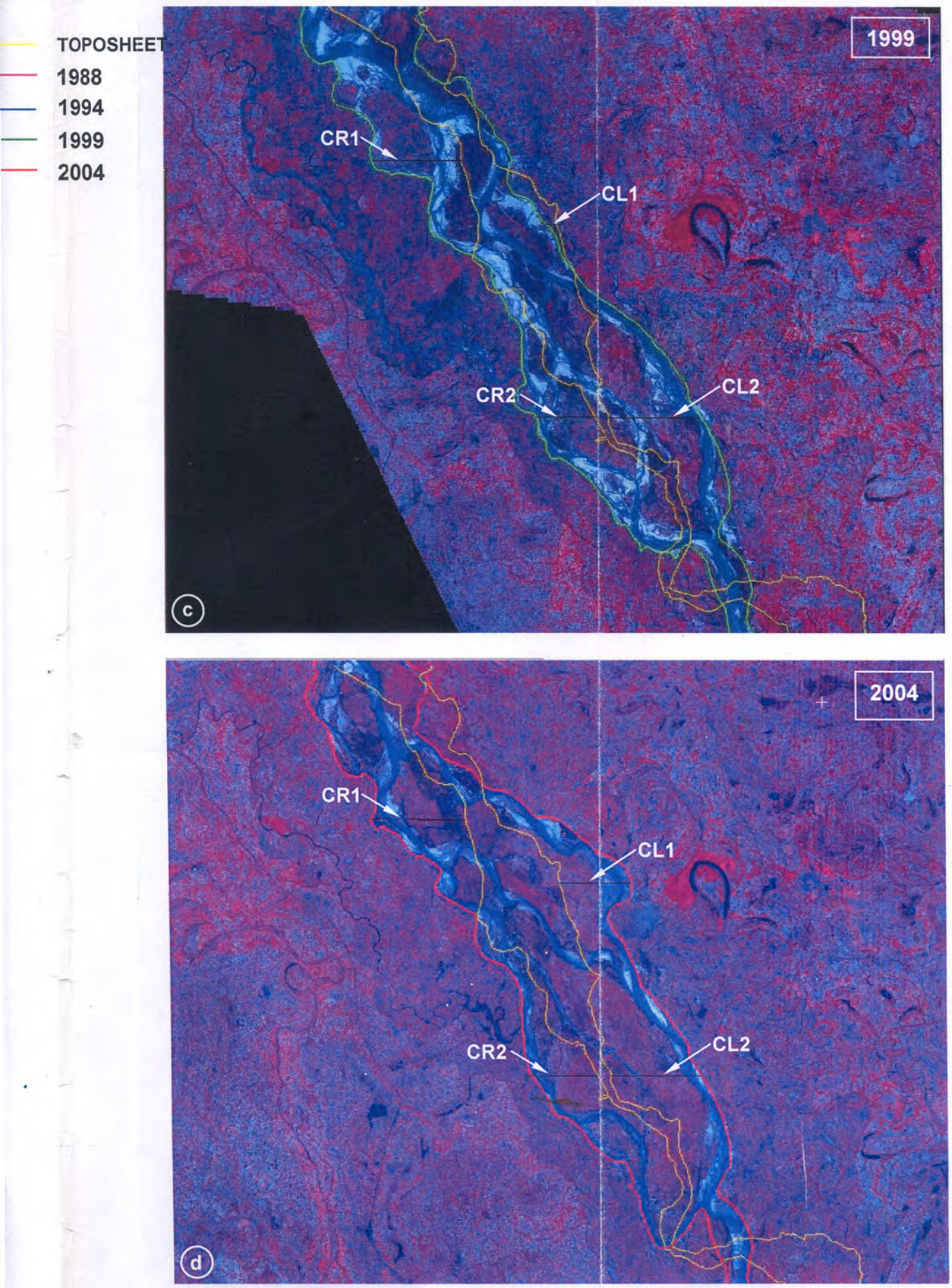
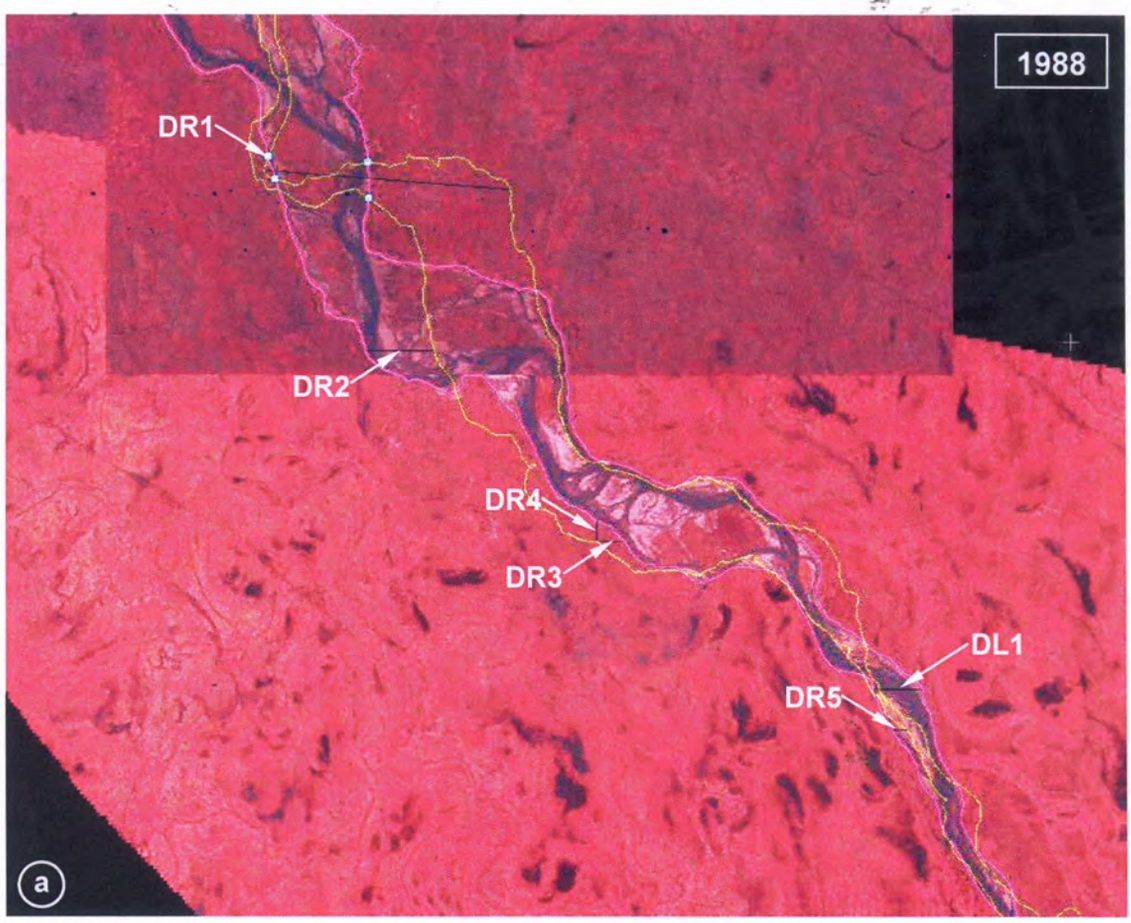


FIGURE 4.13: CHANGES IN BANK LINES OF



LINES OF RIVER GANDAK FOR ZONE C

24B



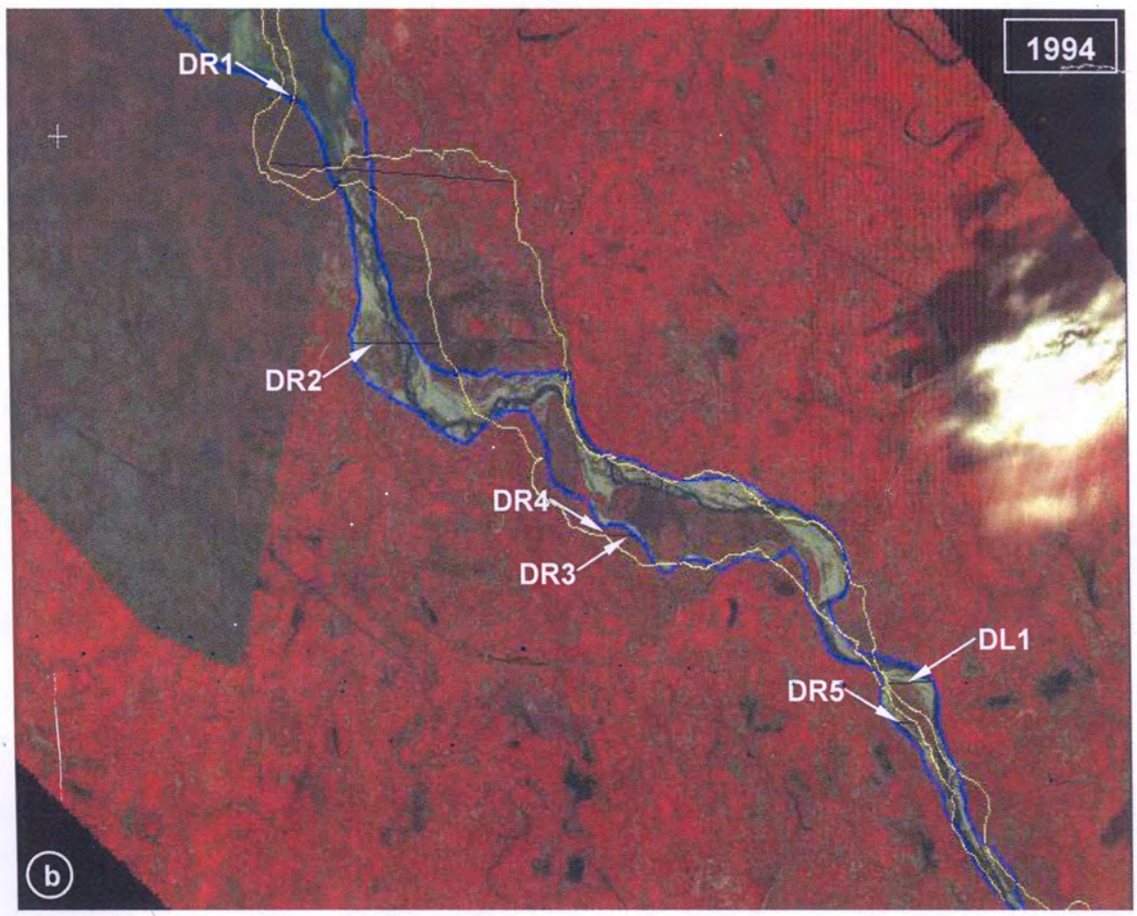
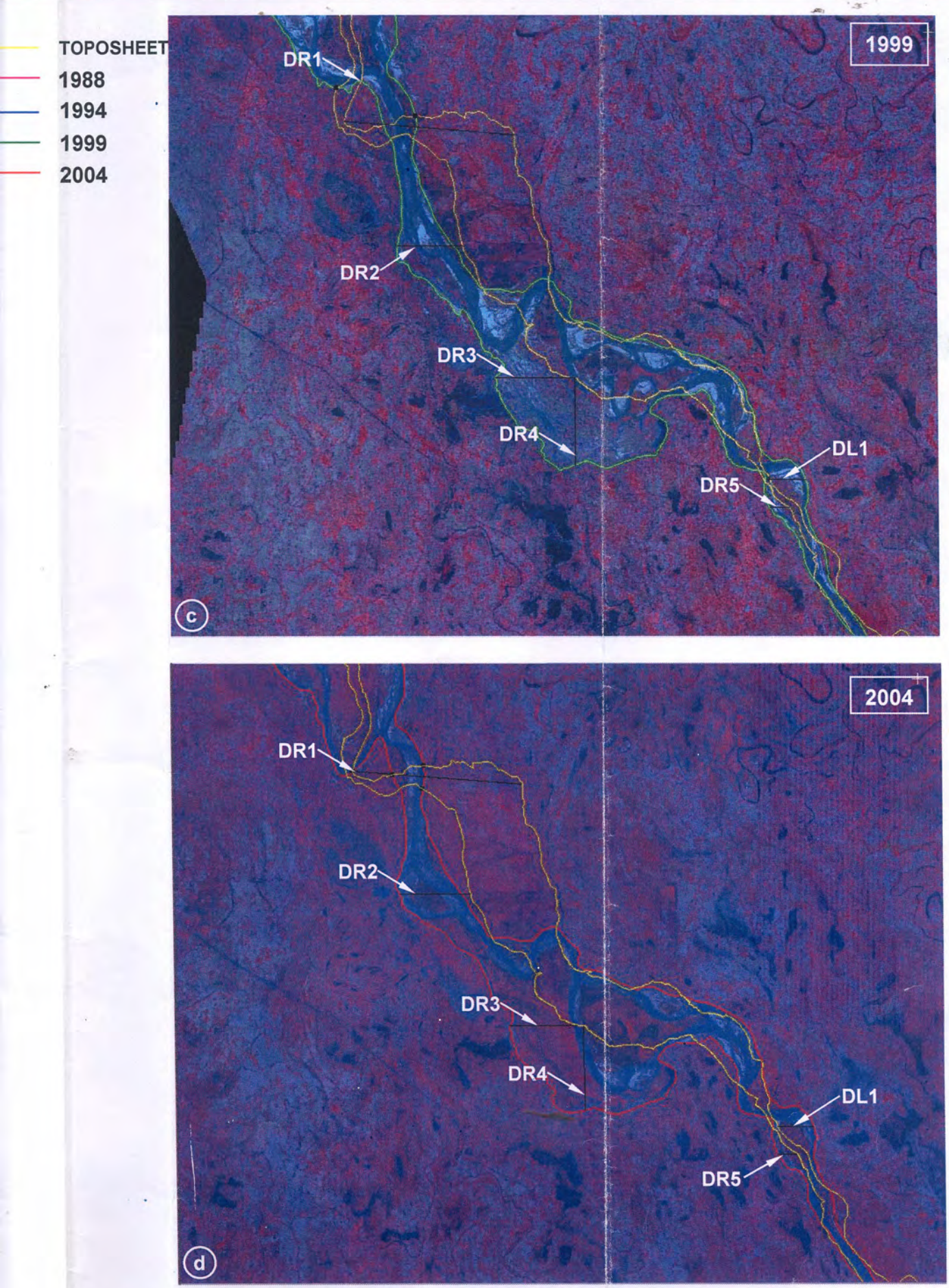
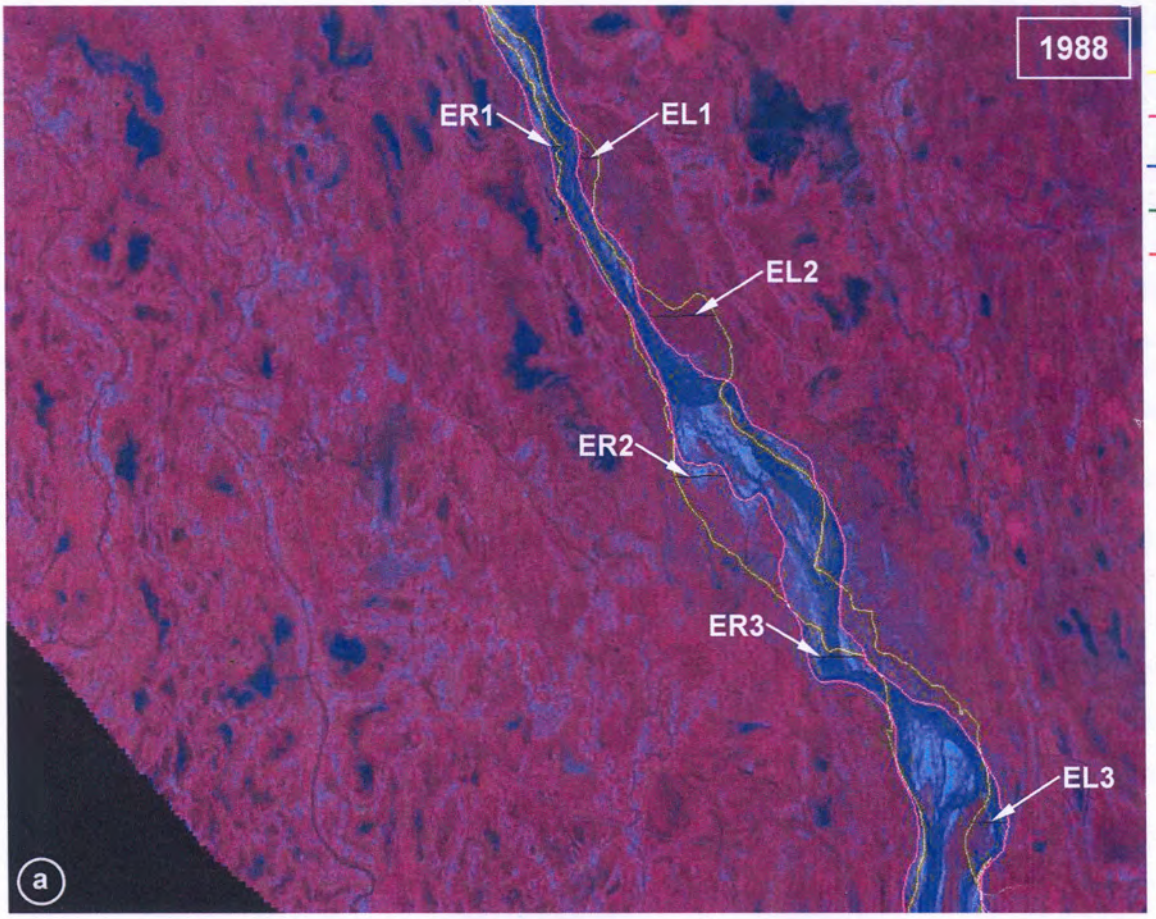


FIGURE 4.14: CHANGES IN BANK LINES



BANK LINES OF RIVER GANDAK FOR ZONE D

25 B



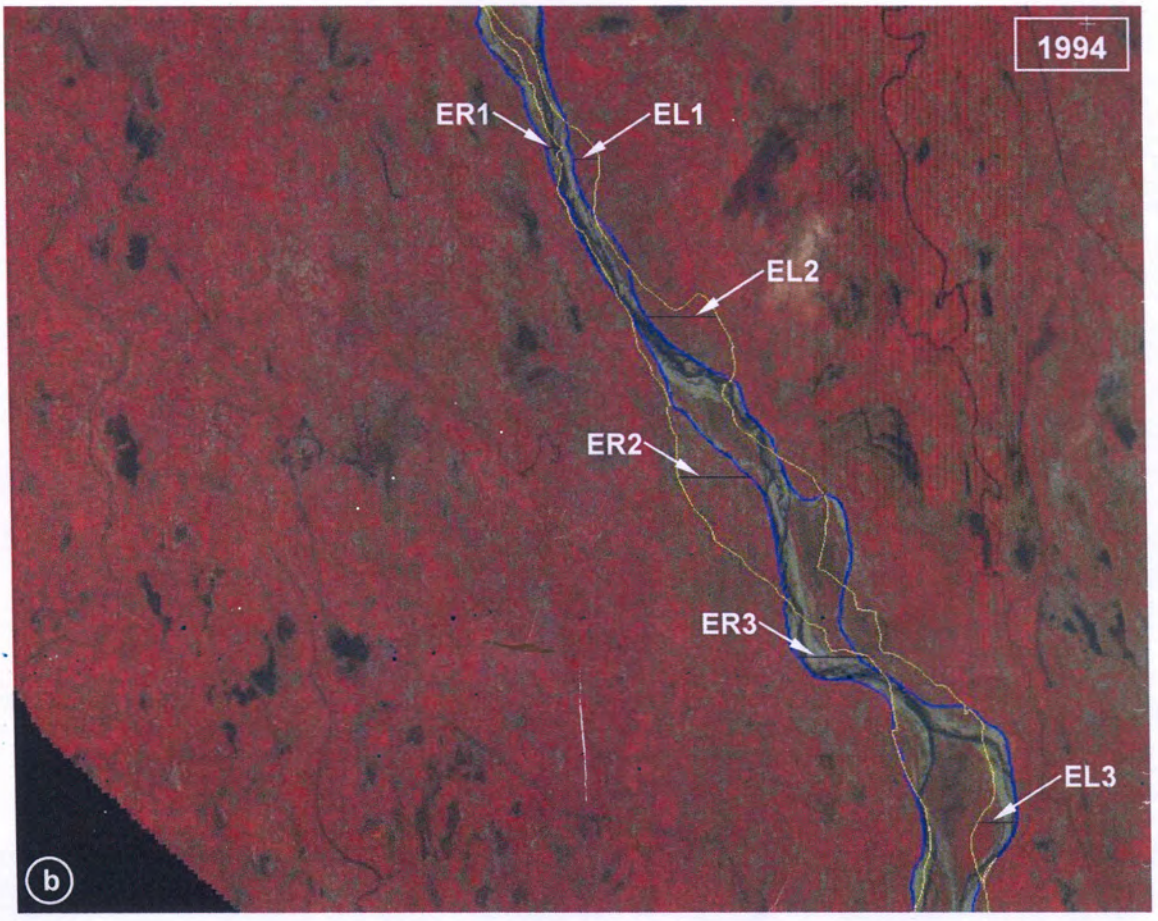
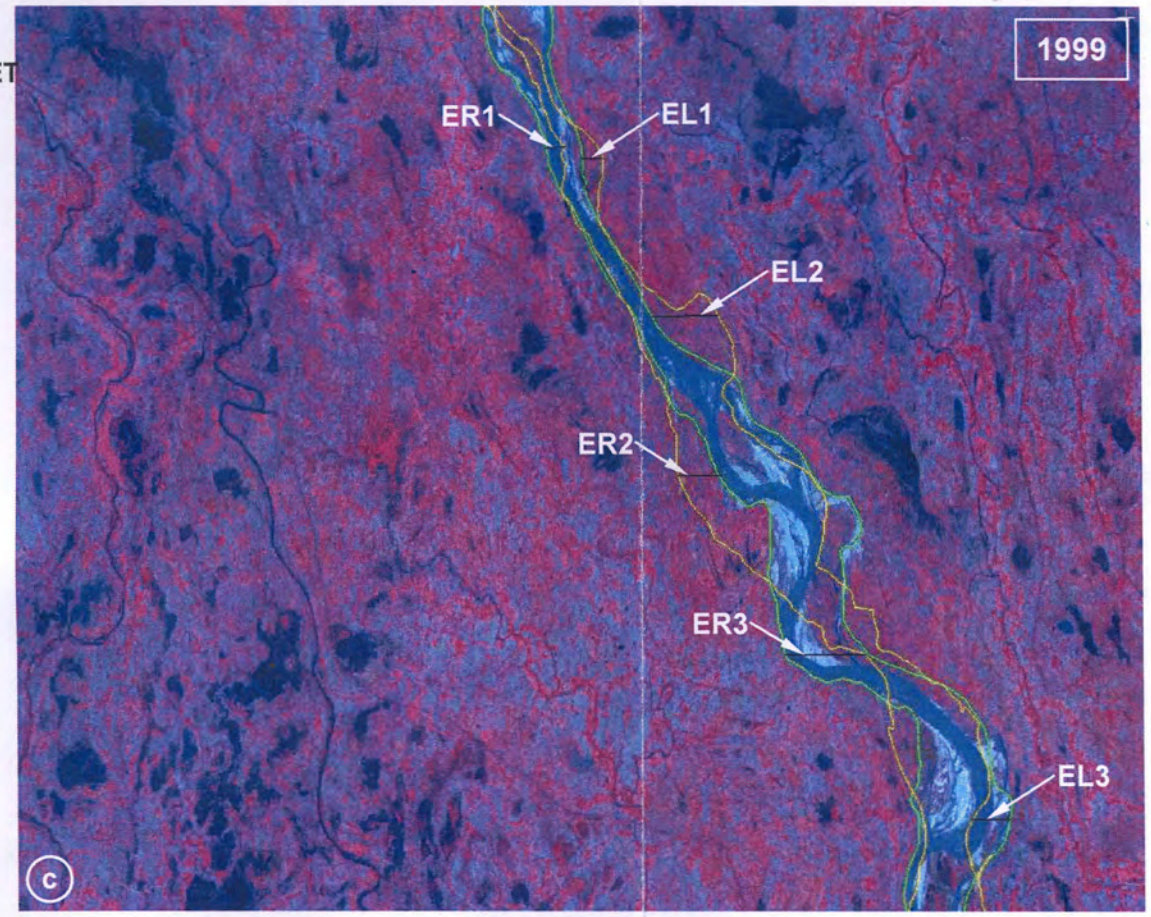
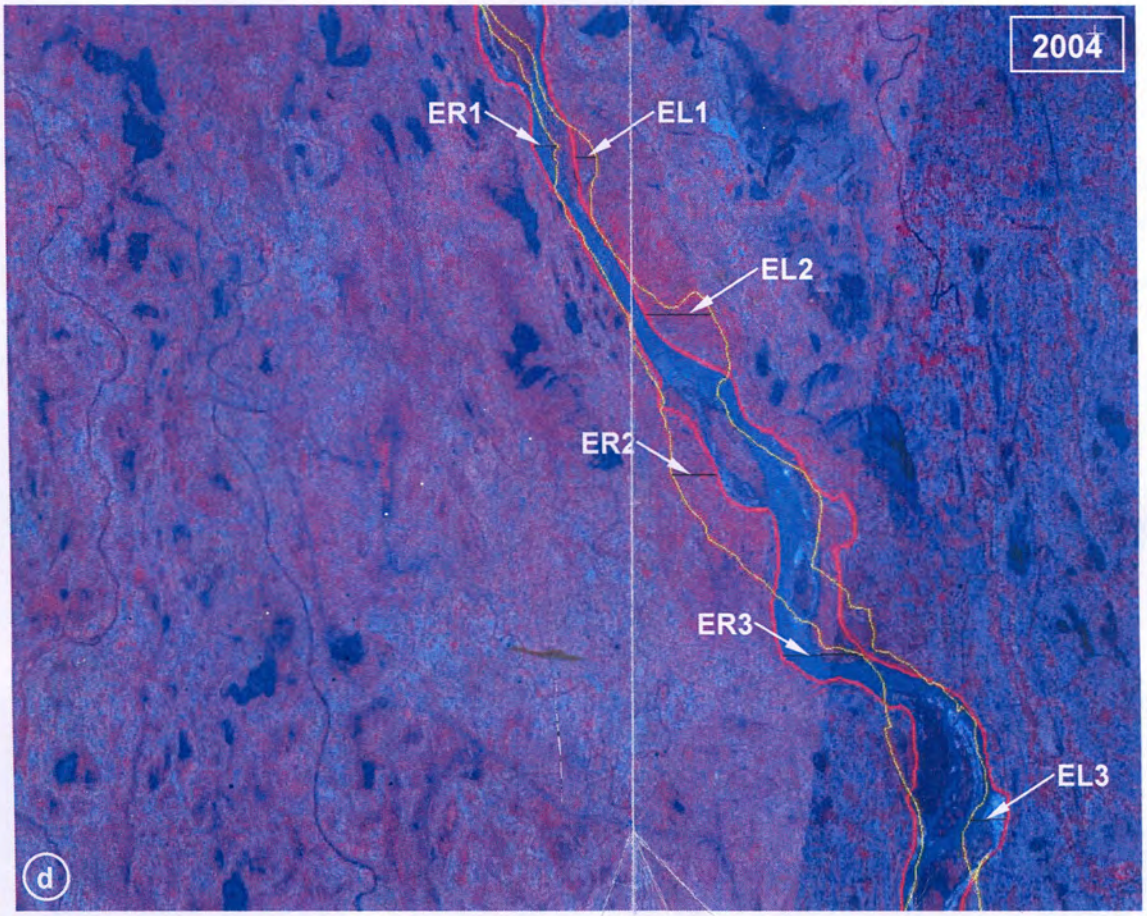


FIGURE 4.15: CHANGES IN BANK LINES

TOPOSHEET
1988
1994
1999
2004





BANK LINES OF RIVER GANDAK FOR ZONE E

26 B