JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

CHANNEL PLANFORM CHANGES WITHIN TWO EMBANKMENTS OF KOSI: 1975-86

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ABSTRACT

The planform of the channel is "plan-view" of streams seen in a panoramic view observed at a glance. Channels are products of several geographic and geomorphic components determined by numerous factors. Since channels are created by carving out the surface by exogenetic forces, they are formed by erosion and deposition. Therefore, dynamics of erosional and depositional components shape the layout plan of channels. Some of the important factors determining are volume and velocity of discharge, slope, structure and composition of rocks, climate and status of vegetative cover, land use and human footprint in the catchment. Change in any of these components is reflected on channel planform found in any particular area operated by any external processes. The Kosi River is notorious for its flood and an epitaph about the Kosi, "sorrow of Bihar" is very well suited since unknown time. The flood fury of this river has engulfed almost whole of north Bihar due to damaging potential of the river. It is an example of one the highest lateral shifting courses of rivers in the world. It has been embanked since more than 60-years, but still its lateral swing is continuing in spite of several engineering efforts. In this background, an attempt has been made here to (i) trace planform changes of the river during 1975-86, (ii) explain the causes of changes, and (iii) suggest some remedial measures for better stability of the river to avoid regular flooding. For the present study, secondary data has been used to substantiate the analysis. It is assumed that this study will help in finding out some long lasting solution to the flood in the Kosi particularly in the plains of Nepal and India (Bihar).

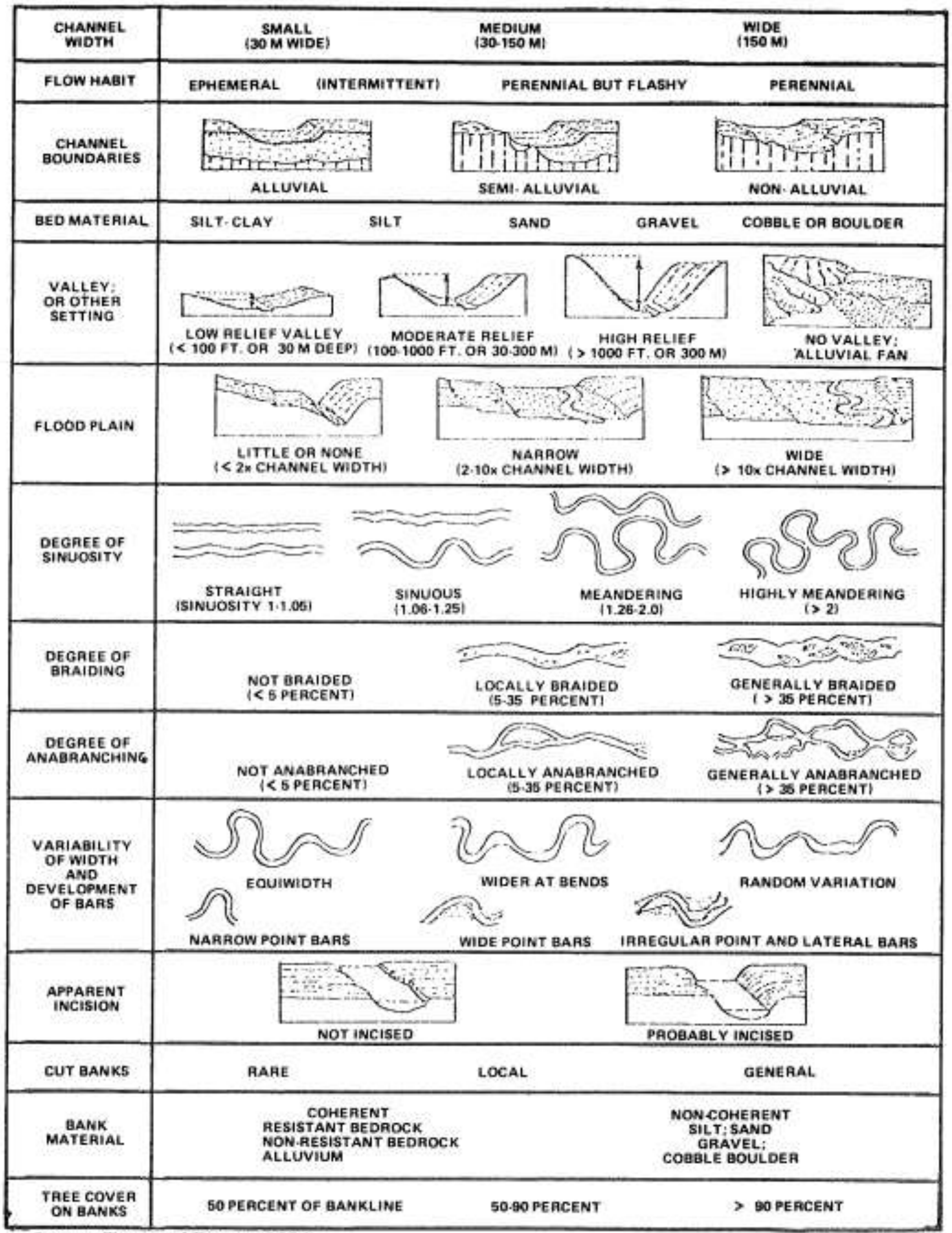
Keywords: Planform, Erosion and Deposition, channel and Non-channel Area, Lateral Shift, Discharge and Channel Energy

INTRODUCTION

The planform of a channel is the shape of streams seen in a panoramic view observed almost vertically from air at a glance. So, general appearance of layout plan of the channels is known as "plan-view or planform". Channels are basically creation of flowing water and response to its actions of erosion and deposition. Therefore, channels are product of water actions dominated either by degradation and aggradation especially in the plain. But erosion and deposition is again dependent upon several factors. Probably, the most important factor is water discharge and its velocity. Other important factors are geology of the area, slope, vegetative cover, land use and human footprints, sediment yield, intensity of weathering and denudation. Velocity is influenced by slope of flowing water, shape and size of the channel, structure and composition of rocks and overall volume of draining water. Hence, channels are carved out by erosional and depositional actions in which transportation plays very important role in shaping and laying-out channel.

The forms of river are, broadly, affected by three major factors namely, (a) discharge regime which is dependent upon climate and surface conditions, (b) gradient and relief of the area in general and water flow in particular, and (c) erodibility of river bed and sediment characteristics. Depending on these factors, several permutations and combinations of channels parameters have been presented in Figure 1, and it is very vividly explained by Trent and Brown (1984).

Figure 1: Stream Characteristics and Channel Classification



Source: Trent and Brown (1984)

From Figure 1, it is obvious that changes in channel parameters cause change in channel pattern and their appearance. Channel planform or pattern like sinuosity, meandering and braiding index change with change in inputs in the river system (Knighton, 1984). The input may be natural like hydrological or anthropogenic like human activities in the catchment. Human encroachments in the catchment lead to change in discharge and sediment yield. Rivers are occupying a geographical space since their evolution but their location of occupancy has never been the same in past and would never be the same what we observe today. Most of the rivers of the world have changed their courses at different times and under supportive conditions with different intensity and magnitude. Therefore, tracing their changing courses in historical past is considered to be one of the important parameters to understand their dynamics (Winterbottom, 2000).

When rivers are at spate with exceptionally high discharge, there is higher channel energy. Hence, many of the rivers have changed their courses during such situations. Channel avulsion and cut-offs are associated with floods in the Gangetic plain (Ray, 1953; Geddes, 1960; Das, 1968; Prasad, 2000; Jain and Sinha, 2004; Sinha, 2005; Jain et al., 2012). Flooding process is a natural phenomenon in the plain but its frequency, magnitude and intensity has increased due to human interferences in catchment. Significant increase in flooding has been witnessed from mid-20th century (Valdiya, 1985; Kale, 2005). It is also attributed to changing climate and rising temperature (NCVST, 2009; Bartlett, et al., 2010). The rise in temperature in the Himalayan zone is greater than rest of the world and the severity of the flood is expected to be more in coming years (NCVST, 2009).

Braiding process is associated with high sediment delivery accompanied with discharge. Low gradient, lateral expansion of flowing water, decrease in river carrying capacity is responsible for deposition of sediments in the river bed and braiding is resulted. Braiding is the result of characteristics of catchment area from where water and sediment are brought. Hence, geometry of the channel is altered by high discharge and sediment influx. Higher sediment yield is also associated with geological parameters, human activities and land use in the upper catchment. Changing land use can trigger acceleration of sediment delivery.

Braided rivers, usually adjust to varying river environmental conditions. Because of these reasons, braided rivers cannot maintain steady state equilibrium. It leads to continuous alteration in valley bottom where it is always on way to evolve through erosion, deposition and bed migration as well as bend formation. Higher sediment charged water and deposition of sediment causes aggradation and leading to widening of the course. So, further widening and progressively occupying valley space by river is resulted. The processes of valley widening of active channels are bound to migrate laterally by bank erosion or by avulsion.

Rivers are always dynamic because they are constantly on changing path and are affected by several factors. Bringing dynamism in the river system is very well be understood by changing volume of water and its velocity along with sediments carried. But apart from that other less understood aspects are migratory tendency of channel bed, changes in orientation of river, changing bends/meander (Trent and Brown, 1984) etc. There is strong relationship of water and sediment load of any stream with that of channel size, shape and sinuosity. Hence, channel geometry changes with change in its parameters. It has been investigated by several researchers (Leopold et al., 1964; Singh, 2003; Wohl et al., 2004; Han et al., 2019; Pelletier, 2021). Geometry of natural channels is dependent upon many factors like volume and velocity of discharged water and associated sediments, gradient, geological setup, soil types and properties (Dominguez et al., 2018). Brandt (2000) concluded, “slope-, discharge-, and sediment transported changes are changing in bed material, both grain size and the resulting bedforms, planform configuration, pools and riffles, but also response of tributaries to change in the main stream channel. Hence, changes in water and sediment input to the downstream reach may induce a change in planform configuration.”

Kosi has a long history of shifting its course through avulsions. The record of its shift is traced since 1736 when it was flowing to its known easternmost channel named Parman River (Singh, 1971; Das, 1968). There is a long recorded history of changes of Kosi channels. The channel shift studies have been conducted by many researchers (Gole and Chitale, 1966; Das, 1968; Singh, 1971; Wells and Dorr, 1987; Prasad, 2000; 2002; 2008). Devkota et al. (2009) found that average quantity of sediment at Chatara brought down by Kosi River is about 120 million cubic meters every year. Out of this, 90 percent (about 108 million cubic meters) is carried during high discharge days of monsoon period (Nayak, 1996;

ICIMOD, 2009). Very high variation with regard to discharge and sediment flux is observed from an uplifting hinterland of Kosi basin lying in the Himalayas (Sinha et al., 2008).

The then Prime Minister of the country, Jawahar Lal Nehru explained flood fury on 23rd August 1953 as "the Kosi River in Bihar, which has misbehaved so often in the past, has this year caused unprecedented floods and a considerable part of Bihar has been under water" (Ray, 1953). "A flood goes on and on for days and sometimes weeks and then it leaves a whole area plastered down in mud and stench" (Ray, 1953). In 1951, a joint committee of India and Nepal was constituted and its recommendations were accepted in 1953 by Central Water and Power Commission (CWPC). It is known as 1953 Kosi Project in which a barrage was proposed to be construct at Bhimnagar, 48 km downstream to Chatara. It would serve as control structure to divert water to canals for irrigation and marginally reduce river flow.

Construction of embankments on both sides of the river was also proposed. The embankments construction of Kosi was started in 1955 and it was completed by 1959. The barrage at Hanuman Nagar was completed by 1963. After embanking the river, overflow of water was restricted and was forced to flow within confined embankments. High charge of sediment coming from the upstream started getting deposited. It has resulted in the rise of the bed level (aggradation) in the embankment area (Sinha et al., 2008). Other major river in western part of Bihar plain is Gandak and it has also the same tendency of aggradation within the embankment area.

OBJECTIVES, DATA AND METHODS

Objectives

The main objectives of this study are to (i) trace planform changes of the river during 1975-86, (ii) explain the causes of changes, and (iii) suggest some remedial measures for better stability of the river to avoid regular flooding.

Data Source and Methods

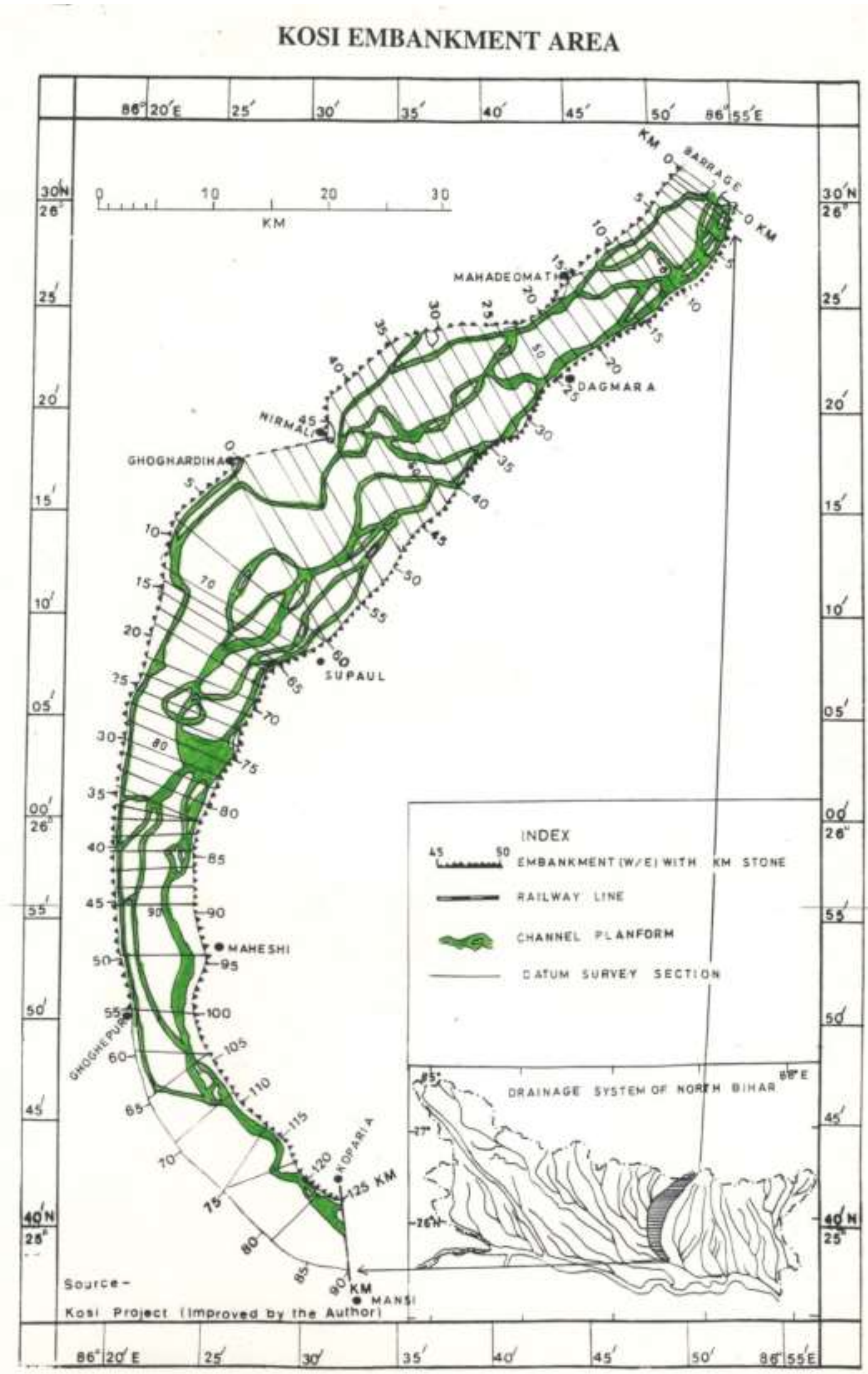
The data used in this paper is secondary in nature. Most of data are collected from Kosi Project Authority Office, Research and Investigation Division, Birpur, Bihar. They are related to channel planform of the Kosi Embankment area from Bhimnagar Barrage in the north to Mansi-Koparia Railway Bridge in the south. This stretch is 125 km along Eastern Embankment. The area is surveyed every year during December-January when discharge is the least in the river. There are 98 cross sections with pre-decided and fixed azimuth (Table 1) along which datum level survey is conducted. A total number of 32 cross sections are falling in the upstream to Bhimnagar Barrage. Therefore, there are only 66 cross sections under present study. During survey, planform of the channels of embankment area is also prepared by the Kosi Project authority. The researcher collected huge sized ammonia print map for 1975 to 1986 except 1985. They were reduced very precisely and brought to printable size used in this paper.

Within the embankment, areas falling within channel as well as area lying above channel at the time of survey have also been calculated by researcher to quantify changes in terms of percentage and ratio between the two. It has been done by dividing entire embankment areas into four distinct reaches. Addition of the same is giving a clear-cut picture of entire study area. Based on all this, channel planform changes have been studied and analysed. Average width of the reach, average channel and non-channel area, their respective percentages as well as ratio between channel and non-channel areas have been computed. Their standard deviations have also been calculated to analyse stability or variations in the reaches.

STUDY AREA

The area under present study is lying between two man-made embankments of the Kosi River – Eastern and Western starting from Bhimnagar Barrage axis in the north to Mansi-Kopari Railway Bridge in the south (Figure 2). Eastern Embankment is a continuous while the western is not so. In western part, embankment starts from barrage axis and runs for a distance of 46.8 km till Nirmali Railway Station. From there, a railway line/embankment runs for 8.5 km. From this point, embankment continues for 55 km more. After a distance of 110.3 km (46.8+8.5+55.00), river is not embanked from western side. Unembanked distance (projection of embankment) is 34 km to facilitate water of Balan, Kamla and Kareh rivers to meet Kosi. The study area is lying completely in the plain. Marginal narrow northwest corner of the embankment area falls in Nepal and rest of the area is in Bihar (India). It extends in northeast to southwest direction till about half of the length. After that it takes a southerly direction. In the last one-third length of the area, it starts taking easterly direction. Overall, it looks like a banana in shape.

Figure 2: Location of Study Area with Cross Sectional Width and Direction



Source: Prepared by author based on planform received (Prasad, 2008)

The study area occupies 1251 km^2 (area computed by author based on map received from Kosi Project Authority, Research and Investigation Division, Birpur, Bihar). This area extends from 25°43' north to 26°36' north latitudes and 86°20' east to 86°55'east longitudes. The entire area is similar in characteristics in terms of physiography. There are no variations in east west direction but difference in altitude may be seen in north-south direction. The average height near barrage in north is about 72 meter whereas in the southernmost part near Mansi-Koparia Railway Bridge, it only 34 meter. The difference is of 38 meter in a distance of 125 km, an average gradient of 30 centimetres/km. The gradient is higher in upper part in comparison to southern region. Due to non-differentials in the area, it cannot be divided distinctively in different categories, but on the basis of spacing between embankments as well as morphological behaviour of the river, study area is divided into four reaches.

Reaches of the Kosi River in Plain

On the basis of variations in morphological characteristics and spacing between embankments, it is divided into four reaches (Table 1). They are:

Table 1: Different Reaches and their Expansion Details

Reaches	Location along Eastern Embankment (in km)		Cross Section	Distance along Eastern Embankment (in km)		Area in km^2
Reach I	Bhimnagar	Dagmara	B. Axis-49	0.00	25.25	156.0
Reach II	Dagmara	Supaul	50-70	25.25	62.82	545.2
Reach III	Supaul	Maheshi	70-90	62.82	94.25	293.2
Reach IV	Maheshi	Koparia	90-98	94.25	125.00	256.6
Complete Area	Bhimnagar	Koparia	Barrage Axis-98	0.00	125.00	1251.0

Source: Prepared by author based on Kosi Project Authority information

The details of study area in terms of cross sectional alignment, their direction from eastern embankment by azimuth and spanning distances between embankments are given in Table 2. From Table 2 and Figure 2 it is very clear that spacing between embankments are bigger in central part of the area and at both ends – north and south – it is narrower. The summary of Table 2 is presented in Table 3. It is diagrammatically presented on graph paper, it looks like a man/women with big belly (Figure 3). The details of these reaches are given in results and discussion part.

Table 2: General Description of the Kosi Embankment Area

Sl No	CS No	Distance	Spacing	Azimuth	Sl No	CS No	Distance	Spacing	Azimuth
REACH I									
0	Axis	0.00	6.800	306°	9	41	11.25	7.235	328°
1	33	1.50	7.458	306°	10	42	12.75	7.011	321°
2	34	3.00	7.832	306°	11	43	14.25	7.680	321°
3	35	4,25	7.933	306°	12	44	16.00	6.275	321°
4	36	6.00	7.744	306°	13	45	17.25	6.705	321°
5	37	7.75	7.934	321°	14	46	19.00	6.210	321°
6	38	8.75	7.600	321°	15	47	20.75	5.608	321°
7	39	9.75	7.325	321°	16	48	23.50	5.505	321°
8	40	11.00	7.323	328°	17	49	24.00	5.950	321°
REACH II									
1	50	25.25	6.665	328°	12	61	44.75	15.535	328°
2	51	26.25	8.118	328°	13	62	46.50	15.495	328°
3	52	28.00	10.000	328°	14	63	48.00	12.733	328°
4	53	31.25	11.935	328°	15	64	51.75	14.840	328°
5	54	33.75	12.087	328°	16	65	53.75	16.539	328°
6	55	35.00	12.122	328°	17	66	55.80	17.071	328°
7	56	36.50	13.785	328°	18	67	58.00	18.540	328°
8	57	38.25	14.085	328°	19	68	59.50	18.100	328°
9	58	40.00	14.725	328°	20	69	60.00	17.634	300°
10	59	41.75	13.551	328°	21	70	61.25	16.080	300°
11	60	43.00	15.502	328°					
REACH III									
1	71	62.82	14.332	300°	11	81	78.50	9.279	292°
2	72	64.00	13.747	300°	12	82	81.25	9.307	292°
3	73	66.00	12.485	300°	13	83	81.25	9.110	292°
4	74	67.25	10.850	300°	14	84	81.25	8.400	280°

5	75	68.75	11.156	292°	15	85	82.00	8.560	270°
6	76	70.25	9.930	292°	16	86	82.85	8.400	270°
7	77	72.00	10.710	292°	17	87	84.25	7.972	270°
8	78	73.25	11.065	292°	18	88	86.25	7.620	270°
9	79	75.25	10.810	292°	19	89	88.00	7.490	270°
10	80	76.75	9.923	292°	20	90	89.50	7.450	270°
REACH IV									
1	91	94.25	8.853	270°	6	96	114.00	2.789	N.A.
2	92	99.00	6.060	270°	7	97	119.00	2.970	N.A.
3	93	104.25	7.310	270°	8	98	123.00	4.249	N.A.
4	94	104.25	2.105	N.A.	9	Bridge	125.00	5.000	N.A.
5	95	109.25	3.570	N.A.					
Sl = Serial; **CS** = Cross Section; **Spacing** = between embankments starting from east in km; **Azimuth** = degree from due north measured from eastern embankment,									

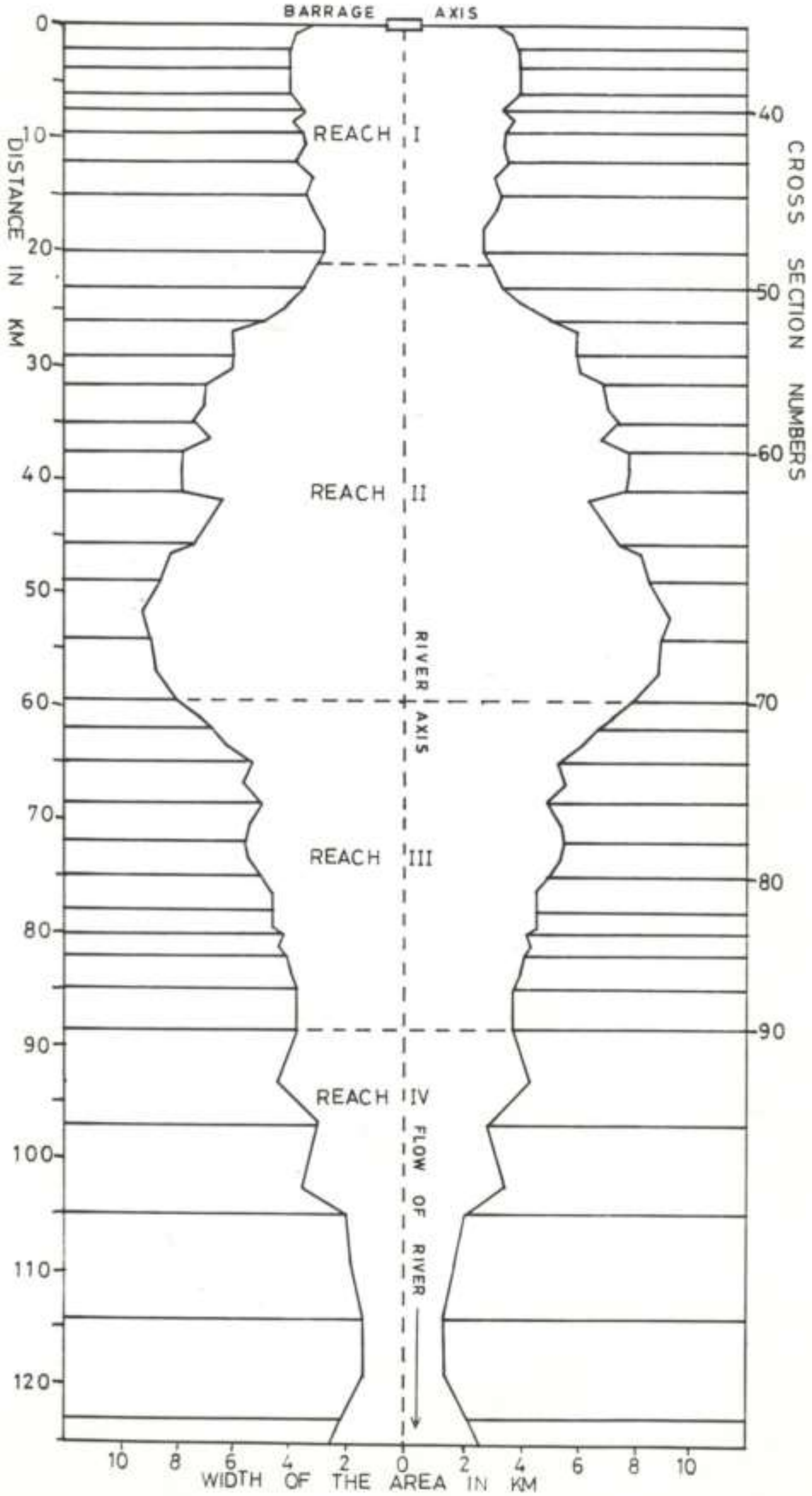
Source: Compiled by author based on Kosi Project Authority information

Table 3: Reach-wise Summary Statistics of Cross Sections

Detail	**Reach 1**	**Reach II**	**Reach III**	**Reach IV**	**Complete Study Area**
Longest Cross Section (Serial No)	37th	67th	71st	91st	67th
Length, Longest Cross Section (km)	7.937	18.540	14.332	8.853	18.540
Smallest Cross Section (Serial No)	48th	50th	90th	94th	94th
Length, Smallest Cross Section (km)	5.505	6.665	7.450	2.105	2.105
Mean Width (km)	7.00	14.05	9.93	4.77	9.863

Source: Computed by author based on Table 2

Figure 3: Diagrammatic Presentation of Kosi Embankment Area



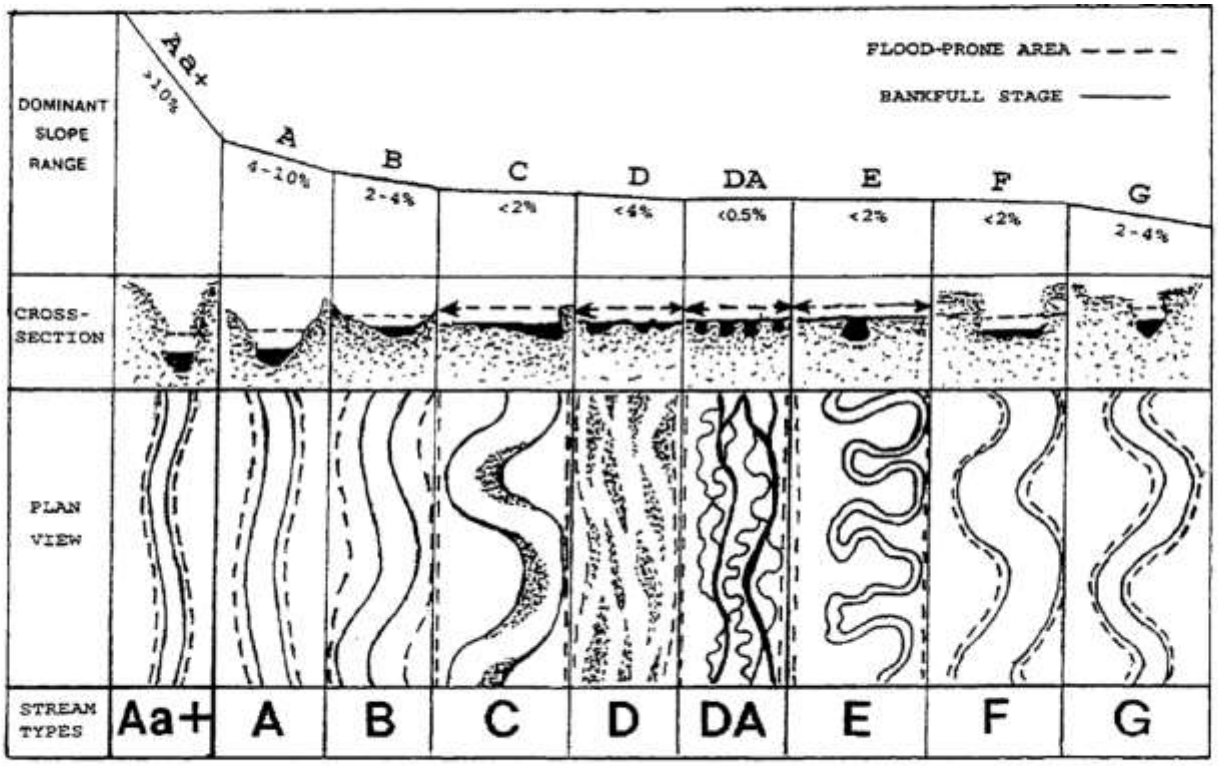
Source: Prepared by author based on Kosi Project Authority information

RESULTS AND DISCUSSIONS

Relationship among Slope, Sediment and Channel Planform

It is a well-known fact that there is strong correlation between slope and erosion. Higher slope causes water to flow very rapidly. Rapidly flowing water has greater energy to perform its work of erosion, transportation and deposition. Therefore, with higher slope, water is rapidly flowing and deep cutting of the river bed is prominently done, and hence has narrow channel. When slope is getting reduced in the downstream, velocity comes down, water spreads on wider surface, and channel becomes broader. In such situation, deposition is resulted and rivers start running with meanders. The morphology of meander is also unique as lateral erosion is observed on its outer bend and deposition on the inner bend. Cut-offs and bars develop within meanders. Later rivers are observed to form braiding pattern and it happens due to higher amount of sediment carried with water. Several channels are meeting and bifurcating time and again. Numerous channels with multiple bars and islands are seen, if one crosses from one bank of the river to another. A very nice sequential development of channel planform is explained by Rosgen (1994) which is presented in Figure 4. From this figure, it is quite obvious that change in slope, channel energy, transported sediment etc. play significant role in planform development.

Figure 4: Development of Channel Planform with Changing Slope and Sediment Load



Source: Rosgen (1994)

Year-wise Survey: 1975-86

Datum level survey is conducted every year during December-January when flow of the river is minimum and river traversing is easier. This is conducted along a pre-defined azimuth from eastern embankment (details in Table 2). The spacing between two surveyed points is normally 600 meter but when channel approaches on cross section, surveyed point are brought to 300 meter, 150 meter, 50 meter or even 5 meter also to incorporate bed level of the river. Otherwise, river/channel may pass through space of 600 meter and bed would not be recorded in general spaced survey. Hence, standard datum level measurement spacing is reduced to include every changes occurring across the section. During this survey recording of existing channels on the day of survey is noted down and planform of channels for entire embankment area is prepared for use of Research and Investigation Division of Kosi Project Authority. The datum level survey data is also provided to Central Water and Power Research Station, Khadakwasla near Pune where Kosi River is simulated for research studies. Hence, planform maps of channels prepared by Kosi Project Authority were and are utilized in this study. Total 11 years planform were collected from 1975 to 1986 except 1985 because of its non-availability. Reach-wise planforms for all years are prepared and have been shown for visual observation in changes over years.

Planforms of Reach I

Total area of Reach I is 156 km^2, the smallest reach in area. Its yearly Planforms are presented in Figure 5. It is quite evident that entire area is witnessing change in the channels as per plan shown here. Channels are shifting their positions year after year. Migratory behaviour of the channels is observed but one thing is very clear that main channel is observed along eastern embankment over entire study years. Other parts are showing more changes. Based on yearly planform, area above channel and area under channel have been calculated and their percentages and ratio is presented in Table 4.

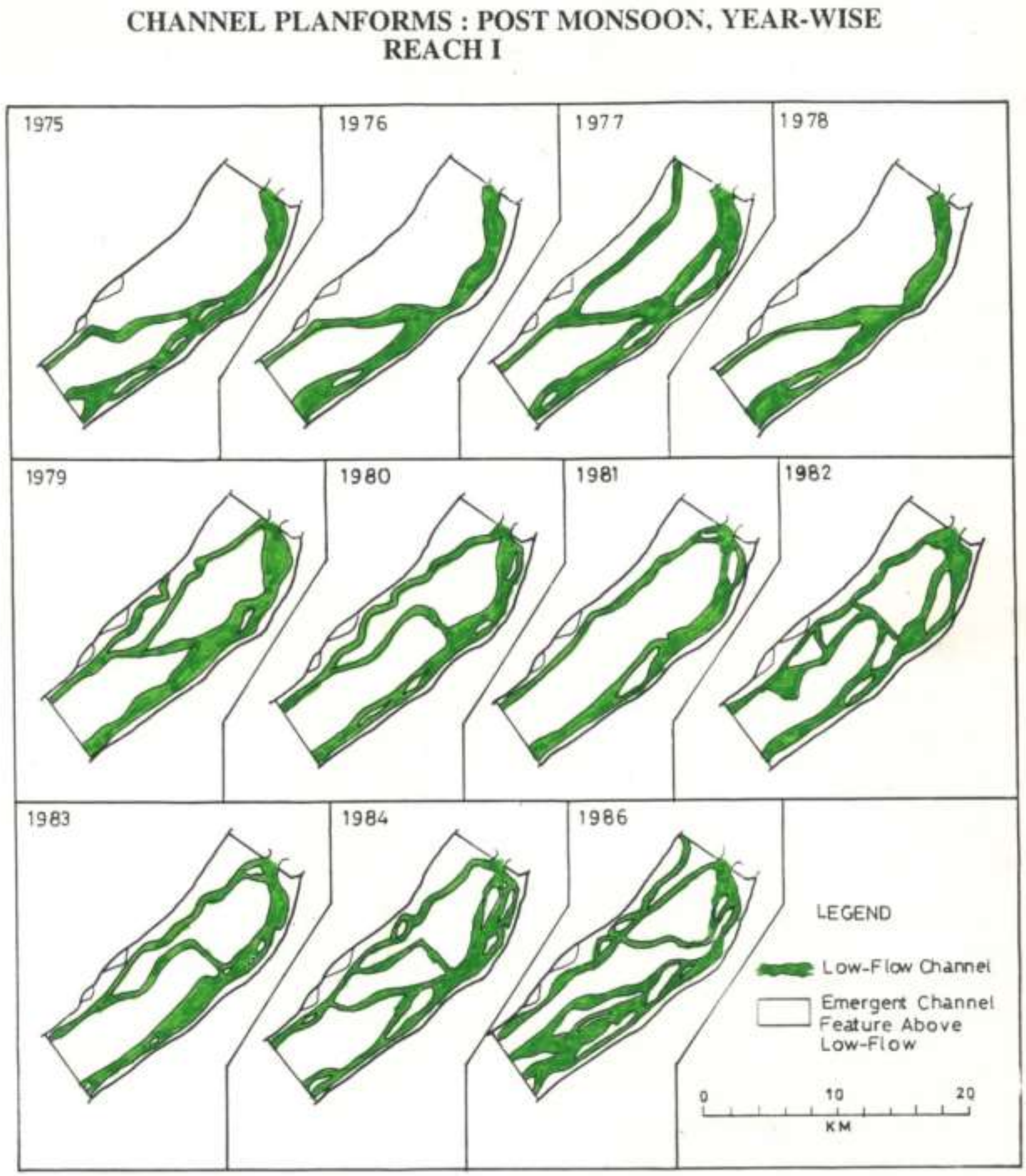
Table 4: Percentage and Ratio Channel and Non-Channel Area: Reach I

Year	Channel Area (km^2)	% to Total (Channel)	Non-Channel Area (km^2)	% to Total (Non-Channel)	Ratio (Chanel: Non-Channel
1975	25.9	16.6	130.1	83.4	5.02
1976	35.7	22.88	120.3	77.12	3.37
1977	33.3	21.35	122.7	78.65	3.66
1978	77.1	49.42	78.9	50.58	1.02
1979	37.3	23.91	118.7	76.09	3.18
1980	36.2	23.21	119.8	76.79	3.31
1981	28.1	18.01	127.9	81.99	4.55
1982	36.5	23.4	119.5	76.6	3.27
1983	35.8	22.95	120.2	77.05	3.36
1984	35.6	22.82	120.4	77.18	3.38
1986	46.4	29.74	109.6	70.26	2.36
Mean	38.9	24.94	117.1	75.06	3.32
St. Dev.	13.71	8.79	13.71	8.79	1.04

Source: Computed by author based on yearly planforms

From table 4, it is obvious that about one-fourth area of Reach I is occupied by channel and three-fourth is non-channel area (area above channel at the time of survey) during December-January. The variation is very large, which is 16.60 percent in 1975 to 49.62 percent in 1978. For two years, channel area percentage is less than 20 (1975 and 1981) and in only one year it is more than 30 percent (1978). The percentage of channel area and non-channel area is sufficient enough to express the changing character, but still ratio between the two has been computed and given in the last column of Table 4. The mean channel area, non-channel area as well as their percentages are also computed and given in the last two rows of the table.

Figure 5: Year-wise Channel Planforms: Reach I

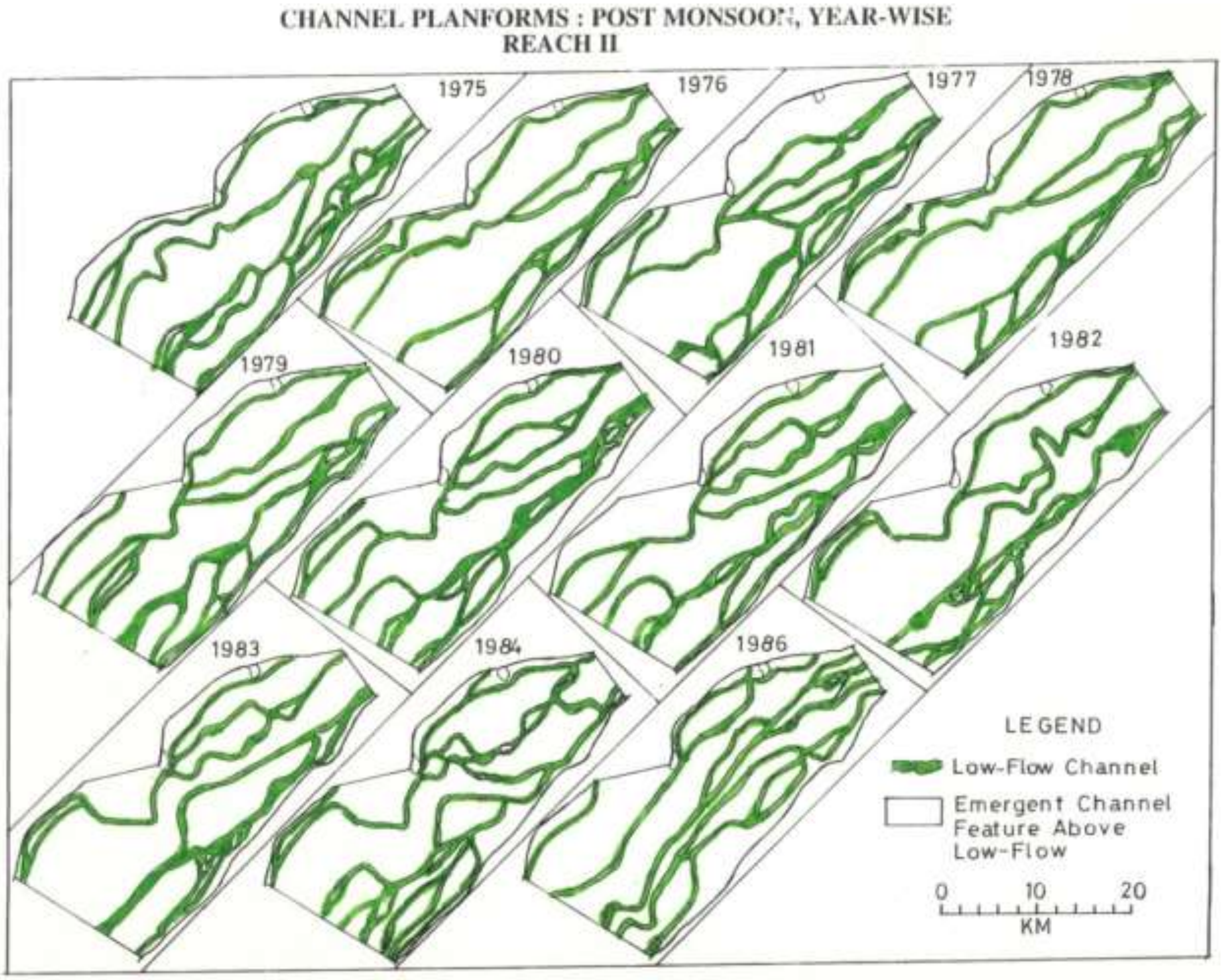


Source: Prepared by author based on planform received from Kosi Project Authority

Planforms of Reach II

Total area of Reach II is 545.2 km^2, the largest reach in area among four reaches. Planforms of Reach II is shown in Figure 6 and it describes very clearly the changing pattern of channels from 1975 to 1986. It is approximately 3.5 times bigger than Reach I. In this Reach, two embankments are very far. It is the widest reach measured along cross section number 67 and its length is 18.54 km. It is also bigger in north-south expansion. That is why; area of this reach is largest among four reaches under study. Channels are well distributed over entire area falling in Reach II. Multiple rivers across sections and braiding are very well observed. Still in this reach as well, like in the Reach I, main river channel is flowing along eastern embankment. Big bars are resulted due to lean flow during December-January. In monsoon days, when Kosi is at spate, embankments area is almost full of flood water. At this point of time, ocean like situation arises (except some trees/ some houses, nothing is visible except water). Other side of the embankment is also not visible (Table 2) as it is more than 18.5 km away. Therefore, during flood time, the Kosi River becomes a single thread flowing water body. Due to changes in the channels and deposition, bars are made and removed because of channel migration. The percentages of channel and non-channel area as well as ratio between them are calculated and are shown in Table 5.

Figure 6: Year-wise Channel Planforms: Reach II



Source: Prepared by author based on planform received from Kosi Project Authority

Table 5: Percentage and Ratio Channel and Non-Channel Area: Reach II

Year	Channel Area (km^2)	% to Total (Channel)	Non-Channel Area (km^2)	% to Total (Non-Channel)	Ratio (Chanel: Non-Channel
1975	94.5	17.33	450.7	82.67	4.77
1976	86	15.77	459.2	84.23	5.34
1977	70.3	12.89	474.9	87.11	6.76
1978	75	13.76	470.2	86.24	6.27
1979	83.3	12.28	461.9	84.72	5.55
1980	84.1	15.43	461.1	84.57	5.84
1981	87.2	15.99	458	84.01	5.25
1982	73.9	13.55	471	86.45	6.38
1983	100	18.34	445.2	81.66	4.45
1984	78.2	14.34	467	85.66	5.97
1986	74.8	13.72	470.4	86.28	6.29
Mean	82.48	14.85	462.69	84.87	5.72
St. Dev.	9.19	1.89	9.16	1.69	0.72

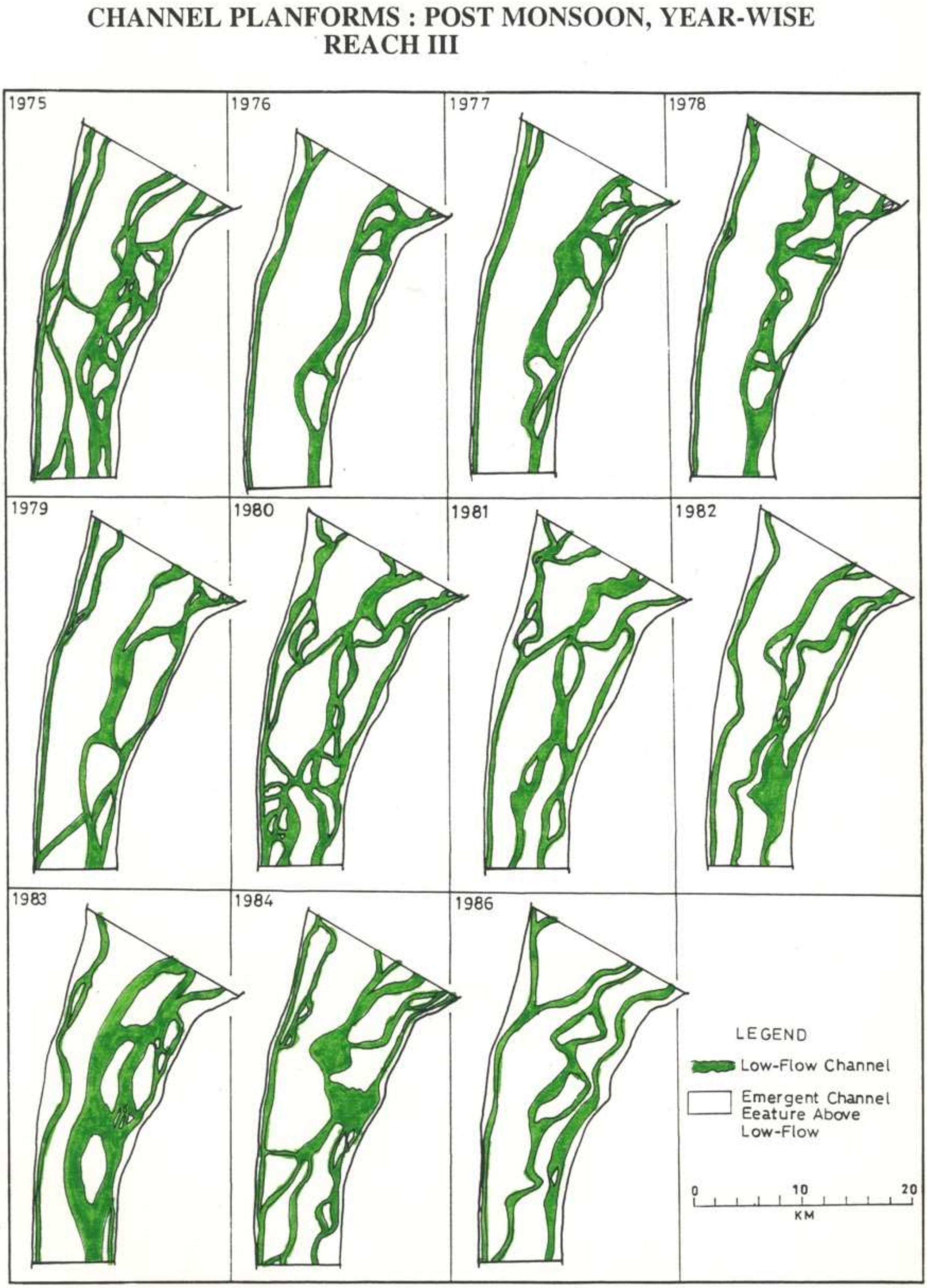
Source: Computed by author based on yearly planforms

Table 5 reveals that less than 15 percent area is under the channel to reach's total area at the time of survey in December-January. On account of larger area in comparison to Reach I, the channel area is not big in terms of percentage. Channel area in Reach II varies from the lowest, 12.28 percent (1979) to the highest, 18.34 percent (1983). So, departure is confined to a range of only about six percent during all years under study. Among all reaches, Reach II has lowest variations in terms of channel area. Again the standard deviation of the ratio between channel and non-channel area is computed and found that Reach II has to lowest variation as well.

Planforms of Reach III

Reach III occupies an area of 293.2 km^2, second largest reach in terms of area. Yearly planforms of this reach is shown in Figure 7. This reach is lying in almost in north-south direction. Western boundary of this reach is the westernmost demarcation of the basin as well. Large part of this reach is criss-crossed by several channels on over different years. In all years, channels along both embankments are seen. During different years, channels are appearing at different parts of the reach in one year and the same is eliminated in other years. It is signifying great changes in the channel shifting and planform variations. The percentages of channel and non-channel area as well as ratio between them are calculated and are shown in Table 6.

Figure 7: Year-wise Channel Planforms: Reach III



Source: Prepared by author based on planform received from Kosi Project Authority

Table 6: Percentage and Ratio Channel and Non-Channel Area: Reach III

Year	Channel Area (km²)	% to Total (Channel)	Non-Channel Area (km²)	% to Total (Non-Channel)	Ratio (Chanel: Non-Channel
1975	70.3	23.98	222.9	76.02	3.17
1976	51.7	17.63	241.5	82.37	4.67
1977	54.6	18.62	238.6	81.38	4.37
1978	58.0	19.78	235.2	80.22	4.06
1979	59.4	20.26	233.8	79.74	3.94
1980	93.0	31.72	200.2	68.28	2.15
1981	64.5	22.00	228.7	78.00	3.55
1982	62.2	21.21	231.0	78.79	3.71
1983	105.0	35.81	188.2	64.19	1.79
1984	52.4	17.87	240.4	82.13	4.60
1986	52.5	17.91	240.7	82.09	4.59
Mean	65.78	22.44	227.38	77.56	3.69
St. Dev.	17.59	6.00	17.56	6.00	0.98

Source: Computed by author based on yearly planforms

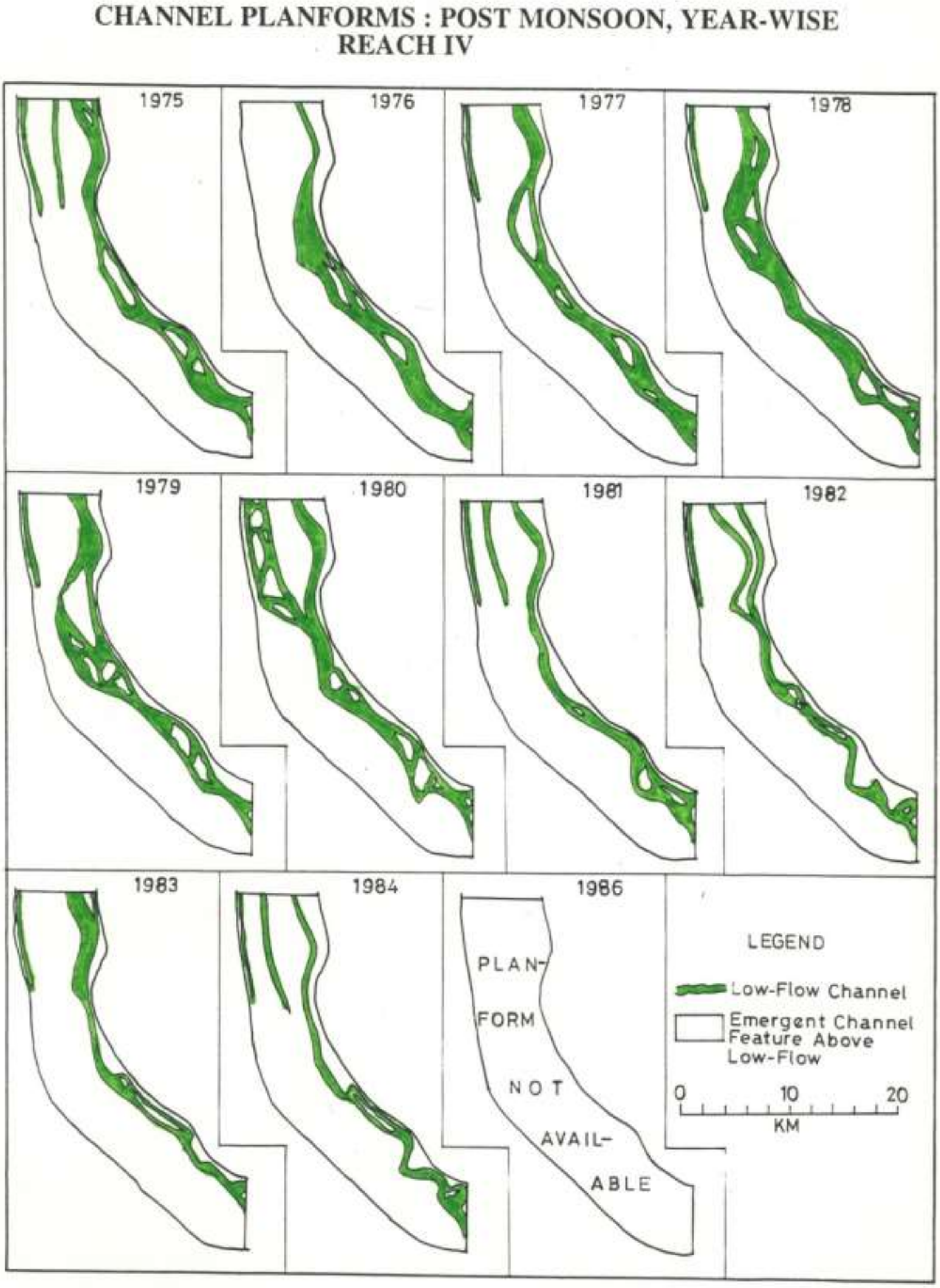
Table 6 shows that less than one-fourth area of Reach III is falling under channel and more than three-fourth is above channel. Maximum area under channel category is during 1983. In this year channel area is more than one-third (35. 81 percent) under channel. The other year when it is more than 30 percent is only during 1980 (31.72 percent). During rest of the years under study, it is less than 24 percent. The lowest channel area is recorded during 1976 (17.63 percent). From last two rows, mean and standard deviation of all parameters can be seen. In the same way, last column shows mean and standard deviation of the ratio between channel and non-channel area during different years under study.

Planforms of Reach IV

Reach IV covers an area of 256.6 km^2, and it is the second lowest in areal coverage. Yearly planforms of Reach IV is given in Figure 8. It is the lowermost reach among fours. It is relatively higher degree of stability it has lowest variations among four reaches. It is the narrowest reach with average width of 4.77 km. The direction of the flow of the river is taking turn from northwest direction to southeast. In almost all of the years under study, the main Kosi channel is confined near the eastern embankment with greater stable channel. Variations in the channel change are less in comparison to all other reaches.

Table 7 shows less than one-fifth area of the channel under channel category and rest of the area is above channel/ non-channel area. The maximum recorded channel percentage to the total area is 24.24 percent in 1978 while the lowest is 11.34 percent during 1984. Three years are recording channel area more than 20 percent – other two years are 1979 and 1980. In terms of variations for the ration between channel and non-channel area, this reach records the highest with 1.62, while with other reaches, it is near one. The details of the conclusive figures of the reach for mean and standard deviation can be seen from last two rows of the table.

Figure 8: Year-wise Channel Planforms: Reach IV



Source: Prepared by author based on planform received from Kosi Project Authority

Table 7: Percentage and Ratio Channel and Non-Channel Area: Reach IV

Year	Channel Area (km²)	% to Total (Channel)	Non-Channel Area (km²)	% to Total (Non-Channel)	Ratio (Chanel: Non-Channel
1975	44.4	17.3	212.2	82.7	4.78
1976	49.1	19.13	207.5	80.87	4.23
1977	47	18.32	209.6	81.68	4.46
1978	62.2	24.24	194.4	75.76	3.13
1979	57	22.21	199.6	77.79	3.5
1980	51.5	20.07	205.1	79.93	3.98
1981	33.6	13.09	223	86.91	6.64
1982	33.5	13.06	223.1	86.94	6.66
1983	30.7	11.96	225.9	88.07	7.36
1984	29.1	11.34	227.5	88.66	7.82
1986	44.8	17.46	211.8	82.54	4.73
Mean	43.90	17.11	212.70	82.90	5.21
St. Dev.	11.00	4.29	11.00	4.29	1.62

Source: Computed by author based on yearly planforms

Analysis of Planforms: Entire Area under Study

The entire area under study is occupying 1251 km^2 within two embankments of the Kosi River. The mean channel area for 11 years of study is 231 km^2 which is little less than 18.5 percent of the total area. Area under channel is varying from 15.61 percent (1984) to 21.77 percent (1978). The departure between these two is little more than six percent. In other words, it is around one-fifth area is under channel. In the same way, ratio between channel and non-channel area has the similar variation. Larger channel area is represented during 1978 as the ratio is lowest (non-channel area 3.59 times than channel area). Smallest area is also recorded during 1984. During this year, non-channel area is 5.41 times than channel area. The standard deviation of the channel area is higher in comparison to individual reach areas standard deviations. The reason is quite clear that reaches are divided on the basis of their widths. Therefore, within the reach, widths have lesser variations, and so are with standard deviations. When entire area is taken into account, variation is greater on account of larger departures in terms of the width of study area.

Table 8: Percentage and Ratio Channel and Non-Channel Area: Complete Study Area

Year	Channel Area (km²)	% of Total (Channel)	Non-Channel Area (km²)	% to Total (Non-Channel)	Ratio (Chanel: Non-Channel
1975	235.1	18,79	1015.9	81.21	4.32
1976	222.5	17.79	1028.5	82.21	4.62
1977	205.2	16.4	1045.8	83.6	5.1
1978	272.3	21.77	978.7	78.23	3.59
1979	237	18.94	1024	81.06	4.28
1980	264.8	21.17	986.2	78.83	3.72
1981	213.4	17.06	1037.6	82.94	4.86
1982	206.1	16.47	1044.9	93.53	5.07
1983	271.5	21.7	979.5	78.3	3.61
1984	195.3	15.61	1055.7	84.39	5.41
1986	218.5	17.47	1032.5	82.53	4.73
Mean	231.06	18.44	1020.85	82.44	4.48
St. Dev.	27.64	2.33	27.59	4.24	0.63

Source: Computed by author based on yearly planforms

Summing Up of Analysis

Table 9 presents a summary of the analysis discussed above. Important statistics about the area reveals very clearly pertaining to its characteristics like reach wise area, longest and smallest cross sections with their positions. The same is compiled/ derived for the entire area under study. The average channel and non-channel area recorded during study period is also reflected in the table. Their percentages have also been computed for their respective total area. In the last column of the table also represents the ratio between channel and non-channel areas. It simply states that non-channel area is how much larger in comparison to channel area.

Table 9: Conclusive Statistics of Kosi Embankment area

Details	Channel Area (km^2)	% to Total (Channel)	Non-Channel Area (km^2)	% to Total (Non-Channel)	Ratio (Chanel: Non-Channel
Reach I: Area 156.0 km^2, Longest Cross Section No 37th 7.934 km, Smallest 48th 5.505km					
Reach I, Mean	38.9	24.94	117.1	75.06	3.32
Reach I, SD	13.71	8.79	13.71	8.79	1.04
Reach II: Area 545.2 km^2, Longest Cross Section No 67th 18.540 km, Smallest 50th 6.665 km					
Reach II, Mean	82.48	14.85	462.69	84.87	5.72
Reach II, SD	9.19	1.89	9.16	1.69	0.72
Reach III: Area 293.2 km^2, Longest Cross Section No 71st 14.332 km, Smallest 90th 7.450 km					
Reach III, Mean	65.78	22.44	227.38	77.56	3.69
Reach III, SD	17.59	6	17.56	6	0.98
Reach IV: Area 256.6 km^2, Longest Cross Section No 91st 8.853 km, Smallest 96th 2.789 km					
Reach IV, Mean	43.9	17.11	212.7	82.9	5.21
Reach IV, SD	11	4.29	11	4.29	1.62
All Reaches: Area 1251.0 km^2, Longest Cross Section No 67th 18.540 km, Smallest 48th 2.789 km					
All Area, Mean	231.06	18.44	1020.85	82.44	4.48
All Area, SD	27.64	2.33	27.59	4.24	0.63

Source: Computed by author based on yearly planforms and their analysis

CONCLUSIONS

Channel planform is a pattern or "plan-view" of channels seen in a panoramic view. The way, they are developed, are function of numerous factors. Probably, most important among them are discharge. It is discharge which is dynamic in character and has greater variation over time and space. Discharge determines erosive power of the river, but erosive power is also determined other factors as well. They are structure and composition of rocks, slope, nature and amount of rainfall (climate), vegetative cover, human footprint and land use etc. They are decision makers in generating sediment load carried by running water. Channel planforms in plain is the product of discharge and associated sediment load. When slope becomes lower in the plain, carrying capacity of flowing water is reduced. Hence, sediments are deposited in the river bed. Numerous bars and channels appear and they give a plan-view of the area.

The Kosi River brings excessively charged sediments from its upper Himalayan catchment. Since, the Himalaya is a new fold mountain with weak geology, fragile rocks and ecosystem. With changes in land use on the Himalayan slope is causing generation of enormous sediments. This area is seismically active, regular earthquakes, landslides produces loose and shattered material. Torrential rain and high snowmelt during summer produces more water to flow. The Kosi River has been embanked and a narrow constricted area is provided to discharge huge sediment loaded water. Large amount of sediment is deposited and causing channel layout changes with channel migration, bar formation, meandering and braiding in the area.

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