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FLOODPLAIN MAPPING IN A PART OF YAMUNA RIVER

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ABSTRACT

A flood is markedly high stage or flow in a river. A flood may also inundate adjoining land. This inundated area is named 'floodplain' of a river. Floodplain is also flat land between valley walls. Floodplain is land inundated by a flood of given frequency. A river creates sculptural and constructional landscape in a basin. In a floodplain river creates landscape between valley walls. Floodplain deposits or alluvial deposits, natural levees, oxbow lakes, channel fillings, clay plugs, sand plugs, sand bars, backswamps, backswamp deposits, channel scour routes, alluvial cones, deltaic deposits occur in a floodplain. In this study, floodplain deposits are mapped. The study area is the Yamuna basin between Gangoh and New Delhi. Data are satellite FCC paper prints and SOI topographic maps. The deposits are oxbow lakes, old or filled channels and sand bars. River channels, tributaries are mapped. Satellite data are georeferenced digitally. Maps are digitized and output using ILWIS Window version. River migration is depicted graphically. Bend statistics are computed from satellite data and median values are found.

CHAPTER 1 INTRODUCTION

Flow in river changes each day and each year. A flood in a river is caused due several reasons, e.g., cloud burst, synchronization of a flood in the main channel and tributaries. Meteorological factors causing floods are rain, snowmelt and both. A partial meteorological factor is surge due to storms. Other factors are earthquakes, landslides and dam breaks. Flood intensifying factors, namely, catchment shapes, storm directions, also play an important role. There are many measures adopted for flood control. The measures are both structural and non structural. Structural measures include embankment construction. Non structural measures include flood warning, flood plain zoning, restriction to human settlement in the flood prone areas (Annonymus 1993). In past, sculptural aspects of geomorphology are studied more than constructional aspects using available topographic maps. Subsequently, several studies are completed on floodplains and deltas using aerial photographs and detailed topographic maps (Thornbury 1986).

Floodplain deposits

There are many classifications of floodplain deposits. Floodplain deposits are formed by both vertical and lateral accretion. Vertical accretion is normally smaller than lateral accretion. Colluvium is formed from a slope wash and is mixed with a talus. Colluvium is a flood plain deposit.

Bars are deposits of gravel and sand. A Channel bar is formed in a river course. Point bars are formed on a convex side of a river meander. They grow outwards into meanders. Point bars are made of alternate arcuate ridges and sloughs or swales. Sloughs are plugged and filled with finer particles. Delta bars are formed at tributary junctions.

Natural levees are low alluvial ridges parallel to a river course. They are highest near river channels and gradually slope away from it. Natural levees may be of many kilometres in width. Natural levees of older rivers are normally fragmented. Levees are formed by silty soil and possess good drainage characteristics. They are suitable for agriculture. They are seen in lighter tone on remotely sensed data.

Floodplain scour routes are shallow river courses used by flood water. They are either abandoned channels or new channels in process of formation. Meander scars are old meanders. Meander cutoffs occur by both chute and neck cutoff processes. A chute cutoff is formed by cutting point bar across swale. Flow continues to occur through both channels for several years. A neck cutoff occurs in an ultimate stage of meander loop development. A neck cutoff causes both shortening of a river course and increase in gradient. The previous course is abandoned to form oxbow lake. Oxbow lake is filled by finer particles to form a clay plug. Both clay plugs and sand plugs are called channel fills.

Areas of backswamp deposits are extensive. Both silt and clay form backswamp deposits at the back of natural levees. They are formed due to flooding. They are characterized by drainage network of an older river course. The network may get obscured due to repeated flooding.

Crossings are straight reaches in channels where meander bends change curvature. Pools are deeper reaches in channels with triangular cross sections. They occur in river bends. Cross section at bends is triangular with a vertex close to an outer side of the bend. Cross section of crossings is rectangular. At higher discharges both scouring of bends and aggradation of crossings occurs. At low discharges, converse occurs. Both erosion and deposition take place at bends in meanders. Erosion occurs at an outer side and in the bed at bends. Deposition occurs at an inner side of bends.

River morphology

River morphology is study of river structure and form including channel configuration or plan form, channel geometry or cross section, bed form and profile. Morphology of a river is effected by discharge, velocity, sediment load and its characteristics. Rivers are classified as young, mature and old.

Young rivers are mountain streams with steep slopes and 'V' shaped valleys. Mature rivers possess flat slopes. In mature rivers valley side cutting occurs. Old rivers have very wide valleys. Oxbow lakes are characteristic floodplain deposits in old rivers.

Sinuous rivers are mainly classified as sinuous canaliform, sinuous point bar and sinuous braiding. A sinuous canaliform river exhibits narrow crescent shaped arc, narrow channel widths, moderate to high sinuosity and vegetated or clay banks. Channel bottoms consist of silt or sand. Less often bottom is made of gravels. In sinuous point bar rivers, bare point bars are formed along a river course. When bed is of gravel, an irregular channel pattern is originated. Braiding in rivers may or may not be conspicuous. When braiding occurs in only 5 to 35% of channel length, braiding is local. When braiding occurs for more than 35% channel length, it is called general. Anabranching occurs in all sinuous rivers. It is caused by bank overflow and ice jams. Anabranched channels possess well-defined banks. On an increase in sediment load and increase in slopes, non sinuous braiding rivers are formed. In these rivers, sand bars may not be connected with river banks.

There is no single theory that convincingly describes formation of a river meander. Essential to meander formation is that deposition occurs at an inner side of meander bends and in equal amount erosion occurs at an outer side of meander bends. In this manner crooked shape is developed. Meander further develops until a cutoff occurs. River length does not change since both developments of new meanders and cutoffs of meanders occurs together at different reaches (Petersen 1986).

Channel patterns are studied in several ways, e.g. through graphical representations, bend statistics. In graphical representation, a channel pattern is studied through graphical, photographic and diagrammatical means. Sequential graphs are used in interpretation of channel pattern changes over time. Meander loop dimensions are measures of a channel pattern. Several loop dimensions are widths, radius, amplitudes, arc angles and wave lengths. A standard practice in measurements is not followed. A study shows that a ratio of meander amplitude to a loop width is large (Lewin 1986). Measurements are taken for the largest meander loop in a river. Loop width is distance between point of inflection within a meander loop. A radius is computed by fitting an arc to the meander loop. Arc between points of inflection at the centre is called an arc angle. Wave length is straight distance between start of a loop, simple or compound and end of adjacent loop, simple or compound.

Other measure of channel pattern is sinuosity. Sinuosity is a ratio of distance along channel (thalweg distance) to air line distance between similar direction change points in a channel. Air line distance is a distance along valley.

In channels both translation and expansion occur. In a channel with confined valleys only translation may occur. There may be more change occurring near straight channels. Channel pattern changes are rapid geomorphic process. Channel pattern changes are influenced by external factors namely climatic changes, changes in sediment load, upstream vegetation, stream slopes, channel protection or occur as natural processes. A channel possesses a static pattern or changing pattern. Shifting rivers may be in equilibrium (Lewin 1986).

Bank erosion is directly proportional to catchment area in meandering rivers. Bank erosion is measured by dividing central line of recent channels into equal divisions. For each division, distance between banks is measured to know width of bank erosion. Median value is the rate of bank erosion. It is expressed in meter/year or river width/year.

Above description is for meandering rivers. Morphology of rivers is studied by geomorphologists, engineers and environmental scientists. Morphology has also been a subject for river's physical modelling. In remote sensing and GIS technologies, new data sources and tools are available. These techniques are increasingly being used. Remote sensing and GIS are used here to study river morphology and migration for a reach in Yamuna river.

CHAPTER 2 LITERATURE SURVEY

Shah and others (1996) have mapped wet land of Uttar Pradesh, India. Maps of both man made and natural wetlands are prepared. Man made wetlands are reservoirs, tanks, ash ponds. Natural wetland includes lake/pond, waterlogged (seasonally), oxbow lakes, marsh/ swamp. A minimum mapping unit is 56.25 ha. Many features possess dimensions smaller than 56.25 ha. Rivers are also shown on maps. Wetland areal extent before monsoon and after monsoon, geographic location, nearest villages are given for districts and Tahsils. Wetland put to agriculture is not included. Mapping is completed using both IRS LISS I FCC of year 1991 and 1992 at scale of 1:250000.

Middle Ganga flood plain is mapped using satellite data and aerial photographs. Area lies in state of Bihar. Tributaries to Ganga in the area are Burhi Gandak, Baghmati, Kamala and Kanera. Aerial photographs are at scale of 1:60000. Flood plain features, e.g., channel bars, point bars, meander scrolls, oxbow lakes, backswamps, natural levees etc. are mapped. A limited field check is completed. Filled up oxbow lakes, channel breaches are field checked in Burhi Gandak river flood plain. There lies underground ridge in the area now overlaid by alluvial deposits. This has been proved by geophysical survey. Data are of January and May. (Philip 1994).

Middle Ganga plain is studied for channel form using sequential data in form of topographic maps, aerial photographs and visual and digital data from a satellite platform. Sequential data represent a period of 50 years. Flood plain features, e.g., oxbow lakes, palaeo channels, sand bars and natural levees etc., are delineated. Aerial photographs are used at scale of 1:60000. All interpreted maps are brought to scale of 1:250000. By joining oxbow lakes and abandoned channels, palaeo courses of both Burhi Gandak and Ganga are constructed. A palaeo channel of Baghmati river confluencing of Burhi Gandak is observed on satellite data. It is interpreted that once Burhi Gandak carried much greater discharge than present value. Width of past palaeo courses has been wider than the present course. Lithologs of wells are collected. Interpretation of lithologs shows presence of natural levees and backswamps of the Ganga river. At natural levee depth of clay is only 0.6 metres. Elsewhere, depth varies from 10 to 13 metres. Ganga is shifted southwards by 0.5 to 30 km. Burhi Gandak has migrated by a distance of 30 km southwards (Philip and others, 1989)

Vinod Kumar and others (1994) have mapped flood plain of Hooghly, West Bengal, India. Several flood plain features, namely deltaic plains, oxbow lakes, swamps, Mangroves, creeks, meander neck cutoffs, non flood plain features, namely upland, valley fills, deltaic fans, are mapped. Area lies between Farakka Barrage and confluence of Hooghly with Roopnarayana. There has been migration of the river westwards. Migration is restricted by upland in the west. Lateritic upland is of the Pleistocene era. They have NNE-SSE trend. Valley fills are formed by erosion of upland. Deltaic plains are divided into upper, middle and lower plains. They are formed in respectively early to middle Holocene, middle Holocene and late Holocene to recent geological eras. Meander cutoffs are observed in middle deltaic plains. Width of the river is more in lower plain. Satellite data are of post monsoon dates of year 1986 and 1991. Visual interpretation technique is employed. Topographic maps are of 1971.

Jain and Ahmad (1993) have mapped the Ganga course between Allahabad and Buxar. Satellite data of two dates are used.

Agarwal and Mishra (1987) have studied channel migration in Ghaghara. Ghaghara is a left bank tributary of Ganga. Data are topographic maps and satellite data. Visual interpretation technique is used. No geometric correction is done in the data. Two reference lines are established using set of control points. Channel north bank distance from the reference lines is measured at 0.5 kilometres least count for both topographic map and satellite data. A maximum rate of the shift is four hundred m/year in east-west direction.

CHAPTER 3 STUDY AREA

Indian rivers are divided into three types based on their catchment area. The division is made as those with catchment area above 20000 sq. km, between 20000 and twenty hundred and below twenty hundred. They are respectively named major, medium and minor rivers. There are 14 major, 44 medium and several minor rivers. Other than these there are rivers that ultimately disappear in a desert. Minor rivers are rivers on the east and west coast and in Kerala. Major rivers are three northern, seven central and four peninsular India rivers. Northern rivers are Himalayan rivers. Besides rainfall, Himalayan tributaries carry discharges due to melting of snow and glacier and therefore are perennial. Himalayan rivers also have southern tributaries. The tributaries carry discharges due to rainfall alone. Himalayan rivers carry heavy silt load and discharges. Several rivers shift their course in plains. Flood is a large problem in northern rivers as compared to southern rivers in India. Brahmputra river experiences large floods, followed by northern tributaries of Ganga. Central and peninsular river courses are stable and they do not experience floods of similar magnitudes (Rao,1979). Yamuna is a tributary of Ganga. Yamuna excluding Chambal experiences flooding in Uttar Pradesh and Harayana States. A part of Yamuna is selected for plan form and river migration study.

Yamuna is a tributary of Ganga. The river originates at the Yamunotri glacier at an elevation of 6330 metres in Uttar Kashi, Uttar Pradesh. It flows through Himanchal Pradesh, Harayana, Uttar Pradesh, Union territory of Delhi, Rajasthan and Madhya Pradesh. A reservoir is built at Tajewala. Eastern and Western Yamuna canals take off from the reservoir. Average annual flow in the river are respectively 10750, 13700 Million cubic metres at Tajewala, Okhala. Flood protection measures have been adopted in Yamuna to protect Union Territory of Delhi. Three Barrages are constructed near Delhi on Yamuna. The Agra canal takes off from Okhala Barrage. Several embankments are built in Yamuna flood plain. A flood warning system is operational in Yamuna. Right ınk tributaries of Yamuna in Himalaya ranges are Tons and Giri.

The left bank tributary in Himalaya ranges is Asan. It joins Yamuna below Giri. In the study area, rivers are Katha and Hindon. Both are left bank tributaries. They respectively make a confluence with Yamuna near Kairana and Ballabhgarh.

Area lies in the Northern plain physiographic division, Ganga Yamuna doab and Punjab plain physiographic region. Yamuna divides two physiographic regions. Yamuna emerges from Western Himalaya in to plains. Physiographic section in Punjab plain is Harayana plain. Average annual rainfall varies between 800 and 600 mm. Gangoh receives higher mean annual rainfall than Delhi. Mean annual rainfall in upper catchment exceeds 2400 mm. Highest mean annual rainfall occurs near Mussorrie. Yamuna forms a boundary of Uttar Pradesh and Harayana. Revenue districts are Saharanpur, Muzaffarnagar, Meerut in Uttar Pradesh and Karnal, Sonipat in Harayana. Soils are entisol, alfisols and inceptisols (Dutta and Kundu 1987, Kundu 1989). Mean annual temperature at Delhi, Dehradun and Shimla are respectively 24.8°, 21.6° and 13.3°C. Satellite imageries are 29-47 A1, A2 at scale of 1:250000. SOI topographic maps are 53G/1, 2, 3, 4 at scale of 1:50000 and 53G at scale of 1:250000.

CHAPTER 4 STATEMENT OF THE PROBLEM

River meandering is a natural process occurring in river's alluvial reaches. This process has been a subject of scientific research for past several years. There have been several physical modelling experiments. Experimenters have tried to investigate causes for meander developments. Regressions relationships between meander morphological parameters and river hydrological variables e.g. discharge etc are developed in other studies. Remote sensing technique has opened new possibilities in study of river morphology. Remote sensing provides temporal images. Temporal data can be superimposed to study river processes in meandering rivers.

In meandering rivers, several processes take place e.g. movement of river meanders, river migrations, changes in flood plain features etc. River meanders may be in equilibrium. Due to several reasons, e.g. tectonic disturbances, hydrologic changes, anthropogenic changes etc., there may be changes in river morphology and migration may takes place in a river. River Yamuna is proposed for this study. This river carries significant discharge. This river is part of Ganges river system. In earlier studies, no uniform definitions are used for morphological parameters. Here, GIS and manual calculations are used for this purpose. Also, for more uniform measures, median values are adopted for the measured morphological variables. These measurements will provide useful information in river engineering applications. Further, a graphical representation is selected for river channel migration study. This is a standard method for such studies. This study is also useful due to large agricultural activities, Yamuna forming boarder between two states, several engineering structures e.g. bridge, embankments in place, upstream reach to National Capital Territory etc.

CHAPTER 5 DATA AVAILABLE AND METHODOLOGY

5.1 DATA AVAILABLE

Satellite data are from LISS II sensors onboard the IRS satellite. Path, row and date for FCC paper print available are respectively 29-47 A1, A2 9 October 1989. SOI topographic maps are 53 G, 53 G/1, 2, 3 and 4. Years of SOI topographic maps 53 G/1, 2, 3 are 1970 and 71. The Yamuna in 53 G/3, 4 is surveyed in 1974 and 75.

5.2 METHODOLOGY

Geographic Information System (GIS) is a computer based system that stores, retrieves, captures, corrects, transforms, integrates, manipulates, analyses and output spatial data for the real world for solving a spatial problem. GIS is also defined as a computer based system that uses spatial data to answer queries of geographic nature. Raster or grid and vector or polygon data encoding are two main encoding schemes used in a GIS. A vector follows natural boundaries of objects and correctly represents them. They are difficult to store, retrieve and manipulate. This is due to irregular shapes of polygons. The rasters are simple to store, retrieve and manipulate. Several sizes of grids may be selected in a raster.

Integrated Land and Water Information System (ILWIS)

ILWIS version 2.0 is an image processing, tabular data base software and a GIS. It requires operating system Microsoft Window 95. It requires single colour monitor, graphic display card, a hardware key, PC 486 and higher machine. The interface in the software is point and click. Both menu and selected icons are provided. Data types are depicted by icons for their easy identification. Special files are also shown with icons placed beside their names. This software supports stream mode digitizing. Main data structure is raster. Although limited vector data handling capabilities are also available.

Visual interpretation

Visual interpretation is identifying features on images. Qualitative information for the features is derived. There are several steps followed to complete interpretation. These are listed below:

1. Reconnaissance interpretation of an image for orienting and referencing the image with respective to topographic maps is completed. For this purpose quickly broad details are delineated on images and GCPs are identified on both images and topographic maps.

2. Listing features to be interpreted on images.

3. Spectral information for features of interest for a selected sensor is gathered.

4. Interpreting images.

For interpretation of images, principles of image interpretation are followed. Many characteristics of images are observed. These are sizes, shapes, tones or colours, textures, patterns, locations and associations. A river possesses width depending upon an amount of discharge in the river, bed material and climate. A trunk stream possesses broader width as compared to a tributary channel. Width of canals is dependent on whether a canal is a main or a branch canal. Highways can be easily identified in satellite data e.g. Landsat MSS and IRS LISS-1, LISS-2. Other roads may be visible if contrast is good. Oxbow lakes are of curved shape. Both Canal and transportation networks are usually straight. Tone or colour of a feature is dependent on type of feature and sensor. Water possesses smooth texture. A river exhibits different drainage patterns, e.g., dendritic, parallel. In cities a converging pattern of a transportation network is seen. Cities possess a pattern formed by network of roads within city limits. Oxbow lakes are found in alluvial plains near rivers. Sand bars are associated with rivers channels.

Geometric rectifying and output

Standard processed satellite data are without several geometric distortions. They are not oriented north-south. Further for a change detection study e.g. river migration, satellite data are required to be registered to a topographic map or other spatial collateral data. This is achieved by selecting ground control points (GCPs) in both data. GCPs are well defined points in both satellite and reference data. For a visual interpretation map, GCPs can be marked on transparent sheet from satellite data and later these points can be digitized. All satellite data are digitized to same arbitrary coordinate system. Selected features from satellite interpreted map can be rasterized and rectified. These features can be output with a vector overlay from topographic map and map annotations.

CHAPTER 6 RESULTS

Features on a FCC, made using bands green, red and infrared, depict particular signatures. Water both canal and river possess dark black colour. A canal is straight in shape and width of branches is less as compared to a main canal. Canal may not pass through a town. Road and rail are linear in shape and dark in colour. Human settlement is seen in cyan colour. A converging pattern of road or rail is observed in human settlements. The image characteristics of roads, rails, canals, human settlements are used to select ground control points (GCPs) on images. GCPs are identified on images and SOI topographic maps. GCPs locations are marked from satellite data on transparent sheet. These GCPs locations are digitized with an arbitrary coordinate system selected. GCPs from topographic map are digitized directly. Total 55 GCPs are selected. Four GCPs are deleted due to larger residual values. Total r.m.s. error in remaining GCPs is 105 metres. GCPs from 1:50000 scale topographic map are transferred to 1:250000 scale topographic map manually. From this map, GCPs are transferred to GIS file. This is done for keeping same accuracy level in source and reference data. For rectification of satellite map, satellite derived map is rasterized for selected features.

Flood plain features namely main river channels, tributaries, oxbow lakes and sand bars are delineated on FCC paper prints. Main and other channels, tributaries, oxbow lakes are water features. Sand bars are land features. Water possesses dark tone and black colour. Width of tributaries is least. River and oxbow lakes possess curved shape. Oxbow lakes are both straight and bow shaped. They are located near a river course. Sand bars possess bright tone and white colour. They are located close to a river course. Fully or partially filled up oxbow lake is red or cyan in colour. Filled oxbow lakes are located in continuation to oxbow lakes or are located near river channels. Filled channels and new oxbow lakes show constructional activities of a river in floodplain. Several new oxbow lakes are formed during time spanning satellite data and SOI topographic maps.

Flood plain features and cultural features are digitized in ILWIS window version. Coordinate system selected is Polyconic. Parameters for coordinate system namely central meridian, false easting, false northing, the earth's radius are respectively 77° 15'00", 500000 metres, zero metres and 6371007 metres. Maps are printed using ILWIS software (Fig. 6.1 to 6.4).

Channel migration and pattern are depicted graphically (Fig 6.3). Main channel length in satellite map is larger than that in topographic map. This could be due to a large meander loop development in middle reach. Oxbow lakes lengths, river bend statistics are given in tables, respectively 6.1 and 6.3. Measurements are arranged in an increasing order of the amount and are given in table 6.2. The river meanders between embankments. Embankments restrict river meandering. They act as valley walls. It is seen at a bridge site in middle reach. The main river in both topographic map and satellite imagery flows through the same location at this point.

Table 6.1 Oxbow lakes lengths and geographic coordinates

S. No.	Len-Sat	Len-Topo	Geographic coordinates(Sat topo)		
1	1.39		77 13 03	29 54 10	
2	.64		13 03	53 53	
3	.51		12 17	52 39	
4	.64		12 28	52 26	
5	.52		12 07	50 43	
6	.59		08 48	47 18	
7	.47		08 38	44 55	
8	1.08		08 11	41 08	
9	.93		07 04	38 21	
10	.60		07 50	33 31	
11	.70		07 34	32 59	
12	.61	2.71	08 54	31 00	08 46 30 44
13	.60		09 08	30 37	
14	1.04		06 44	30 53	
15	1.23	1.15	08 16	30 22	07 53 30 03
16	.55	.58	05 46	29 16	05 27 29 03
17	.74	2.14	06 30	28 59	06 26 29 02
18	.52		06 45	29 22	
19	.55		07 15	29 34	
20	.43		08 32	28 44	
21	.67	.9	09 59	23 47	09 29 23 54
22	.51	2.80	07 14	22 35	06 40 22 06
23	1.93		07 13	21 56	
24	.72	2.41	09 56	21 31	09 26 21 28
25	.64	1.05	09 25	20 49	08 59 20 50
26	1.14		10 02	20 23	
27	.65		10 01	19 34	
28	.21		10 07	18 55	
29	1.59		09 33	17 57	
30	.65		08 08	18 37	
31	.37		08 27	18 21	
32	.52	.72	06 24	18 26	06 02 18 23
33	.25		08 00	11 42	
34	3.99		08 00	11 32	
35	2.29		08 56	09 14	
36	.28		10 02	08 31	
37	1.96	1.58	09 36	05 46	09 21 05 36
38	1.04		10 08	02 01	
39	1.66		10 27	01 58	
40	.27		09 52	12 58	
41		.96			05 46 29 32
42		.73			09 00 24 08
43		.49			07 44 23 10
44		.46			04 52 15 48
45		.26			09 46 16 39
46		.55			07 26 20 09
47		.94			07 58 19 23
48		.55			07 20 18 38
49		1.35			07 37 34 39
50	.48		06 51	33 35	
51	.45		06 54	33 12	
52	1.97		06 43	30 20	
53	1.78		08 36	19 48	
54		1.46			07 39 30 45
55		1.01			05 10 18 27

Table 6.2 Bend measurements and oxbow lakes

Oxbow lake Km	Wave length Km	Arc angle Degree	Loop width Km	Arc radius Km	Amplitude Km
0.21	2.25	67.00	0.50	0.25	5.00E-02
0.25	2.25	73.00	0.88	0.25	5.00E-02
0.27	2.50	75.00	1.00	0.44	5.00E-02
0.28	3.00	76.00	1.00	0.56	0.10
0.37	3.00	76.00	1.00	0.56	0.10
0.43	3.25	78.00	1.13	0.56	0.10
0.45	3.25	80.00	1.25	0.56	0.10
0.47	3.25	81.00	1.25	0.56	0.10
0.48	3.25	89.00	1.25	0.63	0.10
0.51	3.50	92.00	1.25	0.63	0.10
0.51	3.50	95.00	1.25	0.75	0.10
0.52	3.75	101.00	1.25	0.75	0.10
0.52	3.75	105.00	1.25	0.81	0.10
0.52	4.00	110.00	1.38	0.81	0.10
0.55	4.25	111.00	1.50	0.81	0.15
0.55	4.25	115.00	1.50	0.81	0.15
0.59	4.25	115.00	1.50	0.81	0.15
0.60	4.25	117.00	1.63	0.81	0.15
0.60	4.38	118.00	1.75	0.94	0.15
0.61	4.50	118.00	1.75	0.94	0.20
0.64	4.50	119.00	1.75	0.94	0.20
0.64	4.50	124.00	1.88	0.94	0.20
0.64	4.75	128.00	2.00	0.94	0.20
0.65	4.75	131.00	2.00	1.06	0.20
0.65	5.25	132.00	2.00	1.06	0.20
0.67	5.50	133.00	2.00	1.06	0.20
0.70	5.50	135.00	2.00	1.06	0.20
0:72	5.75	137.00	2.00	1.06	0.20
0.74	5.75	140.00	2.00	1.06	0.25
0.93	5.75	143.00	2.25	1.06	0.25
1.04	5.75	145.00	2.25	1.06	0.25
1.04	6.25	151.00	2.25	1.06	0.25
1.08	6.25	153.00	2.25	1.06	0.30
1.14	6.50	154.00	2.50	1.19	0.30
1.23	6.50	155.00	2.50	1.25	0.30
1.39	7.25	155.00	2.75	1.25	0.30
1.59	7.25	157.00	2.75	1.25	0.30
1.66	7.50	161.00	2.88	1.25	0.35
1.78	8.75	161.00	3.00	1.25	0.35
1.93	8.75	170.00	3.00	1.25	0.40
1.96	0	180.00	3.00	1.25	0.40
1.97	0	180.00	3.00	1.25	0.40
2.29	0	180.00	3.00	1.25	0.40
3.99	0	180.00	3.00	1.31	0.56
0	0	180.00	3.25	1.44	0.60
0	0	200.00	3.50	1.94	0.60
0	0	200.00	3.50	2.00	0.60
0	0	221.00	4.00	2.13	0.75
0	0	248.00	5.00	2.25	1.06

Table 6.3 Fluvial statistics for Yamuna

Valley length in the topographic map	114.20 km
Lengths of the main channel in topographic map	125.95 Km
Lengths of the main channel in satellite data	138.84 Km
Sinuosity from topographic maps	1.10
Sinuosity from satellite data	1.21
Median wave length	4.50 Km
Median arc angle	132°
Median loop width	2.00 Km
Median arc radius	1.06 Km
Median length of oxbow lakes	0.64 km
Median loop amplitude	0.20 Km

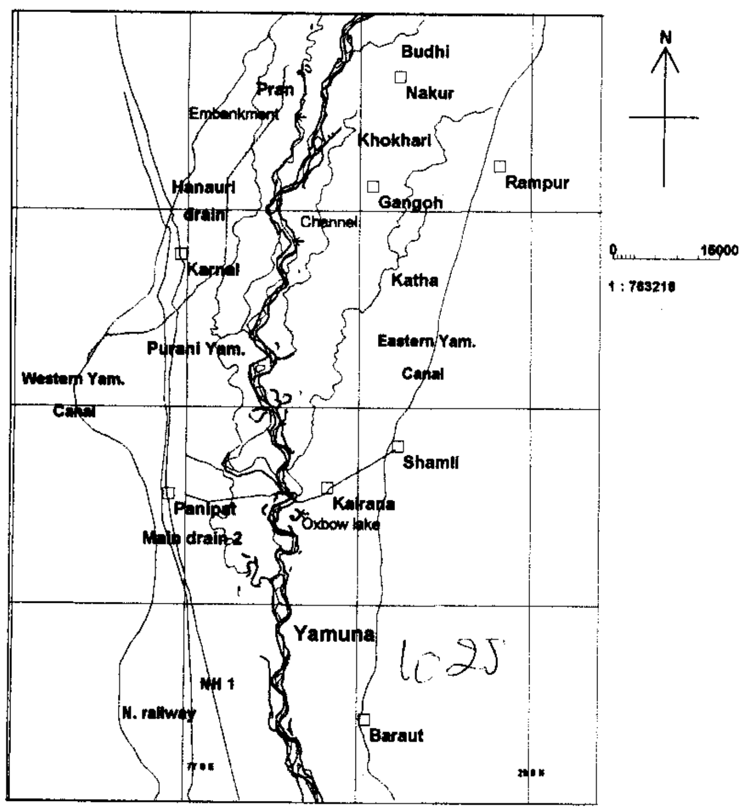

Fig. 6.1 Location map

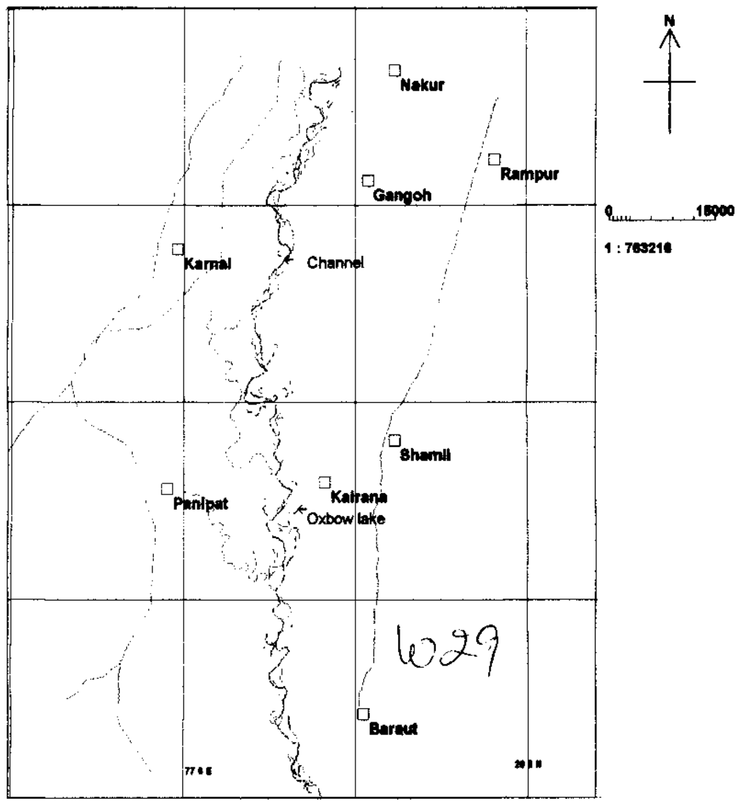

Fig. 6.2 Yamuna basin (Gangoh to New Delhi) using satellite data

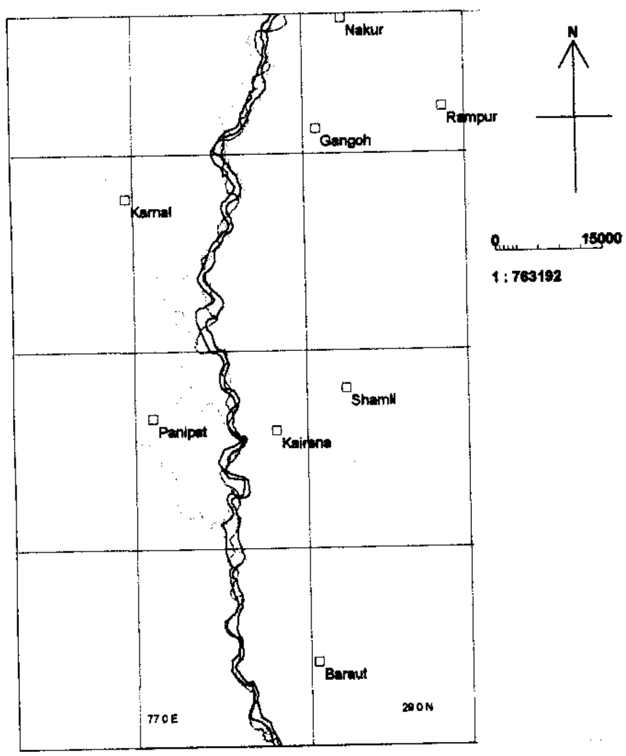

Fig. 6.3 River migration between 1973 and 1989

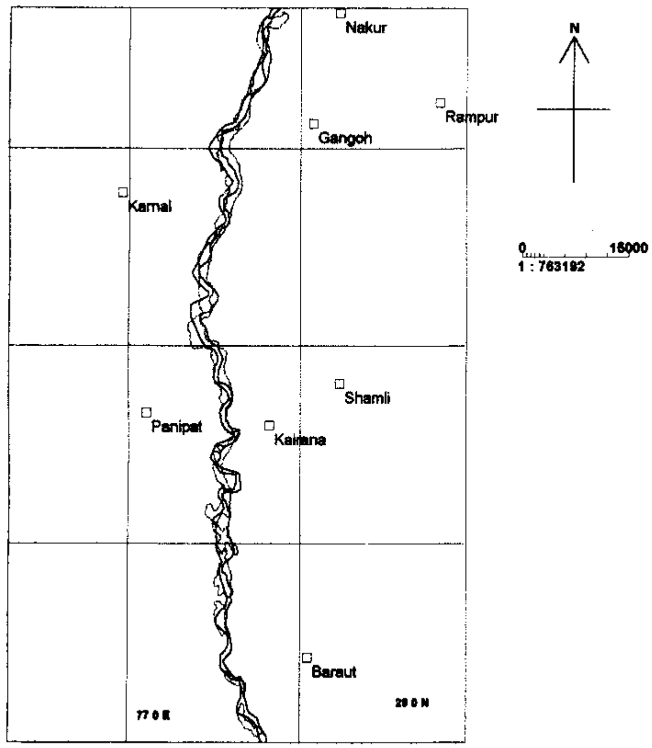

Fig. 6.4 Sand bars
using topographic map and satellite data

CHAPTER 7 CONCLUSIONS

1. Here, visual interpretation technique is used. A small r.m.s. error is resulted in geometric rectification within a GIS. There has been larger spatial changes in river meanders as seen graphically as compared to r.m.s. error in image rectification. This shows effectiveness of visual interpretation technique for similar data and river morphology.

2. Due to several engineer structure in place, a regular monitoring of alluvial river is essential. Thus, remote sensing technique is useful for this purpose. Although other survey technique can also be used.

3. Morphological measurements are useful in river engineering. Median values computed for morphological variables are more representative than measurements for a largest loop. Although these measurements can be affected by meander characteristics changes in a selected reach.

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