

## Recent Land Use/Land Cover Changes in the Floodplain of the Highly Regulated River Yamuna Upstream of Delhi

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### ABSTRACT

River Yamuna, the largest tributary of River Ganga, has been extensively regulated by construction of several barrages and embankments. A barrage, constructed in 1872 at Tajewala (now a few km upstream at Hathnikund) diverts almost all of its water for irrigation, except during the rainy season. The vast floodplain of the river downstream have been brought under agriculture, industry and urban settlements by increasingly greater channelisation by constructing embankments on both sides of the river. Consequently, the riverine ecosystem has undergone rapid degradation in many ways. This paper presents data on the changes in river morphology and in the land use/land cover of the remaining floodplain over a 85-km stretch upstream of Delhi. The information available from the 1970 topographic maps and the 2002 satellite imageries have been analysed through the tools of GIS, and ground survey of the entire area. The study shows the loss of meanders, side channels and floodplain water bodies and a decrease in sinuosity (straightening of the river course). The floodplain as well as the river channel are under cultivation and sand mining occurs indiscriminately. Consequently, the vegetation of the river bank is completely lost and the aquatic/wetland vegetation on the floodplain is extremely rare. The observed changes are related directly or indirectly to the intensive river regulation, especially its flow. It is suggested that both flow and habitat restoration are required for rehabilitating the river ecosystem for its goods and services traditionally and culturally valued by the human population.

*Key Words:* Floodplain Agriculture, Fluvial Morphology, River Channel Morphology, River Regulation, Meandering, Riparian Vegetation, Sinuosity

### INTRODUCTION

Rivers are highly dynamic three dimensional systems which exhibit a great diversity of form and behaviour, and evolve over time. Transporting water and sediments from their catchments on land to oceans, they act as major geo-morphological agents and respond to natural and anthropogenic environmental change (Leopold et al. 1964, Charlton 2007).

The dynamic behaviour of river constantly alters the floodplain environment in terms of topography, texture and structure. These aspects of floodplain help in examining the fluvial processes operating therein and its environmental history (Hudson 2003). River channel form and its dynamics over time in response to

environment and humans have long been studied in river research (Petts 1995, Liebault et al. 2002). Petts and Gurnell (2005) identified three main factors as the driving forces behind ecological changes in flow and sediment transfer that lead in turn to changes in the channel form downstream: (1) channel dynamics, (2) the role of riparian vegetation, and (3) channel change. The changes in morphology and pattern of river channels over time have been referred to as river metamorphosis (Schumm 1969).

The changes in the river course may be natural or in response to human induced factors. But their rate and direction depend on local topography, geology and other environmental aspects of the region. Leopold and Wolman (1957) identified two primary controlling

variables on channel planform; discharge and slope. In recent decades natural river dynamics have been altered in numerous catchments throughout the world by human intervention (Surian 1999). Dams, barrages and other structures for flow diversion for irrigation and domestic supplies, hydropower generation and other uses constitute the most common forms of intervention in fluvial systems and have for long been recognised to cause substantial changes to the river channels, flow and sediment regimes and fisheries (Thomas 1956, Knighton 1989, Petit et al. 1996, Kondolf 1997, Gregory 2006). Construction of dams and diversion structures across the rivers have minimized the frequency of occurrence of floods in the river valley but on the other side, drastically altered the flow regime of the river which affect the whole ecosystem including the floodplain downstream (Norris et al. 2007, Harwood 2004). Numerous publications from different parts of the world have discussed a variety of impacts of flow regulation on various ecosystem attributes, riverine biodiversity (Dudgeon 2000, Bunn and Arthington 2002, Poff et al. 2007), riparian/floodplain vegetation (Kingsford 2000, Nilsson and Berggren 2000, Nilsson et al. 1997, 2005) and the riverine habitats including channel morphology (Assani and Petit 2004, Maddock et al. 2005, Hauer and Lorang 2004, Wellmeyer et al. 2005). The river flows are further regulated by constructing embankments that channelise the river course to a smaller area for flood control and floodplain reclamation for agriculture, urbanisation and other uses. The restriction of flows to a small channel, coupled with the changes in flow regime, is another major cause of the degradation of river ecosystems and the loss of their biodiversity and various ecosystem services (Ward et al. 1999, Parsons and Gilvear 2002). Further changes in the river morphology and its ecosystem characteristics occur because of land use/land cover changes throughout the river basin (e.g., Harding et al. 1998, Allan 2004, Boix-Fayos et al. 2007, 2008, Wozniak 2009). After much damage has been done to the rivers, the discussion has turned to environmental flows - the water requirement of the rivers for maintaining their ecological integrity and major ecosystem goods and services (Richter et al. 1997, 2003, Poff et al. 1997, 2003).

The Indian subcontinent has 14 major and numerous medium and minor river systems most of which are extensively regulated by embankments and flow diversion structures (Gopal 2000). There have been many studies on the fluvial morphology of these rivers and floods are seen as an important geomorphic

agent (Sharma 1991, Bhattacharji and Raman 1991, Kale 2002, 2003, Parua 2002, Sinha et al. 2005). However, the consequences of flow regulation on river morphology, channel dynamics or other ecosystem attributes have never been studied.

Here we provide an overview of the changing morphology of the highly regulated River Yamuna during the past three decades. We emphasize mainly on (a) changes in the river channel and the immediate floodplain between the two embankments and (b) the land use/land cover changes in the adjoining floodplain. Although the data on flows in the river, being classified, are not available, we interpret the changes in response to declining flows and increasing human intervention.

## RIVER YAMUNA

River Yamuna, the largest tributary of River Ganga, originates from Yamunotri glacier at Bandar Punch in the region of Simla ( $30^{\circ} 58' N$ ,  $78^{\circ} 27' E$ ) at 6,320 m above mean sea-level (msl), in the lower Himalayas. Several tributaries join it along its 200 km sojourn in the Himalayan region, transforming it into a fourth-order river. After flowing through the Sivaliks, River Yamuna emerges on the plains near Tajewala at about 370 m above mean sea level (MSL). Then the river flows south-west and southwards for 275 km to enter the National Capital Territory of Delhi at 215 m above MSL. After meandering through Delhi for about 30 km to Okhla, the river continues southwards for 272 km to Agra (146m above MSL) and then turns south-east until its confluence with the River Ganges at Allahabad (100m above MSL). No major tributary, except some wastewater drains, joins River Yamuna between Tajewala and Delhi (Figure 1). Along its 1170 km flow through the Gangetic plain, the average slope of the river bed decreases from about  $0.56 \text{ m km}^{-1}$  between Tajewala and Delhi to less than  $20 \text{ cm km}^{-1}$  between Delhi and Agra before becoming less than  $5 \text{ cm km}^{-1}$  thereafter.

The drainage basin of River Yamuna, extending over  $366,233 \text{ km}^2$ , constitutes 42.5% of the total Ganga River basin (Anonymous 1980). The climate of the area is, in general, subtropical monsoonal, marked by strong seasonality. The rainfall is concentrated over the short period of the monsoons (June to September), when up to 90% of the total annual precipitation occurs. However, the temperature and rainfall regimes vary considerably in different parts of the basin. The

Himalayan part of the basin experiences very low winter temperatures and high rainfall (1,200 to >1,600 mm). In the plains, peak temperatures rise above 45 °C during summer (late May-June), but during winter the temperature (average 2-9°C December-January) rarely drops below the freezing-point. The annual rainfall decreases steeply towards the south and south-west — from 1,000 mm in the foothills to less than 400 mm in the western part of the basin. More details of the river are provided in Gopal and Sah (1993).

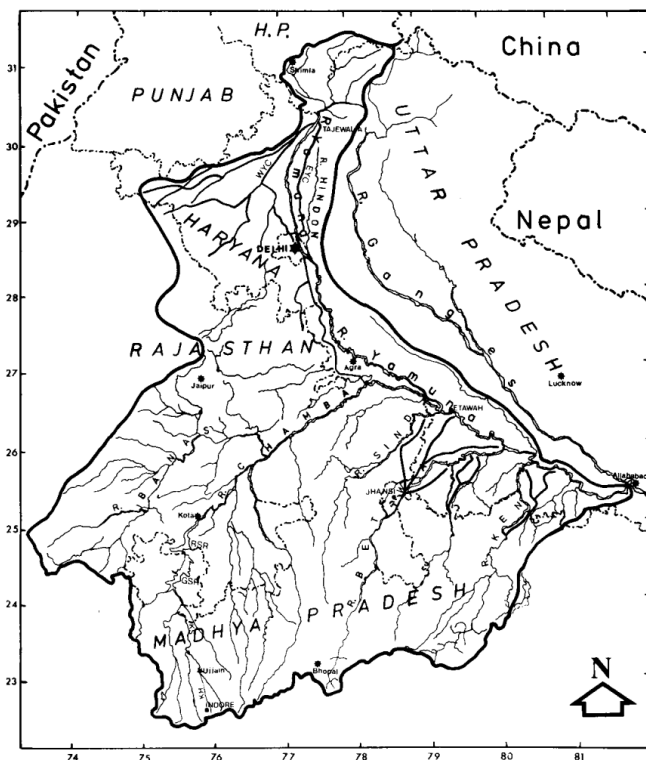


Figure 1. River Yamuna and its drainage basin, showing major tributaries, reservoirs, and canals. The thick line marks the boundary of the drainage basin. EYC = Eastern Upper Yamuna Canal, WYC = Western Upper Yamuna Canal, AC = Agra Canal, RSR = Rana Pratap Sagar Reservoir, GSR = Gandhi Sagar Reservoir, KS = River Kshipra, and KH = River Khan.

River Yamuna is relatively shallow, with an average depth of about 3 m during the monsoon season. During the winter and summer seasons, its channel width ranges from about 30 m in the Himalayan stretch to 300 m in the tail reach; but due to the very flat terrain, the river spreads laterally to several km

during the monsoons. In the plains, the bed sediments are silty or clayey, being derived chiefly from basaltic rocks, and are rich in organic matter.

### River Flow and its Regulation

Although recent and accurate water-flow data are not available officially, Rao (1975) reported an average annual flow of River Yamuna at its Tajewala head-works to be only 10,750 million cubic metres ( $Mm^3$ ). The natural flow of River Yamuna at Delhi increases from  $25 m^3 s^{-1}$  during summer to  $616 m^3 s^{-1}$  during the monsoon season. The natural flow of River Yamuna at Delhi increases from  $25 m^3 s^{-1}$  during summer to  $616 m^3 s^{-1}$  during the monsoon season.

For over a century (since 1872), River Yamuna has been extensively regulated by diverting its water for irrigation through three major canal systems, namely the Eastern and Western Upper Yamuna Canals at Tajewala (now a few km upstream at Hathnikund) and the Agra Canal at Okhla (Delhi). In recent decades, several so-called run-of-the-river schemes have diverted its flow for hydropower generation. A few relatively small dams are also planned in the Himalayan stretch.

Diversion of flow at Hathnikund leaves practically no water in the river up to Palla where the river enters the territory of Delhi, during most part of the year except the rainy season. The river experience flood conditions for a few days during August/September when water is not stored behind the barrage. Since 1960, two barrages at Wazirabad and Indraprastha in Delhi (25 km above Okhla) hold water for purposes of domestic supply and a thermal power-station. The flow at Okhla has again been diverted since 1872 into Agra Canal which leaves the river practically dry until some flow is regained after River Hindon and other rivulets join it between Delhi and Agra. Water is again withdrawn at Agra for domestic supplies. The river's flow-increases sharply only after major tributaries such as Rivers Chambal, Sind, Betwa, and Ken, join it downstream so that the average annual flow of the River at Allahabad is  $93,020 Mm^3$ .

Further, the river flow has been regulated by constructing embankments along increasingly more reaches of the river. Many of these embankments in the river stretch between Hathnikund and agra have been constructed during the past three to five decades. Currently, the lateral spread of the River is restricted to a relatively narrow belt and most of the natural floodplain, thus protected from periodic flooding, has been brought under human habitation.

## THE STUDY AREA

We investigated, in the middle Yamuna plain, a 85-km stretch of River Yamuna and its floodplain north of Delhi up to Panipat. Here the river forms the boundary for nearly 70 km between Meerut and Muzaffernagar districts of Uttar Pradesh and Sonapat and Panipat districts of Haryana. This part of floodplain is fairly flat and covered with thick deposits of alluvium. The general slope of the area is from northwest to southeast and the width of the floodplain is approximately 3 to 6 kilometers in the east-west direction between embankments on two sides of Yamuna River. It is liable to flooding once in every 2 to 3 years. The elevation varies from 235 m near Panipat to 211 m above MSL near the border of Delhi. The river drops by about 24 meter over a distance of about 70 km, i.e. an average gradient of approximately 40 cm km<sup>-1</sup>. However, there are some variations in the elevation on two sides of the river. Floodplain of the study area evolved in recent geological period and its surface has been built by the silting action of Yamuna during Quaternary to recent age.

The soil of the floodplain is entirely formed of alluvium. It consists of coarse sand, silt and clay formed by thick deposition of sediments brought by the river. There is thin layer of clay alternating between sandy layers. Clay layers are apparently formed by deposition of suspended fine sediments during the period of flooding. The vegetation on the both side of the river is characterized by total absence of trees and shrubs in the floodplain areas. Except for some trees planted on the bunds at higher elevation, there is no perennial woody vegetation in the entire area.

## MATERIALS AND METHODS

Satellite remote sensing and Geographic Information Systems (GIS) are widely applied in identifying and analyzing land use and land cover change over several periods (Treitz et al. 1992, Yeh and Li 1996, Weng 2002, Quan et al. 2007). Satellite remote sensing provides multi-spectral and multi-temporal data that can be used to quantify the type, amount and location of land use change. On the other hand, GIS provides a flexible environment for displaying, storing and analyzing digital data necessary for change detection. Satellite remote sensing is also very effective in investigating river channels and the floodplain over a wide area. This technology has often been used to

investigate river channel morphology, migration and regulation, bank erosion, and to identify palaeochannels on terrace surfaces (Winterbottom and Gilvear 1997, 2000, Yang et al. 1999, Gilvear et al. 2004, Takagi et al. 2007, Ormeci and Ekerici 2008).

Accordingly, river morphology and changes in the river course and land use/land cover during the period 1970 to 2002 were studied using topographical maps and satellite imageries in False Colour Composite (FCC). Indian Remote Sensing data for the period of post- monsoon (i.e. later part of September) and late winter (i.e. February) were identified to prepare various landuse/landcover map. The following remote sensing data were used in the present study:

Sensor	Path	Row	Date of Pass
IRS-I D, LISS –III	96	50	18 Sept 2001
IRS-I D, PAN	96	50	18 Sept 2001
IRS-I D, LISS III	96	50	15 Feb 2002
IRS- I D, PAN	96	50	15 Feb 2002

Topographical maps published by Survey of India on 1:50,000 Scale (53 G3, 53 G4, and 53 H1) were used for preparing the base map and for geo-coding the digital satellite data. The general methodology comprised of: digital data processing, visual interpretation and field survey for ground truth verification. Visual interpretation involves systematic study of image features through detection, identification, analysis and classification. Classification uses logical reasoning aided by appropriate knowledge about the area and the ground truth done in the study area. Photo elements like colour, texture, tone, size and pattern along with association of features were followed as interpretation keys for demarcating different land use and land cover categories. Ground truth helped in developing meaningful correlations of image interpretation units with thematic classes. Systematic ground surveys were made in selected locations in the study area.

ERDAS Imaging 8.7 and ARC View 3.2a software were used for processing digital satellite data and for calculating area statistics for the study area. These techniques were also employed for mapping and analyzing the extent of different land use/land cover categories. This procedure involved:

- Orientation and annotation of satellite imageries with reference to Survey of India (SOI) topographical sheets,
- Plotting study area boundary,
- Systematic interpretation of imageries by following pattern recognition and using subtle

differences in image elements of colour, tone, texture, shape, size, pattern, location, association and shadows,

- Correlation of image interpretation units with thematic classes based on knowledge and information sought from collateral data,
- Verification of pre-field interpretation units and land use classes, and
- Preparation of Land Use and Land cover map,

Changes in the pattern and shifting of the channel were determined by overlaying the scenes of 1970 and 2002 through GIS environment. Shifting of the channel was quantified by measuring the distance from the older channel. The meandering pattern of the river is quantitatively described in terms of channel sinuosity (Schumm 1963), which has been used as criterion for changes in the meandering pattern of River Yamuna. Channel sinuosity, when applied to the entire reach, gives a measure of intensity of meanders of a stream channel. The sinuosity index has been calculated for about 85 km stretch of Yamuna River for two time periods - 1970 and 2002. The whole stretch has been divided into nine sections to analyse at the micro level. The Sinuosity index was calculated by the mathematical formula:

$$S.I = L_{\text{cmax}} / L_R$$

where,

S.I = Sinuosity index

$L_{\text{cmax}}$  = mid channel length of the widest channel through reach.

$L_R$  = is the overall length of the channel belt reach measured along straight line.

A value of 1.5 for the sinuosity has been used as the criteria for the meandering channel.

The study area was categorised into nine major land use/land cover types, following CLUMA (2004): Settlement, Agricultural Land, Wasteland, Open Forest Land, Scrub and Grasses, River channel, Sand bars and Islands, Lakes and Ponds and Ox-bow lakes/ Cut-off meanders. CLUMA (2004) recognised lakes and ponds and oxbows as separate categories of LU/LC but these are difficult to distinguish in the floodplain. We have clubbed them together and call all of them within the floodplain as 'water bodies'.

## RESULTS

Field surveys made during 2002 to 2005 showed that the water depth in the river channel was less than 1 m at Hathwala (near Samalkha, District Panipat). Similarly, near Jhundpur (Sonipat) the water depth during the summer was just ankle deep (a few cm). The channel width was 490 m at Hathwala, 487 m at Jagdishpur and 376 m at Jhundpur. Maximum discharge in the river at Kairana (Baghpat in U.P.) was  $230 \text{ m}^3 \text{ s}^{-1}$  on July 12 2005,  $229.6 \text{ m}^3 \text{ s}^{-1}$  on 4 Aug. 2005, and  $229.58 \text{ m}^3 \text{ s}^{-1}$  on 20 September 2005.

There were no water bodies in the floodplain within the embankments. The aquatic/wetland vegetation in some patches comprised of a few submerged macrophytes, a few sedges and occasionally *Typha angustata*. *Phragmites karka* was very rare. There was no woody vegetation except a few rare occurrences of stumps of *Tamarix dioica*. The floodplain was extensively cultivated with cucurbits, vegetables, wheat, and even rice by irrigating with groundwater. The cultivation of cucurbits extended to the entire river bed wherever the land was even a few cm above the water level. More details of the soils, water quality, vegetation and socio-economic profile of the settlements in the area are given in Gopal et al. (2003).

### Change in Channel Morphology

The morphology of the floodplains is affected to a large extent by changes in the meandering pattern of the channel. The meandering pattern of Yamuna River has changed considerably during 1970 to 2002, and the channel has become relatively straight (Figures 2-5). Between these two periods the course of Yamuna was shortened from 123.2 km to 110.8 km.

A marked change in channel sinuosity has been observed over a period of 30 years. Almost all the reaches except IV and V (Table 1) have recorded a decline in the sinuosity index. Through Reach I near Patthargarh village, the river flows in a meandering pattern and the sinuosity index has decreased from 1.3 to 1.1 during the past 30 years. Reach II shows drastic decrease in the sinuosity index from 1.7 in 1970 to 1.2 in 2002. The river course has become straighter over this reach. The meandering is not very prominent in Reach IV, the value of sinuosity index for 1970 is 1.02 and has slightly increased to 1.22 in 2002. However, index has increased from 1.2 to 1.54 in Reach V.. Reach VIII has again straightened with a marked decline in the sinuosity index, from 1.74 to 1.19. The

river in 1970 was flowing in a large meandering pool in this reach that presently has become completely straight. The sinuosity index in reaches VII and IX also declined but with little deviation from the older channel. The total reduction in the sinuosity index is 1.5 to 1.3 between the two time periods and clearly indicates the shortening the meandering pattern of the river.

Thus, the river has undergone significant changes in its meander amplitude. Consequently there has been a considerable loss of other complex features such as pools, riffles and side channels, etc.

Table 1. Changes in Sinuosity Index of river Yamuna in different reaches from Panipat to Delhi during 1970 to 2002.

Reach	Valley length km	1970		2002	
		Channel length km	Sinuosity Index	Channel length km	Sinuosity Index
I	9.3	12.4	1.33	10.5	1.13
II	9.3	16.4	1.76	12	1.29
III	9.3	14.2	1.52	13.6	1.46
IV	9.3	11.2	1.2	11.4	1.22
V	9.3	11.6	1.25	14.4	1.54
VI	9.3	13.5	1.45	13.5	1.45
VII	9.3	12.5	1.34	10.7	1.15
VIII	9.3	16.2	1.74	11.1	1.19
IX	9.3	15.2	1.63	13.6	1.46

### Changes in River Course

GIS based analysis of stream location in 1970 and 2002 reveals a relative shift of the channel over the period. The approximate movement of loops was estimated through the "centroid shift" i.e. the distance between the centre points of the two river channels and their direction of flow from 1970 to 2002. The distance and direction of the shift of the stream from 1970 to 2002 are given in Table 2. The changes in the course of Yamuna are shown in Figures 2 to 7. The maps show that the direction of channel migration is generally towards the east. This conclusion is also supported by the presence of several abandoned meander loops situated to the west of the present channel. This shows a gradual shift mostly towards the

left bank within the area between the two embankments. Several meanders have become straight and there has been a decrease in the width of the main channel in most places.

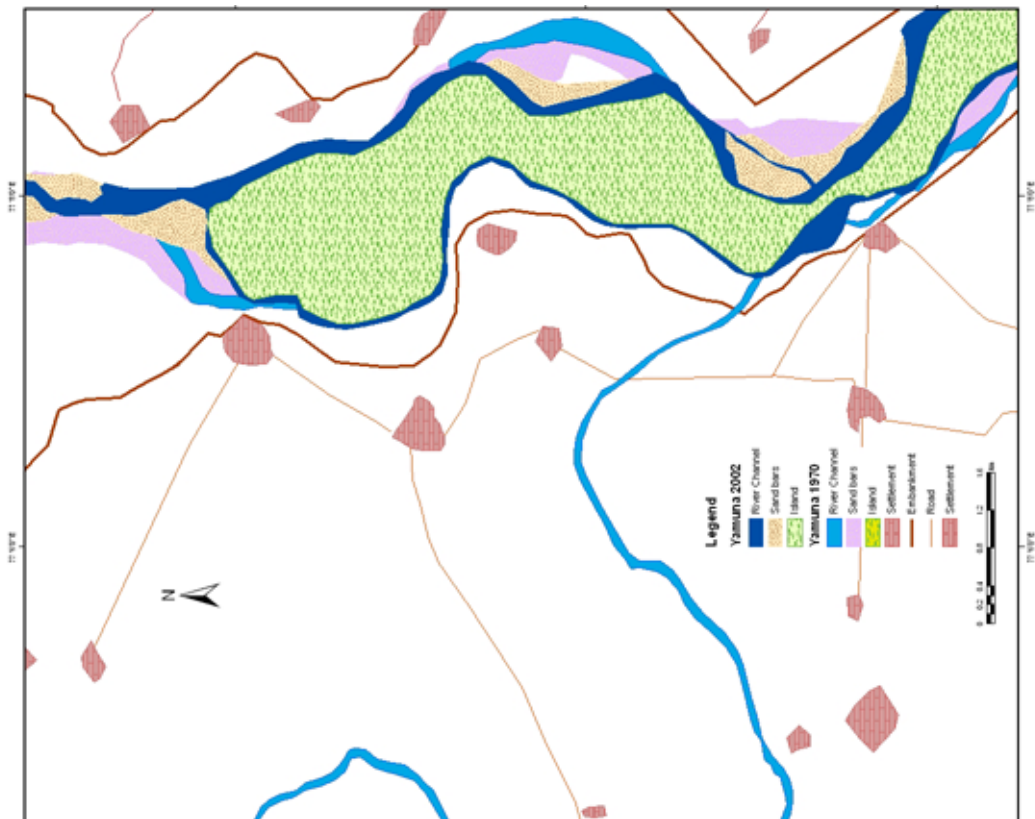
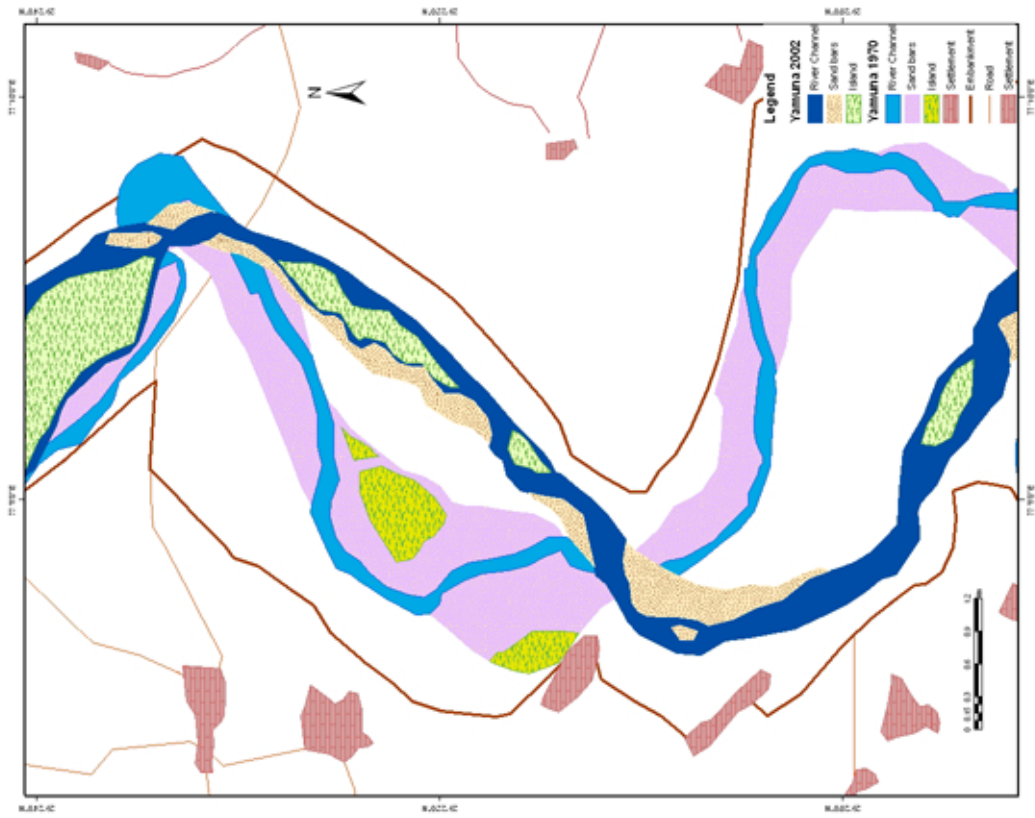
Table 2. Direction and distance of shift in the river channel during 1970-2002 between Panipat and Delhi

Reach	Direction	Distance (km)
I	East	1.38
II	East	2.21
III	East	3.39
IV	East	1.90
V	West	2.11
VI	West	1.06
VII	East	1.19
VIII	East	2.53
IX	East	1.38

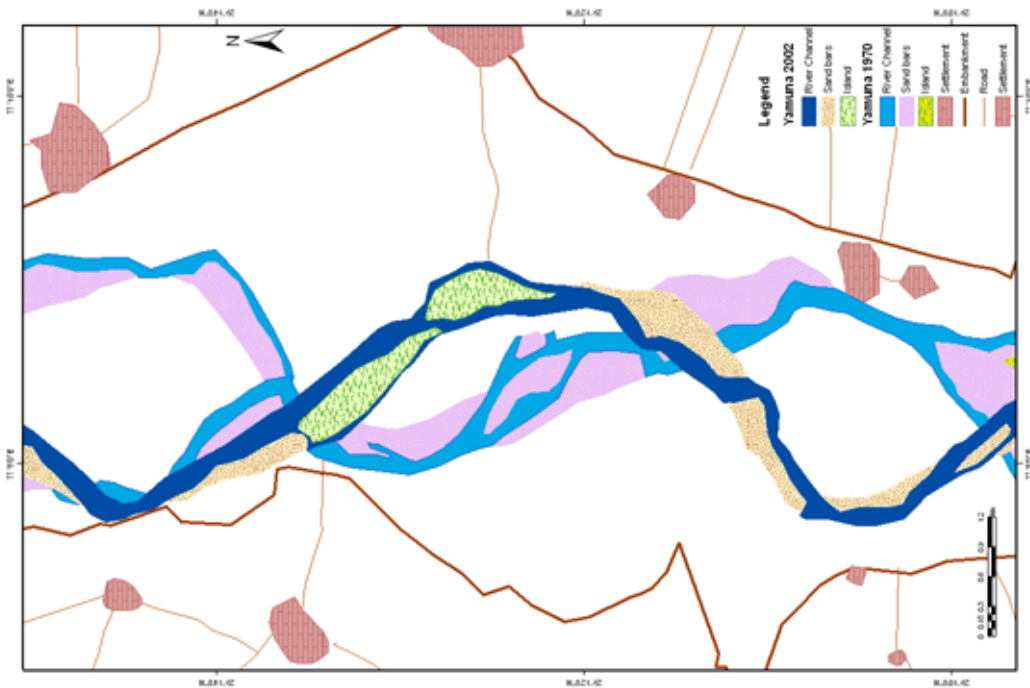
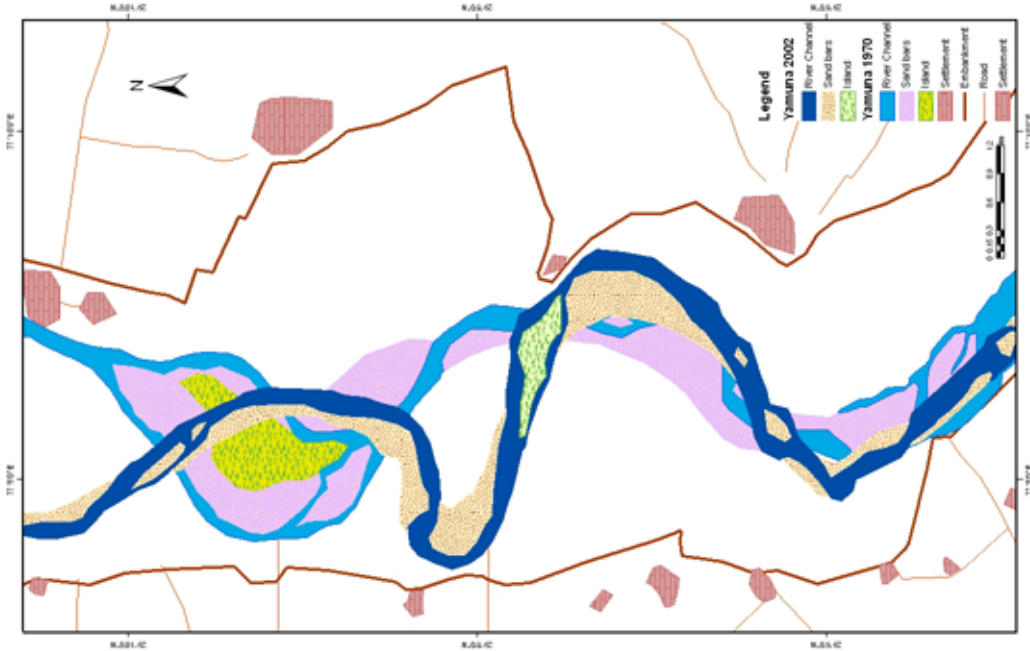
The channel of R. Yamuna has moved from 1.09 km to 3.3 km in different reaches from 1970 to 2002 (Table 2). The most remarkable change has taken place in Reach III where the river meander loop has shifted eastward a distance of more than 3 km. The channel used to flow in two equal branches separated by a large island near drain No. 2 (Figure 3). The map reveals that this island has shifted northward and its size has reduced. The orientation of the meander loop suggests that general tendency of the river is to shift eastward. The river course at Reach VII near Drain No. 8 has shifted eastward for a distance of about 2.53 km. Another major change has occurred at Reach II near Mirzapur village (Figure 3) where the river has shifted towards both the east and west and has also witnessed a downstream meander migration. A major change has occurred near Panipat- Karaina Bridge where Chhoti Yamuna stream, a side channel of the Yamuna, has disappeared since 1970 (Figure 2). This has been caused by the creation of an embankment along the main river channel, isolating the side channel which has nearly dried up.

### Land Use Change in the Floodplain

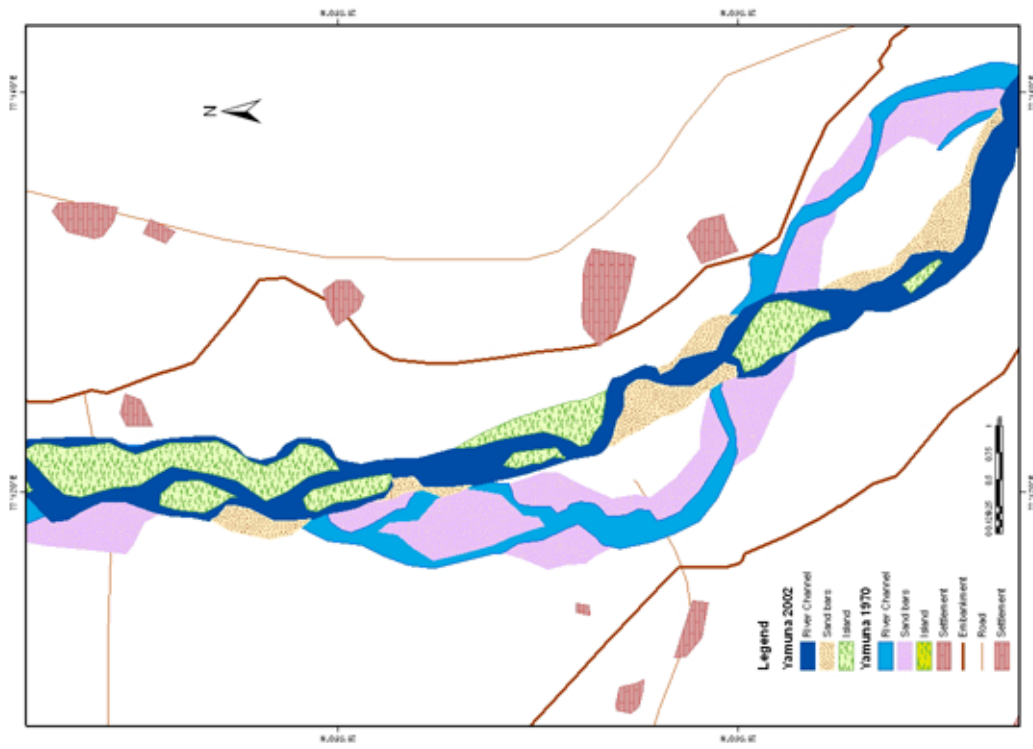
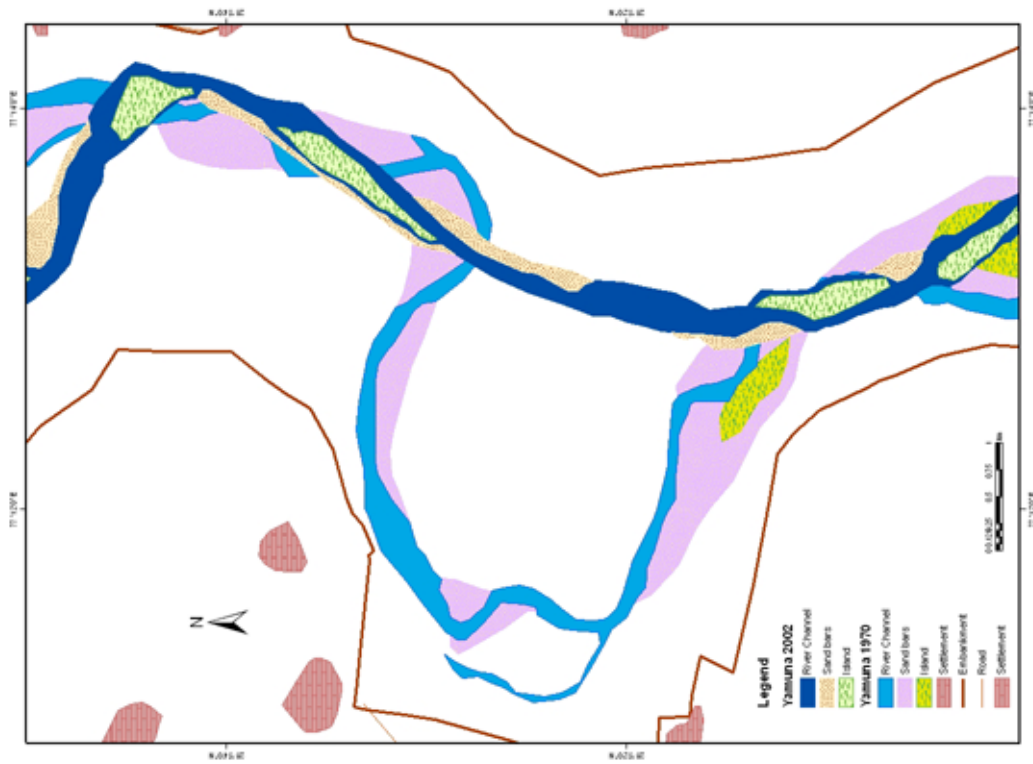
The Yamuna floodplain lying between the two embankments to the north of Delhi up to Panipat, covers an



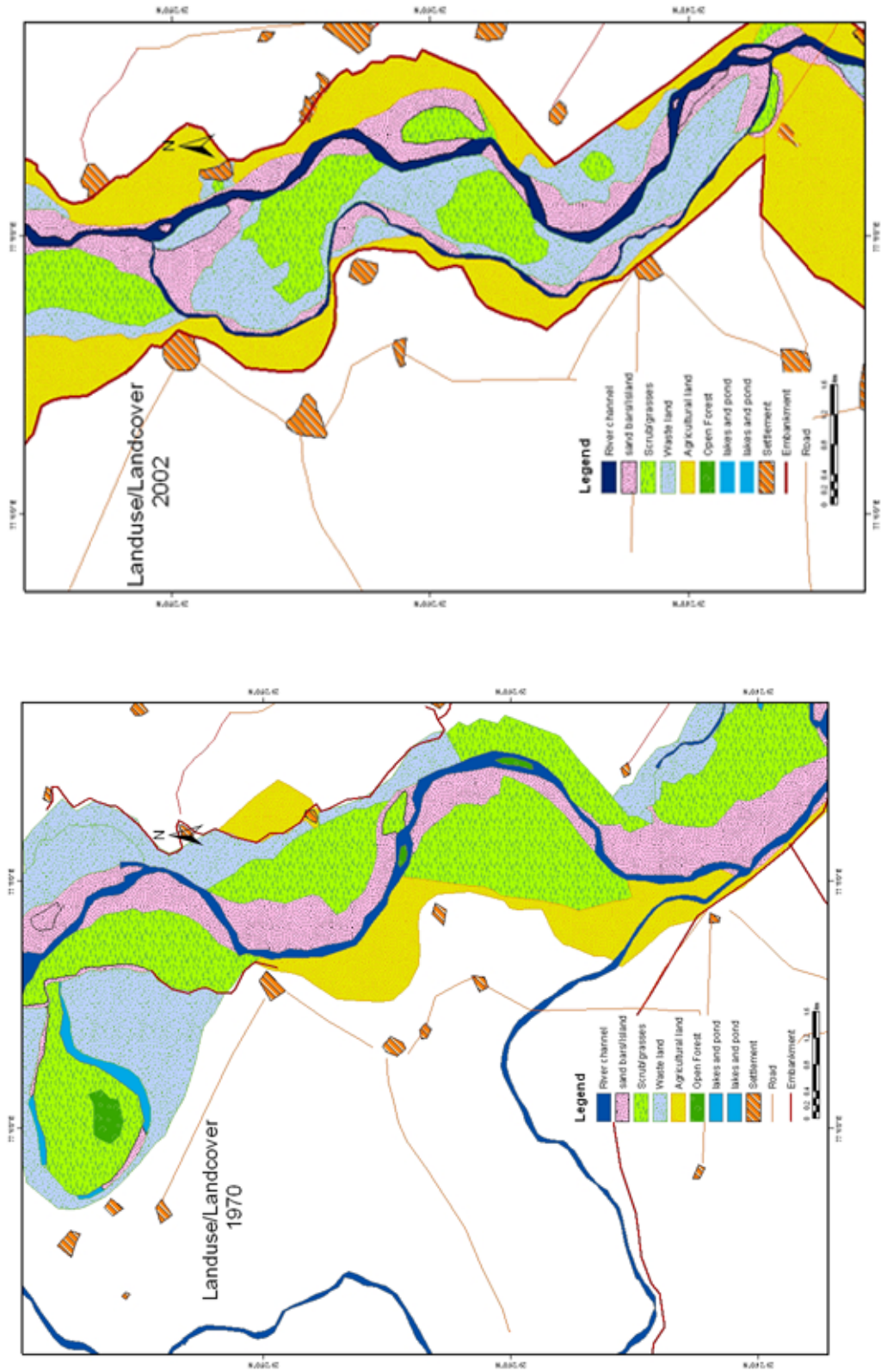
Figures 2-3. Changes



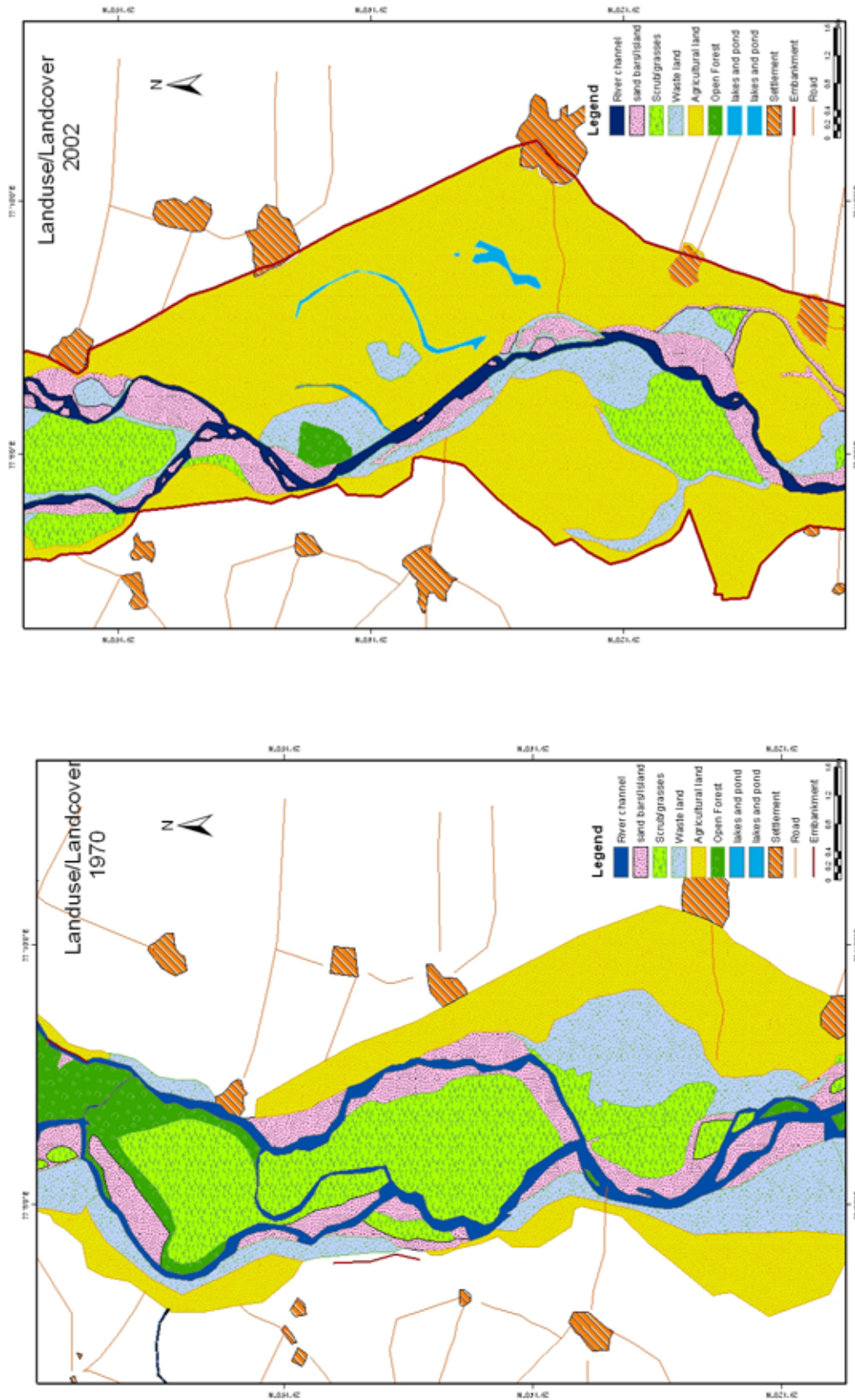
Figures 4-5. Change



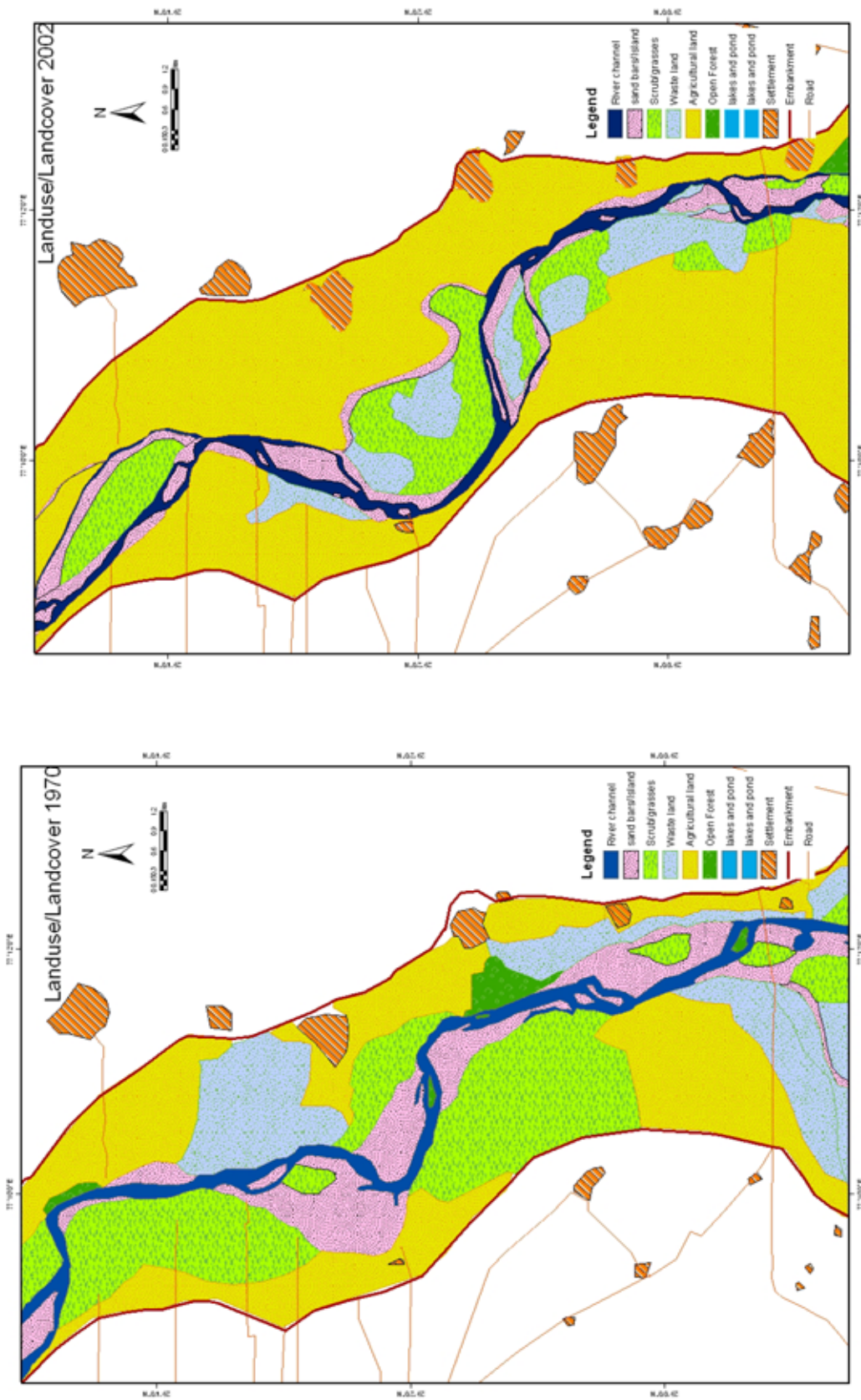
Figures 6-7. Change



Figures 8. Land use



Figures 9. Land use



Figures 10. Land u

area of about 262 km<sup>2</sup>. Significant changes have occurred in the area during the past 30 years. Land use changes between two time periods are given in Table 3 and for only three reaches in Figures 8 to 10.

Table 3. Land use/ Land cover changes (area in ha and % of the total) in the flood plain of R. Yamuna between embankments from upstream Delhi to upstream Panipat

Land Use/ Land Cover	1970		2002		Change %
	Area	%	Area	%	
Settlements	706.0	2.6	2023.1	7.7	186.5
Agricultural Land	6646.0	24.9	13475.5	51.3	102.8
Waste Land	5630.8	21.1	3665.9	14.0	-34.9
Sand bars/Islands	3405.8	12.8	2142.5	8.2	-37.1
River Channel	2665.7	10.0	2431.5	9.3	- 8.8
Open Forest	1748.3	6.6	283.3	1.1	-83.8
Scrub & grasses	5653.2	21.2	2161.0	8.2	-61.8
Waterbodies	210.9	0.8	92.9	0.3	-55.9

### Settlements

The study area is exclusively comprised of rural settlements. The population of villages along Yamuna floodplain is increasing very rapidly and consequently the size of settlements has also increased. As most of the growing human population is dependent on agricultural activities, the people are increasingly using the floodplain and the riverbed. The area of settlements that accounted for only 2.6% of the total floodplain in the study area, has increased by 186% to 2023 ha in 2002 (a three fold increased to about 7.7% of the total geographical area). Along with the settlements, connectivity through metalled and un-metalled roads also increased over time. New settlements and expansion of the existing settlements identified through satellite imageries and their name and location confirmed with the help of topographical sheets, show that many of the new settlements are encroaching upon the inside area of the embankments. There is also more encroachment towards the eastern side of the river. This may also be because the river has generally shifted eastward and some villages lying away from floodplain in 1970 may have now been covered by it. However, the village Jajal has encroached upon the western bank of R. Yamuna as the area of the village has expanded inside of the

embankment. The size of Baghpat village lying along the eastern bank has also increased almost three times since 1970. Thus, the human settlements along or adjacent to the floodplain of river Yamuna are primarily contributing to land use changes. This phenomenon is adding to depletion of soil erosion and has promoted river bed cultivation.

### Agricultural Land

The importance of agriculture in the study area can be visualized by the fact that more than 90% of the people residing in the villages largely depend upon cultivation for their livelihood. Moreover, with increasing demand for food and other agricultural commodities, people have heavily encroached the floodplain for farming purposes. Land under cultivation has increased rapidly in the last three decades, from 6646 ha in 1970 (25.6% of the total study area) to 13475.5 ha in 2002, accounting for about 51.3% of the total area, and a net change in land use/land cover by 102.8 percent.. Most of the land under scrubs, grasses and trees in the floodplain was transformed into agricultural land. Empirical observations during the field visits showed intensive cultivation within the two embankments. This land remains under cultivation throughout the year except during monsoon months owing to the possibility of flooding. Wheat is main crop in the area in rabi season while paddy is cultivated in kharif season (especially in areas having clay loam soil). Along with these two grains, vegetable farming is quite common in both the seasons.

Agriculture is not only confined to the floodplain but even extends to the dry parts of riverbed where a variety of cucurbits like pumpkins, watermelons and kakri etc are grown. This kind of cultivation depends mainly on ground water that is freely extracted and involves intensive use of fertilizers, pesticides and other agrochemicals. Their overuse pollutes the water of Yamuna River. Consequently, the riverbank and its floodplain are under severe human impact from intensive agricultural practices.

### Wasteland

Wasteland includes degraded land that can be brought under vegetative cover with effort but is currently underutilized for want of water and appropriate soil management or on account of some other natural cause. Wasteland occurs mainly found in the form of permanently fallow land in the study area of Yamuna

floodplain. About 5630.8 ha of land was classified as wasteland in 1970 and accounted for approximately 21% of the total area. Due to population pressure on the limited cultivated land, local people seem to have started converting wasteland into cultivable land and some of this land might have gone under settlements as both these categories registered substantial increase during this period. The wasteland declined to only 3665.9 ha, comprising only 14.0% of the total flood plain area, in 2002 (Table 3).

### Sand Bars and Islands

Sand bars are among the most common features of the Yamuna floodplain. Sand bars are low ridges of sand that border the shore and are built near the water surface by the river current. As the flow of the river water reduces, sand previously in suspension gets deposited along the channel. These are of different shapes and sizes and vary considerably along the Yamuna channel. Their elevation in most places varies from 15 to 30 cm above the water level. In some areas the sand bars are 1 to 2 m thick. These are subjected to submergence during high flows during monsoon season, which eventually changes their shape and location. Large sand bars were seen near Patthargarh village in 2002. However, no such deposits were noticed on the topographic-sheet based on the survey conducted in 1970. The area under sand bars has decreased to 100 ha in 2002 (Figure 2) compared to 467 hectares in 1970. Overall there were fewer sand bars in 2002 than in 1970. In many places, sand bars appear to have shifted downstream over time. Our observation of sand bar deposits indicates that the phenomenon is more active along the channel, where the river flows in a meandering pattern. River islands are an important feature of the Yamuna floodplain. There was an extensive large island near Patthargarh village in Panipat district covering an area of about 820 ha in 2002. However, there was no such island in 1970. Other new island (about 450 ha) was seen near Tanda village while a large island with an area of 90 ha near Bega village in 1970 disappeared completely in 2002. Near Bhagpat village, three large islands were observed in 2002 while no such island existed in this area in 1970. Mostly these islands are 2-3 meters above the riverbed. These Islands are subjected to cultivation in summer months.

Total land area under sand bars and islands has remarkably decreased since 1970 due to encroachment for agricultural activities, from about 3405.8 ha to

2142.4 ha (an overall decrease of 37.1%). Sand bars and islands that exist along or in the riverbed have been silted with fine sand and continuous layers of clayey loam soil due to low flows and frequency of flooding. Thus, this land becomes highly suitable for cultivating a variety of cucurbits. Extensive sand mining in the riverbed was observed at many places in the study area during field visits. This creates a number of semi-circular and rectangular pits forming pools of water that affects the natural flow of Yamuna.

### River Channel

Flow of water in the river channel is very low except in monsoon months. Since all the flow of River Yamuna is diverted at Tajewala (now at Hathnikund), the entire stretch of river between Tajewala and Delhi remains dry (Gopal et al. 2002). The absence of flow causes deposition of huge amounts of sediments in the river channel raising its bed. Flushing downstream is also not large enough considering the regulation there. The river channel covering an area of about 2665 ha (10%) in 1970 was reduced to 2431 ha (9.3%) in 2002. The width of the channel proper has been reduced in most places. The water in the main channel is only 1 to 1.5 m and at most places is less than knee deep during dry season.

Abandoned channels, an ancillary feature due to changes in the river course, are generally dry except during floods. These channels that existed as depressions in the study area of Yamuna floodplain are presently silted up but can be identified through traces of drainage lines in satellite imagery. These represent former stream regimes. Upstream of Panipat-Kairana Bridge (Panipat District), Chhoti Yamuna, a large side channel of Yamuna River can be seen in the 1970 map that has now dried out. Presently, this appears as a shallow depression but has been converted into agricultural land. Remnants of the old channel are also observable as depressions near Toki Jhajal village in Sonapat district of Haryana. At present this land is under cultivation.

### Open Forest

The study area is poorly vegetated with some degraded open forest can be seen in patches. Table 3 shows a sharp decline in the area under forest during the last three decades, from about 1748 ha or 6.9% of the total land in 1970 to 283 ha in 2002 (~1%). Thus, about 84% of the 1970 open forest cover has been cleared

and converted into agricultural land. This decline in the vegetative cover has increased the incidence and intensity of bank erosion and adversely affected the diversity of flora and fauna of the study area, as well as shifting of the river channel.

### Scrub Land and Grasses

Scrub and grasses formed dominant land cover in 1970 along the bank of the river and also within embankments. This land decreased by more than 60%, from 5653.2 ha in 1970 to 2161 ha in 2002. The land seems to have been largely converted to arable land. Consequently, a very small proportion of land is left for grazing within the floodplain of Yamuna River.

### Water Bodies

water bodies are formed either by the meandering river where meanders get cut off during the course of time or the depressions left by abandoned old channels. Yamuna floodplain has undergone tremendous change in terms of the number of water bodies on the flood plain. In the past, there were many ox-bow lakes and other water bodies but most of these have been filled up and converted into agricultural fields. In terms of total area, the water bodies have declined from 211 ha to only about 90 ha between 1970 and 2002. Even this area does not retain water for long after the monsoon floods. There was a large oxbow lake in 1970 near Duvpur village and it disappeared in recent time. Water bodies that existed near Rishpur and Buchakheri villages in 1970 had disappeared by 2002. The oxbow lake of 1970 near Jhudpur village has now been totally filled up and converted into an agricultural field.

## DISCUSSION

The shifting of the river course is a common phenomenon of natural fluvial processes. Its rate and direction depends on local topography, geology and other environmental aspects of the region. The river channel moves laterally by eroding existing deposits and creating new ones; and in turn maintains the dynamic character of floodplain. Yamuna in its khadar plain has been shifting for a long time (Singh 1971). It is one of the most dynamic and unstable regions and the Yamuna has frequently shifted its course after Tajewala. These changes can also be seen readily in the

form of older terraces in the floodplain, as well as by very thick deposits on the bank.

Significant changes in land use/ land cover pattern have occurred within the Yamuna floodplains and these have adversely affected the river ecosystem. Both natural and human factors are responsible for these changes. The study area is situated in the upper middle course of Yamuna River where both erosion as well as depositional actions are operating which are responsible for the changes in land use and land cover. Yamuna floodplain has undergone long geomorphic processes since the evolution of Great Indo-Gangetic plains (Singh 1965). The impact of the river action has brought a tremendous change in its course through the geomorphic history of Yamuna River. While in the absence actual data on flows in River Yamuna, all the observed changes cannot be correlated directly, the indirect evidence is overwhelming. Until 1960, the river still had adequate flow during the dry season because all of its lean season flow was not utilised for irrigation. As the land under irrigated agriculture has increased substantially, no water is allowed to escape the sluice gates of the barrage at Tajewala (personal observation). The absence of flow in the river has motivated the people to exploit the floodplain and the area is cleared and levelled to eliminate all depressions. No sooner than the water recedes after floods, the land is ploughed and turned into fields for wheat on the higher elevation and cucurbits nearer the water. Further, the expansion of agriculture both outside and within the embankments has exploited the shallow groundwater to an extent that during the past few years the water table has gone down by up to 12-15 m. The cultivation of rice on the sandy plain depends upon excessive pumping of groundwater and often the pumps are run throughout the night to allow shallow water to stand in the fields. Moreover, the flood plain has also emerged as a hub of human settlements with increasing population pressure around this area. Population has increased to such an extent in the last three decades that the people are forced to use every bit of available land. The growing human settlements have become a major problem within this part of the floodplain and have drastically altered its landscape.

Thus, changes in the river channel are partly explained by the significant decrease in the water flow that has led to the narrowing of the stream channel, channel straightening and lateral migration. These changes have adversely affected the riparian vegetation with obvious negative impacts on the floodplain environment.

Changes in morphology and loss of stream complexity of river Yamuna has been instrumental for the ever-increasing human interferences in the natural environment of the floodplain. The disappearance of meanders, side channels, water bodies and other wetland habitats affect the biodiversity of the flood plain. The changes in land use/land cover have been caused by humans taking advantage of the absence of flow to exploit the land. The altered flow regime has thus contributed both directly and indirectly to a change in the river morphology and land use/land cover in this region.

#### ACKNOWLEDGEMENTS

This study was funded by the National River Conservation Directorate of the Ministry of Environment and Forests, New Delhi, and formed a part of a feasibility study for floodplain restoration as a measure to enhance river flow, besides water quality and biodiversity in river Yamuna. We are grateful to Mr A.M. Gokhale, the then Additional Secretary & Project Director, Dr Subodh K. Sharma, Adviser, Dr R. Dalwani, Director, Dr Manju Raina, Additional Director of the NRCD in the ministry for their interest and support to the studies. We are thankful to all student members of the research team that helped in ground survey of the entire area.

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