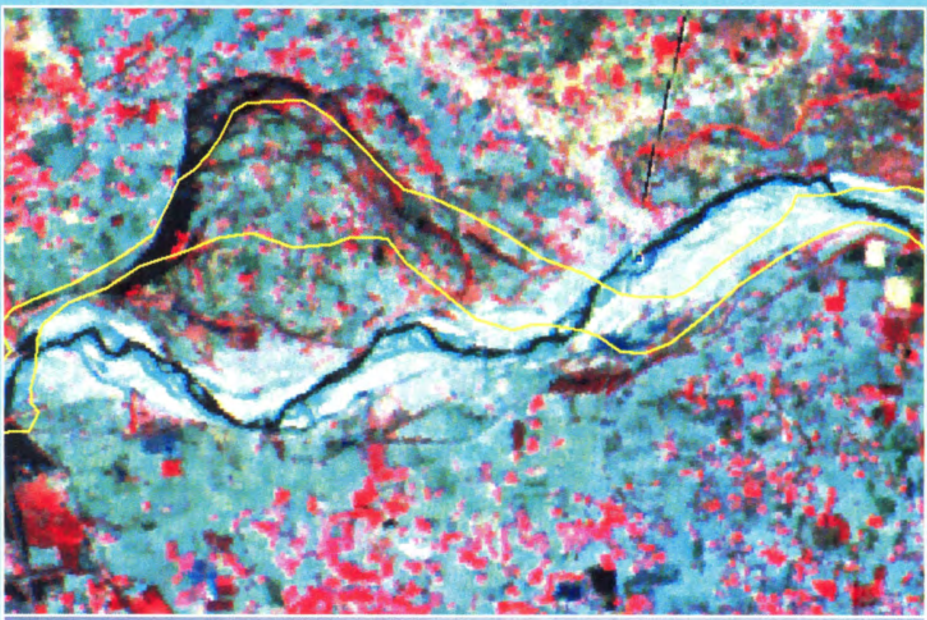
FINAL REPORT

MORPHOLOGICAL STUDY OF SATLUJ RIVER



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ROORKEE

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Rivers are essentially agents of erosion and transportation, moving the water and sediment supplied to them from the land surface to the oceans. They provide the routeways that carry excess precipitation to the oceanic store, thereby completing the global hydrological cycle. Rivers are dynamic entities whose characteristics vary over time and space with changes in environmental controls (Knight, in1998). River morphology is concerned with the structure and form of rivers, including channel configuration (planform), channel geometry (cross-sectional shape), bed form, and profile characteristics. Channel morphology changes with time and is affected by water discharge, including velocities; sediment discharge, including quantity and sediment characteristics; the composition of bed and bank materials apart from varied geological controls.

The processes responsible for the formation and evolution of rivers and their features are erosion, sediment transport, and deposition. Rivers are able to do work on the landscape because the energy stored in the water, or potential energy, is translated as it flows downhill owing to gravity into the kinetic energy, which is used for erosion, transport, and deposition. The amount of potential energy available to a river is proportional to its initial height above sea level. In order to minimize the loss of potential energy to thermal energy (or heat) as a result of friction, and thus maximize available kinetic energy, the river follows the path of least resistance downhill. Even so, it is estimated that 95 per cent of a river's potential energy is used to overcome friction, which occurs mainly along the channel boundaries (the bed and banks), although the internal friction of the water and air resistance on the surface are also important.

A river is in a state of equilibrium if the discharge, sediment load, sediment size and slopes are delicately balanced such that there is no change in bed elevation in a given reach over a long period of time. A change in any of these controlling variables or the imposition of an artificial change by the construction of structures along or across the stream will disturb its equilibrium and the stream then aggrades (i.e., there will be rise in bed level) or degrades (i.e, lowering of bed level). This process of aggradation or degradation may continue for a long time till a new equilibrium is established. In their natural condition, rivers seldom reach a state of equilibrium, even over short reaches. Each river is different and every reach of a stream is different from almost all other reaches of the same stream. Meandering is one of the means through which rivers tend towards the so-called dynamic or quasi-equilibrium state. River training and the construction of training works are also designed to achieve a proper equilibrium. The more the planned channel pattern, channel geometry, slope conditions, etc., correspond to the natural conditions of the river in question, the better will the river accept the new artificial state.

The aggradation and degradation are quite important from the engineering point of view as they extend over long distance and over bed level, the flood level of the river increases and channel capacity decreases. Hence, due to decrease in channel capacity, the channel will not be able to carry more water and flooding of the areas will take place even at lower discharges as compared to previous years, on the other end excessive degradation, i.e., lowering of bed, endangers the foundation of structures, affect energy dissipation devices on the d/s side on account of the reduced tail water depth, and lowers the ground water table in the vicinity. However, some of the effects of degradation are useful. For example, lowered bed levels help in lowering the flood stages and in increasing the effective head which help in lowering the flood stages and in increasing the effective head which can be utilized for more power generation. Hence, it is very important to know whether the river is aggrading, degrading or apparently poised i.e., stable.

Prediction of when and where future erosion will occur and the extent of such erosion are very uncertain because of the many interacting factors involved. The proper understanding of meander development and channel pattern changes of alluvial rivers is of vital importance for locating varied river valley development and water hazard control structures in the backdrop of proliferation of human settlements in the flood plains. The practical reasons for studying river pattern change are wide and varying. These include, firstly, awareness that human activity in the vicinity of river channels has unfortunately proceeded in ignorance of the pattern changes that may be expected and that this ought to be corrected. Secondly, channel pattern change is one of the more rapid forms of geomorphologic change, with developing forms and patterns of erosion and sedimentation that should be incorporated more fully into a general understanding of fluvial geomorphic systems. Thirdly, pattern changes involve the reworking of floodplain environments, and the soils, sedimentation, and morphological patterns that result, are of very broad concern.

1.2 MORPHOLOGY OF ALLUVIAL STREAMS

A thorough understanding of the hydromorphology of alluvial streams requires actual knowledge of their plan-form. The plan-form of alluvial streams can be classified into the following three categories:

1.2.1 Straight Channels:

These are usually relatively short reaches and are transitory because even minor irregularities in channel shape or alignment or a temporary obstruction can create a local disturbance that sets up a transverse flow leading to meandering. Straight reaches (See Figure 1.1) have negligible sinuosity at bankfull stage. At low stages there are sand bars along the banks on alternate sides of the stream and the thalweg (the line of maximum depth) meanders in a sinuous path around the bars. If the stream banks are not stable, more than one channel will develop, and the reach will become braided. It is extremely difficult to find straight reach of stream over large lengths. Straight reach implies neither constant depth across the channel nor a straight thalweg. Even though the channel is straight, thalweg moves back and forth one bank to another.

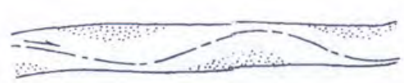


Fig.1.1 Straight Channel Reach

1.2.2 Meandering Stream:

These, in plan, consist of a series of bends of alternate curvature connected by straight crossing reaches. Slopes are usually relatively flat. Meandering channels are unstable, with banks caving in the downstream reaches of concave bends. As shown in Figure 1.2, there are deep pools in the bends and high velocities along the outer concave bank. Depths in crossing are relatively shallow compared to depths in bends.

Meandering streams are of two types: those with "surface" bends and those with "entrenched" bends. Streams with free surface bends generally flow in alluvial valleys and change their course on the floodplain with time. Streams with entrenched bends, however, are cut into resistant parent material and generally maintain a stable course.

Fig.1.2 Meandering Pattern of Stream

1.2.3 Braided Channels

There are numerous channels, which divide and rejoin in braided reaches (Figure 1.3). The stream is wide, and the banks are poorly defined and unstable. At low flows there are two or more main channels which cross each other, subsidiary channels, sand bars, and islands. At high flows, most bars are inundated. Such rivers often have relatively steep slopes and carry a large sediment load.

Fig.1.3 Braided Channel Reach

Some of the braiding and meandering parameters are:

- Sinuosity
- Tortuosity
- Braiding index

1.3 PHYSICAL CHARACTERISTICS OF RIVERS

Different rivers and different reaches of the same river have different alignments, channel cross-section shape, bed and bank material, slope, and valley characteristics.

Lane (1957) stated that while a great many factors affect stream channel form directly, others affect it indirectly by their influence on the directly affecting variables. He identified the most important variables as:

- Stream discharge
- Longitudinal slope
- Sediment load
- Resistance of banks and bed to movement by flowing water
- Vegetation
- Temperature
- Geology
- Works of man

Lane stated "these factors are not all independent ones, as many depend, to a greater or less extent, on the others. The interrelation between longitudinal slope, sediment load and resistance of the banks and bed to movement is particularly close and complex." Anding 1970), while discussing about the more important variables, stressed the following: "Stream discharge is the most obvious factor in determining stream form. The discharge of a natural stream influences its form not only because of the magnitude of the discharge, but also because of the integrated effect of its constant fluctuation".

The longitudinal slope is set largely by the geology and topography of the area through which the stream flows. It also follows that the slope is related to the sediment size of the material of the bed and banks, which were laid down by the stream. The amount and character of the particles comprising the sediment load exercise an important influence on the shape of the channel. The configuration of the channel cross-sections and the alignment of the stream are affected by the sediment load and pattern of deposition.

Channel shape changes with changing discharge, and changes occur more rapidly during high flows than during low or moderate flows. Overbank flow, in general, has a negligible effect on channel shape.

Anding quotes Schumn (1963) as stating that classification of river channels might be based on the independent variables - discharge and sediment load. Since discharge mainly determines the size of the channel, Schumn (1963) used sediment load as the basis of classification because of its influence in determining channel stability, shape, and sinuosity. He established three classes of channels—stable, eroding, and depositing—and then established three subclasses based on the predominant mode of sediment transport—bed load, mixed load, and suspended load. Schumn's classification of alluvial channel is based on data from rivers transporting materials finer than coarse gravel.

1.4 REMOTE SENSING APPROACH

Conventional measurements of planform characteristics of meandering rivers are a time consuming, laborious and expensive procedure. Their main disadvantage, however, is that they provide information only at a particular point and instant of time. On the other hand, remote sensing techniques are capable of providing information through time and space, which can never be appreciated from the ground. Further, the migratory rivers invariably leave their footprints behind. These include meander scars, abandoned channels, oxbow lakes and natural levees, thus giving clues as to where and how the river migrated. However, because of the large size of these features, they cannot always be recognized in the field. Aerial photographs and satellite sensor images can provide an extremely powerful means of detecting these clues for the delineation and reconstruction of the river courses (Baker, 1986).

Satellite remote sensing presents an expedient, reliable and cost effective alternative method for demarcation of rivers at suitable time-space intervals to establish the stability or otherwise of their channels. Advantages of the information acquired by satellite remote sensing are of synoptic coverage and receptivity. Because of the repetitive nature of satellite coverage, space borne observations are particularly suited for monitoring dynamic changes in surface parameters in remote areas or areas that are difficult to access. Various satellites having sensors which operate both in the optical as well as in microwave region of electro magnetic spectrum at different spatial resolutions can be used for obtaining valuable information on planform characteristics of river courses.

1.5 OBJECTIVES OF THIS STUDY

(i) To delineate the course of Satluj River along with the major roads, railways and important places from SOI toposheets and the digital data of IRS LISSII and LISSIII for the years 1990, 1995, 1999, and 2003.

(ii) To study the shifting course of Satluj river from SOI toposheet to 1990, 1995, 1999 and

2003, and identify the critical locations along the river where major shifting has taken place.

(iii) To identify all major morphological problems both natural and man made.

(iv) Evaluate performance of major flood control structures executed so far from morphological point of view as well as their effect on river morphology.

(v) Preparation of detailed morphological report as per 'Guide lines for preparation of river morphological reports of CWC (April 1991).

2005 and identify the critical locations along the river where major siltation has taken place.

(iv) To identify all major morphological problems both existing and new ones.

(v) To study performance of major flood control structures, existing and new, from morphological point of view as well as their effect on river morphology.

(vi) Preparation of detailed morphological report as per "Guidelines for preparation of river morphological reports of CWC" (April 1991).

CHAPTER 2

RIVER SHIFTING AND REVIEW OF LITERATURE

The manner in which rivers change the form and pattern of their channels has been a recurring theme in river studies for many years. In this chapter, first the shift in river course and its causes has been described. Then the work carried out in this field has been discussed under review of literature.

2.1 SHIFT IN RIVER COURSE AND ITS CAUSES

A river is a dynamic system and tends to adjust its channel roughness, geometry, pattern and profile with time. When a river carries high sediment loads, it tends to deposit it wherever the slope is gentle leading to the formation of multi-channels and development of meanders. Braided rivers occur in high-energy environments with large and variable discharges carrying heavy sediment load on steeper gradients. Channel geometry, water flow and sediment transport in braided rivers interact and vary in time and space, resulting in erosion and deposition, growth and migration of bars and the formation, migration and filling of channel segments. It is important to understand this interaction in modern environmental and engineering problem such as flood risk evaluation, construction of embankments or levees, sedimentation in navigational channels and reservoirs, bank erosion and channel migration, construction of artificial channel.

A river tries to maintain its course unless it is disturbed by diastrophic movements, natural calamities like flood, land slides or by human activity. A change in discharge, sediment load size and slopes may disturb rivers equilibrium state, resulting in aggradations or degradation of the stream/river. This process of aggradatation or degradation continues for a long time until a new equilibrium is established.

When a river is affected by a change in discharge or sediment load, it may develop sediment transport discontinuities such as knick points. The discontinuities move along the channel, resulting in erosion or deposition, which changes channel morphology and gradually restores stability to the system. The discontinuity is created by changes in channel morphology at one end of a reach and result in the addition or removal of sediment from a storage reservoir made up of the bed and banks of the channel. These changes affect the rate of sediment transport and thus feed back to and modify the transport discontinuity. A straight knick point at downstream end creates a sediment transport discontinuity.

The pattern of changes in bed elevation with time should that as channel development proceeds, the intense erosion occurring with the passage of a knick point is succeeded by a period of rather less intense deposition. The increase in sediment transport capacity at the knick point creates a deficiency of load, which is satisfied by erosion. Downstream of the knick point, channel slope decreases and the cross section changes so that transport capacity is reduced and the supply of load from upstream become excessive, resulting in deposition. As the channel develops, both the erodic knick point and the zone of deposition below it move upstream and the sediment supply is no longer excessive. Instead, the increased slope, which is developed on the downstream side of the zone of deposition, result in an increase in transport capacity and erosion is renewed.

The extent of human impact on channel changes is highly variable, and depends largely upon the activities over a proportion of drainage basin, which is directly affected. Man induced channel changes are of two basic types; direct and indirect. Direct changes are brought about by some direct and generally purposeful human action upon the stream channel and these are generally related to engineering schemes designed to alleviate existing or impending trials of flowing sedimentation or erosion. Channel stablization schemes, for example, involving upper bank paving, subaqueous mattressing, dikes and jetties, directly modify the stream channel in cross section profile, and possibly also planform, although in many cases the stabilized channel conforms to the channel morphology dimensions, which existed before intervention. Indirect changes are those brought about by the effects of human activity upon the processes, which control the stream channel form. In alluvial rivers channels form adjusts to maintain hydraulic relationships between the channel boundary and the water and sediment discharge through the channel reach.

Slope adjustment can be brought about by aggradations, degradation or changes to channel sinuosity, occurring singly or in combination. Channel gradient decreases where a river adopts a more sinuous course. The processes of aggradations and degradation respectively increase and decrease streambed elevation, usually over long river distances, and operate most often in response to changes in watershed controls or changes in base level. The spatial distribution of aggradation and degradation is frequently more complex than given in Table 2.1.

Modifications to bed elevation and slope result from changes in watershed conditions, which upset the continuity of sediment, transport, degradation reflecting bed load starvation and aggradation excessive bed load input.

Table 2.1 Main causes of change in streambed elevation

Type	Degradation	Aggradations
Downstream progressing Change in water discharge Changes in sediment supply	 Increase Decrease	 Decrease Increase
Upstream progressing Change in base level	Fall	Rise

2.2 BANK EROSION

The composition of bank material of natural channels is usually highly variable but does tend to become finer and more uniform downstream, with combination of sands, silts and clays dominant, especially where a well-developed flood plain exists. Most channel banks possess some degree of cohesion because of finer material, so that the analysis of bank erosion is not a simple extension of the non-cohesive bed case with a downslope gravity component added. Two main groups of processes are involved: hydraulic action and mass failure. The removal of bank material by hydraulic action is closely related to near-bank velocity conditions (Odgaard, 1987; Hasegawa, 1989) and in particular to the velocity gradient close to the bank, which determines the magnitude of hydraulic shear. The high rates of bank retreat commonly associated with bend apices are explained by the steep velocity gradients and high shear stresses encountered against the outer bank of meander bends. The flow not only entrains material directly from a bank face but also scours the base of a bank, which leads to over steepening and induces gravitational failure. The high shears generated within large-scale horizontal eddies can scour both bed and banks, enlarging existing embankments and increasing the amplitude of bank projections which become more susceptible to subsequent attack as the bank retreats discontinuously. Hydraulic action is probably the dominant process eroding non-cohesive bank and it depends upon the moisture content and degree of preconditioning of the material (Thorne, 1982). Hard, dry banks are very resistant, while wet ones are relatively easy to erode, especially if loosened by repeated wetting and drying or frost action.

The susceptibility of riverbank to mass failure depends on their geometry, structure and material properties. Processes of weakening and weathering related in particular to soil moisture conditions reduce the strength of intact bank material and decrease bank stability (Thorne, 1982). Cycles of wetting and drying are especially important as they cause swelling and shrinkage of the soil, leading to the development of interpedal fissures and tension cracks, which encourage failure. Seepage forces can reduce the cohesivity of bank material by removing clay particles and may promote the development of banks, while the dominant mechanisms in bank of high and low cohesivity seem to be deep-seated rotational slip and slab-type failure, respectively (Thorne, 1982).

The amount, periodicity and distribution of riverbank erosion are highly variable because many factors are involved, influencing these three aspects of erosion to differing extents. Little erosion is likely to take place in the absence of high discharges, but similar flows need not be equally effective because bank wetting or frost action may not have reduced the strength of bank material to the same degree. Consequently correlations between flow volume and amount of erosion tend to be rather weak, although stream power (product of discharge and slope) accounted for 48 per cent of the variation in migration rate along meandering channels in western Canada (Nanson and Hickin, 1986). Wolman (1959) found that a large summer flood attacking dry banks produced little erosion, while lesser winter flows acting against thoroughly wetted bank caused considerable bank retreat.

2.3 REVIEW OF LITERATURE

Many workers have carried out studies on channel changes (Dury, 1977; Knight, 1975; Hickin and Nanson, 1975; Lewin and Hughes, 1976) and the field has been reviewed by Gregory (1977, 1979, 1983). River migration or river changes are taken to include any change in river geometry within the context of the cross section, the pattern or network of a drainage basin (Gregory, 1977). Planform analysis helps us to understand, the changes in channel pattern in both time and space. Planform properties of meandering rivers include not only the geometry and sinuosity of the meandering course, but other properties such as variability of width and development of bars (Brice, 1984). Planform and planform changes are not independent of other aspects of river geometry, and together with these other aspects they deserve to be considered in relation to the hydraulics of channels with loose boundaries.

Many investigators have studied channel changes of different rivers. Thomas et al. (1998) studied the shifting of Ravi. In this study, remote sensing data of IRS-1A and IRS- 1B of LISS-II of the period 1991-1993 were analysed. They found a drastic changes in the course of Ravi due to human activities along its course. Another study was carried out by Jain (1993) on migration behaviour of Ganga River between Allahabad and Buxar. In this study, Landsat MSS and TM data of winter season in the form of FCC of year 1982 and 1987 were used for delineation of Ganga River. Visual Interpretation technique was used for assessment of channel migration. They found maximum shift in mid channel. Vinod et al. (1994 carried out a study on Hooghly River. In this study, time series analysis between 1971 to 1991 period was carried out. Thematic maps were generated from Landsat MSS and IRS- 1A LISS-I satellite data for 1986 and 1991 period. Critical zone with respect to cut-off and future channel migration for river stabilization were identified. Safuddin et al. (1999) carried out a study on migration of Yamuna River from Mahabharat period to the present. They also used IRS-1B LISS II data for their study. Netramani et al. (2003) also studied the shifting pattern of the Ganga River during different periods of time. This study shows that the shifting direction of the river varies through out the course of the river. Shifting was not in a uniform pattern; at some place it was westward and at other places it was eastward. Westaway et al. (2003) have done a remote survey of large- scale braided, gravel- bed rivers using digital photogrammetry and image analysis. For this study ariel photographs were used.

Ghosh (2002) studied the shifting pattern and braiding character of Kosi River with the help of satellite data. In this study the analysis was carried out on yearly basis and river position was identified and compared to previous years of data to calculate the shifts in the river position. Result shows that the river is moving westwards and it was predominantly braided in character.

Rannel (1979), Ferguson (1963) and Shilling field (1993) studied the behavioural pattern of Kosi River. However, no published records of their observations are available. Mookerjea (1961), and Mookerjea & Aich (1963) have studied the rapidly shifting nature, hydrological and sediment load characteristics of Kosi River. On the basis of this, a map showing positions of the Kosi River over its mega fan in the last 200 years has been published. Singh and Singli (1971) published a detailed map showing sixteen paleocourses of the Kosi. Dhanju (1976) has described the changes in course of the River Kosi within embankments in recent years using Landsat imagery.

Other notable studies on Kosi region have been carried out by Gupta et. al. (1980) who described changes in the planform of the Kosi River bed. Gohain and Prakash (1990) correlated downstream and temporal changes in planform of the river with relative aggradation and degradation in different reaches using Landsat images, air photos and topographic maps.

Prasad (1970) studied some aspects of meandering streams of the Barakar basin, Bihar, and their sinuosity indices. The Barakar basin ($23^0$41'30" N to $24^0$31'30" N Lat. and $85^0$10' E to $86^0$54' E Long.), is characterized by meandering and sinuous courses of streams. The basin is drained mainly by Karkara, Saghar, Harnaro, Keso, Pachkara, Baretu, Irga Khakho, Usri, Beri, Rajoya and Barki Jhar from the north, and Kewta, Kolhuwatari, Barsoti, Khero, Bakra, Chirki, Khudia and Pusai from the south including the main stream Barakar (a tributary of the Damodar) in the basin area of about 7026.1 km^2 in the Chota Nagpur Highlands of Bihar (India). Barsoti is its principal tributary from the south and the Usri from the north.

Philip et al. (1989) selected an area in the middle Ganga basin lying around Monghyr, Bihar, for channel migration investigations, using mainly remote sensing data. Changes in planform of the rivers over approximately 50 years are evaluated and the palaeocourses of the Ganga and Burhi Gandak rivers are reconstructed using the disposition and pattern of, among other things, oxbow lakes, meander scars and abandoned channels. It is inferred that the Ganga and the Burhi Gandak rivers moved from north to south by 20 km and 30 km respectively. The study demonstrates the utility of remote sensing data in such channel migration investigations. The study was based on a variety of data including aerial photographs (black-and-white, of 1:60 000 scale, 1966), Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data (black-and-white images, False-Colour Composites and digital data for 1975, 1982, 1983, 1984, 1985 and 1986), topographic maps (from surveys in 1935 and 1978 at 1:250 000 and 1:50 000 scales), lithologs of 45 wells and field observations.

Nagarajan et al. (1993) studied the migration behavior of Rapti River using temporal remotely-sensed data. The Rapti is a tributary of Ghagara River , which is a major tributary of Ganga. The study was taken up with an aim to (i) delineate the river course and its flood plain, (ii) identify surface indicators of channel migration, and (iii) predict the river stretches, which are likely to shift. Landsat MSS images acquired in years 1975, 1982 and 1983 and Landsat TM image of 1990 were used to form a time series of flood related features of river Rapti. Aerial photographs of year 1982 and with a scale of 1:15,000 were used to study in greater details the palaeo channels and the process of channel migration. Topographical maps on a scale of 1:50,000 and prepared in 1972 and 1977 were used as base maps.

Bardhan (1993) studied the channel behavior of the Barak River from the Manipur-Assam border on the east to Assam-Bangladesh border on the west through IRS imagery to identify the river stretches, if any, which remained reasonably stable during the period 1910-1988. The study revealed that considerable channel pattern changes have taken place during the 78 years from 1910 to 1988 in the main river as is evident from the number of ox-bow lakes, abandoned channels and buried channels etc., which are seen on both sides of the present course of the river. However, eleven stretches on the main river, ranging in lengths from less than 1 km to more than 2 km and a few stretches on the tributaries could be delineated as the stable segment of the river/stream.

Bhagawati (1993) carried out performance evaluation of a system of spurs and tie bunds constructed in order to check bank erosion on the Brahmaputra at Gumi near Palasbari. Effects of a training measure on the river regime is reflected in changed river configuration, most of which may be studied through multi-dated satellite data. The relevant information was collected with the help of visual interpretation of multi-dated Landsat-5 data products. Landsat-5 data products including B&W and FCC of the post construction period, before and after the great flood of 1988 have been used to extract relevant information for evaluating the performance of the spur system. Temporal changes in the morphological features of the river were determined with reference to toposheets prepared by survey of India during 1967-68. The changes were quantified using the parameters 'Braiding Index' (ratio between the land area to the water area of the planform of the study area) and 'Arc-chord ratio' (ratio of length of embayed bank to the straight line between the tips of adjacent spurs). The adopted training measures seem to stabilize the bank line but indicate inadequacy in spacing certain spurs, which are adjacent to each other.

CHAPTER 3

THE STUDY AREA AND DATA USED

3.1 THE STUDY AREA

3.1.1 Description

In the present study, evaluation of the shifting characteristics of reaches of Satluj between Bhakra to Harike site, having length of 175 km (approx.) has been carried out. A brief description about the river system is given in the following sections.

Satluj is one of the major river of Indus systems. It originates at Mansarovar, Tibet and enters in India near Namigia. It flows through Himachal Pradesh and Punjab states of India. Near the Nangal Town, Satluj enters the Anandpur Dun, a valley/plain area between the Siwalik and the outer range of the Himalayas. This valley runs from Nangal in the North to Kakrala village in the South over a distance of about 50 km (31 miles) and has an average width of 10 km (6 miles). With elevations ranging between 366m (1200 ft) and 278m (900ft) above MSL, it has a North- South gradient of 2 m per km (10.6ft per miles). The river flows along the valley's longer axis finally to leave it near Ropar. The Soan Nadi joins the Satluj in the upper sections of this valley from the North-West and the Sirsa Nadi merges with it in the Southern part of the valley left bank (Eastern bank). Due to its general gradient, the Satluj along with its tributaries runs through a braided course. Elongated strips of land between the river and the peripheral hills have a general slope towards the Satluj. These parts of Dun are traveled by a large number of seasonal torrents, locally called Khads, which descend quickly from the neighboring hills. Some of the important streams, which contribute their flow to the Satluj on its way to Ropar are Donala Khad, Dabawali Khad, Charan Ganga Khad, Lohand Khad and Kundlu Ki Khad. Some small flashy streams also outfall in the Satluj from the right-bank above Roper. After flowing sluggishly through Anandpur Dun, the Satluj debauches from the Shiwaliks just above Roper, and emerges on to the plains of Punjab. There used to be a weir at Roper with falling shutters and under- sluices for the diversion of water into Sirhind canal. This was later replaced with a barrage as a component of the Bhakra- Nangal Project in fifties. Another canal, named as Bist Doab canal, takes off from the right-bank of the river. Several natural streams and man- made drains join the Satluj between Roper and Ferozepur. There is a group of streams below Ropar, which flow in a NE- SW direction Siswan Nadi is another important seasonal stream, which initially flows NE to SW, but gradually turns NW to merge with the Satluj near Khizarpur village after traversing a distance of over 40 km over the plains. Immediately under the high bank along the old course of the Satluj, runs a perennial stream called Budha Nala, which rises at Chamkaur in Ropar district. It enters Ludhiana district near Bahlopur. Passing just below the town of Ludhiana, it flows into the Satluj in Tehsil Jagraon, a few km east of the Ludhiana-Firozpur district boundary. East Beas and West Beas merge with the Satluj from the right bank, upstream of its confluence with the Beas, which joins the Satluj at Harike. A number of surface drains have been constructed to facilitate drainage of the catchments in the plains. These outfall in the Satluj and contribute to its discharge during the rainy season of July September.

After Nangal Dam (Punjab), Satluj enters in plains. Therefore, we have selected the reach between Bhakra Dam to Harike for evaluation of the shifting characteristics. This area is bounded by Latitude 3105' N to $31^{0}25'$ N and Longitude $74^{0}55'$ E to $76^{0}30'$ E. The land through which the Satluj flows, is alluvial in nature. The inundation spreads over low lands on both sides during high stages of the river, i.e., medium and high floods. The river courses were very unstable and were subject to constant shifting. On an average, the width of the flood plains was in the range of 7 to 8 km (WAPCOS, 1996). A heavy flood occurred in the year 1988. The heavy rainfall downstream of Bhakra dam had resulted in locally generated floods. Releases from Bhakra with local floods resulted in acute flooding in the downstream areas.

Like all Punjab rivers, the Satluj constantly shifts its course. During the twenty years (1882 to 1903) it has moved by about 1.6 km. at several points in the Ludhiana and Samrala Tehsils and about a mile towards the North in Jagraon Tehsil (WAPCOS, 1996).

3.1.2 The Flood Plains Description

A brief description of flood plains of each district through which the river passes is provided in the following section:

i) Ropar District

The flood plain of the Satluj takes the shape of a strip running for a distance of about 20 km (12.5 miles) along the Satluj River from Ropar in the East to the Western boundary of the district and continues further west in Ludhiana district. It is one to two km wide in the east but widens to about 4 km in the western part. Flooding is a location specific feature of this plain.

ii) Ludhiana District

The Satluj flows along the district boundary with Jullunder district for some 98 km (60 miles). As it leaves Jagraon Tehsil, it turns slightly to the north towards its impending junction with the Beas. When the discharge is at its lowest in the middle of the winter, the river is very shallow. The width of the main stream seldom exceeds 150 meters and the depth is about 1 to 1.5 m. When in flood, it used to spread 3 to 5 km wide over the country. Even where confined to its narrowest by the Phillaur Bridge works, its width is about 1.6 km. The opening of the Sirhind canal has considerably reduced the volume of water in the river except during flood.

Like all Punjab Rivers, the Satluj constantly shifts its course. During the twenty years (1882 to 1903), it has moved by about 1.6 km at several points in the Ludhiana and Sarnrala Tehsils and about a mile towards the North in Jagraon Tehsil. The main physical divisions of the district are a low-lying alluvial tract along the river, called *Bet,* and the uplands called *Dhaia.* About 120 years ago it is said to have flowed just under the ridge which separates the *Dhaia* from the *Bet.* The old towns and villages of Bahlolpur, Machhiwara, Kum etc. were built on its banks. The division between uplands and low lands is distinctly marked everywhere by the ridge or high bank. The *bet* lies between the high bank and the present bed of the river. In the east of the district the river and the high bank are 5 to 10 km apart, and this is the width of the *Bet* for the first 48 km (30 miles). But below the town of Ludhiana, the width of flood plains gradually narrows

iii) Jullunder District

The greater part of the district, which lies to the north of the Satluj, belongs to the basin of the Satluj and only a small portion further north to that of the Beas. A line drawn from the middle of the North-East of Jullunder Tehsil to the Kapurthala border nearly due west of Jullunder city represents the watershed of the two rivers. The direct drainage into the Satluj is insignificant and the area so drained extends at the most 3 to 5 km inland from the old bank of the river. The minor drainage channels of Nawashahr and Phillaur and the East of Nakodar, instead of running South into the Satluj, run North-West and empty themselves into the Eastern Bein, which flows North-West for first half of its course in Jullunder, and then south-west for the second half of the course, joining the Satluj just where the Satluj leaves the Nakodar Tehsil.

The North West of the Jullunder district drains into the Western Bein. When there is heavy rain, Western Bein overflows its banks and floods alt the low land in the country for several kms into the South-West. It merges with Satluj upstream of its confluence with the Beas.

The Beas joins the Satluj about 6.5 km outside the district. Its bed is sandy and contains very few islands. It is about 1 km wide. In high flood the river inundates a large tract, partly directly by over-flowing its banks in places, and partly through old branches and depressions. Opening of the Ropar Canal has greatly reduced the flow of the water, and for eight months of the year the river remains almost dry.

iv) Ferozepur District

The Satluj performs a total journey of about 200 km (125 miles) along the Northern and Western borders of Ferozepur district. It enters this district near the village of Bhodiwala after passing through the Jullunder and Ludhiana districts. From here, it follows a north westerly course for about 40 km (25 miles) till it reaches Harike where it is joined by the Beas coming from the North East. Thereafter, Satluj flows towards west, a direction that it keeps for the rest of its journey in the district. It passes into Pakistan at Sule-Manke.

3.1.3. The floods of 1988

There were a number of storms, which adversely affected the catchments during this century. Of them, the most important ones which produced significant rainfall depths resulting in high floods in the catchment were 11-13 August 1925, 31st. August-2nd. Sept. 1928, 22-26 August 1929, 7-10 August 1935, 23-26 August 1936, 6-10 August 1942, 11-14 August 1943, 3-5 August 1944, 1-3 August 1946, 24-27 September 1947, 2-5 September 1950, 20-22 August 1951, 2-4 August 1952, 31 July-4 August 1953, 25-28 Septmeber 1954, 3-6 October 1955, 110-13 August 1956, 1-4 September 1957, 18-20 September 1959, 29 August-1Septemver 1960 and 24-26 Septemver 1988. Among 21 storms mentioned above, two storms, namely 3-6 October 1955 and 24-26 September 1988 top the list of storms, which produced un unprecedented floods. In the following section, the details of 1988 flood are provided.

The monsoon in 1988 has been good and the reservoir stood at 1687 feet level at 2400 hrs on 20 September, the day rekoned as the end of filling period. However, inflows started increasing at about 0700 hrs on 23 September and crossed 1 lakh cusecs mark by 20 hrs on 23 September. The outflows were stepped up to 74787 cusecs. As the reservoir level continues to rise and touched 1687.24 feet at 24 hrs on 23 September, the outflows has to be stepped further up to 1.05 lakh cusecs. The inflow continued to increase and the outflow was also increased almost in step with the inflow. This flood routing continued through entire 24 September and up to noon of 25 September, The inflow started showing signs of falling only by 1500 hrs on 25 September. Accordingly the outflow was also gradually reduced. At 1200 hrs. on 26 September, the reservoir level was 1685.41 feet, the inflow was 86688 cusecs and the outflow was 84160 cusecs. However, all of sudden, the inflows started rising very rapidly crossing 3 lakh cusecs mark in just four hours. At 1600 hrs on 26 September the inflow was 3.18 lakh cusecs. The outflow has to be increased but was restricted to a maximum of 1.48 lakh cusecs. The flood continued till early 27 September. As soon as the flood showed definite signs of receding, the outflow was stepped down.

The floods in September 1988 were caused by a most unusual combination of meteorological factors. Moreover, this occurred at the end of filling period, that too in an year with good rains resulting in full reservoir. It can be concluded that the Bhakra reservoir has successfully moderated floods during the September 1988 flood event. While the damage during these floods was catastrophic, it would have been more so, had these reservoirs not been built.

3.1.4. Embankments and their performance

The land through which the Satluj flow is alluvial in nature. When un-embanked, the river courses were very unstable and were subject to constant and unpredictable shifting. Therefore, the spread of the flood plains can not be estimated on the basis of their stream width maintained ordinarily during monsoon season. The inundation spreads over low lands on both sides during high stages of the river i.e. medium and high floods.

In the pre-Bhakra days, Satluj River used to flow in a width of 7 to 8 km inundating vast areas on both side during high flood. As per the records, the highest flood discharge, which passed downstream Ropar, was the order of 4.9 lakh cusec in the year 1947. Out of this, 2.75 lakh cusec was the contribution of the catchment upstream of Bhakra and the remaining 2.15 lakh cusec was from the catchment between Bhakra and Ropar. With the construction of Bhakra dam, it was visualized, that the frequency and intensity of the floods downstream would be considerably reduced.

Flood embankments have been constructed in the flood plain downstream of dams. These have been designed for a certain discharge (2,00,000 cusecs). Subsequent to constructions of Bhakra dam, embankments have been built on both side of the Satluj River downstream of

Ropar. River Satluj stands canalized in a comparatively narrow channel by embankments spaced 3000 to 3500 ft. apart on either side from Ropar to GiderPindi near which place it joins the flood protection/river training embankment of Harike barrage on the left side and the west Bein flood protection embankment on the right side. Beyond this, there is a continuous flood protection embankment on the left side upto Hussainiwala. There is no continuous embankment along the river downstream of Hussainwala except for a few vulnerable reaches, particularly in the Mamdot sector.

Canalisation

After the construction of Bhakra Dam across the Satluj, it was expected that due to flood moderation at the dam, the intensity and frequency of floods d/s of Bhakra would be considerably reduced. Accordingly, embankments were constructed along both banks of the river to Jacket the river in a canalized section. It was projected that as a result of canalisation, the flood plains of the Satluj which were up to 7 to 8 km wide in certain reaches, could be restricted to about 1 km. This was expected to result in "reclamation" of nearly 36000 hectares (80000 acres) of land. Embankments were also expected to check the meandering of the river. Apart from the river training works as adjuncts to Nangal Dam and Ropar barrage, there are no flood protection works on the river up to Ropar, where it enters the Punjab plains

Below Ropar, the river stands canalized in a comparatively narrow channel by embankments on both sides, spaced 914 to 1067 metres apart (3000 to 3500 ft.) up to Giderpindi. Here onwards, the embanments join the flood protection/river training works of Harike barrage on the left side and the West Bein Flood Protection embankment on the right side. There is a continuous flood protection embankment on the left side up to Hussainiwala. There is no continuous embankment along the river downstream of Hussainiwala except in selected vulnerable reaches. These embankments were mostly constructed during the period 1963 -1966

The concept of canalisation of the Satluj below Ropar owed its origin to the Bhakra dam project's perception that the bulk of the runoff that led to the flooding below the projected dam site would be stored in the reservoir and that the outflows from the reservoir would be regulated to the extent of the canal requirements. The gains between Bhakra and Ropar, based on actual observations spread over a long span of years were duly accounted for in the projected releases from Bhakra reservoir to meet the canal requirements It was concluded that the catchment up to Ropar will not contribute significantly to runoff below Ropar particularly from flood aspect.

The main purpose of these embankments was to keep the smaller spills, resulting from moderated flood discharges, away from the major portion of erstwhile riverbed area, which was intended to be reclaimed for agriculture purpose.

The canalised section from Ropar to Harike was designed to cater the last observed high flood level with sufficient free board. In the post construction stage, the embankment project showed promise of success as envisaged. But it came under stress after about a decade for the first time in 1973, then in 1975, 1978 and again in 1988. It is in the background of the 1973, 1975, 1978 and 1988 flood events that performance evaluation of the canalized section is described here under.

In 1973, the flood discharge escaping below Ropar caused as many as 20 breaches in the canalized section on both banks of the river due to erosion casued by meandering action of river current. The embankment could not withstand the meandering and out-flanking movements of the river current resulting from continuous discharge from Bhakra. In 1975, the river experienced heavy floods with recorded high flood levels since canalization. Although, these high flood levels were still lower than the designed ones by 2 feet, the water level rose almost up to the top of the banks and their over-topping was narrowly avoided by constructing dowels. During the flood season of 1978, high flood discharge of 1,10,000 cusecs was experienced at Ropar on 2-3 August, 1978. To this was added the flood discharge from torrents on both sides downstream Ropar. As a result of this, the HFL exceeded the design HFL by about 3.5 feet. The last designed HFL at Phillaur Railway bridge was 776.60 feet. Against this, the HFL on 3/8/78 was 780.1 feet i.e. 3.5 feet higher. As a result, the banks were over-topped at many places resulting in breaches at nine locations in the vicinity of villages Machhiwara, Mattewara, Kasabad, Talwandi, Laddowal, Khaire and Kot Umara, mostly in reaches where free board was inadequate i.e. less than designed.

There was a heavy rainfall in September 1988. The heaviest rainfall occurred on September 24-28, which gives rise to a very high flood in Satluj. The canalized section was designed to pass 2,00,000 cusecs discharges. For a discharge of 4,90,000 cusecs, the increase in high flood levels below Ropar should be 8 ft. and at Phillaur bridge, for a discharge of 6,30,000 cusecs the increase should be 12 ft. Such high flood levels could have resulted in overtopping and near complete destruction of the embankments. The flood level reported at Phillaur Bridge was RL 783.5 feet against the design high flood level RL 776.6 feet. The high flood level observed in 1978 at Railway marginal bund near Phillaur Railway bridge was RL 780.10 feet corresponding to a discharge of 3,55,000 cusecs against 6,30,000 cusecs in 1988. The rise in HFL on account of 2,75,000 cusecs additional discharge was 2.40 ft. There were remarkable breaches in the embankments. The spurs, shanks and other flood protection works suffered heavy damages.

3.1.5. Review of Damages

River channel below the Bhakra Reservoir may be divided/classified into 3 segments

1) Nangal -Ropar segment,

2) Ropar- Harike segment, and

3) Harike to Ferozepur segment.

Nangal- Ropar Segment

Nangal -Ropar segment of the Satluj channel consists of the original course of the river channel excepting that the active channel cross section has shrunk considerably due to absorption/moderation of floods by virtue of the Bhakra Dam. Riverbed cultivation and settlements have developed on the river channel fringes. The Nangal -Ropar catchment can generate flood discharges up to 2,00,000 cusec on its own. When flood releases from the Bhakra reservoir synchronize with the floods originating from the Nangal -Ropar catchment, the river inundates the areas adjoining its course, which originally were part of the river. Excepting local protection works, no embankments have been provided in this segment of the river channel.

Ropar- Harike Segment

This segment of the river channel has been canalized by construction of embankment on both sides. Studies carried out by some consultants in association with Punjab Engineering College, Chandigarh, have indicated that the channel capacity has been reduced significantly due to silting of the riverbed and wear and tear of the embankment section. In 1988, the embankments breached because of high discharge but in 1973 and 1978 it was found that breaches occurred even at low discharge.

Harike to Ferozepur Segments

In this segment of the river channel also, embankments have been constructed mostly on one side only with reference to high flood levels and not for any specified discharge. These embankments behave like all other similar flood protection embankments, which are liable to be out flanked/breached at high discharges. Meandering of the river current and scouring along the toes of the embankment aggravate the situation.

Since the river embankments are liable to breaches both at low floods and high floods, due to meandering at low floods and due to outflanking and over-topping at high floods. Damages are liable to occur in either case. Accordingly, the damages have been estimated with reference to low, medium and high floods.

3.2 FIELD VISIT

To get a feel of the existing ground condition, we went for the field visit. A field visit to some of the critical locations on Satluj River was made during April 5-6, 2005. The first point where shifting seems to be high is Phillaur in Luhdiana district. We reached Phillaur and discussed with the local people about the behaviour of the river. S.D.O Drainage Division, Phillaur, told that an embankment of 1 to 1.5 km have been provided on Satluj River in 1962. The reasons of shifting as told by him are due to mining of sand area and floods of the year 1988. Just before Phillaur, the behaviour of Satluj River was seen at a bridge (plate 1, 2 & 3). There we found that the river has shifted towards western direction. In plate 1 the river course at present is flowing towards west. The plate 2 shows important features of river Satluj and here one can see that the flood level was high during 1988-89. It means that due to flood during this period the river course was shifted. In plate 3, a pier of the bridge is shown where we can see the mark of water level which suggests that the river was passing through that point and now the course is far away from this point in left direction. Then we visited to Nakodar, another site where some shifting has taken place. There also we talked to local people and they also said that the river has shifted in that reach. The behaviour of the river (Plate 4) was observed from a bridge. Also construction of embankments is under progress at this site (Plate 5). Then we went to the last point of the river Satluj where it meets with river Beas, i.e., Harike site. The meeting point of these two rivers is shown in Plate 6.

3.3 DATA USED

For the present study, remote sensing data and Survey of India (SOI) toposheets were used. The details of the toposheets and satellite data used are given in Table 3.1 to Table 3.2 and depicted in Figure 3.2 and 3.3. These data were procured from Survey of India, Dehradun and National Remote Sensing Agency (NRSA), Hyderabad.

Table 3.1: List of topographical maps (Satluj River)

1:250,000		**1:50,000**	
No.	**Survey Year**	**No.**	**Survey Year**
44 I	1972-73	44 M/12	1957-58
44 M	1956-59	44 M/16	1957-58
44 N	1957-62, 1973-74	44 N/9	1958-59
53 A	1962-63, 1964-65	44 N/13	1958-59
53 B	1964-66, 1967-68	53 A/4	1964-65
		53 B/1	1964-65
		44 N/5	
		44 M/8	

Table 3.2: Remote sensing data used for the 1990, 1995, 1999 and 2003 (Satluj River)

LISSIII			**LISSII**		
Path/Row	**1999**	**2003**	**Path/Row**	**1990**	**1994/1995**
93-49	23/04/1999	25/04/2003	31-45 A2	10/11//1990	30/10/1995
94-49	28/04/1999	22/04/2003	30-46 A1	10/11/1990	30/10/1995
IRS 1 C PAN			31-46 A1	11/11/1990	22/02/1994
102-53 A	19/05/1999	01/05/2003	31-46 B1	11/11/1990	22/02/1994

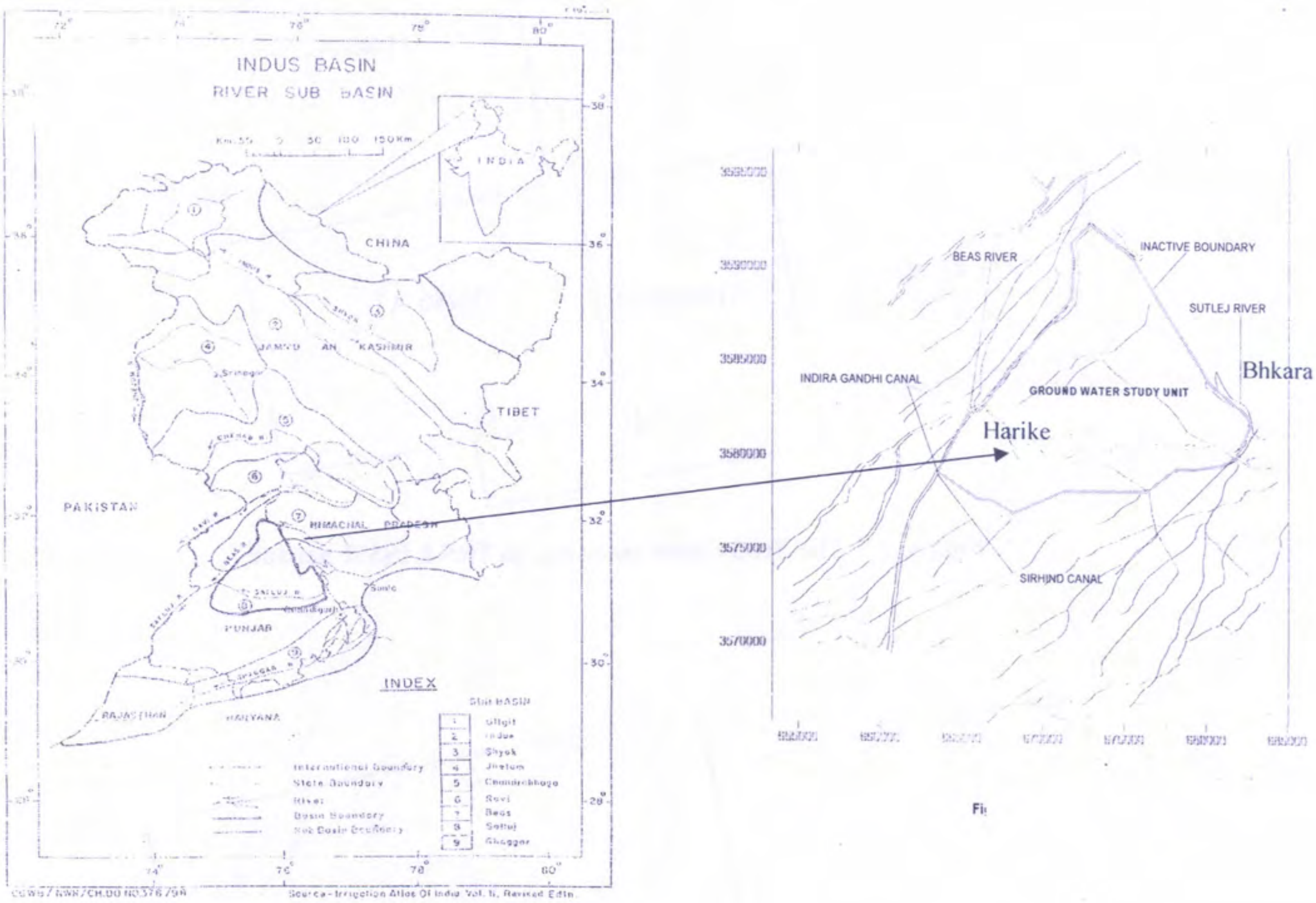


Figure 3.1 Location of the Satlui River

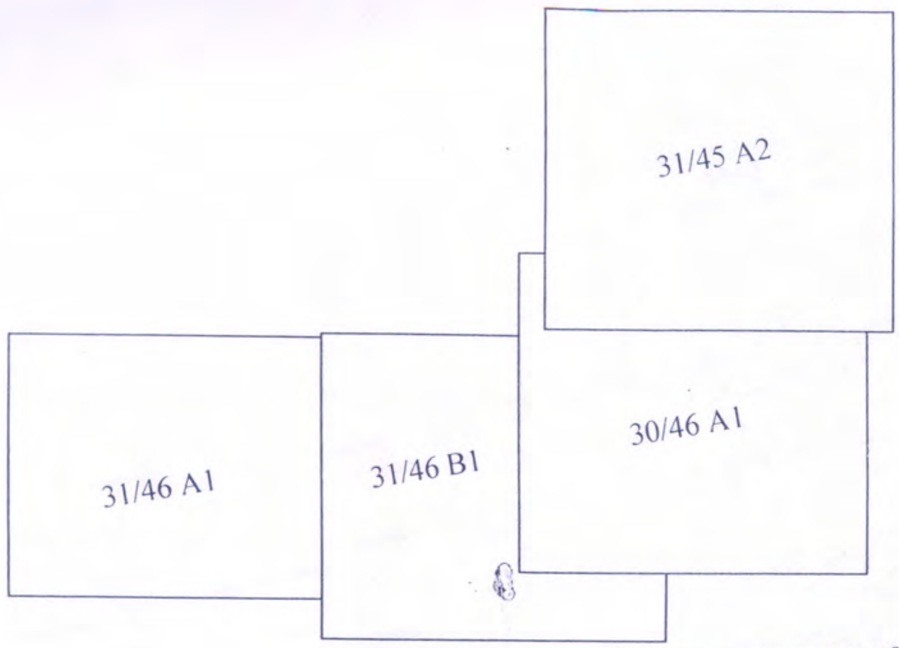


Figure 3.2 The Study area coverage in IRS LISSII Sensor

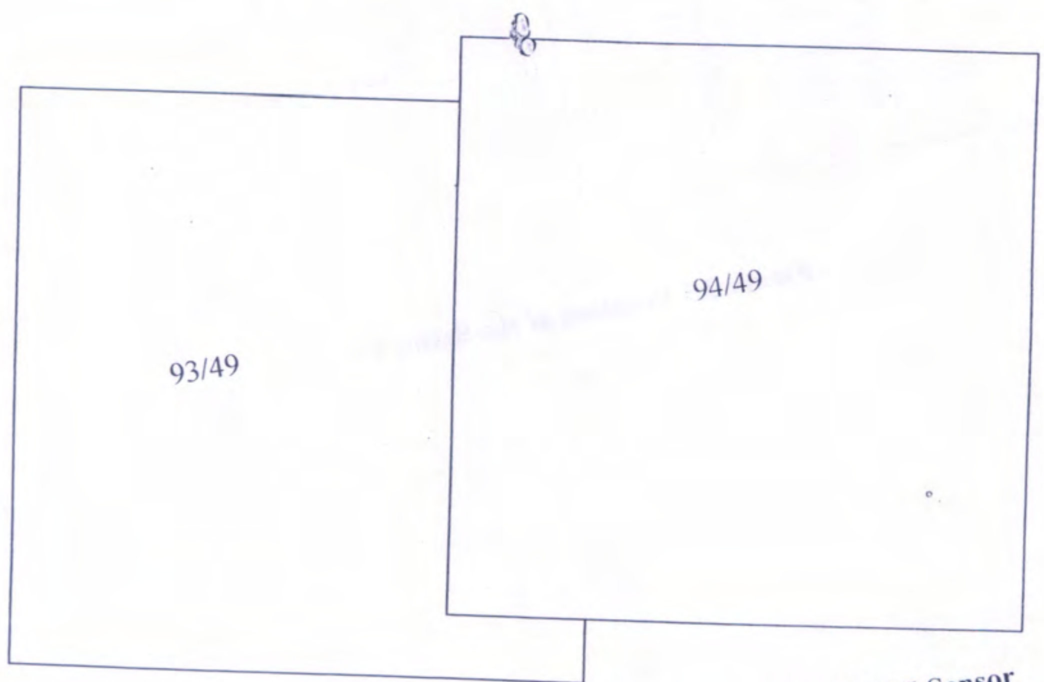


Figure 3.3 The Study area coverage in IRS LISSIII Sensor

Plate 1 : Satluj river at Phillaur (Railway bridge)

Plate 2 : Important features of Satluj River at Phillaur

Plate 3 : Satluj River at Phillaur (Below railway bridge)

Plate 4 : Satluj River at Nakodar showing flood

Plate 5 : Embankment along Satluj River at Ludhiana

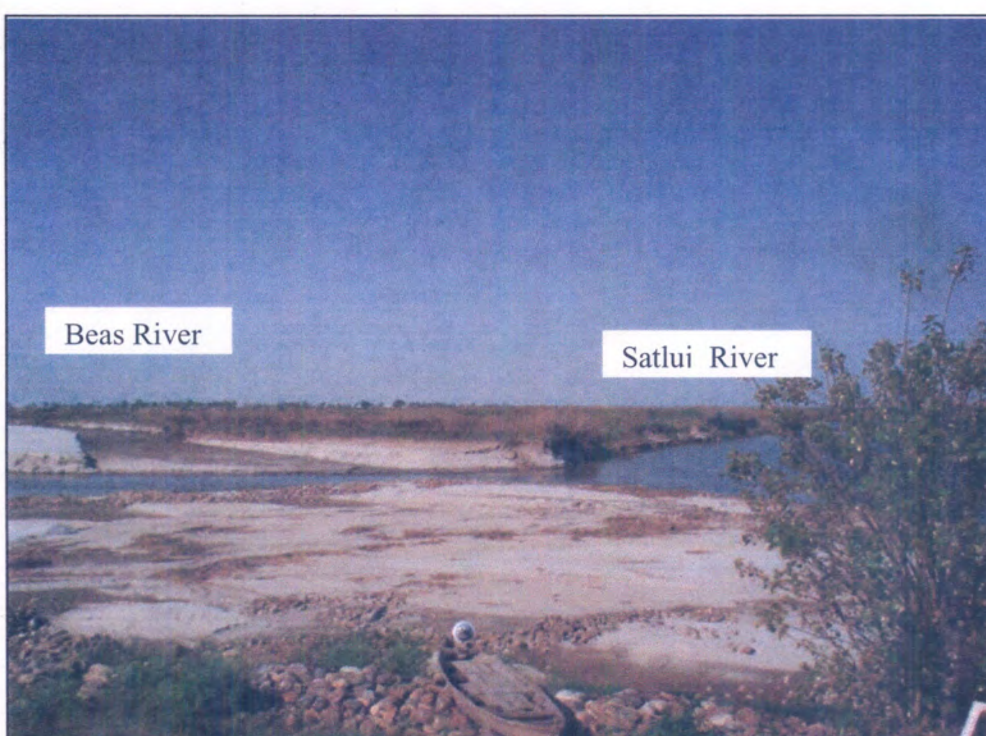


Plate 6 : Satluj River at Harike meeting with Beas River

Plate 5 : Embankment along bank of Ludhiana

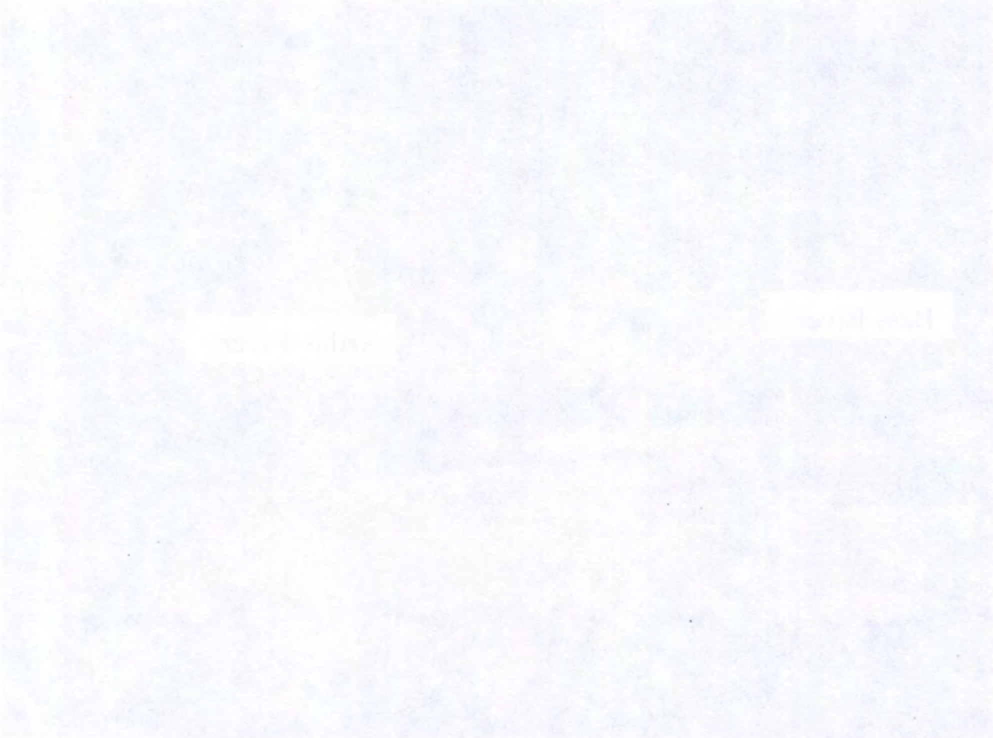


Plate 6 : Satluj River at Harike meeting with Beas River

CHAPTER 4

METHODOLOGY

In this study, Survey of India toposheets and satellite data have been used to delineate the course of Satluj River. All the digital maps were geo-referenced with the same projection and then the shifting course of the river eas studied in a GIS environment in the ERDAS Imagine 8.5.

The remote sensing data were analysed to identify the water bodies and thereby which represents the river course. In the present study, the river course for all the years were delineated using digital analysis of IRS-1C LISS-II and LISS-III and PAN digital data.

4.1 CREATION OF DATA BASE

The river course has been delineated from Survey of India toposheets at a scale of 1:250,000. The analog maps were converted to digital form through scanning. These digital data was then edited and converted to vector form using R2V software. The drainage map and boundary maps were then imported to Integrated Land and Water Information System (ILWIS) GIS Software.

4.2 PROCESSING OF REMOTE SENSING DATA

4.2.1 Import and Visualisation

The data of IRS satellite of LISS-II and LISS-III sensors for different dates pertaining to the years 1990, 1995, 1999 and 2003 were obtained from NRSA on CD-ROM media. The data were processed and analysed using the ERDAS Imagine 8.5 software.

Initially, each band was checked individually for the pixel values. The spectral and spatial profile tools of ERDAS Imagine were used to check for the pixel values of water, soil and vegetation and verify whether the bands 1, 2, 3 and 4 correspond to the actual red, green, NIR and MIR bands. It was found that the bands specified by NRSA represent the true bands. Subsequently, False Colour Composite's (FCC's) of bands 3, 2 and 1 were prepared for all the scenes and used.

4.2.2 Geo-referencing

While using the temporal satellite data, it is required to geo-reference the imageries of different dates. These images were first registered by taking various control points from the Survey of India (SOI) toposheets. The projection type used was polyconic. Some clearly identifiable features like crossing of roads, railways, canals, bridges etc. located on toposheets and image was selected as control points. Some of the points, which generated big errors, were deleted and replaced by other points so as to obtain satisfactory geo-referencing. The error in geo-referencing was less than one pixel. Then using swipe function the matching of image with toposheet was checked.

4.2.3 Mosaicing

After geo referencing, the scenes were joined together to cover the full reach of the river course. For this purpose Mosaic function was used in ERDAS. For LISS II data, Satluj River is covered in four scenes and after stitching, the total product is shown in Figure 4.1 and 4.2 for the year 1990 and 1995. For LISS III data, this river is covered in two scenes and shown in Figure 4.3 and 4.4 for the years 1999 and 2003. The PAN data for two locations was taken for detailed analysis and shown in Figures 4.5 and 4.6 for the years 1999 and 2003 respectively.

4.2.4 Separation of Area of Interest (AOI)

The sizes of the full scenes of the satellite remote sensing data were large in comparison to the study area. Hence, the study area was separated from the full image using a utility in the ERDAS Imagine software, namely, area of interest (AOI). A polygon was digitized which covered the entire study area and some portions surrounding it. The data corresponding to the AOI was saved in a new file. Separation of the area of interest from the full scene resulted in less consumption of computer space and appreciable reduction of analysis time.

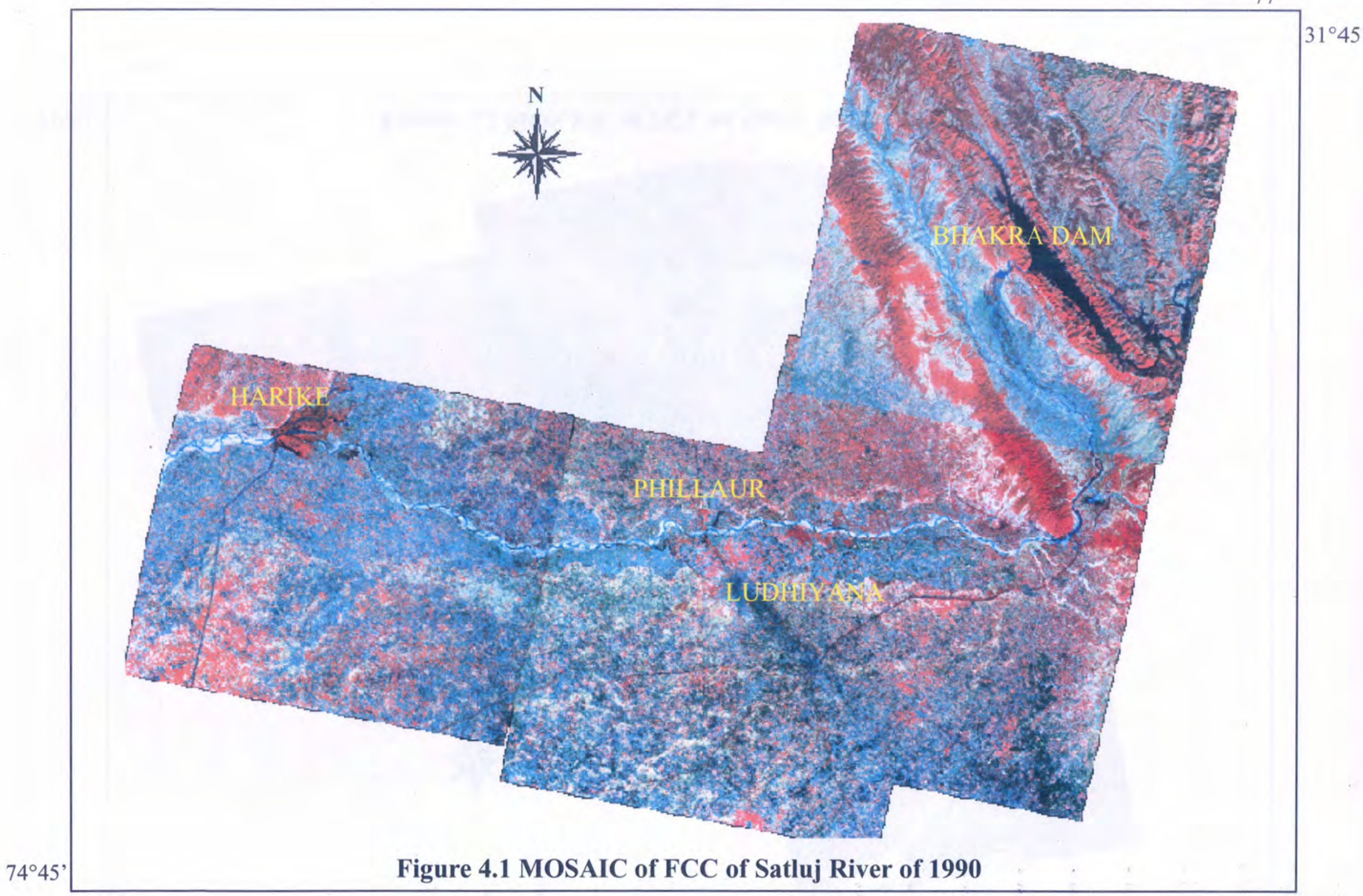


Figure 4.1 MOSAIC of FCC of Satluj River of 1990

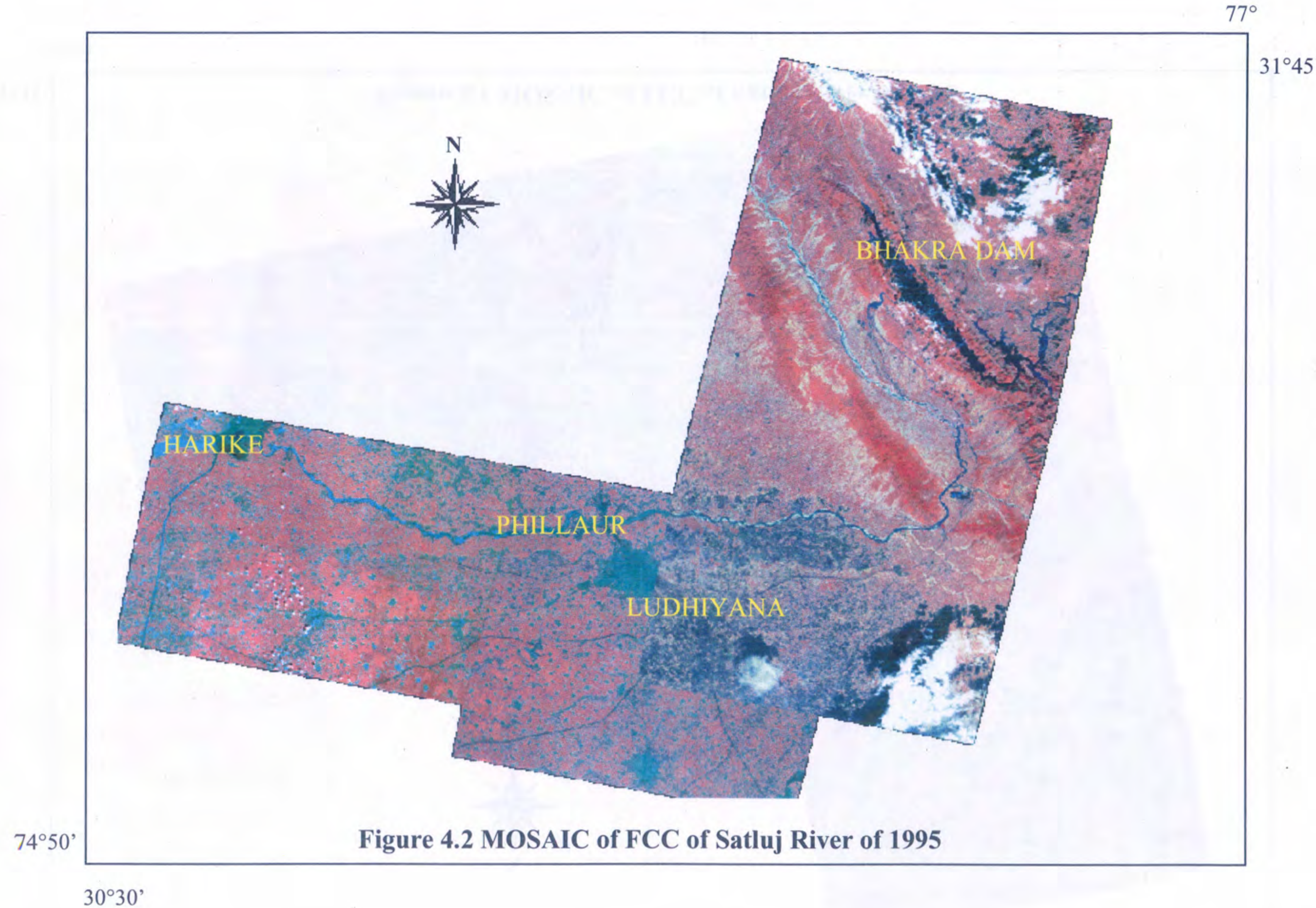


Figure 4.2 MOSAIC of FCC of Satluj River of 1995

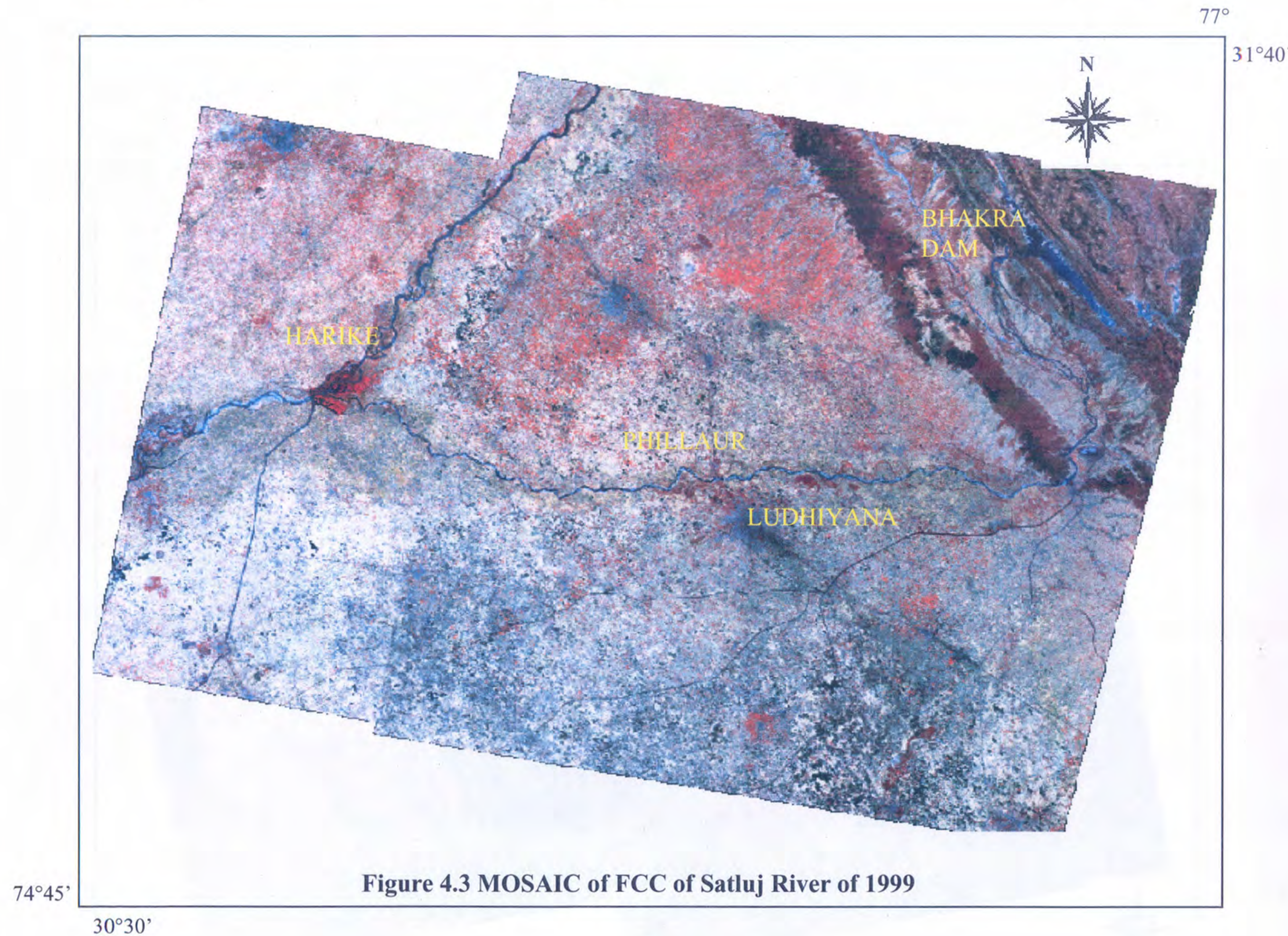


Figure 4.3 MOSAIC of FCC of Satluj River of 1999

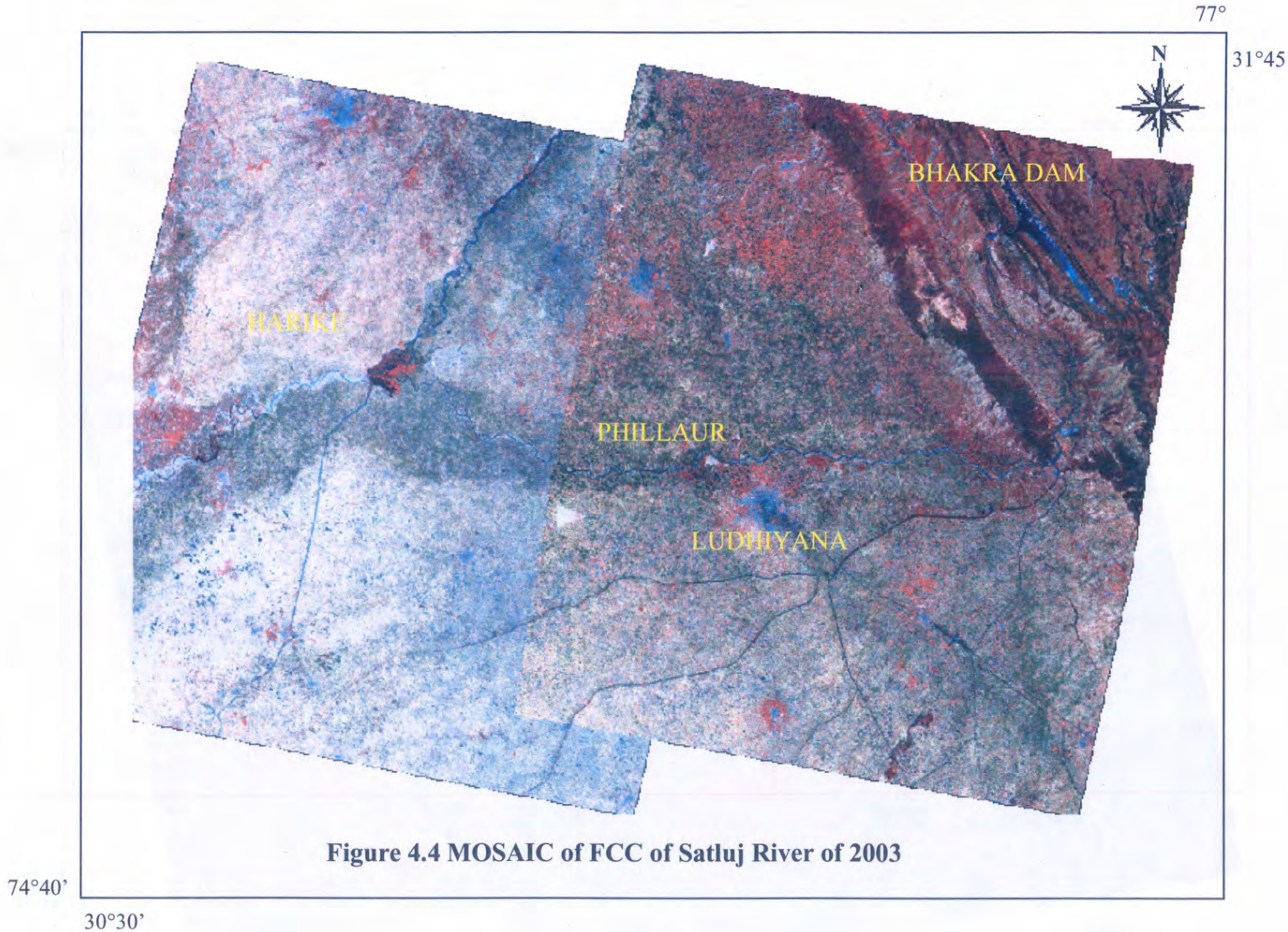


Figure 4.4 MOSAIC of FCC of Satluj River of 2003

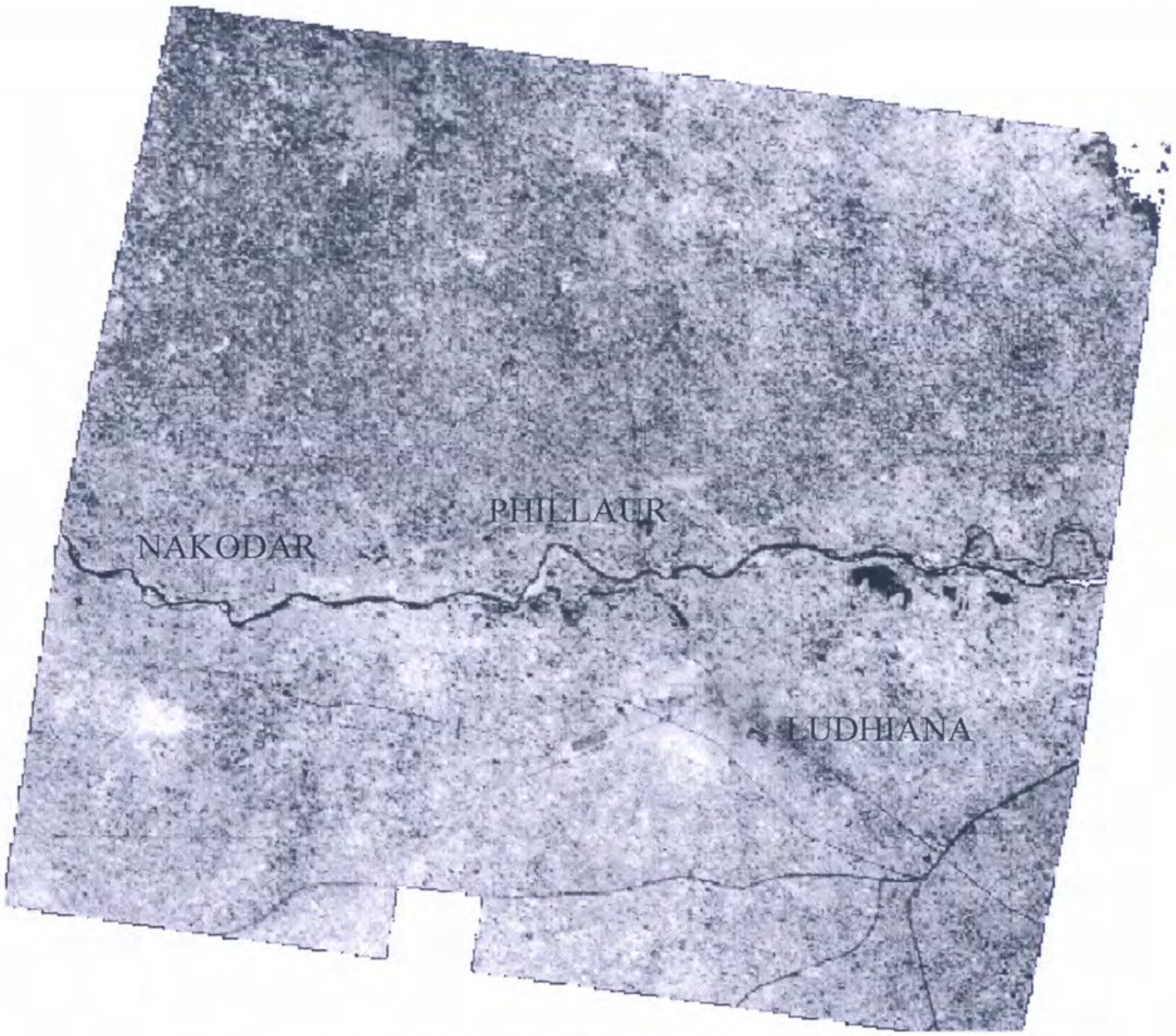


Figure 4.5 PAN IMAGE OF SATLUJ RIVER 1999

4.3 DELINEATION OF RIVER COURSE FROM REMOTE SENSING DATA

The remote sensing data were analysed to determine the water spread area, which represents the river course. There are two techniques of remote sensing data interpretation, i.e. visual and digital, for delineation of the water spread area. The visual techniques are purely based on the interpretative capability of the analyst and it is not possible to use the information of different bands, after the visual product is generated. Around the periphery of the water spread area, the wetland appears very similar to the water pixels and it becomes very difficult for the eye to decide whether a pixel near the periphery is to be classified as water or land. Using digital techniques, the information of different bands can be utilised to the maximum extent and consistent analysis can be carried out over the entire area. It is also easy to compute the water spread area. For these reasons, digital techniques are superior and are gaining recognition now-a-days.

In the present study the river course from all the years were delineated using digital analysis of IRS-1C LISS-III digital data in the Digital Image Processing (DIP) Software – ERDAS Imagine 8.5.

4.3.1 IDENTIFICATION OF WATER AREA

Numerous vegetation indices have been developed to estimate vegetation cover/water area etc. with the remotely sensed imagery. A vegetation index is a number that is generated by some combination of remote sensing bands. The most common spectral index used to evaluate vegetation cover is the Normalized Difference Vegetation Index (NDVI). McFeeters (1996) developed an index similar to the NDVI, which is called the NDWI. This stands for the Normalized Difference Water Index. Data of any instrument having a green band and a near infrared band can be used to compute this index. The NDWI was derived using principles similar to those that were used to derive the NDVI. The NDWI is calculated as follows:

$$\mathrm{NDWI} = \frac{(\mathrm{GREEN} - \mathrm{NIR})}{(\mathrm{GREEN} + \mathrm{NIR})} \qquad (2)$$

where GREEN is a band that encompasses reflected green light and NIR represents reflected near-infrared radiation. The selection of these wavelengths was done to: (1) maximize the typical reflectance of water features by using green light wavelengths; (2) minimize the low reflectance of NIR by water features; and (3) take advantage of the high reflectance of NIR by terrestrial vegetation and soil features. When equation (2) is used to process a multi-spectral satellite image that contains a reflected visible green band and an NIR band, water features have positive values; while soil and terrestrial vegetation features have zero or negative values, owing to their typically higher reflectance of NIR than green light. Image processing software can easily be configured to delete negative values. This effectively eliminates the terrestrial vegetation and soil information and retains the open water information for analysis. The range of NDWI is then from zero to one. Multiplying equation (2) by a scale factor (e.g. 255) enhances the resultant image for visual interpretation. Now in the output obtained water related features were identified. The river course obtained in this way is having gaps in some parts, which have been improved manually using digitizing tools in ERDAS. The above methodology is depicted in the form of flow chart in Figure 4.6.

4.4 COMPUTATION OF SHIFTING

Shifting of the river is calculated with the help of offsets drawn from a base line. The river course as obtained from ERDAS has been exported to ILWIS software. The base line has been drawn connecting first and last point of the river reach. Then at a regular interval of 5 km, offsets have been drawn from base line. The length offsets have been measured with respected to both the banks. Offsets at fixed interval of the both riverbanks were measured on the topographical maps as well as on the maps prepared from satellite data. From these measurements, the respective shifts of the both the left and the right banks were computed. The offsets of a part of the total reach are shown in Figure 4.7 the river. Details for offsets are given in Table 4.1 and 4.2.

Shifting is calculated by:

Shifting = offset distance for map – offset distance for image

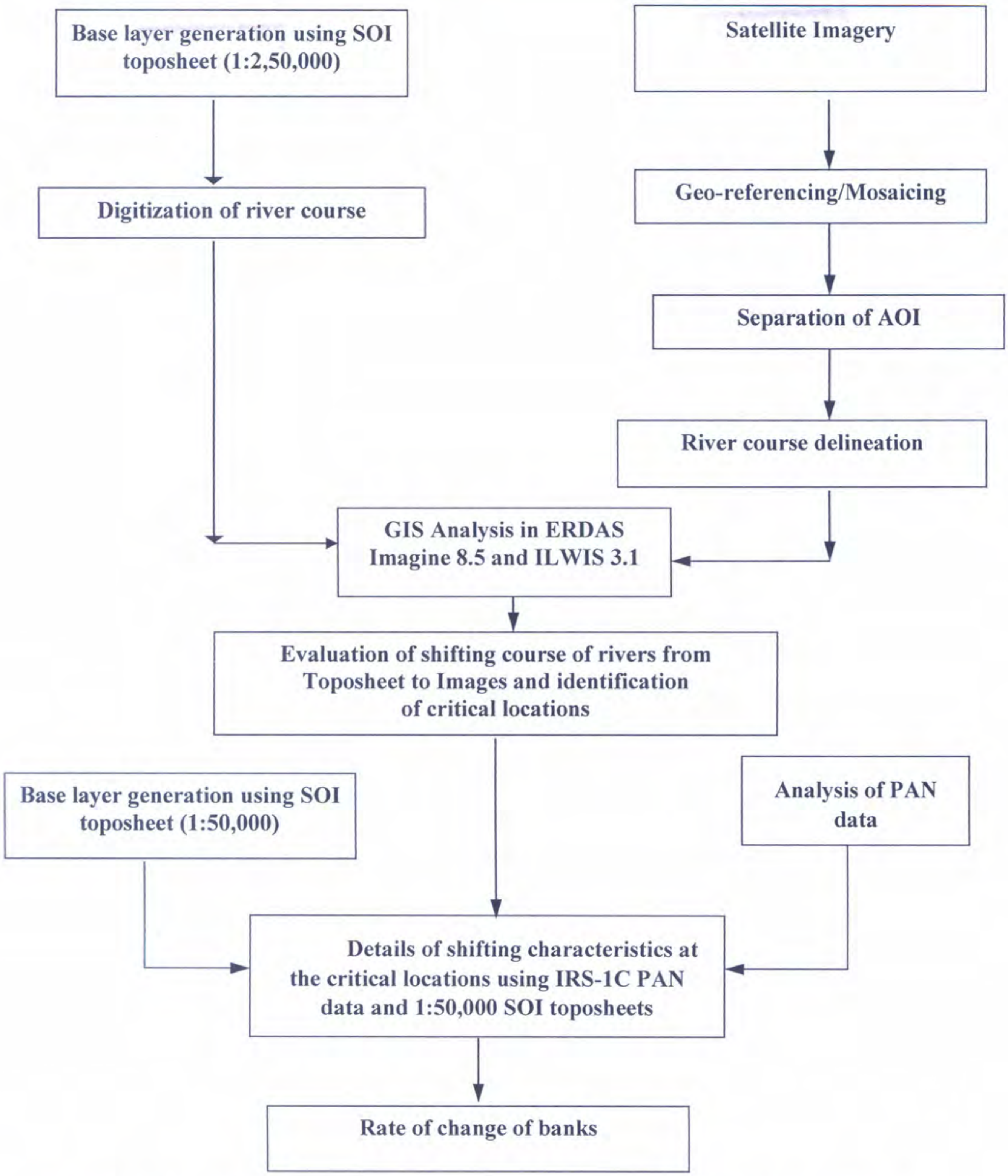


Figure 4.6 : Flow chart showing details of methodology for delineation of river course

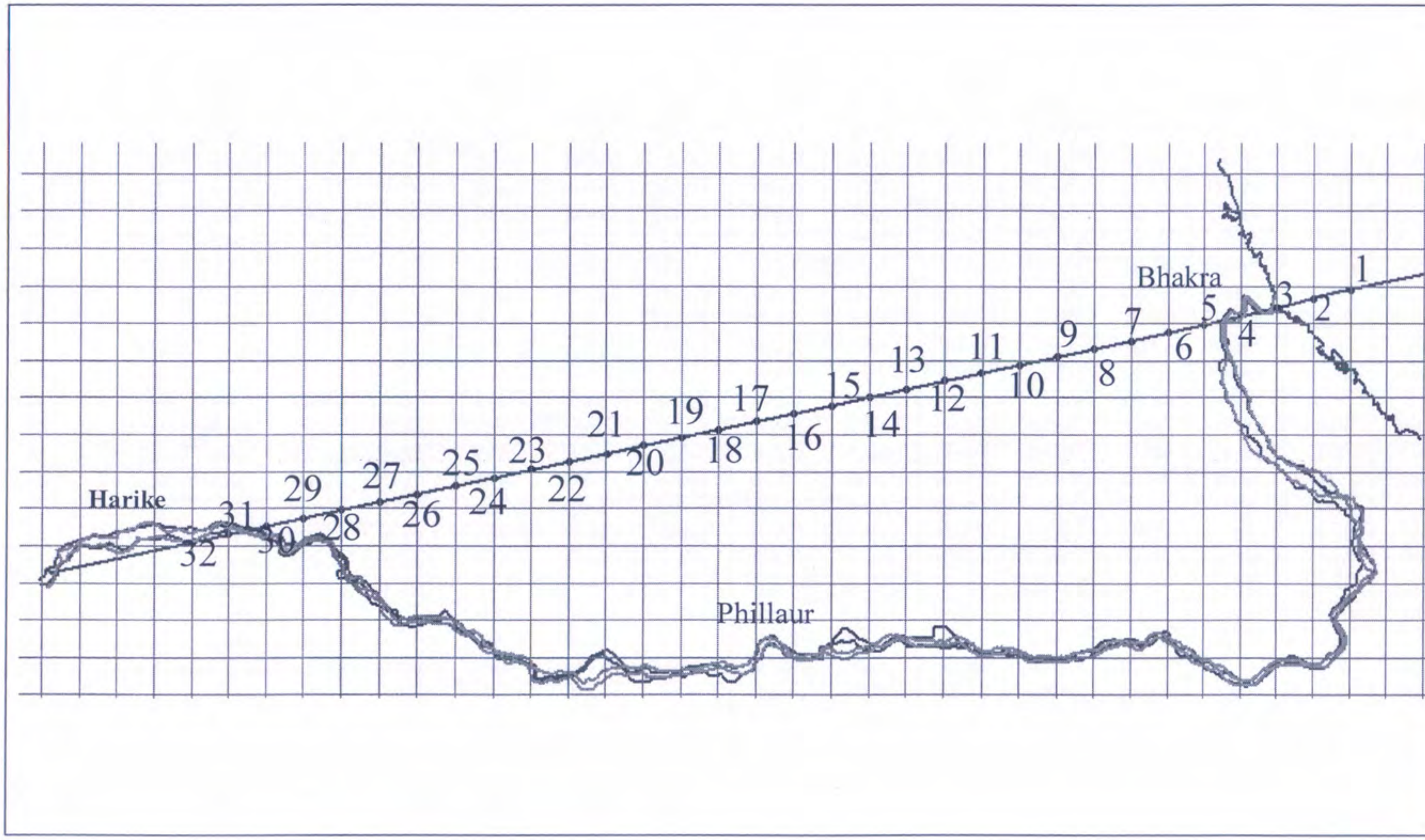


Figure 4.7 OFFSETS SATLUJ RIVER LISS II

Table 4.1: Length of offsets and shifting in meter at an interval of 5 kms from the starting point for Satluj River

Point No.	Toposheet		Image 1990		Image 1995		Image99		Image2003		Topo-img90		topo-img95	
	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank
1	9419.4	14358.8	8845.05	14358.8	8823.2	14479.3	9275.67	14403.7	9419.4	14358.8	574.35	0	596.2	-120.46
2	19869.3	21033.2	21116.4	20118.7	20059.6	20813.7	20135	20738.3	19987.5	21021.3	-1247	914.49	-190.26	219.51
3	24026.1	26437	23194.7	25938.2	23151.5	25715.5	23226.9	23981	23203.9	23778.2	831.35	498.81	874.61	721.52
4	28182.9	30510.6	28099.7	29097.3	28279.5	29033.6	28354.9	29184.4	28373.1	29292	83.13	1413.3	-96.64	1477.03
5	42149.6	40071.2	41733.9	41235.1	41702.8	41250.4	41929.1	41401.2	41812.9	41353.4	415.67	-1163.9	446.75	-1179.16
6	49798	49216.1	49631.8	49216.1	49621.1	49244	49545.7	49319.4	49509.3	49394.4	166.27	0	176.94	-27.95
7	48301.6	47719.6	48218.5	47636.5	48188.3	47660.4	48339.1	47962	48590.3	48245.7	83.13	83.13	113.33	59.26
8	49548.6	48883.5	49714.9	49049.8	49621.1	48716.1	49885	49696.5	49853.9	49394.4	-166.27	-166.27	-72.47	167.39
9	45973.8	45391.9	46056.9	45391.9	45548.8	45322.6	45699.7	45322.6	45603.7	45259.1	-83.14	0	424.95	69.25
10	41401.4	40403.7	41733.9	41152	41401.2	41024.1	41627.4	41174.9	41698.1	41353.5	-332.54	-748.22	0.18	-620.39
11	40736.3	40237.5	41235.1	40653.1	41778.2	41552	41627.4	41552	41812.9	41468.3	-498.81	-415.68	-1042	-1314.54
12	41235.1	40486.9	41401.4	40486.9	41174.9	40647.1	41401.2	41099.5	41353.5	41123.7	-166.28	0	60.14	-160.19
13	41318.2	40902.5	41235.1	40403.7	40647.1	40420.8	40722.5	40496.2	41008.9	40434.5	83.14	498.81	671.16	481.72
14	39323	38824.2	38907.3	38491.6	39666.7	39063.4	38912.6	38687.2	38941.2	38711.4	415.67	332.54	-343.73	-239.25
15	38086	37674.7	38242.2	37327.7	38083.1	37103	38309.3	37706	38366.8	37792.5	-156.25	346.95	2.92	571.72
16	36029.5	33232.7	35581.9	35083.1	35820.7	35368.3	35368.2	35292.8	35495.1	35150.4	447.6	-1850.4	208.8	-2135.62
17	34466.6	33561.7	34085.5	33669.8	33709.2	33558.3	33860	33558.3	33886.9	33599.7	381.12	-108.06	757.42	3.39
18	34055.3	33150.4	34418	33836.1	34463.3	34237	34086.2	33784.6	34231.9	33829.4	-362.71	-685.62	-407.99	-1086.61
19	32327.8	32081.1	33586.6	32755.3	33558.3	33407.5	33784.6	33407.5	33657.1	33312.5	-1258.8	-674.23	-1230.5	-1326.45
20	32903.7	32163.3	33087.8	32755.3	33181.4	32728.8	33256.7	32955	33197.6	32910.5	-184.18	-591.97	-277.71	-565.48
21	32492.4	31669.8	32339.6	31009.5	32728.8	32427.2	30994.3	30315.6	31417.1	31015.1	152.74	660.31	-236.45	-757.39
22	33150.4	31834.3	32173.3	31508.3	32050.1	31748.4	32351.7	32050.1	32336.1	32106.4	977.09	326.02	1100.34	85.84
23	32163.3	31423	32007.1	31425.1	31597.6	31296	32050.1	31522.2	32106.4	31589.5	156.25	-2.15	565.7	127.01
24	31834.4	29942.3	30593.8	29679.3	30843.5	30617.3	30768.1	30391	30900.2	30211	1240.62	263.04	990.89	-674.94
25	27474.6	26652	30344.4	29097.3	30164.8	29863.1	30089.4	29335.3	30096.1	29694.1	-2869.8	-2445.4	-2690.2	-3211.19
26	29037.5	28790.7	28931.1	28349.1	28656.6	28354.9	28581.1	28279.5	28660.3	28373.1	106.4	441.57	380.92	435.79
27	26569.7	26158.4	27185.2	25688.8	26922.1	26620.4	27751.6	26168	27741.3	26190.5	-615.53	469.61	-352.38	-462.03
28	23114.8	22703.5	23652	23070	23528.5	23000.7	24056.4	23754.8	23720.8	23548.5	-537.17	-366.51	-413.73	-297.13
29	18960.7	18088.1	19495.2	18372.9	18890.7	18400.5	19418.6	18815.3	19298.3	19126	-534.49	-284.75	70.03	-312.38
30	17850.2	16780.9	17250.6	16627.1	16741.5	16590.6	17307.1	17005.4	17115.7	16914.7	599.67	153.81	1108.77	190.22
31	13984.1	12709.1	13260.1	13135.4	13159.4	12857.7	13008.6	12631.5	12980.4	12808.1	723.98	-426.27	824.66	-148.64
32	6307.89	5944.17	7710.79	7128.85	7164.14	7013.31	8069.08	7767.43	7969.16	7380.44	-1402.9	-1184.7	-856.25	-1069.14
33	3689.13	3117.57	3315.02	2847.38	2865.66	2752.54	3091.89	2978.77	3115.87	2986.64	374.11	270.19	823.47	365.03

34	1434.08	997.62	1662.71	1486.04	1508.24	1282	1206.59	867.24	962.04	804.45	-228.63	-488.42	-74.16	-284.38
35	-800.18	-1558.79	-924.88	-1091.2	-867.24	-1055.8	-1131.2	-1319.7	-1234.9	-1392.81	124.7	-467.64	67.06	-503.02

topo-img99		topo-img2003		img90-img95		img95-img99		img99-2003		img90-img2003	
leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank	leftbank	rightbank
143.73	-44.85	0	0	21.85	-120.46	-452.47	75.61	-143.7	44.85	-574.35	0
-265.67	294.93	-118.2	11.88	1056.8	-694.98	-75.41	75.42	147.49	-283.05	1128.84	-902.61
799.2	2456	822.2	2658.77	43.26	222.71	-75.41	1734.5	23	202.77	-9.15	2159.96
-172.05	1326.2	-190.2	1218.6	-179.77	63.73	-75.41	-150.83	-18.16	-107.6	-273.34	-194.7
220.51	-1330	336.63	-1282.2	31.08	-15.27	-226.24	-150.83	116.12	47.76	-79.04	-118.34
252.35	-103.4	288.74	-178.34	10.67	-27.95	75.41	-75.42	36.39	-74.97	122.47	-178.34
-37.5	-242.4	-288.7	-526.07	30.2	-23.87	-150.83	-301.65	-251.2	-283.68	-371.87	-609.2
-336.41	-813	-305.3	-510.88	93.8	333.66	-263.94	-980.35	31.13	302.08	-139.01	-344.61
274.13	69.25	370.11	132.79	508.09	69.25	-150.82	0	95.98	63.54	453.25	132.79
-226.05	-771.2	-296.7	-949.73	332.72	127.83	-226.23	-150.82	-70.66	-178.52	35.83	-201.51
-891.14	-1315	-1077	-1230.9	-543.16	-898.86	150.83	0	-185.5	83.67	-577.86	-815.19
-166.1	-612.7	-118.4	-636.85	226.42	-160.19	-226.24	-452.47	47.72	-24.19	47.9	-636.85
595.75	406.31	309.37	468.05	588.02	-17.09	-75.41	-75.41	-286.4	61.74	226.23	-30.76
410.39	136.99	381.8	112.73	-759.4	-571.79	754.12	376.24	-28.59	-24.26	-33.87	-219.81
-223.32	-31.31	-280.8	-117.79	159.17	224.77	-226.24	-603.03	-57.53	-86.48	-124.6	-464.74
661.27	-2060	534.44	-1917.8	-238.8	-285.22	452.47	75.49	-126.8	142.37	86.84	-67.36
606.59	3.39	579.71	-37.97	376.3	111.45	-150.83	0	-26.88	-41.36	198.59	70.09
-30.93	-634.1	-176.6	-679	-45.28	-400.99	377.06	452.47	-145.7	-44.86	186.08	6.62
-1456.7	-1326	-1329	-1231.5	28.31	-652.22	-226.24	0	127.45	95	-70.48	-557.22
-353.03	-791.7	-294	-747.14	-93.53	26.49	-75.32	-226.24	59.04	44.58	-109.81	-155.17
1498.03	1354.1	1075.2	654.66	-389.19	-1417.7	1734.5	2111.5	-422.8	-699.48	922.47	-5.65
798.69	-215.8	814.32	-272.09	123.25	-240.18	-301.65	-301.65	15.63	-56.28	-162.77	-598.11
113.23	-99.23	56.95	-166.47	409.45	129.16	-452.47	-226.24	-56.28	-67.24	-99.3	-164.32
1066.3	-448.7	934.17	-268.68	-249.73	-937.98	75.41	226.23	-132.1	180.03	-306.45	-531.72
-2614.8	-2683	-2622	-3042.1	179.58	-765.8	75.41	527.88	-6.75	-358.82	248.24	-596.74
456.33	511.2	377.22	417.62	274.52	-5.78	75.41	75.41	-79.11	-93.58	270.82	-23.95
-1181.9	-9.56	-1172	-32.12	263.15	-931.64	-829.53	452.47	10.33	-22.56	-556.05	-501.73
-941.61	-1051	-606	-844.98	123.44	69.38	-527.88	-754.12	335.62	206.27	-68.82	-478.47
-457.85	-727.2	-337.5	-1037.8	604.52	-27.63	-527.88	-414.77	120.3	-310.69	196.94	-753.09

543.18	-224.5	734.49	-133.85	509.1	36.41	-565.59	-414.76	191.31	90.69	134.82	-287.66
975.48	77.59	1003.7	-98.99	100.68	277.63	150.82	226.23	28.18	-176.58	279.68	327.28
-1761.2	-1823	-1661	-1436.3	546.65	115.54	-904.94	-754.12	99.92	386.99	-258.37	-251.59
597.24	138.8	573.26	130.93	449.36	94.84	-226.23	-226.23	-23.98	-7.87	199.15	-139.26
227.49	130.38	472.04	193.17	154.47	204.04	301.65	414.76	244.55	62.79	700.67	681.59
331	-239.1	434.68	-165.98	-57.64	-35.38	263.94	263.94	103.68	73.1	309.98	301.66

CHAPTER 5

ANALYSIS AND RESULTS

5.1 DESCRIPTION OF REACHES OF THE RIVERS

As mentioned in the last chapter, offsets at selected interval have been drawn. The total length of the river has been divided in a number of reaches and the details are as follows:

In order to carry out detail analysis for river shifting and morphological parameters, the total length of Satluj River from Bhakra dam to Harike has been subdivided at a interval of 5 km. A base line joining these two stations has been drawn. The total length (175 km u/s of Bhakra dam to d/s of Harike) of this base line is subdivided into seven reaches of 25 km length. Analysis for each part is discussed in the following sections.

0 to 25 km	Reach 1	u/s of Bhakra dam to Nurpur
25 to 50 km	Reach 2	Nurpur to Talwandi
50 to 75 km	Reach 3	Talwandi to Phillaur
75 to 100 km	Reach 4	Phillaur to Baghel
100 to 125 km	Reach 5	Baghel to Bahmanhan
125 to 150 km	Reach 6	Bahmanhan to Bhutiwala
150 to 175 km	Reach 7	Bhutiwala to d/s of Harike

5.2 REACH WISE ANALYSIS OF SHIFTING OF RIVER

The shift of both the banks at different chainage (5 km) is given in the Table 4.1 and 4.2 in Chapter 4. As discussed earlier, some of the reaches are having more shift and these are described as the critical locations. In Satluj River, shifting is high at Nawa Shahar, Phillaur, Nurmahal and Nakodar. The FCCs of the river reach are also shown in Figure 5.1 to 5.4 for the years 1990 to 2003.

The data given in Table 4.1 are also plotted and chainage of 5 km interval has been taken on abscissa and shifting on ordinate. The Figures for River Satluj has been given in Figures 5.5 to 5.8. Some of the critical areas identified in the river was further studied using IRS PAN data and also the river course of these reaches was prepared using toposheets at a scale of 1:50,000 (Figure 5.9). The analysis of the same has been presented later in this chapter. In the following analysis, first the shifting with respect to toposheets has been presented and then shifting in different years with respect to satellite data has been covered. The results here are presented for each reach as described above.

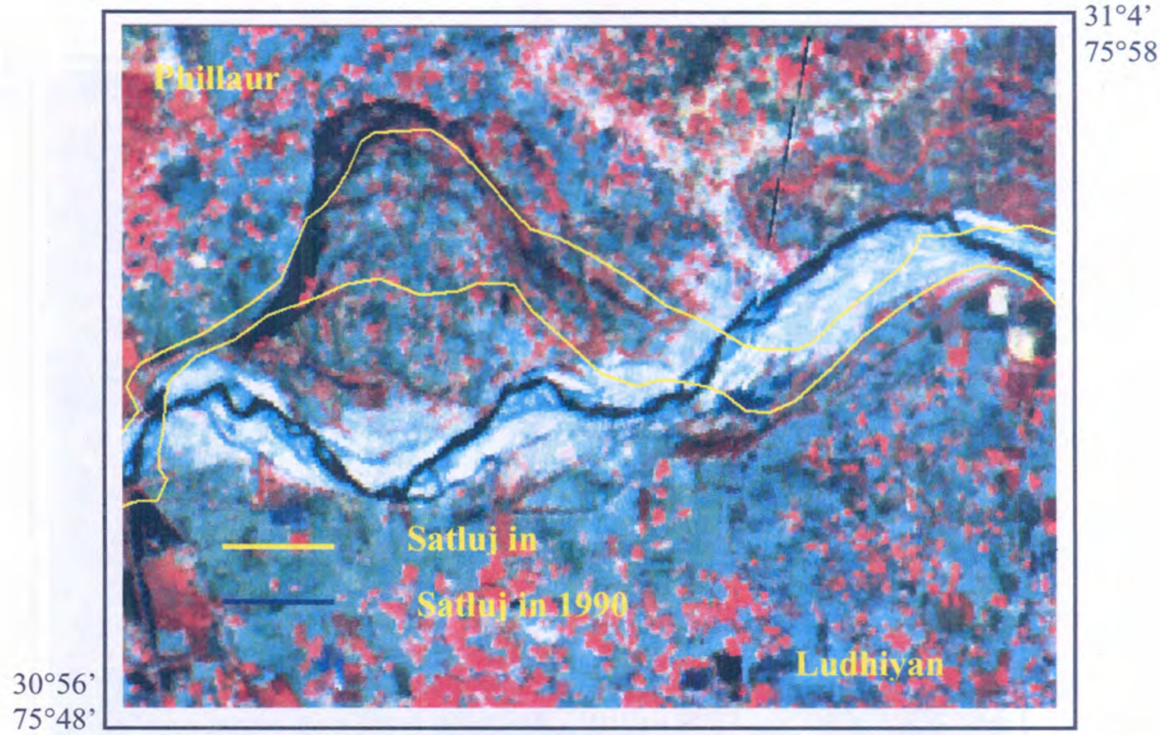


Figure 5.1 False Colour Composite (1990) overlaid by drainage from toposheet (Phillaur)

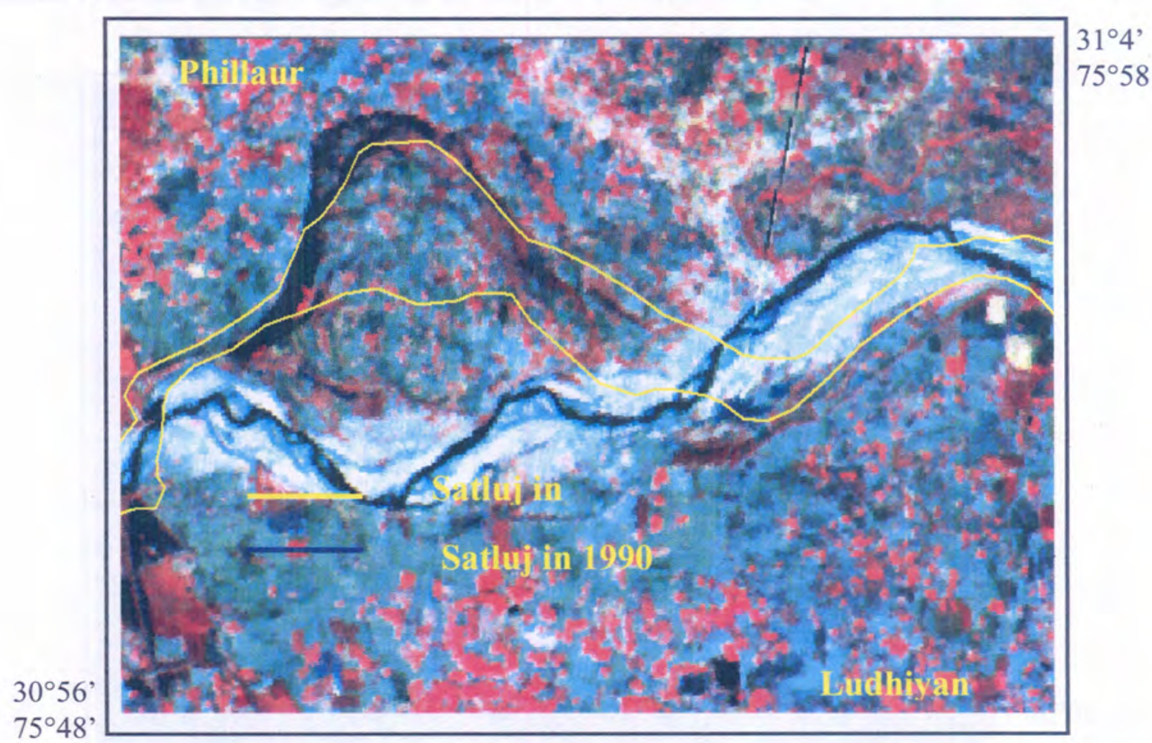


Figure 5.2 False Colour Composite (1995) overlaid by drainage from toposheet (Phillaur)

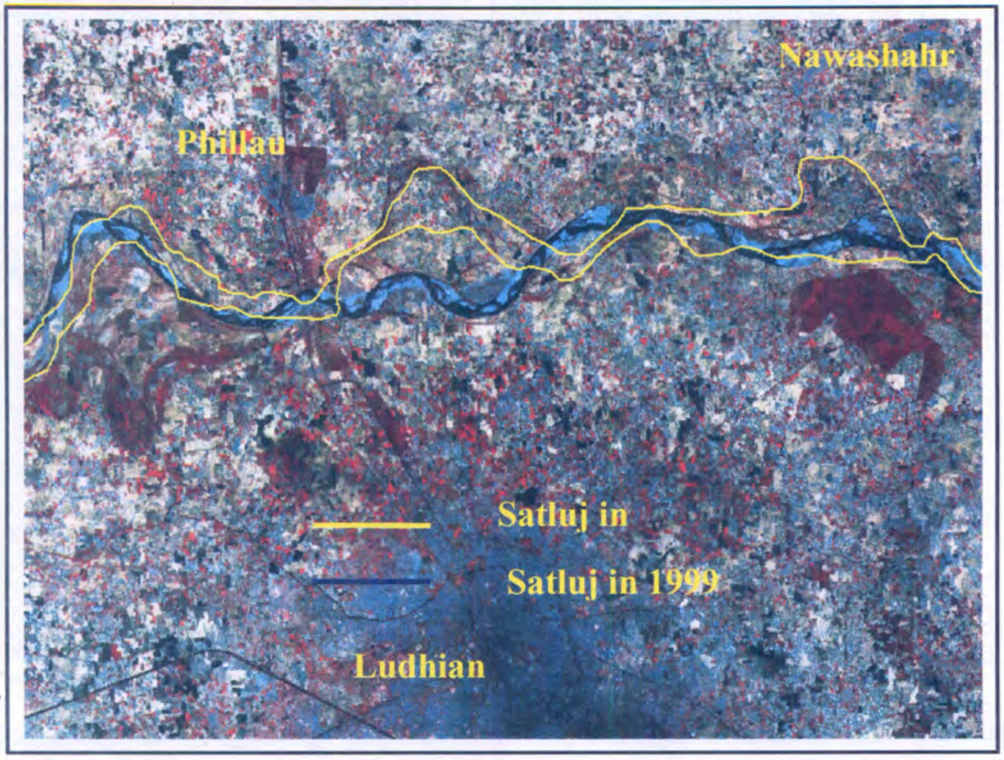


Figure 5.3 False Colour Composite (1999) overlaid by drainage from toposheet (Phillaur)

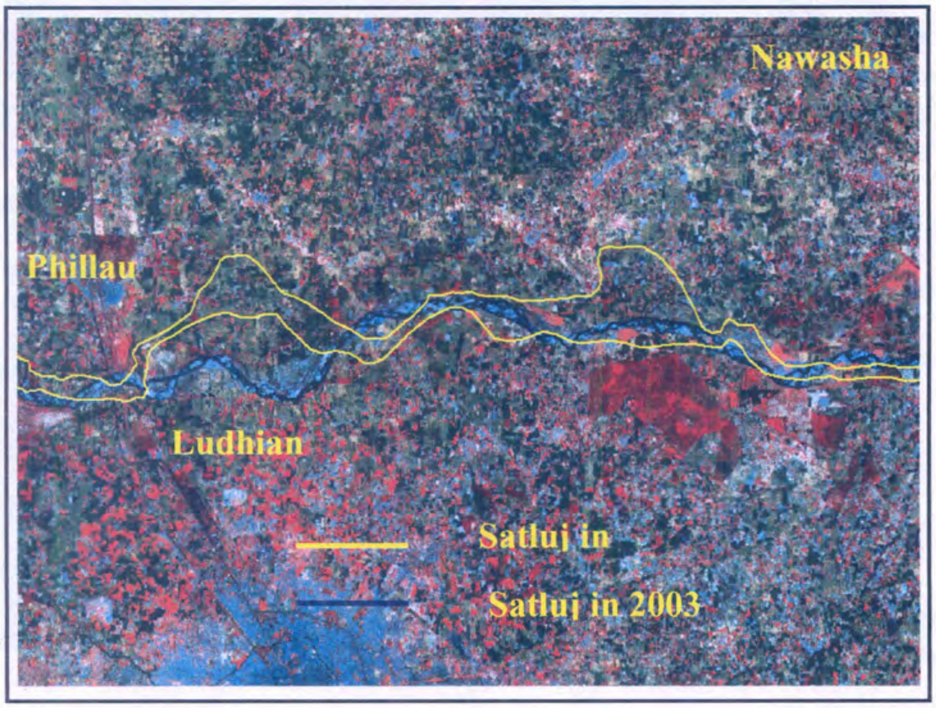
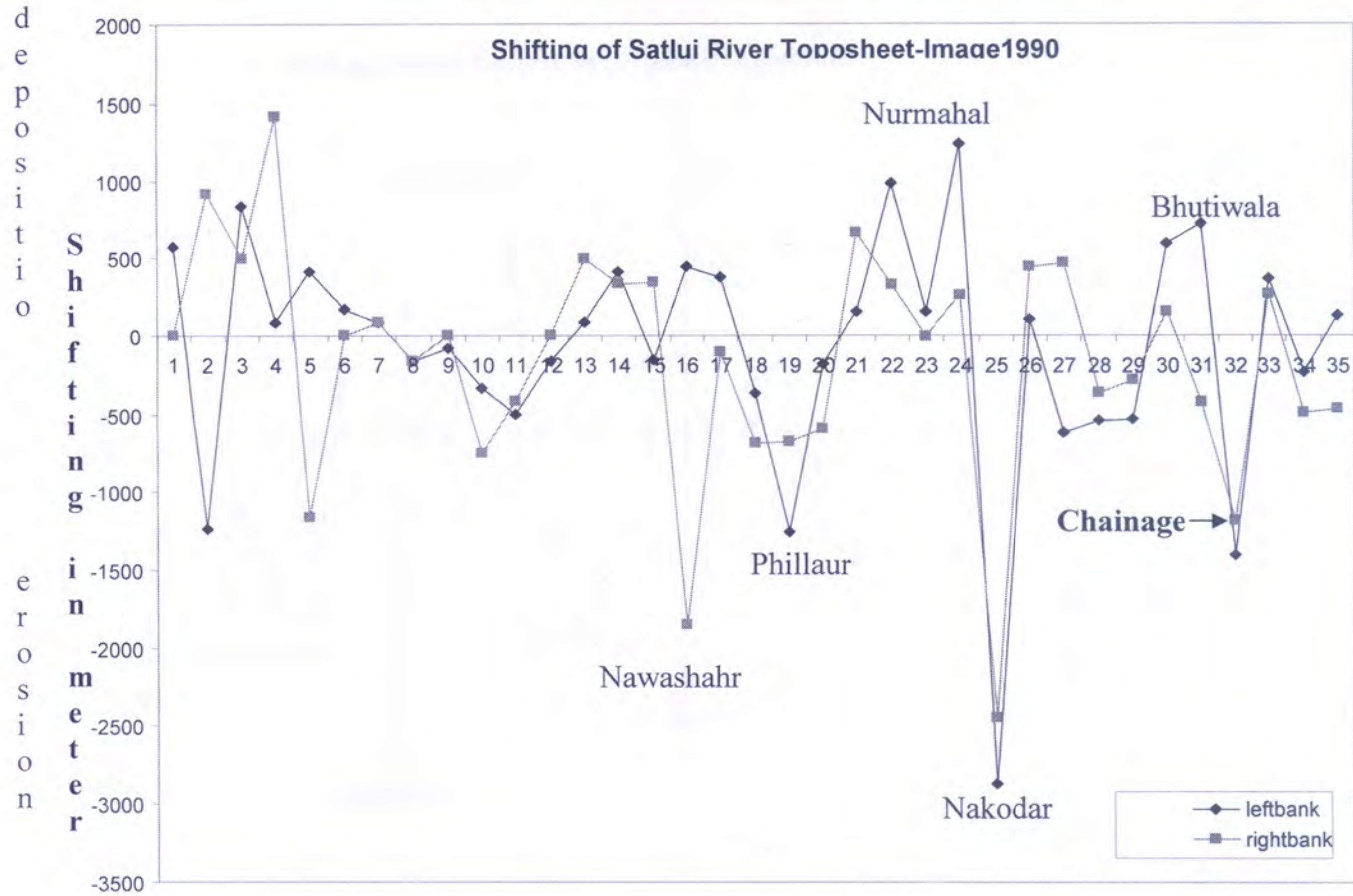


Figure 5.4 False Colour Composite (2003) overlaid by drainage from toposheet (Phillaur)



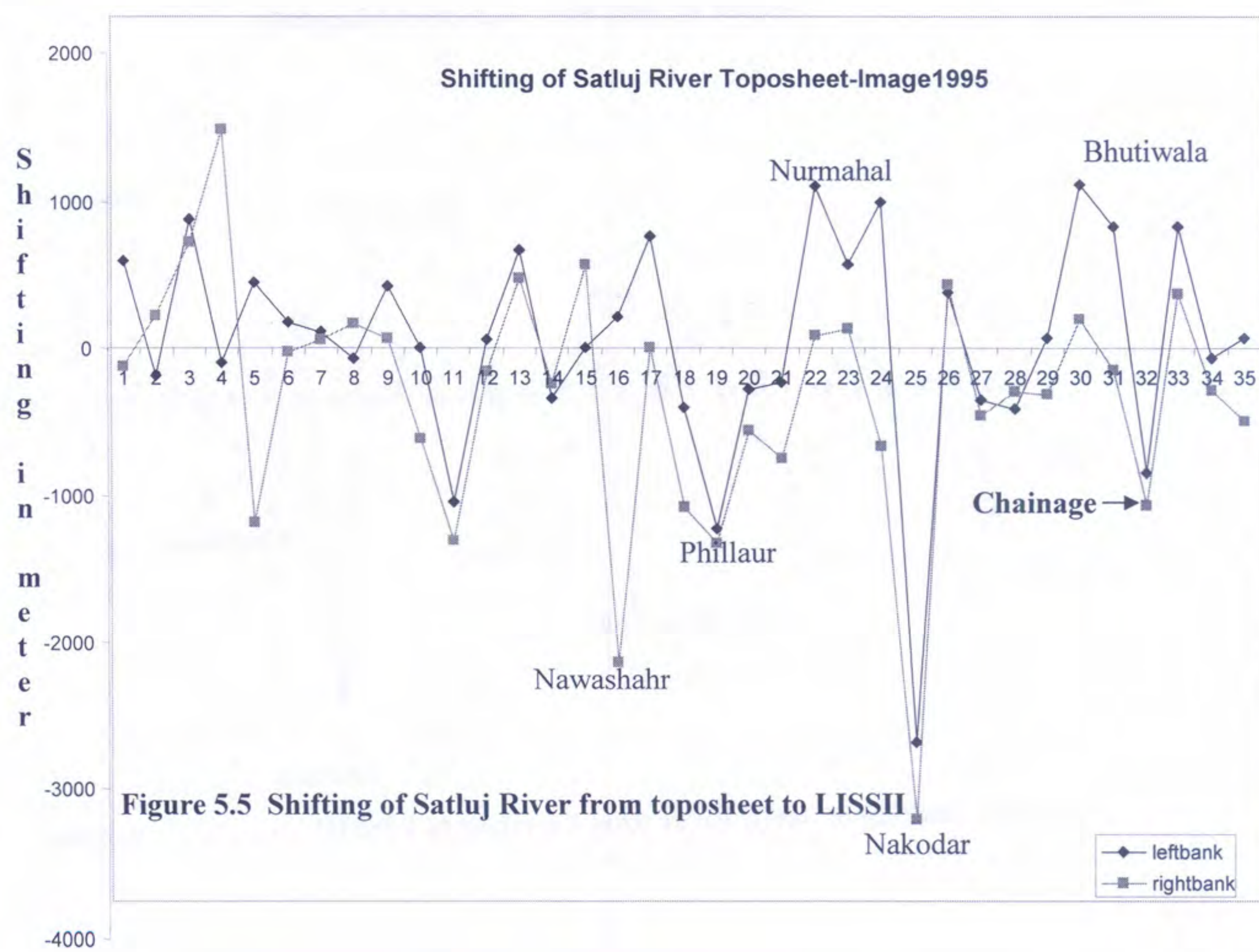


Figure 5.5 Shifting of Satluj River from toposheet to LISSII

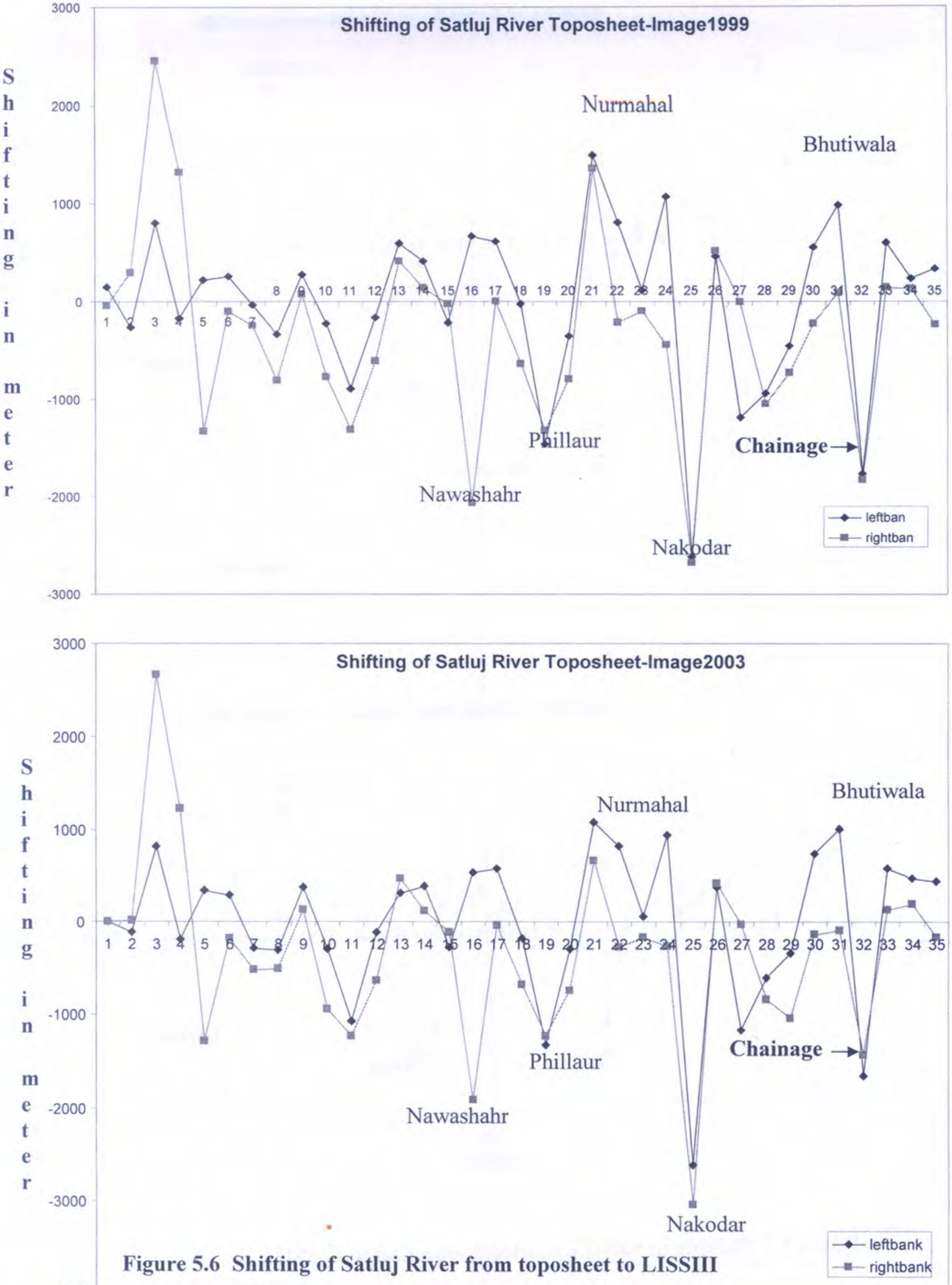
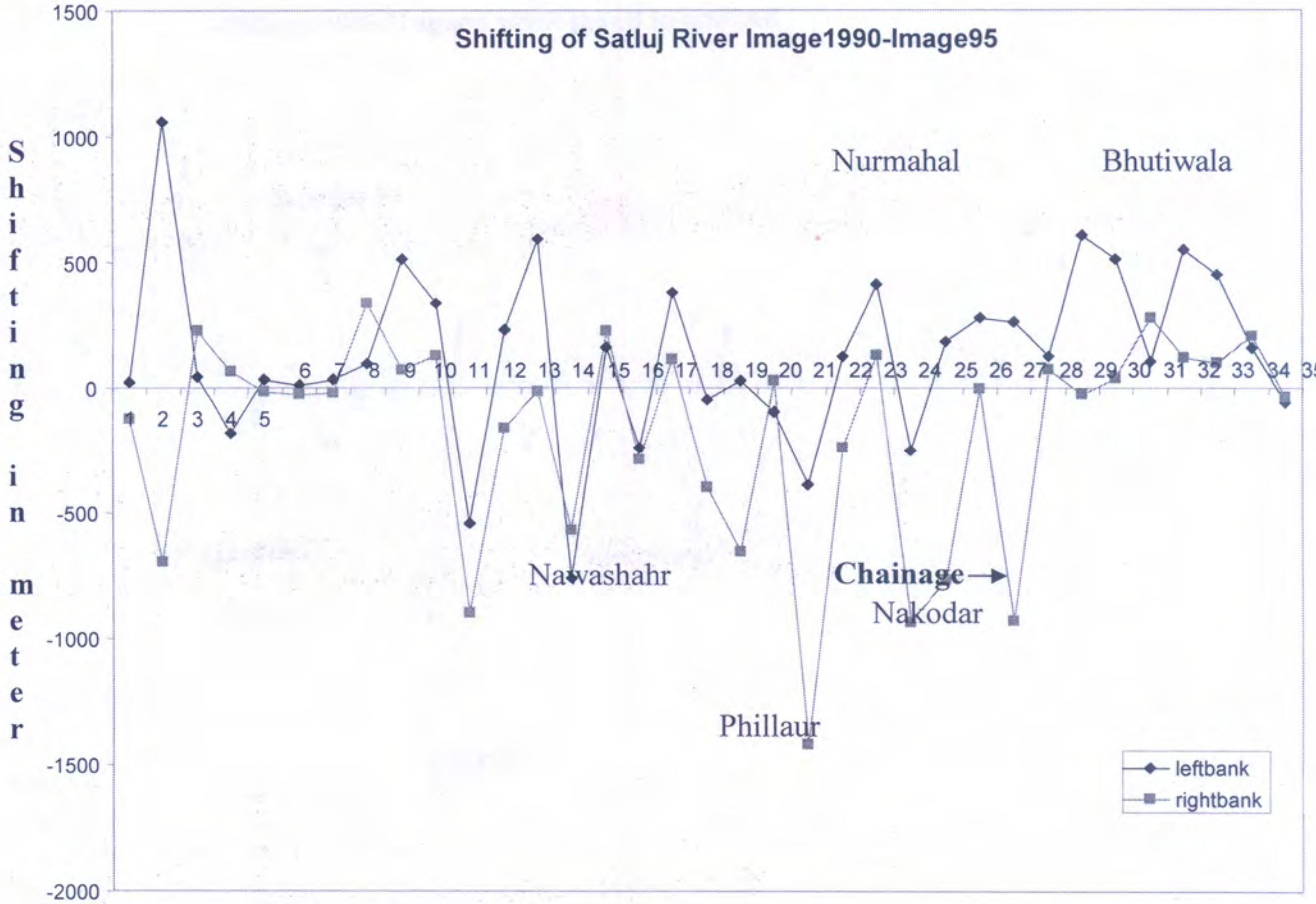


Figure 5.6 Shifting of Satluj River from toposheet to LISSIII



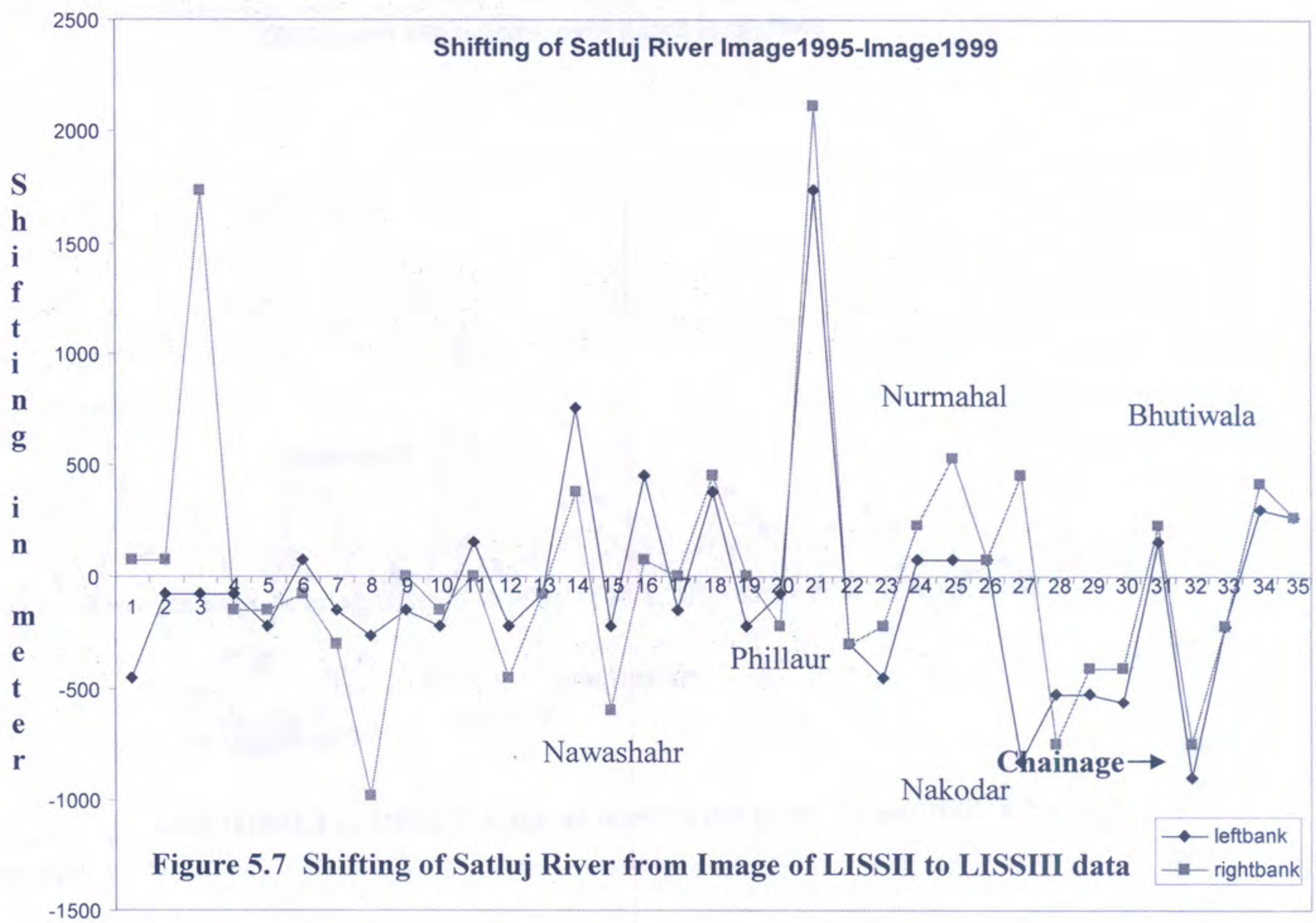
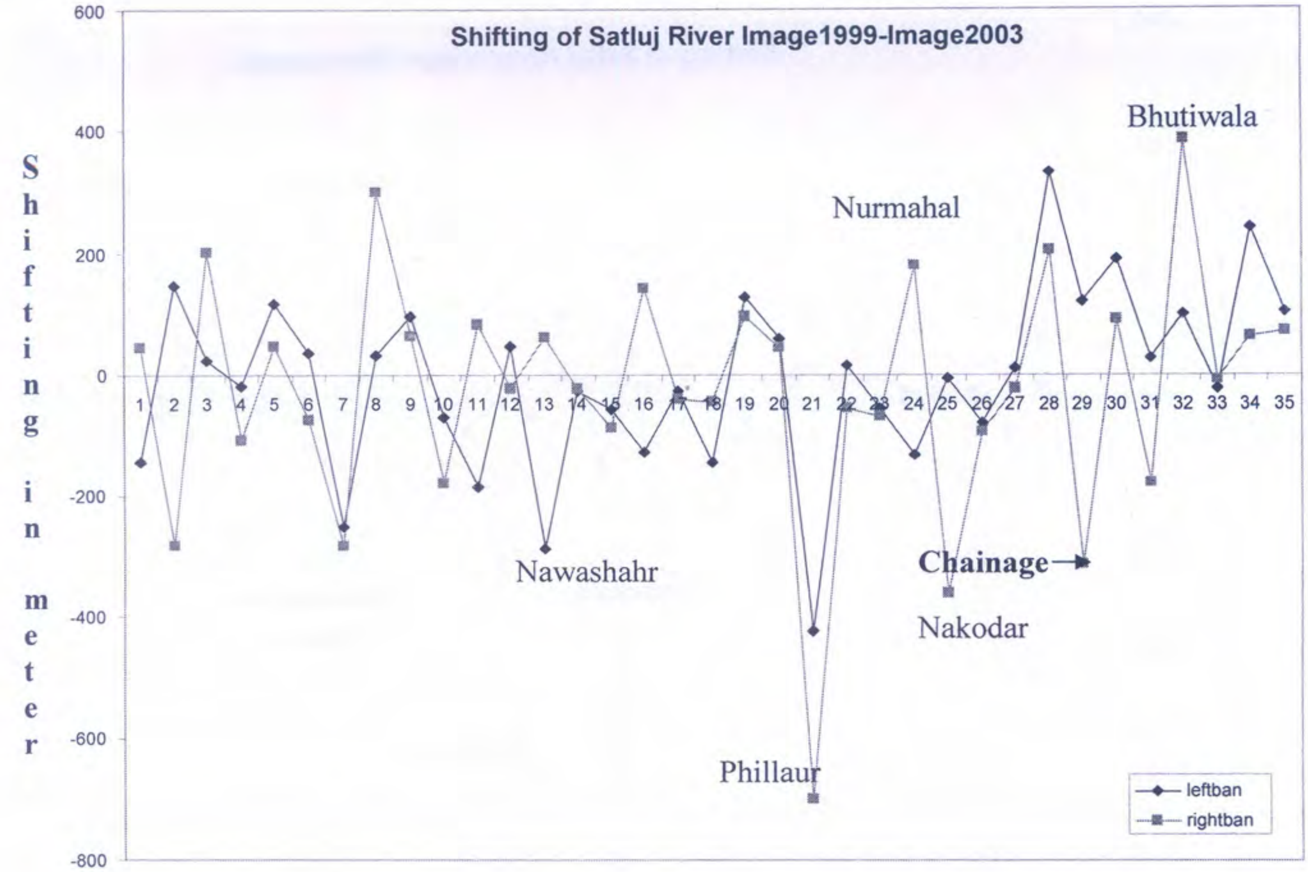


Figure 5.7 Shifting of Satluj River from Image of LISSII to LISSIII data



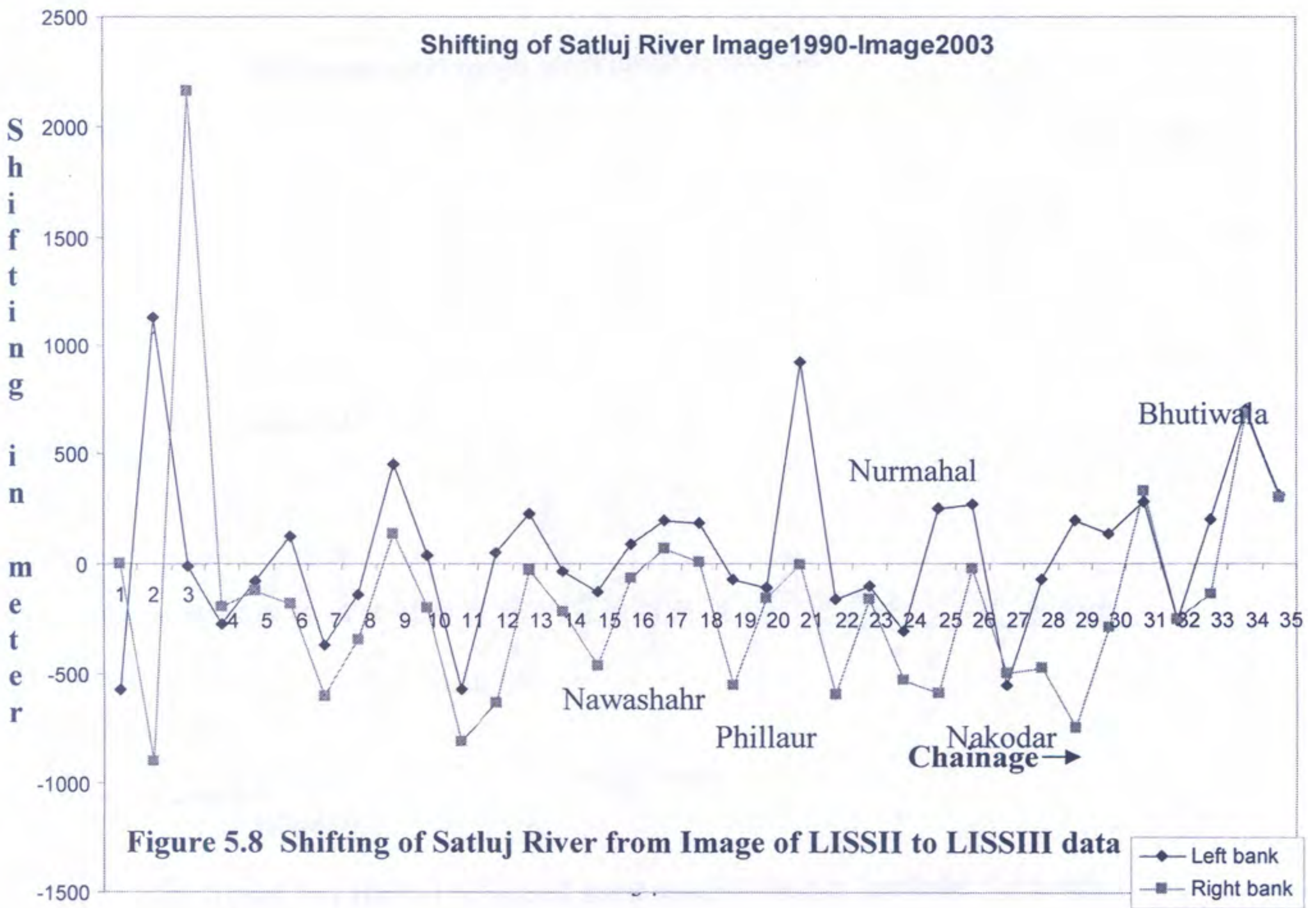


Figure 5.8 Shifting of Satluj River from Image of LISSII to LISSIII data

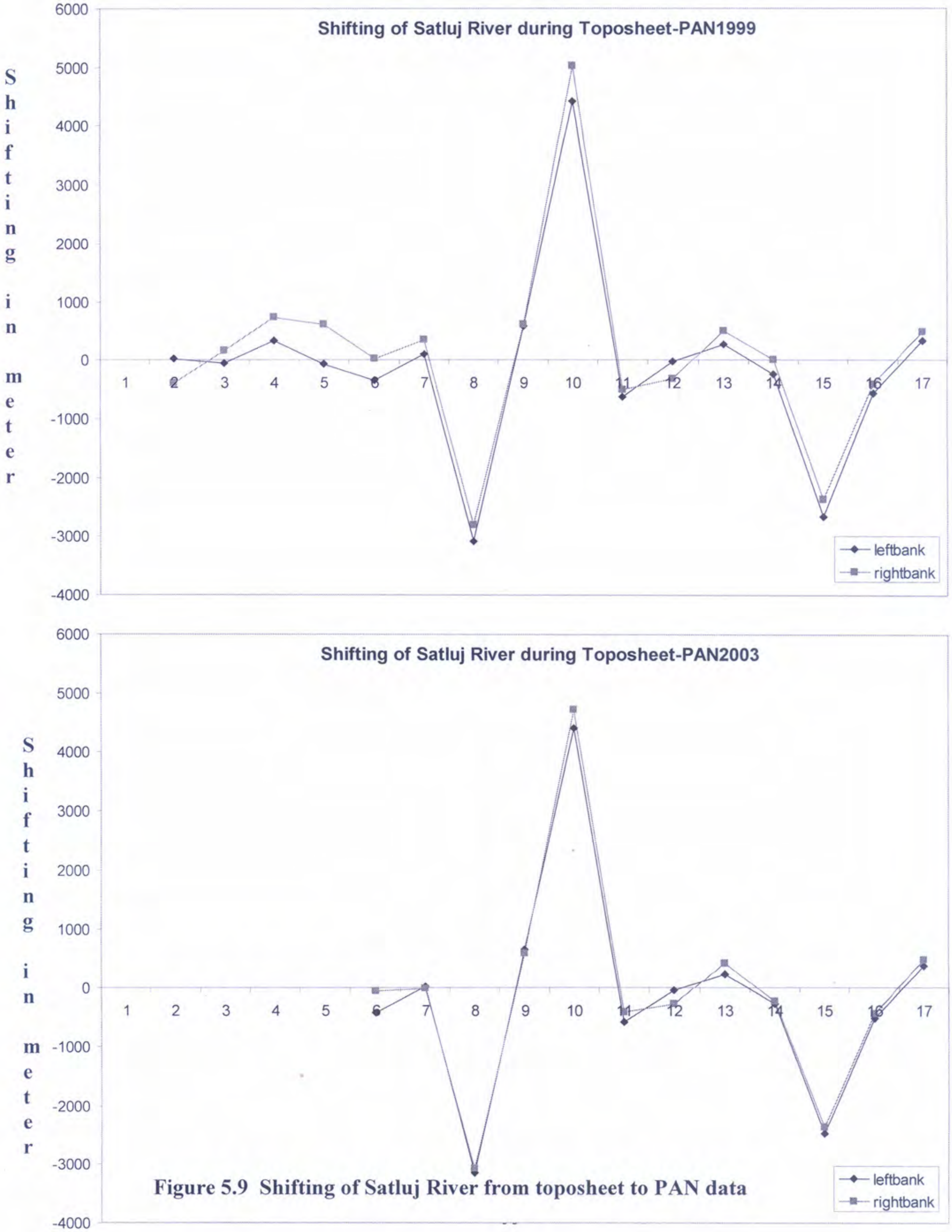


Figure 5.9 Shifting of Satluj River from toposheet to PAN data

5.2.1. Details of shifting of River Satluj in different reaches

The shift have been computed for all the reaches i.e. total 10 reaches and the shift have been given for both the banks. As per the table 4.1 and 4.2, if the difference with respect to toposheet is negative then it is erosion and if the difference is positive then it is deposition.

Reach I: U/s of Nangal to Nurpur (0-25 km.)

Period	Right Bank	Left Bank
Toposheet - Image 90	Both deposition and erosion is there, erosion of the order 1.41 km and deposition of the order 1.16 km.	Mostly deposition is there of the order 0.8 km and erosion of 1.2 km.
Toposheet - Image 95	Both deposition and erosion is there, erosion of the order 1.47 km and deposition 1.18 km.	Mostly deposition is there of the order 0.8 3km.
Toposheet - Image 99	Both deposition and erosion is there, erosion of the order 2.45 km and deposition 1.32 km.	Mostly deposition is there of the order 0.87 km.
Toposheet - Image 03	Both erosion and deposition is there, erosion of the order 1.28 km and deposition of 2.65 km.	Mostly deposition is there of the order 0.82 km.
Image90- Image 95	Both erosion and deposition is there, erosion of the order 0.33 km and deposition of 0.69 km.	Mostly deposition is there of the order 1 km.
Image95- Image 99	Both erosion and deposition is there, erosion of the order 1.73 km and deposition of 0.96 km.	Slight erosion is there.
Image99- Image 03	Slight erosion and deposition both is there.	Slight erosion and deposition both is there.
Image90- Image 03	Both erosion and deposition is there, erosion of the order 2.16 km and deposition of 0.9 km.	Both erosion and deposition is there, erosion of the order 0.5 km and deposition of 1.12km.

Reach II: Nurpur to Talwandi (25-50km.)

Period	Right Bank	Left Bank
Toposheet - Image 90	Both erosion and deposition is there, erosion of the order 0.5 km and deposition of 0.75 km.	Both erosion and deposition is there, erosion of the order 0.5 km. and deposition of 0.5 km.
Toposheet - Image 95	Both erosion and deposition is there, mostly deposition of the order .46 km and erosion of 1.2 km.	Both erosion and deposition is there, mostly erosion of the order 1 km. and deposition of 0.6 km.
Toposheet - Image 99	Both erosion and deposition is there, mostly deposition of the order 0.77 km and erosion of 0.41 km.	Both erosion and deposition is there, mostly erosion of the order 0.89 km. and deposition of 0.59 km.
Toposheet - Image 03	Both erosion and deposition is there, mostly deposition of the order 1.2 km and erosion of 0.46 km.	Both erosion and deposition is there, mostly erosion of the order 1 km. and deposition of 0.37 km.
Image90- Image 95	Mostly deposition of the order 0.9 km.	Both erosion and deposition is there, erosion of the order 0.54 km. and deposition of 0.6 km
Image95- Image 99	Both slight deposition and erosion is there.	Slight erosion but deposition of the order of 0.26 km is there.
Image99- Image 03	Slight deposition and erosion both is there.	Mainly slight erosion of 0.25 km is there.
Image90- Image 03	Only deposition is there of the order 0.21 km erosion 0.61 km	Slight deposition of 0.45 km is there, and mainly erosion of the order 0.45 km.

Reach III: Talwandi to Phillaur (50-75 km.)

Period	Right Bank	Left Bank
Toposheet - Image 90	Mostly deposition is there of the	Both erosion and deposition is there,

	order 0.34 km.	mainly erosion of the order 0.36 km. and deposition of 0.4 km.
Toposheet - Image 95	Mostly deposition is there of the order 2.13 km and slight erosion of 0.57 km.	Both erosion and deposition is there, erosion of the order 0.4 km. and deposition of 0.7 km.
Toposheet - Image 99	Only deposition is there of the order 2.0 km	Both erosion and deposition is there, erosion of the order of 0.25 km and deposition of 0.6 km.
Toposheet - Image 03	deposition is there of the order 1.5 km and erosion is of the order of 1.0 km.	Both erosion and deposition is there, erosion of the order 1.00 km. and deposition of 0.57 km.
Image90- Image 95	Mostly deposition is there of the order 0.57 km.	Slight deposition and slight erosion is there.
Image95- Image 99	Both erosion and deposition is there, erosion of the order of 0.45 km. and deposition of 0.6 km.	Mostly deposition is there of the order 0.75 km.
Image99- Image 03	Slight erosion and deposition is there.	Slight erosion and deposition is there.
Image90- Image 03	only erosion is there of the order 0.46 km.	Erosion of the order of 0.52 km and deposition is of the order of 0.25 km..

Reach IV: Phillaur to Baghel (75-100km.)

Period	Right Bank	Left Bank
Toposheet - Image 90	Mostly erosion is there of the order 0.66 km. and deposition of 0.6 km.	Mostly deposition of 0.97 km is there and erosion of the order of 1.25 km.
Toposheet - Image 95	Mostly deposition is there, of the order 1.32 km.	Mostly deposition is there, of the order 1.1 km. and erosion of 1.23 km.
Toposheet - Image 99	Both erosion and deposition is	Mostly deposition is there, of the order 1.5

	there, erosion of the order 1.32 km. and deposition of 1.35 km.	km and erosion of 1.45 km.
Toposheet - Image 03	Both erosion and deposition is there, erosion of the order 1.23 km.	Mostly deposition is there, of the order 0;80 km and erosion of 1.00 km.
Image90- Image 95	Mostly deposition is there, of the order 1.41 km.	Both slight erosion and deposition is there, of the order of 0.4 km.
Image95- Image 99	Mostly erosion is there, of the order 2 km.	Mostly deposition is there, of the order 1.75 km and slight erosion of 0.45 km.
Image99- Image 03	Mostly deposition is there, of the order 0.7 km.	Mostly erosion of the order 0.4 km.
Image90- Image 03	Only erosion is there of the order 0.6 km.	Both erosion and deposition is there, mainly deposition of the order 0.9 km.

Reach V: Baghel to Bahmanlan (100-125 km.)

Period	Right Bank	Left Bank
Toposheet - Image 90	Both erosion and deposition is there, mainly deposition of the order 2.4 km. and erosion of 0.46 km	Mostly erosion is there, of the order 2.8 km. and deposition of 1.24 km is there
Toposheet - Image 95	Mostly deposition is there, of the order 3.2 km and slight erosion of 0.44 km.	Mostly erosion is there, of the order 2.6 km and deposition of 1.06 km.
Toposheet - Image 99	Mostly deposition is there, of the order 2.68 km. and erosion of the order of 0.5 km is there	Mostly erosion is there, of the order 2.6 km. and deposition of 1.06 km.
Toposheet - Image 03	Mostly erosion is there, of the order 3 km and deposion of 0.8 km.	Mostly erosion is there, of the order 2.6 km. and deposition of 1.06 km.
Image90- Image 95	Mostly deposition is there, of	Mostly erosion is there, of the order 0.27

	the order 0.93 km.	km. and deposition of 0.24 km.
Image95- Image 99	Both erosion and deposition is there, erosion of the order 0.52 km. and deposition of 0.75 km.	Slight deposition is there, mainly erosion of the order 0.82 km.
Image99- Image 03	Slight erosion and deposition is there.	Slight erosion and deposition is there. Erosion of 0.3 km
Image90- Image 03	Only erosion is there, of the order 0.60 km.	deposition of 0.55 km is there, but erosion of the order 0.27 km. is there.

Reach VI: Bahmanlan to Harike (125-175 Km.) Bahmanhan (reach VI to Bhutiwala(reach VII and Bhutiwala to d/s of Harike

Period	Right Bank	Left Bank
Toposheet - Image 90	Mainly deposition is there, of the order 1.18 km. and erosion of 0.27 km	Both erosion and deposition is there, erosion of the order 1.4 km. and deposition of 0.7 km.
Toposheet - Image 95	Mostly deposition is there, of the order 1 km. and erosion of 0.36 km.	Both erosion and deposition is there, erosion of the order 0.85 km. and deposition of 1 km.
Toposheet - Image 99	Mostly deposition is there, of the order 1.8 km.	Both erosion and deposition is there, erosion of the order 1.8 km. and deposition of 0.9 km.
Toposheet - Image 03	Mostly erosion is there, of the order 1.44 km.	Both erosion and deposition is there, erosion of the order 1.6 km. and deposition of 1 km.
Image90- Image 95	Only slight erosion is there.	Only deposition is there of the order of 0.6 km.
Image95- Image 99	Both slight erosion and deposition is there deposition of the order of 0.57 km. and erosion 0.4 km	Both slight erosion and deposition is there, deposition of the order 0.3 km and erosion 0.9 km.

Image99- Image 03	Both slight erosion and deposition is there deposition of the order of 0.57 km. and erosion 0.4 km	Slight deposition is there of the order 0.24 km.
Image90- Image 03	Both slight erosion and deposition is there deposition of the order of 0.57 km. and erosion 0.6 km	Both slight erosion and deposition is there deposition of the order of 0.7 km. and erosion 0.56 km

5.3 DETAILS OF SHIFTING CHARACTERISTICS AT THE CRITICAL LOCATIONS USING IRS-1C PAN DATA

As mentioned in the previous section, the critical locations along the river course where shifting has occurred, were identified as Nawashahr, Phillaur, Nurmahal and Nakodar on river Satluj. Hence, for these locations detailed study was carried out using IRS-1C PAN data, having a spatial resolution of 5.8 m, for the years 1999 and 2003 along with SOI toposheet of the scale of 1:50,000. The river course using these toposheets has been delineated. Then the river course has been extracted from IRS PAN data. Initially, for the critical locations, the shifting of the river course from the SOI toposheet to IRS-1C PAN data was studied and subsequently, the shifting of the river course from the year 1999 (IRS-1C PAN data) to 2003 (IRS-1C PAN data) was studied so as to assess the recent trends in shifting. These shifts are also included in Table 4.1.

Figure 5.9 shows the details of shifting course of river Satluj at Phillaur near Ludhiana as delineated from SOI toposheet (1:50,000) and IRS-1C PAN data for the year 1999 and 2003. It is observed that the river has shifted by approx.5 km. From 1999 to 2003 though there has been no shifting of the river course.

5.4 RATE OF CHANGE OF BANKS

The rate of change of both the banks have been computed and based on the shift of the banks rate of change per year have been computed. The toposheets have been surveyes in different years, the year of survey has been taken as 1975. The rate of change for the years 1990, 1994, 1999 and 2003 have been computed with respect to toposheets i.e. 1975. Rate of left bank and right bank are given in Table 5.1 and 5.2. These rate of changes have been plotted and given in Figures 5.10 and 5.11.

Table 5.1: Rate of change of left bank of Satluj River per year (1975 – 2003)

Location	topo-img90	1975-1990	topo-img95	1975 - 1995	topo-img99	1975 - 1999	topo-img2003	1975-2003
1	574.35	38.29	596.20	29.81	143.73	5.99	0.00	0.00
2	-1247	-83.13	-190.26	-9.51	-265.67	-11.07	-118.20	-6.57
3	831.35	55.42	874.61	43.73	799.20	33.30	822.20	45.68
4	83.13	5.54	-96.64	-4.83	-172.05	-7.17	-190.20	-10.57
5	415.67	27.71	446.75	22.34	220.51	9.19	336.63	18.70
6	166.27	11.08	176.94	8.85	252.35	10.51	288.74	16.04
7	83.13	5.54	113.33	5.67	-37.50	-1.56	-288.70	-16.04
8	-166.27	-11.08	-72.47	-3.62	-336.41	-14.02	-305.30	-16.96
9	-83.14	-5.54	424.95	21.25	274.13	11.42	370.11	20.56
10	-332.54	-22.17	0.18	0.01	-226.05	-9.42	-296.70	-16.48
11	-498.81	-33.25	-1042.00	-52.10	-891.14	-37.13	-1077.00	-59.83
12	-166.28	-11.09	60.14	3.01	-166.10	-6.92	-118.40	-6.58
13	83.14	5.54	671.16	33.56	595.75	24.82	309.37	17.19
14	415.67	27.71	-343.73	-17.19	410.39	17.10	381.80	21.21
15	-156.25	-10.42	2.92	0.15	-223.32	-9.31	-280.80	-15.60
16	447.6	29.84	208.80	10.44	661.27	27.55	534.44	29.69
17	381.12	25.41	757.42	37.87	606.59	25.27	579.71	32.21
18	-362.71	-24.18	-407.99	-20.40	-30.93	-1.29	-176.60	-9.81
19	-1258.8	-83.92	-1230.50	-61.53	-1456.70	-60.70	-1329.00	-73.83
20	-184.18	-12.28	-277.71	-13.89	-353.03	-14.71	-294.00	-16.33
21	152.74	10.18	-236.45	-11.82	1498.03	62.42	1075.20	59.73
22	977.09	65.14	1100.34	55.02	798.69	33.28	814.32	45.24
23	156.25	10.42	565.70	28.29	113.23	4.72	56.95	3.16
24	1240.62	82.71	990.89	49.54	1066.30	44.43	934.17	51.90
25	-2869.8	-191.32	-2690.20	-134.51	-2614.80	-108.95	-2622.00	-145.67
26	106.4	7.09	380.92	19.05	456.33	19.01	377.22	20.96
27	-615.53	-41.04	-352.38	-17.62	-1181.90	-49.25	-1172.00	-65.11
28	-537.17	-35.81	-413.73	-20.69	-941.61	-39.23	-606.00	-33.67
29	-534.49	-35.63	70.03	3.50	-457.85	-19.08	-337.50	-18.75
30	599.67	39.98	1108.77	55.44	543.18	22.63	734.49	40.81
31	723.98	48.27	824.66	41.23	975.48	40.65	1003.70	55.76
32	-1402.9	-93.53	-856.25	-42.81	-1761.20	-73.38	-1661.00	-92.28
33	374.11	24.94	823.47	41.17	597.24	24.89	573.26	31.85
34	-228.63	-15.24	-74.16	-3.71	227.49	9.48	472.04	26.22
35	124.7	8.31	67.06	3.35	331.00	13.79	434.68	24.15

Table 5.2: Rate of change of right bank of Satluj River per year (1975 – 2003)

Location	topo-img90	1975 - 1990	topo-img95	1975 - 1995	topo-img99	1975 - 1999	topo-img2003	1975-2003
1	0.00	0.00	-120.46	-6.02	-44.85	-1.87	0.00	0.00
2	914.49	60.97	219.51	10.98	294.93	12.29	11.88	0.66
3	498.81	33.25	721.52	36.08	2456.00	102.33	2658.77	147.71
4	1413.30	94.22	1477.03	73.85	1326.20	55.26	1218.60	67.70
5	-1163.90	-77.59	-1179.16	-58.96	-1330.00	-55.42	-1282.20	-71.23
6	0.00	0.00	-27.95	-1.40	-103.40	-4.31	-178.34	-9.91
7	83.13	5.54	59.26	2.96	-242.40	-10.10	-526.07	-29.23
8	-166.27	-11.08	167.39	8.37	-813.00	-33.88	-510.88	-28.38
9	0.00	0.00	69.25	3.46	69.25	2.89	132.79	7.38
10	-748.22	-49.88	-620.39	-31.02	-771.20	-32.13	-949.73	-52.76
11	-415.68	-27.71	-1314.54	-65.73	-1315.00	-54.79	-1230.90	-68.38
12	0.00	0.00	-160.19	-8.01	-612.70	-25.53	-363.85	-20.21
13	498.81	33.25	481.72	24.09	406.31	16.93	468.05	26.00
14	332.54	22.17	-239.25	-11.96	136.99	5.71	112.73	6.26
15	346.95	23.13	571.72	28.59	-31.31	-1.30	-117.79	-6.54
16	-1850.40	-123.36	-2135.62	-106.78	-2060.00	-85.83	-1917.80	-106.54
17	-108.06	-7.20	3.39	0.17	3.39	0.14	-37.97	-2.11
18	-685.62	-45.71	-1086.61	-54.33	-634.10	-26.42	-679.00	-37.72
19	-674.23	-44.95	-1326.45	-66.32	-1326.00	-55.25	-1231.50	-68.42
20	-591.97	-39.46	-565.48	-28.27	-791.70	-32.99	-747.14	-41.51
21	660.31	44.02	-757.39	-37.87	1354.10	56.42	654.66	36.37
22	326.02	21.73	85.84	4.29	-215.80	-8.99	-272.09	-15.12
23	-2.15	-0.14	127.01	6.35	-99.23	-4.13	-166.47	-9.25
24	263.04	17.54	-674.95	-33.75	-448.70	-18.70	-268.68	-14.93
25	-2445.40	-163.03	-3211.19	-160.56	-2683.00	-111.79	-3042.10	-169.01
26	441.57	29.44	435.79	21.79	511.20	21.30	417.62	23.20
27	469.61	31.31	-462.03	-23.10	-9.56	-0.40	-32.12	-1.78
28	-366.51	-24.43	-297.13	-14.86	-1051.00	-43.79	-844.98	-46.94
29	-284.75	-18.98	-312.38	-15.62	-727.20	-30.30	-1037.80	-57.66
30	153.81	10.25	190.22	9.51	-224.50	-9.35	-133.85	-7.44
31	-426.27	-28.42	-148.64	-7.43	77.59	3.23	-98.99	-5.50
32	-1184.70	-78.98	-1069.14	-53.46	-1823.00	-75.96	-1436.30	-79.79
33	270.19	18.01	365.03	18.25	138.80	5.78	130.93	7.27
34	-488.42	-32.56	-284.38	-14.22	130.38	5.43	193.17	10.73
35	-467.64		-503.02	-25.15	-239.10	-9.96	-165.98	-9.22

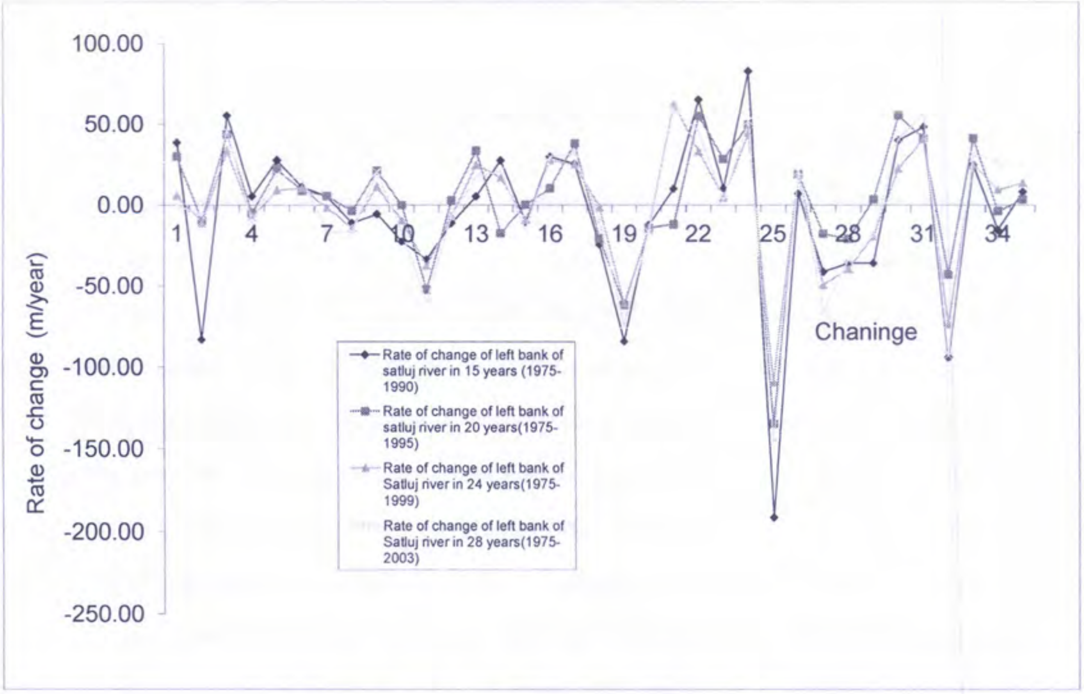


Figure 5.10 Rate of change of Left bank

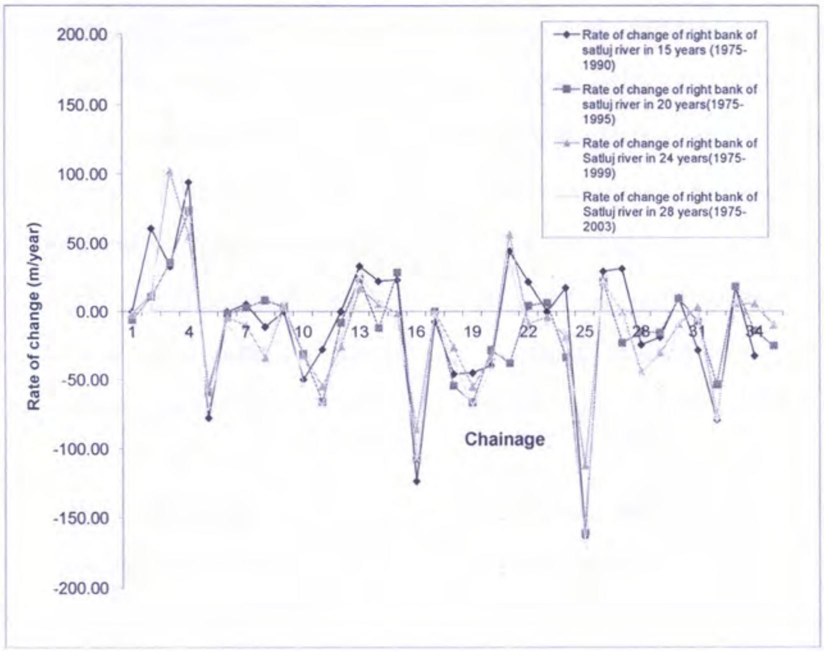


Figure 5.11 Rate of change of right bank

CHAPTER 6

CONCLUSIONS

Conventional measurements of planform characteristics of meandering rivers are a time consuming, laborious and expensive procedure. On the other hand, remote sensing techniques are capable of providing information through time and space, which can never be appreciated from the ground. Further, satellite remote sensing presents an expedient, reliable and cost effective alternative method for demarcation of rivers at suitable time-space intervals to establish the stability or otherwise of their channels. Advantages of the information acquired by satellite remote sensing are of synoptic coverage and repetivity. The present study evaluates shifting characteristics of the river Satluj using satellite remote sensing data. The shifting characteristics were evaluated both on the right as well as left banks of the river courses in the identified reaches, using offset computation method of shifting.

The reache of the Satluj River between Bhakra dam to Harike site, having length of 175 km (approx.) was studied. The Survey of India toposheets have been taken as the base for computation of shifting. The satellite data considered include 1990 (IRS-1A LISS II Data), 1995 (IRS-1A LISS II Data), 1999 (IRS-1D LISS III Data) and 2003 (IRS-1D LISS III Data).

The distance of 175 km between first and last point has been divided into 7 reaches of 25 kms each. In all the reaches the maximum shifting varies between 1.3 to 3.2 km. The reach no. 2 is having minimum shift whereas reach no. 6 is having maximum shift. The points where major shifting has occurred are identified as Nawashahr, Phillaur, Nurmahal and Nakodar. Detailed study of some of the identified critical locations, was carried out using IRS-1C PAN data, having a spatial resolution of 5.8 m, for years 1999 and 2003 along with SOI toposheet of the scale 1:50,000.

To ascertain the reasons of the shift, field visits of some of the points in both the river has been carried out. During the visit, discussions were made with Government officials and local people. The main reason of shifting of Satluj River is the 1988 flood. In 1988, heavy rainfall downstream of Bhakhra had resulted in locally generated floods. Releases from Bhakhra together with local floods resulted in acute flooding in the downstream. So far as the Satluj catchment is concerned the 1988 storm was the most severe storm on records, flood potential wise. Some of the places mining of sand are also the reason of shifting. As such no structure has been constructed on the river during the period of study; therefore effect of the structures on the river shifting could not be studied.

REFERENCES

Bardhan, M. (1993). Channel stability of Barak river and its tributaries between Manipur Assam and Assam–Bangladesh borders as seen from satellite imagery. Proc. Nat. Symp. On Remote Sensing Applications for Resource Management with Special Emphasis on N. E. Region, Guwahati, Nov 25-27, 481-485.

Bhagawati, D. (1993). Performance evaluation of river training measures using remotely sensed data: A case study on the Brahmaputra at Gumi. Proc. National Symposium on Remote Sensing Applications for Resource Management with Special Emphasis on N. E. Region, Guwahati, Nov 25-27, 486-489.

Dhanju, M.S. (1976). Study of Kosi river flood plains by remote sensing. Hydrology Review, 2(4), 43-48.

Dury, G. H. (1977). Underfit streams: retrospect and prospect. In River Channel Changes, edited by K. J. Gregory (Chichester: Wiley Interscience), 281-293.

Ferguson, R.I. (1973). Regular meander path models. Water Resour. Res., 9, 1079-1086.

Gole, C.V. and Chitale, S.V., 1996, Inland Delta Building Activity of Kosi River. Journal of Hydraulic Division, Proceeding of American Socity of Engineering, V-92, p 111-126.

Gupta, S.K., 1986, "Salinisation – desalinization in saline water irrigated soil". Seminar on Problem of Waterlogging and Salinity in Alluvial Soil. New Delhi.

Gregory, K.J. (1979). River channels. In man and Environmental Processes, edited by K. J. Gregory and D. E. Walling (Folkestone: Dawson press), pp. 123-143.

Gregory, K.J. (1977). The context of river channel changes. In River Channel Changes, edited by K.J., Gregory (Chichester: Wiley Interscience), 1-12.

Gregory, K.J. (1983). Background to Palaeohydrology. A Perspective (Chichester: Wiley Interscience).

Jain, S.K and Ahmad, T. (1993). Migration behaviour of river Ganga between Allahabad and Buxar using remotely sensed data. J. Ind Soc. Remote Sensing, 21(1), 37-45.

Knight, M.J. (1975). Recent crevassing of the Erap River, New Guinea. Australian geographical Studies. 13, 77-82.

Knighton, David, Fluvial forms and processes, A new Perspective, Arnold, member of the Hodder Headline Group, London, 1998.

Hickin, E.J. and Nansen, G.C. (1975). The character of channel migration on the Beatton River, Northeast British Columbia, Canada. Geol. Soc. Amer. Bull., 86, 487-494.

Nagarajan, R., Marathe, G. T. and Collins, W. G. (1993). Identification of flood prone regions of Rapti river using temporal remotely-sensed data. Int. J. Remote Sensing, Vol 14, No. 7, 1297-1303.

Nanson, G.C. and Hickin, E.J., 1986, A statistical examination of bank erosion and channel migration in western Canada. Bulletin of the Geological Society of America 97, 497-504.

Philip,G., Gupta, R. P and Bhattacharya, A. (1989). Channel migration studies in the middle Ganga basin, India, using remote sensing data. Int. J. Remote Sensing 10(6), 1141-1149.

Prasad, N. (1970). Some aspects of meandering streams of the Barakar basin and their sinuosity indexes. Chapter 5 in "Perspectives in Geomorphology-Vol IV", 93-101.

Thorne, C. R., 1982, Processes and mechanisms of river bank erosion. In Hey, R.D., Bathurst, J.C., and Thorne C.R. (eds), Gravel bed rivers. Chichester; Wiley, 227-59.

WAPCOS, BBMB (1996), Operation of Bhakra and Pong Reservoirs During Flood and Other Flood Mitigation Measures, Vol-I and II, Water and Power Consultancy Services (India) Limited, New Delhi.

Wolman, M.G., 1959, Factors influencing erosion of cohesive river bank. American Journal of Science 257, 204-16.

ANNEXURE - I

The replies of the comments raised on the report are given below:

(1) Under Section 5.2, heading should be "5.2 REACHWISE ANALYSIS OF SHIFTING OF RIVER".

The corrections have been made in the report

(2) Objectives of the study given at page No. 6 in the report are not exactly same as per the office memorandum no. 4/64/2004/morph/1322.25 dated 20th August, 2004. Some of the objectives mentioned in the memorandum have not been carried out. As per the objective, the river course is to be delineated along with major roads, embankments, railways and important places which is not done. As per the objectives, the rate of shifting is to be worked out which is not done.

The suggestions have been incorporated in the report.

(3) The data in last three columns of Table 4.1 are missing at pages 40 and 41.

Corrected

(4) Sign conventions for the deposition and erosion considered in the report do not give the uniform meanings when the offset line comes on the opposite side. Item no. 11 in the comments for Ghaghara River may be referred in this regard.

Sign conventions have been added.

(5) Erosion and deposition discussed in the report have been taken as shifting of a river which needs to be clarified.

Clarified.

(6) 'Trend analysis at the identified locations' has been shown in flow chart vide Figure 4.6 given in the report but the same has not been carried out in the report.

Flow chart has been modified.

(7) Chainage of the reaches given in section 5.1are not same as shown in Figures 5.5 to 5.9. Locations of all points have also not been shown in Figs 5.3 & 5.4. Figures 5.5 to 5.9 presented to show the shifting are also not understandable. Fig. 5.5 to Fig. 5.9 are indicated

as shifting of the river .But, infact, they exhibit shifting of the left and right banks. How shifting of the river is derived is not clear in the report.

This is shifting of banks.

(8) Conclusions given in chapter 6 of the report may be provided in point wise form. As per the objective, the shifting from toposheet to images 1990, 1994, 1999 and 2003 should be discussed. The magnitude of shifting at critical locations along with rate of shifting should be elaborated in the report. It is said in the report that as there has been no structure constructed in last 20 years; therefore effect of structures has not been studied. But the structures constructed after the base year i.e. of toposheet, should be considered for evaluation of their performance from morphological point of view as well as their effect on river morphology as per the objective. The report should be as per 'General guidelines for preparation of river morphological reports' of CWC as per the objective, which is not so.

Conclusions have been corrected.

(9) Unit of X-axis wherever is required is not mentioned on the graph in the report.

Unit of X-axis is added.

(10) Page nos.47 to 51 are not indicated in the report.

Corrected.

(11) Different spellings of the same word have been given in chapter 5 of the report, for example; Nurmahal, Noormahal etc.

Corrected as suggested.

(12) Observations in general relating to Ghaghara River, may also be incorporated in the report of Satluj River.

Incorporated.