CHAPTER 1: INTRODUCTION

1.1 Rationale and Background

Flood plain sediment preserves both internally generated autogenic forcing (sediment characteristics and hydrology) as well as externally generated allogenic forcing (changes in base level change, subsidence and uplift, climate and source area) (Wonsuk, 2011). Fluvial autogenic processes and their interactions with allogenic controls are quantified by carrying out high resolution, multi-proxy studies of the cyclic strata. The reviews from Loire (France), Mississippi (USA), Colorado (Texas, USA) and Rhine–Meuse (The Netherlands) by Blum and Tornqvist (2000); from Northern Tunisia by Faust et al. (2004) and from Great Britain by Lewin et al. (2005); from Yamé River, West Africa by Lespez et al. (2011); from Ganga plain (India) by Sharma et al. (2004), Sinha and Sarkar (2009) highlights significance of such studies by documenting fluvial responses to allogenic forcing over both shorter (10^2–10^3 years) and longer (10^4–10^6 years) time-scales.

The present study is carried out in subtropics, western margin of Indian subcontinent in the lower reaches of a significant River Narmada, which flows from East to West for 1289 km, across the Indian Peninsula, under the influence of Southwest Indian Monsoon (SwIM). The distribution of rainfall over Indian subcontinent is a seasonal event (June-July-August-September) controlled by monsoonal tracks. As a result, the regions off the tracks are left dry and regions along the track receive excess rainfall and surface runoff events. In such conditions, the geomorphic changes are regulated by more hygric than the thermal component of the climate, whereby geomorphic-sedimentological proxy data therefore provide an opportunity to complement the highly temperature-orientated approach in research of Quaternary climate change (Johnsen et al., 1992; Bond et al., 1997; Cacho et al., 2000; Faust et al., 2004). Globally, the Late Holocene climate history records two important climatic events namely 1.

Medieval Warm Period (MWP) between ca. 800 to 1300 A.D and 2. Little Ice Age (LIA) between ca.1350 and 1850 A.D (Grove and Switsur, 1994; Hughes and Diaz, 1994; Crowley, 2000; Crowley and Lowery, 2000; Cronin et al., 2003; Yamada et al., 2010). The present study aimed at understanding change in landforms in response to the SwIM phase under influence of Late Holocene climate events.

The Lower reaches of Narmada Valley (LrNV) is influenced largely by two monsoonal storm tracks namely, the regular SwIM path, where moisture is carried from Bay of Bengal across Narmada and Tapti basins (from SE to NE and East – West) and Moisture derived through Arabian Sea (N-S and NNE-SSW) at the onset and during the monsoon period. The bank full condition for the river is achieved with torrential rains for 5-7 rainy days. Late Holocene flood plain is submerged with rise in water level to 10 m whereas bank full and flood condition in river Narmada is reached by rise in water to 21 m. Theoretically, a small denudational change in a landform during the surface run off events that regulate a thalweg line, which further in due course of time lead to change in morphology of the channel itself. To understand such dynamical changes, the present study attempts a high resolution, multi-proxy studies of a prominent late Holocene flood plain.

1.2 Defining Study area

The study area falls within latitude 21° 36' 55.67" N to 21° 54' 19.48" N and longitude 72° 55' 49.88" E to 73° 15' 40.20" E covering an overall 540 Sq. km of area, falling in Survey of India topographic sheets (1972) at 1:50,000 scale numbers: 46C/14, 46G/1 and 46G/2 (Figure 1-). The study focused on a neobank surface referred to as “Uchediya surface”. River Amravati, River Kaveri and River Madhumati are the three important tributaries of the river Narmada flowing from South. These tributaries are having catchment over the Deccan basalt and Tertiary sedimentaries in the South and South East portion. The study area is well habituated, having number of villages connected by roads. Important villages

/towns along the southern bank of Narmada are Jhagadiya and Ankleshwar; on the northern bank are Motikoral, Jhenor, Suklatirth, Tavara and Hinglot with Bharuch as major town.

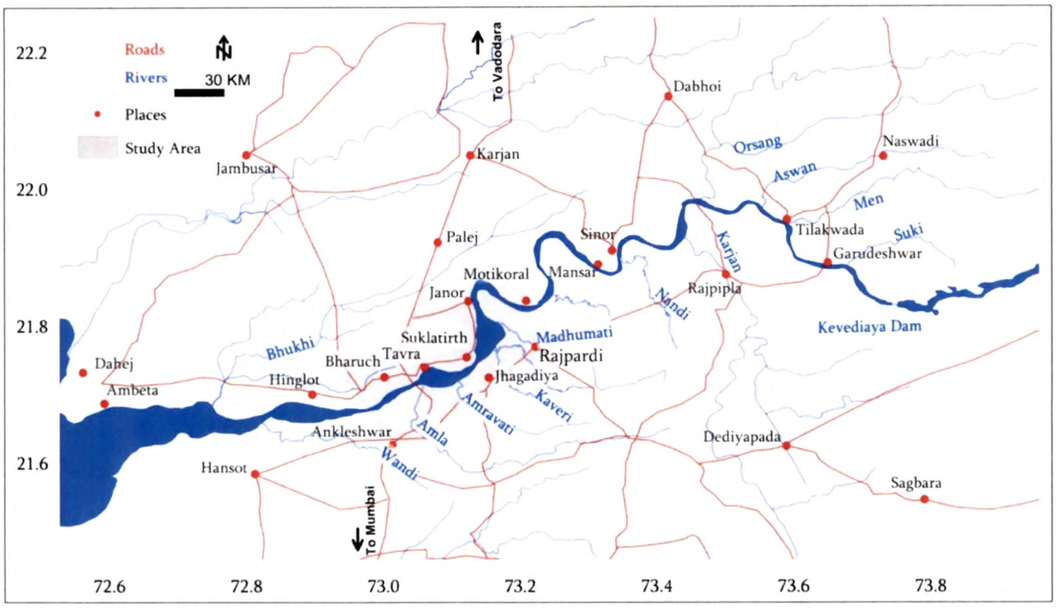

Figure 1-: Location map of study area

The town Bharuch has a historical importance. Its name was derived from “Bhrigukachchha”, after Bhrigu Rishi. By 500 BC, the city was known to the Arab and Ethiopian traders. It was a link port for luxury goods trade from the Far East and the interior of the Indian sub-continent to the South-West Asia, the Middle-East, the Mediterranean basin including Northern Africa and Europe. Archaeological history of Bharuch says that there were ruins of many ancient temples. From 322 BC, Bharuch was a part of the Mauryan Empire, the Western Satraps and the Guptas. Afterwards, it was annexed by the Mughals, and finally by the British.

1.3 Regional Structure and Tectonics

The oldest structural trends in the exposed rocks from lower reaches of Narmada are NW-SE trend belonging to F_1 folding and axial plane schistosity belonging to Aravalli – BGC orogeny. The E-W to ENE-WSW trending, F_2 folding marks Aravalli- Champaner deformation in the north of Narmada. ENE-WSW trend south of Narmada is an extension of the structural grain belonging to Satpura orogeny extending from Central India. ENE-WSW trend is found to have superimposed over the Deccan basalt flows along Rajpipla Hill range and are also recorded along the trends of intrusive (feeder dykes). These trends define Narmada Rift Zone (ENE-WSW) and Cambay Rift Zone (N-S). The intersection of these trends in the lower reaches of Narmada valley define Jambusar –Bharuch block (Figure 1-2), the deepest block of Cambay Basin (Raju, 1968) .

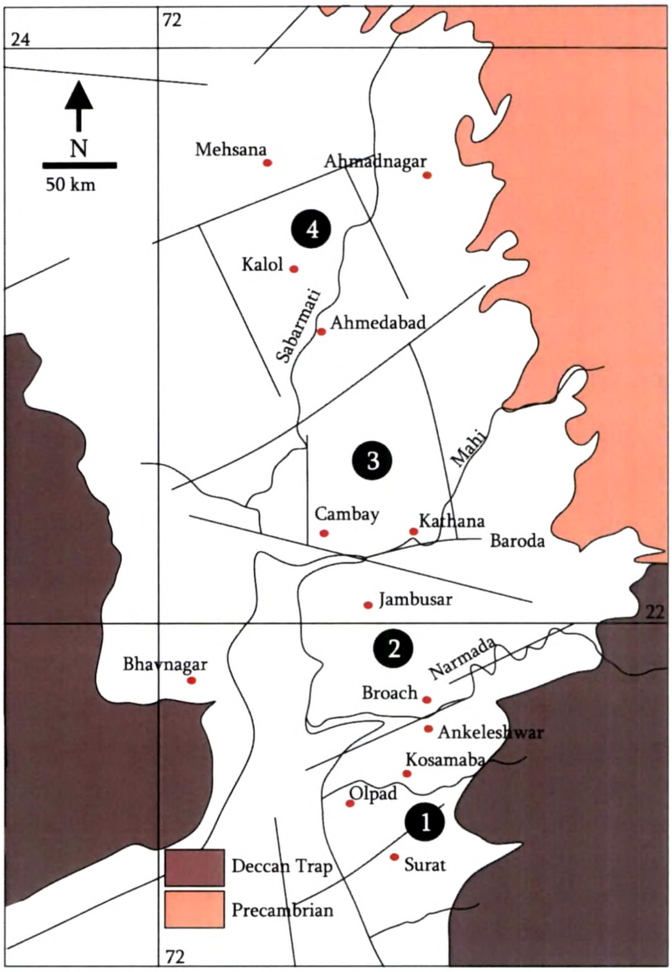

Figure 1-: Tectonic map of Cambay basin (1) Narmada Block, (2) Jambusar- Bharuch Block, (3) Cambay-Tarapur Block, (4) Ahmedabad- Mehsana Block.

Kaila et al. (1981) identified a reverse basin margin fault at Ankleshwar through Deep Seismic Sounding method along Mehmadabad -Billimora profile, about 8 km south of present Narmada. This Ankleshwar fault is observed to merge with Rajpipla escarpment further east (RF_2, Sant and Karanth, 1993). The Lower reach of Narmada valley features numerous ENE-WSW and NW-SE trending Post Trappean faults bringing Bagh bed in juxtaposition with Deccan basalt. Late Tertiary-early Quaternary deformations are best preserved within the Tertiary sediments exposed to the south of Narmada. Agarwal (1984) mapped several anticline structures and faults, deforming Tertiary sediments, exposed between Rajpardi-Jhagadiya-Ankleshwar track.

1.4 Historical and Modern Records of Hydrology of Lower Narmada

1.4.1 Historical Records

Available historical records of hydrology and meteorology of River Narmada in lower reaches is spanning from 1000 to 1900 AD. These records are in the form of historical documents, describing this period, which have encrypted the behaviour of Narmada channel. This very section (Table 1-) summarises such available notes and records in historic literature and scientific reports. The data presented here is only summarising the descriptions which are available only in English language or a translation or reference of regional literature in English literature.

Table 1-: Description of Narmada River in historic documents.

Period	Description
1094-1143	The archaeological structure, Fort Wall built on the right bank of Narmada to prevent the city from erosion was built by Sidh Raj Jaisinhji of Anhilwara during 1094-1143 (Bombay presidency gazetteer 1877-1905, page 551).
1526-1536	Bahadur Shah strengthened and rebuilt the Fort wall. This is also noted that the large ships were reaching up to the city wall during the period (Bombay presidency gazetteer 1877-1905, page 55).
1673-1681	*-Two hundred years ago when Fryer (1673-1681) crossed the river at Broach, he found the stream broad, swift and deep, but adds that , on account of the sand forced down to the rain skilful pilots are required , by whose direction good lusty vessels are brought up to the city walls* (Bombay presidency gazetteer 1877-1905).

1781	A storm passed over the district of Bharuch, of which Mr. Forbs has left an account in the Oriental memories- Forbs Oriental Memories, vol-111, 53. *"Two years before I left India, some weeks before the setting into the south-west monsoon (May), we had the most deadly storm ever remembered in Gujarat. It ravage by sea and land were terrible, the damage at Broch was very great, and the loss of life considerable"*
1822	*Large flood (*Kale *et al., 1997).*
1825	*-Bishop Herber (1825) visited Broch, he noticed that the Narmada was very shallow and that then no vessel larger than moderately sized lighters could come beyond the bar.* (Bombay presidency gazetteer 1877-1905).
1834	Dangerous flood, it says an 866 hour of flood have submerged the Broach city in its water- Secretariat Judicial volume, issue 340 of 1850.
1835	Cold environment (Gazetteer of India, Gujarat State (Broch dist.), 1961, page 303).
1836	Heavy rain (Gazetteer of India, Gujarat State, Broch dist., 1961, page 303).
1837	*-Great flood-1937, when the water of Narbada and Tapi are said to be have joined. No damage would seem to have been caused either to the district or the city of Broch it has not done much damage to the Broach city* (Bombay presidency gazetteer, Gujarat Surat and Broch, 1877, page 410).
1838	Failure of Rain (Gazetteer of India, Gujarat State, Broch dist., 1961, p. 303).
1840	Failure of Rain (Gazetteer of India, Gujarat State, Broch dist., 1961, p. 303).

1860	19th century story of Narmada was much devastating. *-At the time when the original bridge was built the heavy current of the stream lays on the right bank. Since then the main channel of the river has so entirely shifted towards the left bank* (Bombay Presidency Gazetteer of year 1877-1905 is about the built of Golden bridge; from page 419 and 420).
1864	*- a flood rising within 21 feet rail level carried away six spans in the deep water channel* (Bombay Presidency Gazetteer of year 1877-1905 is about the built of Golden bridge; from page 419and 420).
1868	*-August flood rising to 18 feet of rail level carried away four spans* (Bombay Presidency Gazetteer of year 1877-1905 is about the built of Golden bridge; from page 419and 420).
1870-1877	*-during seven years the southern bank was gradually washed away, and driven back upward of 1000 feet.* (Bombay Presidency Gazetteer of year 1877-1905 is about the built of Golden bridge; from page 419and 420).
1878	*Large flood* (Kale et al., 1997).
1891	*Large flood* (Kale et al., 1997).
1894	*Large flood* (Kale et al., 1997).
1897	*-the water rising suddenly to the unprecedented height of 35 feet above high water mark or within 13'6" of rail level, washed away twenty six spans or upwards of 1600 feet of the southern portion of the bridge.* (Bombay Presidency Gazetteer of year 1877-1905 is about the built of Golden bridge; from page 419 and 420).

1.4.2 Modern Records

Modern record of hydrology of Narmada spans from 1900-2002. Major flood events recorded during this period are summarised in the Table 1-2 and

Table 1-3 (Kale et al., 1997). Table 1- summarises the major flood events of Narmada and Table 1- summarises flood records of peninsular rivers other than Narmada and their synoptic conditions.

Table 1-: Narmada flood record (after Kale et al., 1997)

Flood date	Discharge (m^3/s)	Synoptic condition
1926, September 23	-	Cyclonic storm
1937, July 13, 26	-	Depression
1954, September 24	30000	Cyclonic storm
1959, September 15	43200	Depression
1961, September 17	47700	Depression
1964, August 13	22900	Depression
1968, August 6	58000	Depression
1970, September 6	59000	Land depression
1973, August 30	57801	Depression
1984, August 20	49500	Depression

Table 1-: Flood record of peninsular Rivers other than Narmada and their synoptic condition (after Kale et al., 1997)

River	Flood Date	Discharge (m^3/s)	Synoptic Condition
Kaveri	1923, July 9		Low pressure system
Kaveri	1923, Dec	-	-
Kaveri	1924, July 25	13000	-
Kaveri	1925, Nov 9	-	Cyclone
Kaveri	1930, October 23	-	Cyclonic storm
Gadilam	1933, Dec. 16	-	Storm
Godavari	1937, July 30	24825	Cyclone
Tapi	1937, July 13,26	21500, 13600	Land depression
Tapi	1941, July 1, 11	-	Depression
Tapi	1942, Aug. 6	-	Depression
Tapi	1944, Aug. 24	25500	Depression
Krishna	1949, Sept. 24	-	Depression
Godavari	1953, Aug. 11	25900	Depression
Godavari	1958, Aug. 30	64000	Depression
Godavari	1959, Sept. 17	78686	Depression
Tapi	1959, Sept. 17	37300	Depression
Krishna	1961, July	--	-
Krishna	1964, Sept. 28	-	Depression
Tapi	1968, Aug. 6	42500	Depression
Kaveri	1972, Dec. 5	-	Cyclonic storm
Godavari	1976, Sept. 23	55000	-

River	Flood Date	Discharge (m^3/s)	Synoptic Condition
Kaveri	1977, Nov. 12	-	Cyclone
Godavari	1983, Aug. 15	41120	Cyclonic storm
Godavari	1990, Aug. 25	63200	Depression
Tapi	1991, July 31	14722	Depression
Tapi	1994, Aug 6	16697	-

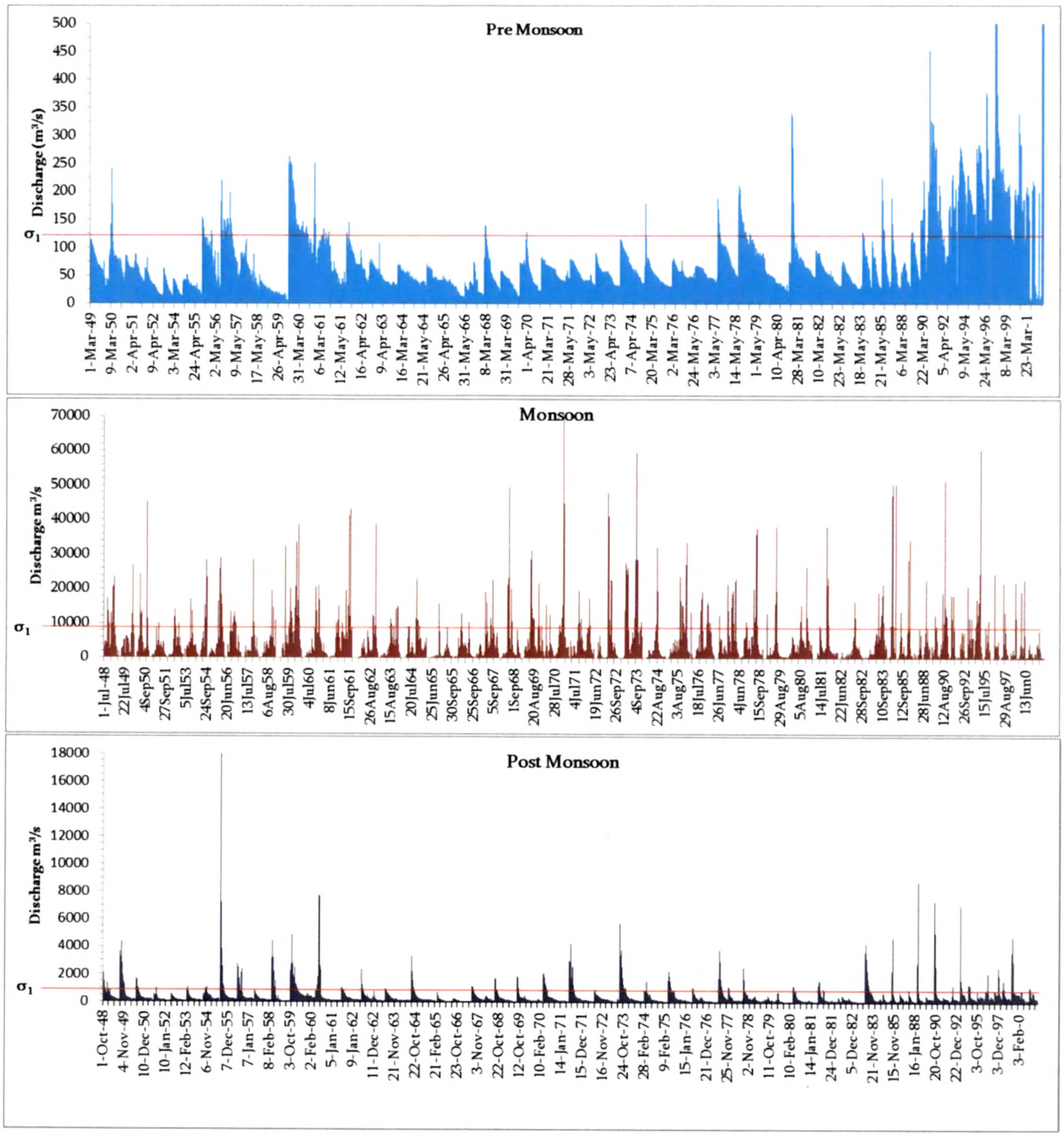

Figure 1-: Hydrograph of Narmada River at Garudeshwar Gauge from 1948-2002.

Comparing these large flood records with other peninsular rivers shows that in terms of large floods, Narmada stands the second position with a peak discharge of 59000 m^3/s. Figure 1- summarise the hydrograph of River Narmada during 1948-2002. The daily discharge recorded at Garudeshwar for the last 54 years (1948 to 2002) are plotted here for pre-monsoon (March, April May); Monsoon (June, July, August and September) and post-monsoon (October, November, December, January and February) periods separately. The plot suggests wide variation in discharge, above significance (σ_1) for pre-monsoon, monsoon and post-monsoon.

1.5 Scope and Objectives

The present study aims to understand denudational processes in the lower reaches of the River Narmada. The study is an attempt to identify sites showing geomorphological changes and establish interrelationship between landforms and channel dynamics through series of analysis and field observations. High resolution multi-proxy records generated from representative site for Uchediya surface will be used to decode landform aggradation, flood events and thereby changes in the channel morphology. The study will further compare the available historical database and analytical results to understand climate and anthropological influence. Broad objectives of the present study can be listed as:

1. To study the morphology of the present Narmada channel, influence of tributaries on the main channel and process intricacies.
2. The study intends to understand channel migration, meandering course, avulsion, and mechanism of Bank erosion-deposition processes.
3. The study aims to reconstruct the depositional history of landforms by high resolution multi-proxy analysis of sediments.
4. The high resolution, multi-proxy studies on the landforms would ultimately aims to infer flood history in lower reaches of Narmada Valley.

1.5.1 Methodology

To attain the objectives, a high resolution multi-proxy approach would be adopted for the present study. It will include mapping of landforms, shallow seismic profiling of the area to understand the roots of the landform, high resolution sampling of representative site for Uchediya surface followed by sedimentological, magnetic, micropaleontological and geochemical analysis. A flow chart given below describes the various stages of the study (Figure 1-).

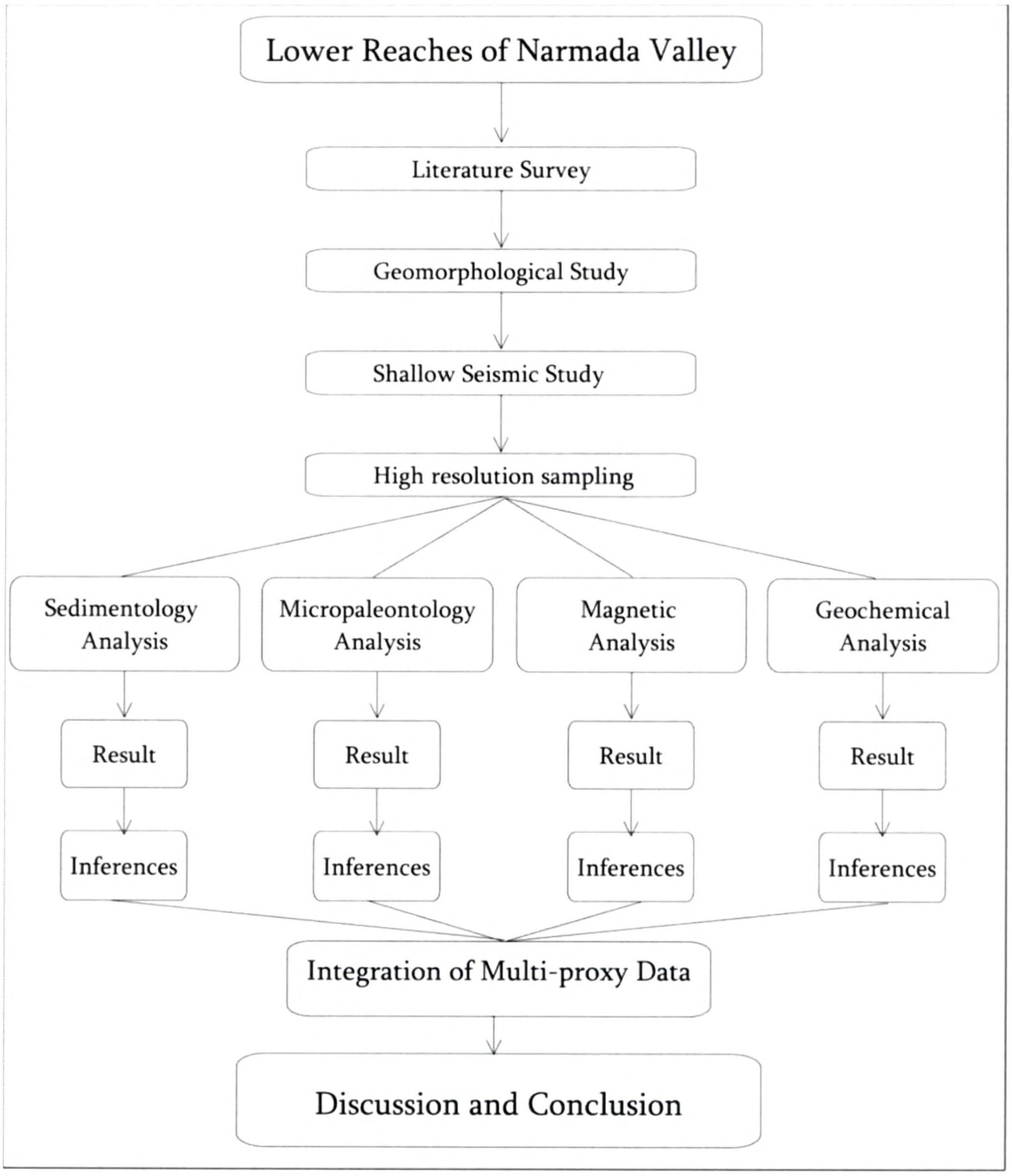

Figure 1-: Flow chart showing methodology adopted in the present study

1.5.2 Earlier Approaches and Results

The lower reaches of Narmada Valley became an area of interest for different researchers since the 19th century. The drainage basin of tributaries that flows into Narmada in the lower reaches exposes Precambrian metasedimentaries and granites, Cretaceous Bagh and Lamata beds, Deccan basalts and intrusive, Tertiary and Quaternary sediments in their catchment as well as along different sectors.

A detailed description of Champaners and associated Precambrian rocks have come out from the works of Blanford (1869), Fermor (1909), Hobson (1926), Rao (1931); Gupta and Mukherjee (1938); Rasul (1965); Gopinath and Krishnamurthy (1968); Jambusaria (1970); Gopalan et al. (1979); Mamtani and Karanth (1997). Bagh and Lamata beds of Cretaceous age have first mapped and decoded stratigraphy based on sedimentology and palaeontological evidence by Blanford (1869) and later by Bose (1884), Vredenburg (1907), Sahni (1936), Chiplonkar et al. (1977a), Chiplonkar et al. (1977b), Singh and Srivastava (1981), Biswas and Deshpande (1983), Karanth et al. (1988a), Ahmad and Akhtar (1990) and Akhtar and Ahmad (1991).

The Deccan basalt and associated rocks cover vast area in the lower Narmada valley. Blanford (1869) was the first to study the basalt flows and associated rocks. A major contributions on the Deccan basalt and associated rocks come from Sukheswala and Avasia (1971), Pal and Bhimasankaran (1971), Sukheswala et al. (1972), Ghose (1976), Krishnamurthy and Cox (1977), Sukheswala (1981), Ramanathan (1981), Mahoney (1988), Sant and Karanth (1990) and Simonetti et al. (1995).

Tertiary rocks are exposed in the South of River Narmada were studied by Carter (1854: cited by Agrawal, 1984), Theobald (1860), Wynne (1862-63: cited by Agrawal, 1984), Blanford (1869), Prasad and Ray (1963) Kathiara and Bhatt (1968) and Singh (1972). A significant understanding of sedimentology, stratigraphy and structure was further given by Prasad and Ray (1963), Gadekar (1975), Gadekar

(1976), Gadekar (1978), Gadekar (1980a), Gadekar (1980b) followed by Agarwal (1984) and Agarwal (1986).

Most of the records on the stratigraphy of Tertiary rocks in lower reaches of Narmada was brought out by Oil and Natural Gas Commission (ONGC) through various publications like Raju (1968), Chandra and Chowdhary (1969), Guha and Pandey (1972), Sudhakar and Basu (1973) and Banerjee and Rao (1993).

A systematic scenario of Quaternary geology and Geomorphology of Lower reaches of Narmada valley comes from the works spanning from 1869 to present. Blanford (1869) was the first one who studied the Quaternary deposits of Gujarat and reported the alluvial deposits of Narmada and Tapti Rivers.

Wainwright (1964) gave a detailed account of the Pleistocene sea level changes and its effects on the lower reaches of Narmada. Allchin and Hegde (1969), during the preliminary investigation of the Narmada valley had noticed the terrace characters of the Lower reaches of Narmada valley. They identified three terraces in the field, in which terrace II, they described is the most prominent terrace. According to them- *"Terrace II is the most obvious, and is the feature which first drew our attention to the terrace system. It takes the form of a cliff cut into the silts of the plain, which can be traced along both banks of the river from the coast upstream to Chandod."*

Allchin et al. (1978) had identified major terraces of Narmada, Mahi and Sabarmati rivers and inferred different phases of aggradation and incision. Gadekar et al. (1981) studied the channel migration and geomorphic evolution of the Lower Narmada valley using satellite imageries. They identified different geomorphologic features like oxbow lakes, point bars and bar islands and suggested at least four stages of geomorphic changes during the Northerly shifting of River Narmada. According to them it was a flood dominated channel shifting or a Neotectonic activity which was responsible for those changes.

Bedi and Vaidyanadhan (1982) mapped detail morphology of lower reaches of Narmada valley using Landsat imageries. According to them, the landforms evolved since late Quaternary period. They further highlighted the role of palaeohydrological and neotectonic activities responsible for the morphological changes in the basin. Murthy and Pofali (1984) had worked out a detailed geomorphological features of the entire Gujarat region using satellite imageries. They had identified five main geomorphological units along with the subunits. The major units were Hill, Table Land, Ridge and Dome, Pediment, Plain and Marine landscape.

Patel et al. (1984) had studied the Geomorphological features along the Mahi-Tapi coastal segment of Gujarat coast and derived a four stage sea level change in the Quaternary age: A marine Transgression in the Early to Upper Pleistocene age, Regression in the late Upper Pleistocene age, Transgression in early Holocene and a Regression in the recent time. Karanth et al. (1988b) had studied the morphometric analysis of selected streams in the lower reaches of Narmada valley and indicated that the river channels are controlled mainly by lithology and structure, and also inferred that the lithological configuration and structural features are in response to the Late Cretaceous and the Late Tertiary tectonic disturbances.

Sundaram et al. (1991) had concentrated mainly on the neo-tectonic activity and Quaternary landforms in the Bharuch area using Landsat imageries and field mapping. They identified five major geomorphological features in the Bharuch area and spatial distribution of these landforms controlled by five linears. They also suggested that the differential movement along these linears due to neo-tectonic activity is responsible for the geomorphologic framework of the area.

Chamyal and Merh (1992) worked out detailed Quaternary stratigraphy for the Narmada, Mahi and Sabarmati river basins of Gujarat. They divided the Quaternary deposit of Lower Narmada valley into three units namely Tilakwada Formation, Ambali Formation and Broach Formation. Merh and Chamyal (1993) had studied the Quaternary sediments of Gujarat and divided it into three main divisions' viz., Marine sediments, Fluvial sediments and Aeolian sediments. They also inferred that the interplay of palaeo-climate and Glacio-eustatic factors were the prime reason for the Late Quaternary landscape of the Gujarat. Sant and Karanth (1993) derived the drainage evolution of lower Narmada Valley since Palaeocene, distinguishing role of regional faults and change in drainage systems.

Chamyal et al. (1994) studied the significance of gravel sequences in Tilakwada and indicated that these sediments are deposited in a tectonically controlled environment of a graben fill.

Maurya et al. (1995) studied the tectonic evolution of the Gujarat alluvial plain and inferred that the Late Quaternary tectonic events were responsible for the current landscape of central Gujarat. Chamyal et al. (1997) and Bhandari et al. (2001) had studied the Narmada alluvial fan near the Tilakwada area. The exposed sedimentary sequences at six locations were divided into five lithofacies. Detailed analysis of the section further inferred that the alluvial fan architecture is dominated by debris flow deposits indicative of a semi-arid condition. They have also inferred that the deposition of alluvial fan event was a major activity responsible to the reactivation of pre-existing lineaments. Chamyal et al. (2002) used geomorphic data combined with stratigraphic records to infer the Late Quaternary geomorphic evolution of the Lower Narmada valley and gave emphasis to the neotectonic activity of Narmada-Son fault. Raj et al. (2003) studied the Karjan River basin, a tributary of Narmada and the major structural features and drainage network analysis of the basin reveals an active tectonic history of this part of the Narmada basin.

Gupta and Chakrapani (2005; 2007) had made an attempt for the first time to study the spatial and temporal variations in water discharge and sediment load of the Narmada River basin, tributaries and also the probable causes of variation. Their analysis showed that 60-80% of the sediment load carried by the river is trapped in Sardar Sarovar Dam. They further pointed that the water flow in the

River Narmada is influenced by rainfall, catchment area, ground water input whereas geology/soil characteristics of the catchment and presence of dams/reservoirs plays a major role in the sediment load.

Bhandari et al. (2005) had studied the Late Pleistocene sedimentation history of the alluvial plain sediments of lower Narmada valley and classified the exposed sediment sequence into two as alluvial fan deposits overlaid by alluvial plain sediments. According to the authors, it was the first study on the alluvial plain sediments of the lower reaches of Narmada valley and indicated that the alluvial plain sediments are characterised by overbank sediments and large scale sandy bed forms. Their study indicated that the Narmada channel has retained a large catchment since 100ka.

Raj (2007) had carried out a detailed analysis of landforms, drainages and geology of the area between the rivers Amaravati and Karjan in order to understand the tectonic history of the lower Narmada basin. Based on the drainage offsetting and tectonic landforms, the study inferred that the area is undergoing an active deformation that is driven by Narmada Son Fault.

Raj (2008) had reported an occurrence of volcanic ash at Quaternary alluvial succession of the Madhumati River, a tributary of the lower Narmada River. The geochemical analysis of the ash correlated well with the youngest Toba Tuff.

Raj and Yadava (2009) had studied the Late Holocene surface near the Karjan River basin, a tributary of Narmada. According to them, occurrence of organic rich clay (dating back to 1900-1200 Years BP) in an elevated terrace having 2-4 meter heights is indication of the latest phase of uplift in this region. Sridhar and Chamyal (2010) demonstrated the sediment accumulation in the Lower Narmada river basin as an effect of hydrological changes caused by climate and tectonic activities.