No. RCJ: 04.9/2014/Saraswati-Integ

Technical Report

RIVER SARASWATI: AN INTEGRATED STUDY BASED ON REMOTE SENSING & GIS TECHNIQUES WITH GROUND INFORMATION

Prepared By

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November, 2014

DOCUMENT CONTROL SHEET

<table>
<tr><td>1</td><td>Security Classification</td><td colspan="4">Non-Classified – For Public Use</td></tr>
<tr><td>2</td><td>Distribution</td><td colspan="4">All Users</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Report / Document Version</td><td>Issue No.</td><td>Revision</td><td>Version</td><td>Date</td></tr>
<tr><td>01</td><td>01</td><td>1.0</td><td>Nov., 2014</td></tr>
<tr><td>4</td><td>Report / Document Type</td><td colspan="4">Project Report</td></tr>
<tr><td>5</td><td>Document Control Number</td><td colspan="4">No. RCJ: 04.9/2014/Saraswati-Integ</td></tr>
<tr><td>6</td><td>Title</td><td colspan="4">River Saraswati: An Integrated Study Based on Remote Sensing & GIS Techniques with Ground Information</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">Particulars of Collation</td><td>Pages</td><td>Figures</td><td>Tables</td><td>References</td></tr>
<tr><td>76</td><td>28</td><td>7</td><td>73</td></tr>
<tr><td>8</td><td>Authors (s)</td><td colspan="4">1. Dr. J. R. Sharma 2. Dr. B. K. Bhadra
2. Dr. A. K. Gupta 3. Dr. G. Sreenivasan</td></tr>
<tr><td>9</td><td>Affiliation of Authors</td><td colspan="4">Regional Remote Sensing Centre – West</td></tr>
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GM, RRSC-W</td><td colspan="2">Approved by
CGM, NRSC</td></tr>
<tr><td>11</td><td>Originating Unit</td><td colspan="4">RRSC-W, NRSC/ISRO, Jodhpur</td></tr>
<tr><td>12</td><td>Sponsor / Name and Address</td><td colspan="4">EOAM Project (R&D)
ISRO, Dept. of Space, Govt. of India</td></tr>
<tr><td>13</td><td>Date of Initiation</td><td colspan="4">1st April, 2004</td></tr>
<tr><td>14</td><td>Date of Publication</td><td colspan="4">28th November, 2015</td></tr>
<tr><td>15</td><td colspan="5">Abstract: The integrated report deals with the findings of paleochannels of Vedic Saraswati River in northwest India using Remote Sensing & GIS. For this purpose, IRS satellite data of WiFS, AWiFS, LISS-III and LISS-IV sensors have been used to delineate the buried palaeochannels through image processing techniques in parts of Haryana, Punjab, Rajasthan and Gujarat. The discovered river course has been validated with ground information like historical maps, archaeological sites, hydrogeology, sedimentology, drilling (litholog) and geochronological data. The integrated study helped in exploring the potential utility of the palaeochannels. Drilling of tube wells on the palaeochannels shows the availability of large quantity of potable water which may be tapped as groundwater source in the water striven Thar Desert.
Keywords: Palaeochannel, Remote Sensing & GIS, Vedic Saraswati River, Archaeology, Hydrogeology, Geochronology.</td></tr>
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PREFACE

The existence of an extinct mighty river `Saraswati' in the Thar Desert region is well known to the people of northwest India. Many workers have come across with the evidences in the form of occurrence of isolated palaeochannels, potable water and good yield in the wells drilled along these channels, archaeological artefacts, channel like anomalies on aerial photographs and satellites images etc. and have tried to suggest a number of courses of the river based on evidences and interpretations. The course of the river had been debated for a long time and also the reasons for its disappearance, necessitating a fresh look through latest available satellite data.

The main objective of the study is to carry out a detailed study to delineate the true course of river 'Saraswati' now covered below the sands in Thar Desert using latest satellite images. This study is carried out taking advantage of the multi-spectral, multi-date and multi-resolution data from new generation satellites / sensors and the developments in digital image processing and GIS techniques and supported by the ground evidences.

Further, the discovered river course has been validated on by a variety of scientific data and investigations carried out by various survey agencies. An integrated study has been carried out to explore the potential utility of the palaeochannels with ground information like historical, archaeological, hydrogeological, sedimentological, drilling (litholog) and geochronological data. Drilling of tube wells on the palaeochannels shows the availability of large quantity of potable water which may be tapped as groundwater source in the water striven Thar Desert.

An attempt has been made to compile the available geochronological ages of fluvial sands, aeolian sands and groundwater samples along the palaeochannels. All these chronological events lead to build drainage evolution of River Saraswati in NW India during Quaternary Period. Finally, the Vedic Saraswati River has been linked to the Himalayan Rivers like Yamuna / Tons River in the east and Sutlej River in the west. The entire course of Vedic Saraswati River has been delineated from Man Sarovar Lake in the Higher Himalaya to Gulf of Kachchh in Arabian Sea.

It is hoped that this scientific findings will give an end to the debate on the existence of `River Saraswati' in the past and the reasons for its disappearance.

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ACKNOWLEDGEMENTS

The authors express their sincere gratitude to Dr. K. Radhakrishnan, Chairman, ISRO and Secretary, DOS for motivation and his kind support to work on Vedic Saraswati based on remote sensing techniques. The entire team is grateful to Dr. V. K. Dadhwal, Director, NRSC/ISRO, Hyderabad for his keen interest and encouragement.

We are highly thankful to Shri Darshan Lal Jain, Director, Saraswati Nadi Sodh Sansthan, Yamunanagar, Dr. S. Kalyanraman, Director, Saraswati Nadi Sodh Prakalp, Chennai, Late Dr. D. S. Chauhan, J.N.V. University, Jodhpur, Late Dr. S P Gupta, General Secretary, Indian Archaeological Society, New Delhi, Dr. Amol Kar, Principal Scientist (Retd.), CAZRI, Jodhpur, Dr. Sanjay Manjul, Suptd. Archaeologist, Archaeological Survey of India, New Delhi, Dr. V. M. K. Puri, Director (Retd), Geological Survey of India and Shri Rajesh Purohit, Director, Sri Krishna Museum, Kurukshetra for their active association, encouragement and fruitful discussion at various stages of the project work.

Kind help in various data collection from Ground Water Department (GWD), Govt. of Rajasthan, Central Ground water Board (CGWB), Jodhpur, Ground Water Cell (GWC), Govt. of Haryana and Punjab, Bhabha Atomic Research centre (BARC), Mumbai, Archaeological Survey of India (ASI), New Delhi is highly acknowledged.

We acknowledge the kind support of Shri F. M. Golani, Chief Engineer (Retd.), Shri K.S. Srivastava, Shri Rajendra Dharmawat, Shri M. K. Babel, Shri Vimal Soni and Shri J. P. Shukla of Ground Water Department (GWD), Jodhpur during drilling and geophysical survey along the palaeochannels in Rajasthan.

We would like to pay our sincere thanks to Dr. S. K. Wadhawan, Shri S. B. Sharma and Shri P. C. Bakliwal of GSI, Jaipur, Prof. M. S. Sishodia, JNV University, Jodhpur, Prof. N. K. Gupta of NIT, Kurukshetra, Dr. R. C. Patel and Dr. A. R. Chaudhary, Kurukshetra University and Mr. Madan Gopal Vyas of Jodhpur for their good suggestions.

Authors

EXECUTIVE SUMMARY

The north-western region of Indian sub-continent witnessed a number of mighty flowing rivers in the past. Like present day Indus River system, a sub-parallel river system known as `Vedic Saraswati River' was flowing with full majesty around 6000 B.C. River Saraswati originated in the Higher Himalayas and flowed through the western part of Indo-Gangetic alluvial plains along several tributaries like Sutlej, Yamuna, Chautang and Drishadvati. The Saraswati river system passed through the states of Himachal Pradesh, Uttarakhand, Punjab, Haryana and Rajasthan and finally discharged into Rann of Kachchh in Gujarat. The river dried up subsequently and disappeared around 3000 B.C. due to climatic and tectonic changes in Himalayan region. The relict of this lost river is still preserved as palaeochannels in the above states. However, establishing the exact course of Vedic Saraswati and its perennial source remains a debatable topic among the researchers due to lack of proper scientific database. The mystery is unravelled through modern tools like Remote Sensing and GIS by using multi-spectral and multi-resolution satellite images.

For this purpose, optical satellite data (IRS P3 WiFS and IRS P6 AWiFS, LISS-III, LISS-IV and Landsat ETM) as well as microwave (Radarsat SAR) data have been used to delineate the palaeochannels. "Piece-wise Histogram Stretching" technique has been used to enhance the palaeochannel signatures on the image. The mapped courses have been validated with a variety of ground information like historical maps, archaeology, sedimentology, hydrogeology and drilling data. The satellite image interpretation shows the obscured signature of `palaeo-rivers' below the aeolian sands in the Thar Desert. An attempt has been made to trace the entire drainage network of the `Lost Vedic Saraswati' from the Siwalik foothills to Arabian sea and its possible link to the perennial source in higher Himalaya.

Occurrence of a number of archaeological sites all along the palaeochannels in Saraswati basin indicates a close affinity of Indus-Saraswati (Harappan) civilisation with the Vedic Saraswati River. Spatial distribution of Early, Mature and Late Harappan sites in Haryana show shifting population from southwest to northeast with the pace of drying Saraswati River.

Drilling data in Jaisalmer district of Rajasthan shows fine to medium and coarse grained sand/gravel in the palaeochannels, formed by fluvial activity. Coarser sediments have been found at a depth range of 40–125m in most of the tube wells. Channels are about 35 to 80m thick with depth of water level ranging from 35-60m. However, litholog data close to the palaeochennels in Haryana show medium to coarse grained sands and associated gravel and pebbles at a depth between 10 to 100m. Electrical resistivity soundings along Ghaggar River indicate thick and extensive sand body in the subsurface in parts of north-western Rajasthan, Haryana and Punjab. The dimensions of the palaeochannel complex suggest a large, long-lived fluvial system existed in this region.

The relative ages of the discovered archaeological sites and the radiocarbon dating of ground water and sediment samples all along the palaeochannels are highlighted in the present study. Radiometric ages of river sediments suggest that the age of Vedic Saraswati River (older palaeochannels) may be as old as 28,000 years. The river was flourished during 8000 to 5000 years ago which may be represented by younger palaeochannels in Haryana. However, the age of trapped ground water in the palaeochannels in Rajasthan shows contemporary age of Saraswati (1340-8910 BP) and as old as 18800BP. Present day perennial sources of Sutlej and Yamuna/Tons rivers upto the Siwalik foot hills have been considered as part of Vedic Sarasvati River. Available sources with the present scientific evidence leads to the conclusion that Saraswati River network might have been in existence as old as 28,000 years BP and ceased to be a dry channel during 3792 years BP.

Sutlej palaeochannel in Punjab links Vedic Saraswati River as the major source at Mansarovar Lake. Other perennial sources of this river may be attributed to Tons/Yamuna river system which is linked to Bandarpunch glacier in Garhwal Himalaya. A linkage of the entire drainage network has been established from Mansarovar (Tibetan Himalaya) to Dwarka (Arabian Sea coast) during late Quaternary period.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AD	: Anno Domini
ASI	: Archaeological Survey of India,
AWiFS	: Advanced Wide Field Sensor
BARC	: Bhabha Atomic Research Center, Bombay
BC	: Before Christ
BP	: Before Present
CAZRI	: Central Arid Zone Research Institute, Jodhpur
CGWB	: Central Ground Water Board
DEM	: Digital Elevation Model
DW	: Dug Well
EC	: Electrical Conductivity
ETM	: Enhanced Thematic Mapper
FCC	: False Colour Composite
GIS	: Geographic Information System
GSI	: Geological Survey of India
GWD	: Ground Water Department
HRSAC	: Haryana Remote Sensing Application Centre
IRS	: Indian Remote Sensing
ISRO	: Indian Space Research Organization
LGM	: Last Glacial Maximum
LISS	: Linear Imagine Self Scanning
MSS	: Multi Spectral Scanner
NIO	: National Institute of Oceanography
NRSC	: National Remote Sensing Centre
ONGC	: Oil and Natural Gas Commission
OSL	: Optically Stimulated Luminescence
PC	: Palaeochannel
PHED	: Public Health and Engineering Department
PRL	: Physical Research Laboratory
PGW	: Painted Grey Ware
RRSC	: Regional Remote Sensing Centre
SAC	: Space Application Center
SAR	: Synthetic Aperture Radar
SOI	: Survey of India
SRSAC	: State Remote Sensing Application Centre
SRTM	: Shuttle Radar Topography Mission
TL	: Thermo Luminescence
TM	: Thematic Mapper
TW	: Tube Well

CHAPTER - 1

1.0 INTRODUCTION

Saraswati is known as the holiest river of India, as much as it has retained its sacred character right from the Rigvedic age to the present day. The name `Saraswati' is frequently used most of the ancient literatures like Rigveda, Yajurveda, Mahabharatha and Puranas. The Rigveda is supposed to be the oldest text which was probably composed more than 8000 years ago. The river Saraswati is described in the Rigvedic literature as the '*Ambitame, Naditame, Devitame'* that is the best of mothers, best of rivers and the best of Goddess. The river was one of the mightiest rivers of the Vedic period and must have been significantly broad and perennial. The Vedic Saraswati, a mighty and holy river of northwest India during 6000-3000 B.C., originated from Bandarpunch glacier in Garhwal Himalayas and finally discharged into the Gulf of Khambat in Gujarat coast and disappeared around 3000 B.C. Several remnants of this river exist as palaeochannels (Ghose et al., 1979; Gupta, 1996; Mishra, 1995; Radhakrishna, 1999; Valdiya, 2002; Yash Pal et al., 1980). Today the Vedic Saraswati River is represented by the Ghaggar River which flows on palaeochannel of Vedic Saraswati, located in the western part of the Haryana state (Bhadra et al., 2006). The Vedic Saraswati River has been flowing sub-parallel to the Indus River in NW India (Krishnan, 1952; Oldham, 1893; Pilgrim, 1919; Stein, 1942; Wilhelmy, 1999).

The discovery of the sites of Harappan civilization along the banks of Saraswati River also indicates towards mighty and its magnanimity. This ancient civilization is believed to have come to a sudden end as a result of neotectonics as well as climatic change. Due to these causes, river Saraswati which once flowed in true majesty dwindled to an ephemeral stream and finally got lost in the sand of Thar Desert **(Fig.1)**. Rivers of Punjab, Haryana, western Rajasthan and the northern Gujarat, present an interesting and complex evolutionary history of drainage development dating back to middle Pleistocene. The study of `Lost River Saraswati' becomes a fascination which leads to unflagging interest in the minds of the Scholars and Scientists in India and abroad.

1.1 Topographical Variation of the Region using DEM

Physiographic features of northwest India can be depicted on the slope map **(Fig.2)** which is generated through SRTM DEM (90m resolution). It shows an extensive stretch of gently sloping flat land from northeast to southwest with an elevation range between 270m in the foothills of the Himalaya and the seacoast of Gujarat. A number of streams emerged from the southern slope of Siwalik Hills and flow towards southwest direction and joins Ghaggar River. Except the foothill tract of Himalaya, a vast stretch of northwest India is comprised of alluvium deposits which are composed of clay, silt and sand. A hot and dry summer, southwest monsoon season and a bracing cold season characterize the climate of the area. Physiographic features of Rajasthan, Haryana and Gujarat are given below.

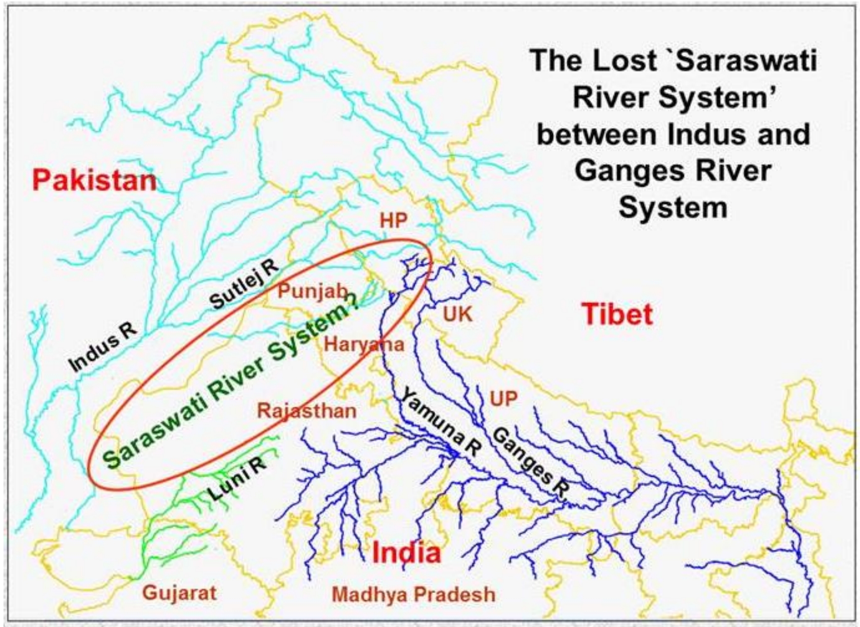


Fig.1: Major Drainage System of northwest India

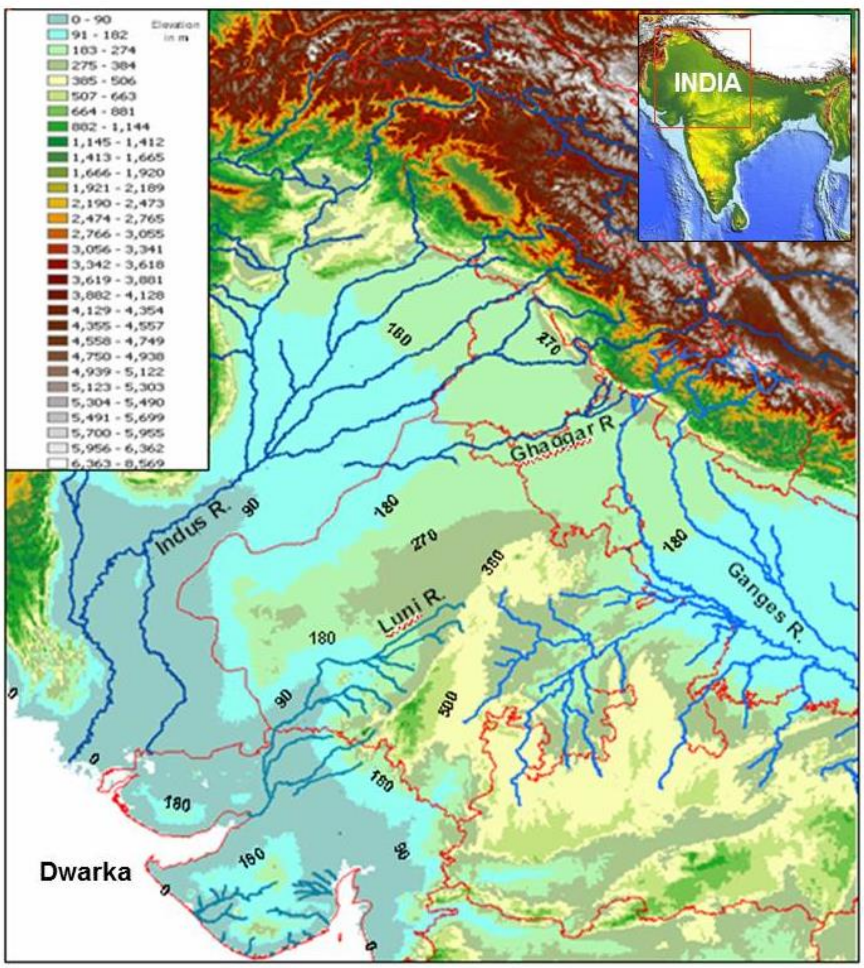


Fig.2: Slope Map of NW India, generated from SRTM DEM

1.2 Physiographic Divisions of Northwest India

1.2.1 Physiographic Divisions of Rajasthan: There are two natural divisions of Rajasthan. The northwest tract is sandy and unproductive with little water, but improves gradually from desert land in the far west and southeast to comparatively fertile and habitable land towards the east. Western part of Rajasthan is charaterised by aeolian sands and alluvium in the Thar Desert. In the southwest of Rajasthan, many hillocks form as a part of Aravalli chain of mountains. The main physiographical features of Rajasthan are as follows:

- (a) Western Sandy plains
  - (i) Sandy Arid plains (Marusthali)
  - (ii) Semi-Arid transitional plains (Rajasthan Bagar)
- (b) Aravalli Range and hilly region
  - (i) Aravalli Range and Bhorat Plateau.
  - (ii) Northeastern hilly region
- (c) Eastern Plains
  - (i) Banas Basin
  - (ii) Chappan Plains
- (d) Southeastern Rajasthan-Pathar (Harauti Plateau)
  - (i) Vindhyan Scarpland
  - (ii) Deccan Lava Trap

1.2.2 Physiographic Divisions of Haryana: Haryana can be divided into four major Physiographical features:

- (a) Siwalik Hills - Altitude varies between 900m to 2300m. These hills are the source of the river like Saraswati, Ghaggar, Dangri and Markanda.
- (b) Ghaggar-Yamuna Plains - It is divided into two parts viz. the higher one is called 'Bhangar' and the lower one is called 'Khadar'. This alluvial plain is made up of sand, calcareous balls like gravel, locally known as 'Kankar'.
- (c) Semi-Desert Sandy Plain - This area is bordered with Rajasthan and Haryana including the districts of Sirsa, parts of Fatehabad, Hisar, Bhiwani and Mahendragarh.
- (d) Aravalli Hills - This is a dry area with uneven irregular landscape.

1.2.3 Physiographic Divisions of Gujarat: Different phusiographic features of Gujarat are given below.

- (a) Coastal Zone – Present in the southern part of the state.
- (b) Kachchh Mainland - The central part of state composed of rocky land with hill in the north and coastal plains.
- (c) Banani Plains - It is characterized by fluviomarine sediments, with mud flats and soft pans.
- (d) Two Ranns - Great Rann in the north and Little Rann in the east, comprising vast saline wasteland

1.3 Drainage System of Northwest India

A few thousand years back several mighty rivers drained the northwestern part of India and these now stands disrupted, partly destroyed and preserved only as poor relicts making up the present day drainage system. The bounty of the Himalayan Rivers sustains the entire Indo-Gangetic plains except for the tract that embraces southwest Haryana, southern Punjab and western Rajasthan. This vast river-less tract is underlained by nearly 10-30 m thick mantles of riverine sediments of younger age characterized by a multiplicity of channels in which only flood waters flow for extremely limited durations. The wide channels are either choked with sediments or are buried under the sands of the Thar Desert (Raghav, 1999).

Presently, northwestern part of India is drained by three major independent river systems namely Yamuna, Sutlej and Ghaggar (Saraswati). Yamuna and Sutlej are perennial river systems while the Ghaggar is mainly ephemeral. The Sutlej River originates in the Himalayas from the holy lake of Mansarovar in Tibet and enters the plains near Ropar (Punjab), where it takes a sharp right-angled turn and flows westward over a distance of 150 km before being joined by the Beas river near Firozpur. The river is joined by Sirsa nadi, Siswan nadi, Chikni nadi, Bakhi nadi and Haripur nadi from the east. It flows as a highly meandering and sinuous river. Further north, Tons River originates from Bandarpunch glacier in Garhwal Himalya and joins with Yamuna River at Paonta Sahib. The Yamuna River originates from the Yamunotri glacier and reaches the plains near Yamunnagar. The Yamuna River and its tributaries are originating from the central Himalayas and display typical rectangular drainage pattern. Most of the streams are joining each other at right angles, which exhibit that it is flowing through a structurally controlled terrain. Giri River meets Yamuna near Paonta about 12km upstream from the confluence of Bata and Yamuna. The Yamuna, which was supposed to be a major tributary of Saraswati, got diverted through the Yamuna tear fault was earlier flowing through the Bata river course and joining the Markanda river. The wide valley of the small Bata River supports this. The Ghaggar River rises in the Siwaliks from the Morni hills and enters the plains near Ambala (Haryana). After covering a distance of 175 km it joins the Saraswati at Rasula (Patiala district). The combined river now known as Ghaggar flows through Sirsa (Haryana), Hanumangarh and Ganganagar districts (Rajasthan) and through the Bahawalpur state (Pakistan). The Saraswati rises in the Sirmur region of the Siwaliks and enter the plains at Adi Badri (Yamunanagar district of Haryana). After flowing through Yamunanagar, Kurukshetra and Karnal districts in Haryana it joins the Ghaggar near Rasula (Patiala district-Punjab). The Ghaggar bed dries up near Sirsa. The Ghaggar is also noticed to have flowed along straight lines joined together at sharp angles. This reflects structural control as the old Ghaggar must have flowed into an unstable channel controlled by lineaments. Markanda River originates from Nahan in Sirmaur district of Himachal Pradesh and reaches the plains in Ambala and later joins the Ghaggar in Patiala district. The river acts as a divide between the Bata-Markanda complex and the Giri river.

1.3.1 Indus River System: The following four major rivers have been mentioned in Rigvedic literature (Sridhar et al., 1999).

(a) Sindhu (Indus) and its tributaries like Vitasa (Jhelam) and Asikni (Chenab)

(b) Shatadru (Sutlej) and its two major tributaries like Vipasa (Beas) and Parasuni (Ravi)
(c) Saraswati and its several tributaries in its upper reaches viz. Markanda, Ghaggar, Chautang, Dangri etc.
(d) Drishadvati with Lavanavati (?) as one of its tributaries.

These rivers originated in the Himalaya and flow across Rajasthan, Gujarat and parts of Pakistan and meet at Rann of Kachchh of Arabian Sea. Out of the four river systems, Indus and Sutlej are still flowing today through vast tract of Indo-Gangetic alluvium plain. However, Saraswati and Drishadvati have been destroyed (dried) completely whose remants can be found below the sands of Thar Desert. Oldham (1893) reported the existence of a dry bed of older Sutlej course as Hakra which flowed through Bikaner abd Bhawalpur. When Sutlej changed its course westward to meet Beas and finally the Indus, its abandoned eastern arm (Hakra) was left as deserted cnhanel. The lower course of Sutlej was referred as Hakra, Sankra, Wandan, Wahind and Nara. Thus, dry channel of Hakra-Nara was presumed to the old course of Sutlej River. Occurrence of a large number of archaeological sites (Harappan) between Indus and Hakra-Nara (Sutlej) indicates the furishment of Harappan civilization. However, recent studies show the existence of an independent river system along Indo-Pak border which runs paralle to Indus River. Based on historical, archaeological and physiographic evediences, this river is regarded as `Saraswati River' which is flowing as sub-surface palaeochannel in northwest India.

The rivers of the Saraswati and the Indus systems have together built a vast floodplain that forms the western part of the Indo-Gangetic Plains. This plain embraces the northern upland of the Indian Shield up to the foothill of the Himalaya. A large part of the Saraswati-Indus Plain is now covered by wind-blown sand, heaped as ridges and dunes in the Thar Desert. The rocky area sloping gently westwards and northwestwards in front of the Aravalli range is covered by a thin discontinuous veneer of varied sediments. This NE-SW trending Aravalli Range thus marks the eastern limit of the domain of the Saraswati-Indus Rivers.

1.3.2 Saraswati-Ghaggar River System: Saraswati Nadi (also known as Saraswati River, Saraswati Nala, Sarsuti and Chautang in certain segments) in northern Haryana is one of the important tributary of the Ghaggar River system. The Saraswati Nadi flows seasonally from Adi Badri and passes through Bilaspur, Mustafabad, Thanesar, Bibipur and Pehowa and ultimately joins river Ghaggar near Rasauli village in Punjab. Presently, Sarswati Nadi is in defunct state and exibitsts as a discontinuous drainage. Existence of a large number of archaeological sites along the river suggests it to be an important drainage of the past. Though Adi Badri is located on the bank of River Somb, but local people believe that Saraswati originates at Adi Badri. Mention of Saraswati Nadi of Haryana has been made in drainage related studies carried out by various authors in this region. However, exclusive studies on this drainage system are very rare. As seen on the SOI topomaps, Saraswati Nadi originates from a place called `Rampur

Herian' which is located south of Adi Badri in Yamunanagar district. The existence of Saraswati Nadi from Rampur Herian to Bibipur is seen clearly on the topomaps and satellite images**.** On Survey of India (SOI) topomap of 1969-70, it is shown as Saraswati Nala / Nadi / River. The name `Saraswati/Sarsuti' Nadi in Haryana has been mentioned elsewhere in the earlier literatures (Chauhan, 1999; Kalyanraman, 1999; Kochhar, 2000; Radhakrishna, 1999; Valdiya, 2002).

Saraswati Nadi is believed to be a sacred river in Haryana. This is evident from the occurrence of several historical temples, pilgrimage and Hindu ritual sites and relics of archaeological sites all along the course of this river indicating it to be a perennial river in the past. Most of these pilgrim sites belong to either Post-Harappan or Mahabharata period. The river passes through Yamunanagar, Kurukshetra, Kaithal and Fatehabad districts and joins with River Ghaggar at Rasauli village near Shatrana in Patiala district of Punjab. Drainage pattern of Saraswati Nadi, derived from the SOI topomaps, shows two southwesterly flowing sub-parallel streams on either side of the Chautang Nala which crisscross at several places between Purangarh and Babain villages. The shifting of their course is possibly due to discontinuous discharge in the past. The local people strongly believe that Adi Badri is the place of origin of Saraswati Nadi which is the main Vedic Saraswati River. Local populace performs different Hindu rituals along this river course.

The floodplain, through which the River Saraswati once flowed, slopes southwest from an elevation of nearly 250m altitude above sea level in the Ambala-Ludhiana tract to the low-lying marshy stretch of the Great Rann of Kachchh. This floodplain was built on the northern marginal shelf of the Indian shield that had sagged gently as it slid under the Himalaya. In this sunken part of the Indian crust, known as the Himalayan Foredeep, huge piles of the detritus were deposited by the rivers originating from the rising Himalaya. Some part of the sediments was also contributed by the Aravallli Hills.

The drainage modification in the last 10,000 years of the Holocene period is manifested by the streams abandoning of old courses. The abumdoned courses are recognizable as curvilinear or meandering segments of dry channels amidst the sea of sand. Remote sensing techniques helped to locate these buried channels on the satellite images. The interpretation of the satellite imagery indicates progressive westward shift of the river courses. This phenomenon is discernable in both the northern Saraswati (Ghaggar) basin and the southern Lavanavati (Luni) basin. As stated earlier, the Barwani-Jaisalmer Ridge that has been rising and has consequently causes shift of the drainage, separates the two independent basins. The Saraswati-Drishadvati system that belonged to the northern basin migrated progressively northwest or west over time, to occupy the present Ghaggar-Hakra line, and the Lavanavati occupied the southern basin and shifted in the southerly direction. The Saraswati and across the Barwani-Jaisalmer water divide, the lavanavati remained independent of one another throughout the geological history.

Sinha et al. (2013) opined that major palaeo-river channel course, the Ghaggar-Hakra, flowed in the interfluve between the modern Yamuna and Sutlej rivers in the western Ganges basin during the Late Quaternary. A thick and extensive sand body is present in the subsurface in parts of north-western Rajasthan, Haryana and Punjab. The dimensions of the palaeochannel bodies imply that these are the deposits of a large river system.

1.3.3 Drishadvati River System: Drishadvati system of Haryana is also an ancient river system, more or less contemporary to Vedic Saraswati. It is proved by the mention of Drishadvati in Rig Veda and occurrence of a large number of Harappan sites along its course (Kar and Ghosh, 1984; Sahai, 1999). There is no continuous trace of River Drishadvati in central Haryana which is attributed mainly due to the disturbance of original ground through digging of dense canal network in this region. But its presence can be inferred from discontinuous drainage, Vedic literature and archaeological findings. It is believed by most of the previous workers that the course of Western Yamuna Canal has been constructed along the palaeo-course of River Drishadvati (Ghosh et al., 1979; Kar and Ghosh, 1984; Oldham, 1893; Wilhelmy, 1999; Yash Pal et al., 1980). The Chautang Nala (1.0 - 1.5 km wide channel) is considered as the main tributary of the Drishadvati River.

1.4 Objectives

The following are the main objectives of the present work.

- Delineation of palaeochannels using IRS P6 AWiFS, LISS-III and LISS-IV data.
- Physiographic study using SRTM DEM.
- Preparation GIS database for road, rail, settlement, administrative boundary, existing drainage, location of archaeological and drilling sites.
- Field validation of the palaeochannels using historical data, archaeological sites, sedimentology (drilling/litholog), hydrogeology and geochronology data.
- Study of available geochronological ages of sand, water, artifacts.
- Possible River Linkages of Vedic Saraswai with Somb, Tons/Yamuna, Drishadvati and Sutlej Rivers.
- Reconstruction of palaeodrainage network from Mann Sarovar to Dwaraka.

1.5 Methodology

In the present study, satellite data from IRS P3 WiFS, IRS P6 AWiFS (56m), LISS-III (23.5m) and LISS-IV (5.8m) of February, 2004 have been used to delineate the course of the palaeochannels in NW India**.** For specific area, Landsat ETM and Radarsat SAR data also have been used for palaeochannel mapping. The extent of Thar Desert and the present day drainages in NW India have been shown on Landsat imge **(Fig.3)**. All these data have been digitally processed in ERDAS/Imagine software (version 10.0). Digital image processing techniques like histogram equalization, piece/scene wise linear stretching, contrast and brightness enhancement, different band combinations and edge enhancement etc. have been applied on the satellite data. Present day drainages are traced from IRS P6 LISS-

IV data (5.8m resolution) and the Survey of India topomaps (1969). For integrated study, GIS database of various thematic layers (administrative boundary, settlement, road, rail, drainage, well location, archaeological sites etc.) have been prepared by using ARC/MAP software (version 10.0). The delineated palaeochannels are validated with various ground data and collateral information from archaeology, sedimentology, hydrogeology and petrography.

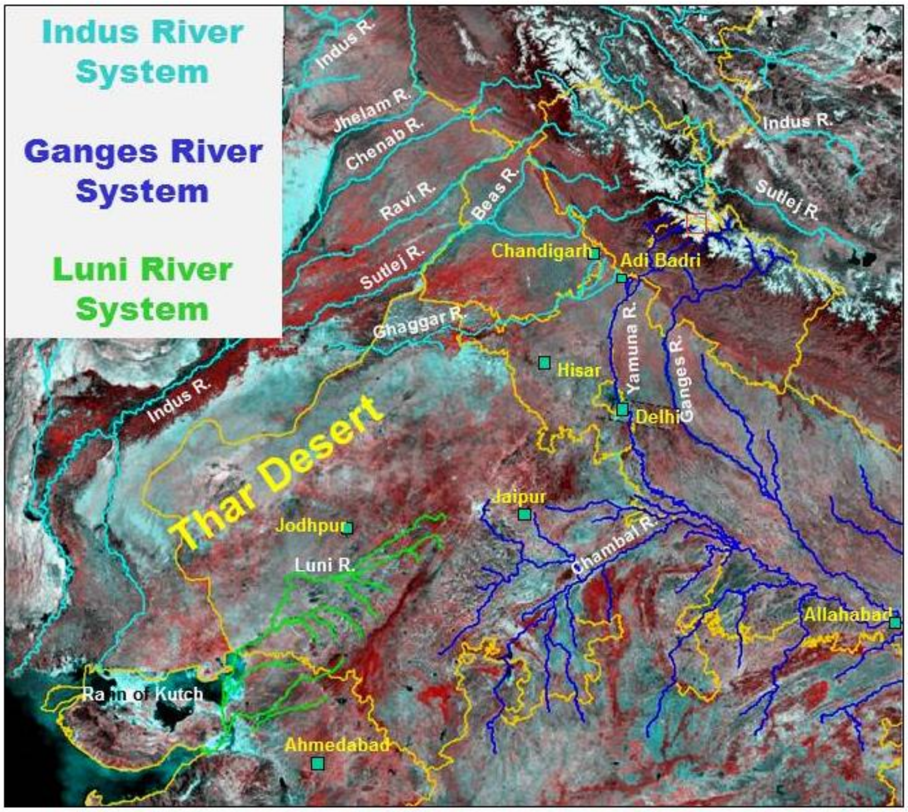


Fig.3: Satellite image showing major drainage systems in NW India

CHAPTER - 2

2.0 LITERATURE SURVEY

The Rigveda, which is supposed to be the oldest texts available to mankind, contain the maximum information about the river Saraswati. Rivers of Punjab, Haryana, western Rajasthan and northern Gujarat, present an interesting and complex evolutionary history of drainage development dating back to Middle Pleistocene. Most of the evolutionary history, Late Quaternary climatic changes and tectonism have played a significant role in modifying the drainage pattern. Many authors have studied Vedic Saraswati River for the poast few decades based on multi-disciplinary approach (Bharadwaj, 1999; Chauhan, 1999, Kalyanraman, 1999; Kochhar, 1997; Radhakrishna, 1999; Rajaram, 1994; Valdiya, 2002).

2.1 Vedic Literature

The Saraswati River is described in most of the scriptures of India. There are frequent references of Saraswati in Vedic literatures (Chauhan, 1999; Kochhar, 1997). No other river has received so much importance and respect as Saraswati. Rigveda, the oldest of four Vedas contains ample information about the lost Saraswati River than that of River Ganges. There are seventy-five *Mantras* spread over all the ten *Mandals* (books) except the fourth. A few hymns are there in Yajurveda and Artharvaveda also. The hymns are composed by different Rishis (scholars) in glory of River Saraswati. Some of them are listed below:

2.1.1 Saraswati as described in the Rigveda:

ambitame nadi tame devitame Sarasvati
aprasasta iva smasi prasastimamba naskridhi

(2:41:16)

Best of mothers, best of rivers, best of rivers, best of Goddesses, Saraswati we are ignorant & untrained, give us wisdom & knowledge.

aa yatsaakam yashaso vaavashaanah Sarasvati saptathi sindhumaataa
yaah susvayanta sudughaah sudhaa raa abhiswena payasaa pipyaanaah

(7:36:6)

May the glorious seventh (stream) Saraswati, the mother of Sindhu & other (rivers) charged with copious volume of water, flow vigorously; come together, gifting abundant food & milk.

Sarasvati sarayuh sindururmibhirmaho mahiravasaa yantu vaksanih
devirapo maatarah sudiyitnvo ghrittavatpayo madhumanno Arcata

(10:64:9)

Let great streams with mighty currents come to protect us- Saraswati, Sarayu, Sindhu, Ye Goddesses give us butter & honey.

2.1.2 Saraswati in Yajurveda:

pancanadhyah Sarasvatimapi yanti sasrotasah
Sarasvati tu pancadhaa so deshe abhavat sarit

(34:11) (1803)

The five equally celebrated rivers, merged with the mighty Saraswati. The same Saraswati got (divide) into five glorified flows in the country.

It is, therefore, obvious that the Saraswati has five important tributaries. They were the Drishadvati, the Satudri (Sutlej), the Chandrabagha (Chenab), the Vipasa (Vyas), & the Iravati (Ravi). This Mantra supports the earlier assumption that all the above stated rivers of Punjab were tributaries of Saraswati.

The second part of the Mantra is still interesting which state that the Saraswati was divided into five parts (pancadha). These ought to be the five distributaries of the Saraswati; through them the river merges to the Sindhu Sagar (the Arabian Sea).

2.1.3 Saraswati in Atharvaveda:

devaa imam madhunaam sanyutam yavam sarasvatyaa madhi manaavacarkriyuh
aasit sirapatih shatakratuh kinasha aasan marutah sudaanavah

(6:30:10)

God bestowed the people on the bank of the Saraswati, with sweet juicy barley, where generous Maruts became farmers & Indra as the Lord of agriculture. This Mantra suggests that farming of cereals was practiced on the fertile soil of Saraswati during Vedic times.

2.1.4 Saraswati in Manusmriti:

Saraswati drisadvatvor devanadhyory dantaram
Tam deva nirmitam desham brahmavart pracakshate (3.17)

The land between the Saraswati & Drishadvati is created by God; this land is defined as Brahmavarta.

2.1.5 Saraswati in Mahabharata: The Saraswati River continued to be a celebrated river during the Mahabharata time also. It was referred as mother of the Vedas.

Vedanam mataram pusya (Mbh. Santiparva 12920)

Mahabharata gives clear geographical accounts of a number of pilgrimage sites spread along the course of the Saraswati River. Sri Balaram's pilgrimage, along the upsteam course of the Saraswati from Samudra Samgam to *Plaska prasaravana* give a vivid desription of most of these holy places.

Saraswati punya vaha - samudraga maha vega (Mbh. 3.88.2)

Holy flow of the Saraswati joins the sea impetuously.' This suggests that the river receives occasionally and attains the satte of rapid flow, even at its point of confluence.

Balaram after visiting a number of holy places reaches to Vinasana, the place where the Saraswati disappeared. During Mahabharata period, the discharge of water in Saraswati became extrely low. As a result, the river vanished in the desert sand at certain place along its regular course i.e. at Vinasana. Hence, the river channel appeared dry. However, underground flow of water continued to exist in the river bed.

2.1.6 Saraswati in Purana: The Saraswati River is widely quoted in Puranic literature. Vamana Purana gives vivid description of the place of origin of the Saraswati like

Markandeya manina santapta paramam tapah
Yatra samayata plakshashajata sarasvati
Sa sabhajya stuta ten munina dharmikena ha
Sarah sannihitam plavya pascima prasthita disam

Rishi Markandeya, close to the place where he meditated and offered sacrifices saw Saraswati rising from the Plaksha tree (Pipal tree). The sage prayed and worshiped the rising river. There from the Saraswati River flowing down and occupying the Sannihitasar Lake, followed a westward course.

2.2 Vedic Saraswati and its Disappearance

2.2.1 Vedic Saraswati River System: It is clear from the Vedic texts that the Rig Vedic people lived on the banks of a river called the Saraswati. The major rivers of northwest India were Saraswati, Sindhu (Indus), Shatadru (Satluj), Vipasa (Beas), Vitasta (Jhelum), Parushni (Ravi), Askini (Chenab), Yamuna, Drishadwati and Lavanavati. All these rivers have changed their courses since Vedic times. Saraswati, Drishadwati and Lavanavati no longer exist. There were about 300 cities and so many towns and villages along the banks of Saraswati. The Vedic Saraswati was a mighty river system that originates somewhere in the Himalayas, entered the plains and followed southwesterly direction through present day Punjab, Haryana, Rajasthan and Gujarat prior to joining the Arabian sea. Important towns like Kurukshetra, Shatrana, Yamunanagar, Sirsa, Kalibangan, Pilibangan, Suratgarh, Beriwal etc. flourished on its bank. Vedic Saraswati was already in existence prior to Ganga River system as per evidences in Rigveda.

The Saraswati River has been one of the mighty river systems of the Vedic age. The very name of the Saraswati in Rigveda means ‘Abounding in pools and lakes’ suggests that ever since the Rigvedic people knew the course of the river looked like ‘lakes’ (Saras). This happens in the structure of a river flowing in plains, when, either its gradient becomes irregular or disturbed by action of earth movements or when as result of setting in of desiccation (an area having rainfall under 10 cm becomes subjected to this process), the gradually shifting sand dunes attack its bed at several places. Saraswati known as Ghaggar (6–8 km wide) in its middle reaches indicate that it must have been once been a carrier of quite a voluminous discharge. The several tributary streams springing from the Siwalik Hills could not have alone contributed that large volume of water. So it is logical to say that the source of Saraswati River lay beyond the Siwaliks in the Himalayas. In it’s hey days the river Saraswati is supposed to have seven tributaries namely Yamuna, Sutlej, Chautang, Vishapa, Kantli, Drishadvati and Luni. The river flowed through four main regions. The first region was the Siwalik Hills near Adi Badri (Haryana) where it comes down to plains. The second region was the area between Kurukshetra and

Sirsa in Haryana where there was a thick population of Pre-Harappan and Harappan settlements. The third region lies in between Anupgarh and the erstwhile Bahawalpur (in Pakistan). The fourth region is the marshy area where it flowed as Hakra parallel to Indus and passing through Sindh province where it meets the Rann of Kachchh.

During the Vedic period the Saraswati River had flowed through the region between the present Sutlej and Yamuna. The present day river systems of the Sutlej – Yamuna divide are the Sutlej, the Ghaggar, the Saraswati, the Markanda, the Chautang and their tributaries. The Sutlej and Yamuna are perennial rivers rising in the Himalayas and fed by glaciers. The river Saraswati, Ghaggar, Markanda and Chautang all rise in the Siwalik Hills and are non-perennial. All the above river systems can be grouped into three main systems viz. the Sutlej system, the Ghaggar system and the Yamuna system.

Saraswati must have been a perennial source from a permanent glacier at Bandarpunch in Garhwal Himalaya. After originating from Bandarpunch glacier, Vedic Saraswati started flowing in southwesterly direction for nearly 40 km and it acquires huge dimension and high discharge from Pabbar confluence. It took a southwesterly course and flowed in a tortuous manner for nearly 100 km before entering in Paonta Doon. In other words, Vedic Saraswati flowed through the course of present day Tons River from Higher Himalaya down to Siwalik foothill upto Paonta Sahib where it joins with Aglar, Yamuna and Giri Rivers. In the past, Vedic Saraswati was possibly flowing towards west along the streams of Bata, Markanda/Saraswati and Drishadvati. At Rasula, the Saraswati met Ghaggar River that comes from southwest from the Morni Hills near Chandigarh. In due course, Yamuna River took a turn towards south, cutting across the Siwalik Range.

Rising in the Himalayas from the holy lake of Mansarovar in Tibet, the Sutlej river enters the plains near Ropar (Punjab), where it takes a sharp right-angled turn and flows westward over a distance of 150 Km before being joined by the Beas river. The Ghaggar River raises in the Siwaliks from the Morni hills and enters the plains near Ambala (Haryana). Yamuna River originates from yamunotri glacier in Higher Himalaya and entered in the plains near paonta Sahib. This river is believed to be flown along Drishadvati River through central Haryana before disversion along Yamuna Tear Fault.

2.2.2 Disappreance of River Saraswati: The Saraswati river system in the Vedic period includes the rivers like Ghaggar, Markanda, Chautang, Sutlej and Yamuna. The diversion of the Sutlej and Yamuna is considered as the main cause of lost of River Saraswati by most of the researchers. The rivers Ghaggar, Markanda, Saraswati and the Chautang rise in the Siwalik Hills. Presently they flow mainly during the monsoon and none of these reaches the sea or join any major river as tributary. Different scholars attempted to establish chronological sequence of events that contributed to the desiccation of Vedic Saraswati. Their compliled works are based on different aspects like climate, tectonism, drainage changes and cultural events which can be combined for the purpose of evaluating the changes in the drainage systems of northwestern India. In turn, it throws light in the events that have contributed the decline and final loss of river Saraswati.

Late Quaternary tectonism in combination with the sudden increase in aridity related aeolian activity disrupted and obliterated the courses of the rivers of NW India mainly the Saraswati River. From the studies by the various eminent researchers for the past several years now it has been clear that the Yamuna as well as the Sutlej were tributaries of the Saraswati River. Around 3700 B.C tectonic disturbances in the area have caused the capture of upper catchment water of Saraswati by Yamuna and westward migration of Sutlej causing the drying up of the river (Oldham 1886; Radhakrishna 1998, Valdiya 2000). Deflection of Sutlej at Ropar might have occurred 2600 years BP (Wilhelmy, 1969) and the deviation of Yamuna at Paonta Sahib had occurred around 3700 BP (Valdiya, 1996) or around 3900 BP (Wakankar, 1987). It may be noted that the deflection of Yamuna occurred much earlier than the deviation of the Sutlej River.

Over a 3000 year long period since the Vedic times, the drainage pattern of many rivers had changed from that described in the earlier religious literatures. The decline of Saraswati appears to have commenced between 5000–3000 B.C. probably precipitated by a major tectonic event in the Siwalik Hills of Sirmur region. Geologic studies indicate destabilizing tectonic events in the entire Siwalik domain extending from Potwar in Pakistan to Assam in India resulting in massive landslides and avalanches. These disturbances, which continued intermittently, were all linked to uplift of the Himalayas. One of these events must have severed the glacier connection and cut off the supply of glacier melt-waters to this river. As a result, Saraswati became non-perennial and dependent on monsoon rains. All its majesty and splendour of the Vedic period dwindled with the loss of its tributaries and the river totally got lost around 3000 B.C.

Considerable tectonic activity connected with Himalayan orogeny continued during the Holocene. Uplifts were at their peak during 0.8 – 0.9 million years. The high elevation of the mountains perturbed the wind circulation patterns and modified climatic changes, which had melted the glaciers and resulted in the formation of rivers. This was the scenario of the Himalayan region when the Saraswati emerged as a major river about 9000 years ago and flowed in full swing till its decline to an impermanent monsoon dependent state some 4000 years later.

Saraswati was totally lost when its water was captured by the Sutlej and the Yamuna (Oldham 1893, Valdiya 1996). This view differed from that of several others who felt that Saraswati vanished due to lack of rainfall. However the recent meteorological research about palaeo climate, oxygen isotopic studies, thermoluminescence (TL) dating of wind-borne and river-borne sands in the Thar Desert region, radio carbon dating of lake-bed deposits and archaeological evidences have all indicated that during early to middle Pleistocene this region has enjoyed wetter climate, heavy rainfall and even recurring floods and that increase in aridity commenced only by mid-Holocene (5000 – 3000 B.C).

The Tons with its tributary Yamuna must have flowed westward in the Dun valley of Paonta Sahib in southeastern Himachal Pradesh. The river terraces at Sudanwala and Garibnath testify to this. There are four generations of gravel terraces in the anomalously wide valleys of the misfit river Bata. The two older terraces at Sudanwala (near Kolar) and Garibnath (north of Paonta) are characterized by an abundance of pebbles of exotic metamorphic rocks and quartzites, derived from the Higher Himalayas (Puri and Verma, 1998). A major seismic activity in the Himalayas resulted in the formation of the Bata-Markanda divide, which is nearly 30m high, restricted the westward flow into the Adi Badri. Later Yamuna Tear fault opening provided new drainage.

Yash Pal et al. (1980) observed a sudden widening of Ghaggar near Patiala which they argue can take place only if a major tributary had joined it. According to them ancient Shatadru (Sutlej) must have been this tributary. Tectonism involving rise of Delhi-Haridwar ridge and uplift of Aravallis, capture of Sutlej by a tributary of Beas River through headward erosion and existence of a fault through which it got diverted are considered to be the reasons for the diversion of Sutlej.

The deviation in the course of the Saraswati river could as well been caused by a process called river piracy. The headward erosion by the Yamuna cut the channel deeper and deeper eventually leading to the capture of the flow of the Saraswati (Bakliwal and Sharma, 1980; Valdiya, 2002). This is accelerated by the NNW – SSE trending fault passing by Paonta Sahib. The faulting had caused the eastern block to move north relative to the western block which had prompted the Yamuna to swing southwards and follow the fault zone. Geodetic measurements indicate that the fault continues to be very active. There was a horizontal movement of 30 cm within a short period between 1962 and 1966 (Krishnaswamy et al., 1970) and 0.7-5.7 cm between 1965 and 1976 (Rajal et al., 1986)ecent work has shown that the land to the east of the River Yamuna is 14-22m lower than the land on the western side of the fault (Thussu, 1999).

Thus, climatic changes and geotectonic movements have led to the migration and abandonment of several rivers and drainage systems. The cumulative effect of reactivation of Yamuna tears constriction of catchments area of Vedic Saraswati by emergence and migration of river Drishadvati. Views of some important authors have been highlighted here.

(a) Bakliwal and Grover (1988) believed that there has been an upliftment of the region along Aravalli hills, which has resulted in the westward shift of streams in the western side of the Aravalli hills (like river Satluj) and eastward shift in streams in the eastern side of the Aravalli hills (like river Yamuna). The authors suggested the following causes for Saraswati migration and drainage desiccation in NW India. The following are the possible reasons for migration and loss of Saraswati River:

1. Rise of Delhi-Haridwar ridge along the NE-SW lineaments.
2. Intermittent reactivation of the Kuchchh fault and Luni-Sukri lineaments (extending from great Rann of Kuchchh to Dehradoon)
3. Rise of Aravalli hills bounded by lineaments on its west.
4. Changes in climatic condition in the region.
5. Reactivation of Cambay garban, Jaisalmer-Barwani lineaments and Khatu lineaments that trends NE-SW.
6. Stream piracy by the rivers like Yamuna and Beas.

(b) According to Ghose et al. (1979), the reasons for the disappearance of Saraswati are attributed to:
1. Climate change from wet to dry spell, as evidenced by geomorphological and stratigraphic records during the Quaternary period.
2. Neo-tectonic changes in the Himalayan and Aravalli regions.
3. Uplift of Himalayas and Siwaliks
4. Uplift of Aravalli range resulting in northward shift of river Saraswati.
5. River piracy of Saraswati and subordinate rivers by Yamuna, Satluj, and Ganga.
6. Climatic changes from humid to desertic condition.
7. Changes in glaciation in Himalayas.
8. Choking of rivers by enormous sand debris.

(c) Bakliwal and Ramasamy (1987) observed northwesterly and westerly migration of rivers on NW side of Luni-Sukri lineament zone and preferential southeasterly migration on SE side of the lineament zone and believed that the rise of Aravalli hills has further added to the rapid migration of the rivers Saraswati and Yamuna.

2.3 Previous Work Done on River Saraswati

Study of River Saraswati has been initiated by various scholars in the past 125 years due to great fascination of Indian culture and heritage. However, it requires systematic analysis and systhesis to establish chronogical evolution of Saraswati River basin. Most of the works are carried out as research projects and not as operational projects to explore the natural resources. Many of the studies have been carried out at departmental level to study particular aspects of the river i.e. palaeochannels, archaeology, geology, groundwater prospects/movement etc. and not as a project to rediscover the entire course of the river right from the origin to its end.

Establishing the exact course of the mighty river Saraswati, causes of its disappearnce, sentimental attachment of the people in the area, archaeological, geological, hydrological and mineralogical importance of the sacred river has led to the involvenment of various agencies in the research work. Different agencies involved in the Saraswati River study are:

(i) Space Application Centre (SAC)/ISRO – Ahmedabad.
(ii) Regional Remote Sensing Centre (RRSC-W)/ISRO – Jodhpur, Rajsthan.

(iii) Central Arid Zone Research Institute (CAZRI) - Jodhpur, Rajasthan
(iv) Ground Water Department (GWD), Govt. of Rajasthan - Jodhpur
(v) Defence Labarotary – Jodhpur, Rajasthan.
(vi) State Remote Sensing Application Centre (SRSAC) – Jodhpur, Rajasthan.
(vii) J.N.V University – Jodhpur, Rajasthan.
(viii) Haryana State Remote Sensing Centre (HRSAC) – Hissar, Haryana.
(ix) Saraswati Nadi Shodh Sansthan – Jagadhri, Haryana
(x) Saraswati Sindhu Research Centre – Chennai, T.N.
(xi) Sarswati Nadi Shodh Sansthan – Ahmedabad, Gujarat
(xii) Bhabha Atomic Research Centre (BARC) – Mumbai
(xiii) Public Health Engineering Department (PHED), Government of Rajasthan
(xiv) Geological Survey of India, Western Region – Jaipur, Rajasthan.
(xv) B.M. Birla Science and Technology Centre – Jaipur, Rajasthan.
(xvi) Central Ground Water Board (CGWB), Western Region – Jaipur, Rajasthan.
(xvii) Institute for Sustainable Development Research Studies– Jaipur, Rajasthan.
(xviii) Institute of Environmental Studies – Jaipur, Rajasthan.
(xix) Oil and Natural Gas Commission (ONGC) – Jodhpur and Dehradun
(xx) Bhabha Atomic Research Centre (BARC) – Mumbai
(xxi) Physical Research Laboratory (PRL) – Ahmedabad
(xxii) Geological Society of India – Bangalore
(xxiii) M.S. University of Baroda – Vadodara, Gujarat

There are varying views on the origin of the river Saraswati. According to geological and glaciological studies the Saraswati was supposed to have originated in Bandarpunchh massif (Saraswati-Rupin glacier confluence at Naitwar) in Western Garhwal Himalayas. Though the search for Saraswati River has progressed a lot with the advancement of Remote Sensing and GIS technology, still there exists controversies among the origin of the river, its exact course and reasons for its disappearance still appears vague. Various workers have postulated different views on these aspects and some are controversial while some match with that of the other workers. But in general all have accepted that the river Saraswati was the mightiest river in the proto-historic times. Salient features of remote sening studies on Saraswati palaeochannels are given below:

(a) Ghose et al. (1979, 1980): Based on the study of aerial photography and LANDSAT imagery, they have suggested that the Saraswati River flowed along NE-SW through the Rajasthan desert and that the Luni was one of its tributaries. The authors invoke this hypothesis to explain the present valley segment of the Luni between Pachpadra and the Rann of Kachchh. The river later shifted westward, severed its connection with the Luni and flowed through channels through the desert terrain in Jaisalmer district. Only later the river occupied the Hakra-Nara-Wahind-Raini course. The authors observe that the Saraswati was forced to shift its course westward at least four times by aeolian sand encroaching on its southerly course to flow to the west. These courses are-
   - The oldest course was Nohar-Surjansar- Samrau-Pachpadra

- The Second course was Sirsa-Lunkarnansar-Bikaner-Samrau-Pachpadra
- The third course was Nohar-Rangmahal-Suratgarh-Anupgarh-Skhi-Hakra-Nara
- The fourth course was Jakhal-Sirsa-Hanumangarh-Pilibangan-Suratgarh-Anupgarh-Sakhi-Hakra-Nara
- The fifth course was the shift at Anupgarh-Fort Abbas to join the Indus drainage basin rather than drain independently into the Rann of Kachchh.

(b) Yash Pal et al. (1980): They studied the multidate LANDSAT imagery to unravel the mystery of the 'Lost' Saraswati. Remnants of old fluvial channels of the river both buried as well as abandoned were delineated on the basis of the pattern of drainage scars, distinct tones, texture, surface manifestations etc. The authors support the hypothesis that the Satluj river once flowed into the Ghaggar river bed and was probably joined by the Yamuna. The Satluj has a sharp westward right-angled bend near Ropar due to the river capture or stream piracy, which could be responsible for the diversion. Other observations made by the authors include-

- A palaeo channel Y1 in the SE of Markanda joins the ancient bed of Ghaggar at Shatrana. The present Saraswati mostly flows through these channels.
- Another channel Y2 which corresponds to the Drishadvati or the present Chautang joins the Ghaggar near Suratgarh.
- The Yamuna probably flowed into the ancient Saraswati before joining Ganga through the Chambal.

(c) Sood and Sahai (1983): In continuation to the earlier study by Yash Pal et al (1980), Sood and Sahai (1983) made a detailed study of the palaeo channels of the Saraswati River in the Jhakal – Sirsa tract. Well-preserved meanders of the palaeo channels were observed indicating that during its active life the channels were meandering not braiding. The channels have two definite directions of flow i.e. NW-SE and NE-SW roughly at right angles to each other. They also observed that the various saline lakes in Rajasthan have a preferred orientation parallel to the regional lineaments. They felt that these regional lineaments have genetic relationship with the basement and might have been propagated to the upper unconsolidated sediments by the mechanism of down faulting.

(d) Kar and Ghose (1984): They traced the former courses of Drishadvati, a major tributary of the Saraswati. Starting from the Siwalik, its course was traced through the Markanda up to Gadauli and in the vicinity of Jagdhauli and then it followed the course of the Chautang up to Jind and Narnaund. Thus, it flowed through the Hansi-Hakra branch of the Western Yamuna Canal up to Hisar. Numerous channels, possibly representing shifting courses, connect it to Nohar, Bhadra and Hanumangarh. At Hanumangarh, most of the old courses join the Saraswati. However, some of these courses show the Drishadvati traversing the Thar Desert in north-south direction. Authors were able to trace only segments of these courses on band 7 of LANDSAT MSS imagery as all these courses are buried under recent deposits including Aeolian sand. According to the author's occurrence of sub-surface water at shallow depth enabled deciphering of the courses. The easternmost course of the Drishadwati is traced through the districts of Churu, Sikar and Nagaur. It flowed through the present dry valley of the Jojri through Khedulil and Mokala up to Plundla. From Plundla, the Jojri is traceable up to its confluences with the Luni through Pipar and Risalpur but is completely an under fit stream. Upstream of Plundla, the valley is fairly wide but at many places blocked by heavy drifts of aeolian sand in the form of dunes and sheets. They have cited litho logs of well sections at four selected sites along the courses of the Drishadvati at Sardarshahar and Churu (Churu district) and at Marwar and Degana Railway Station (Nagaur district), which show the presence of thick alluvium underlain by coarse reverine material. The author's noted that a number of tributaries arising from the Aravalli joined the Drishadvati during its course through the desert, northern most being the Kantli, which joined it, either near Raigarh or near Dudwa Khard. As the Drishadvati moved westward, it lost the supply of the Aravalli streams, which got choked up by the advancing aeolian sands and got lost on the way. **Kar and Ghose (1984)** opined that the imbalance between load and stream capacity were responsible for dwindling supply and the adverse climatic changes in the past which were the main cause for desiccation of the Drishadvati River.

(e) Bakliwal and Grover (1988): The authors suggested that lakes like Lunkaransar, Sambhar and Didwana and Ranns of Jaisalmer, Pachpadra etc. are considered to be the remnants of past river systems. They proposed that the Saraswati had seven stages of migration in chronological order. Their stage seven essentially matches the course suggested by Yash Pal et al. (1980).

(f) Ramasamy et al. (1991): The authors used LANDSAT MSS and TM data and observed that the river Saraswati flowed close to the Aravalli hill ranges, met the Arabian Sea in the Rann of Kachchh. It gradually drifted towards northwest and then finally lost in Anupgarh plains. Interpreted palaeo channels have a width of 60-80 km on either side of the present day Luni river course, especially in Siwana region. The authors suggested that the upheaval along the trace of Aravalli hills to the foothills of Himalaya would have made the Saraswati drift along northwestwards from its earliest course along the Aravallis. Subsequent Luni – Sukri cymatogenic arching would have accelerated the northwesterly drift. If the Saraswati was flowing into the Hakra – Nara bed, the westward shift of the Indus might have also led to the disorganization of the Saraswati system and its final burial in Anupgarh plains. Other observations made by the authors include-

- The meanders of Yamuna in Agra and Dehradun area coincide with the Luni-Sukri graben, suggesting control by Pliestocene tectonism on river migration. Yamuna seems to have migrated 40 – 100 Km towards east due to rise in Aravalli hills.
- Shifting of courses by main rivers leads to the disorganization of the tributaries. The rivers like the Sahibi, the Banganga and the Kantli, which were tributaries of the Yamuna in northeastern Rajasthan, now fail to reach Yamuna. Now these rivers flow in a disorganized manner and often cause flood havoc.
- The Indus has migrated towards northwest in the northern part and towards the west in central and southern parts.
- The authors also confirmed the findings of Yash Pal et al. (1980) and Sood & Sahai (1983) that tectonism was primarily responsible for the drying up of the mighty Saraswati.

(g) Raghav and Grover (1991) have delineated three palaeo-courses of the Kantlil River in parts of Jhunjhunu and Sikar districts using LANDSAT TM imagery and aerial photographs. The river Kantli rises from the Khandela hills (Sikar district). At present, it flows over a distance of 100 km only in rainy session through the district of Sikar and Jhunjhunu. It enters Churu district and lost in the Sandy terrain. It used to flow in SW-NE direction and was once a tributary of the Yamuna (the Drishadvati) before the latter joined the Ganga system. Ganeshwar, where large copper hoard of probably pre-Harappan period have been found is located along the Kanti River in Sikar district. Several tectonic lineaments observed in the area seem to have controlled shifting of the channels.

CHAPTER - 3

3.0 PALAEOCHANNEL MAPPING USING REMOTE SENSING & GIS

With the advent of Remote Sensing technology and the available satellite images, it is possible to trace the drainage course in the form of buried palaeochannels. Remote Sensing techniques helped in locating these buried channels as they are clearly seen on the satellite images (Ghose et al. 1979, 1980; Yashpal et al. 1980; Sood and Sahai, 1983; Bakliwal and Grover, 1988; Ramasamy et al. 1991; Kar, 1995; Sahai, 1999). In ISRO centres, pioneering works in Remote Sensing studies has been carried out by Yash Pal et al. (1980), Sahai (1993), Rajawat and Narain (1996), Rao (1999) and others who have compiled various studies pertaining to the palaeo drainage network of northwestern India. Recently the entire course of River Saraswati has been traced from satellite images by the researchers like Bhadra et al. (2005), Bhadra et al. (2006), Bhadra et al. (2009), Bhadra and Sharma (2011), Bhadra and Sharma (2012), Bhadra and Sharma (2013), Gupta et al. (2001), Gupta et al. (2004), Gupta et al. (2011), Sharma et al. (2006), Sharma and Bhadra (2009) and Sharma and Bhadra (2012).

3.1 Satellite data Used for Delineation of Palaeochannels

Due to having synoptic viewing capability with different spatial, spectral and multi-temporal resolution, IRS satellite images of different sensors viz. WiFS (188m), AWiFS (56m), LISS-III (23.5m) and LISS-IV (5.8m) have been used for palaeochannel delineation and other thematic mapping interpretation. Palaeochannels are basically the old course of river channels which appears on the satellite image as serpentine drainage course with high moisture content (dark tone). For delineation of palaeochannels, digital image processing techniques like histogram equalization, linear stretching, contrast and brightness enhancement etc. have been applied on a small area of the satellite images (IRS P6 LISS-III of Summer, Kharif and Rabi seasons). Drainage features are highlighted on applying local stretching on ~10X10 sq. km area out of the full LISS-III scene (141X141 sq. km). In this process, palaeochannels are delineated with proper care by avoiding the canals, existing ephemeral drainages and water logged areas. A large number of palaeochannels have been delineated in parts of Haryana, Rajasthan and Gujarat. Many of these discontinuous palaeochannels are found to be linked with the existing/abundoned channels as well as dry lakes/Rann. The delineated palaeochannels of Saraswati River in different states have been discussed below.

3.2 Delineation of Palaeochannels in Rajasthan

Gupta et al. (2004) have mapped the course of Saraswati, buried below sands of Thar Desert, using IRS P3 WiFS and IRS 1C LISS-III satellite data. They showed presence of Saraswati channels which are self-evident on satellite images **(Fig.4 and 5)**. "Piece-wise Histogram Stretching" technique has been used to enhance the palaeo channel signatures on the image. This technique has been found unique in enhancing palaeo channel details in the sandy as well as alluvial and vegetated areas. The feature enhancement is carried out by way of loading sub-scenes of 1k x 1k size on computer terminal in full resolution and improving the feature contrast by histogram stretching interactively.

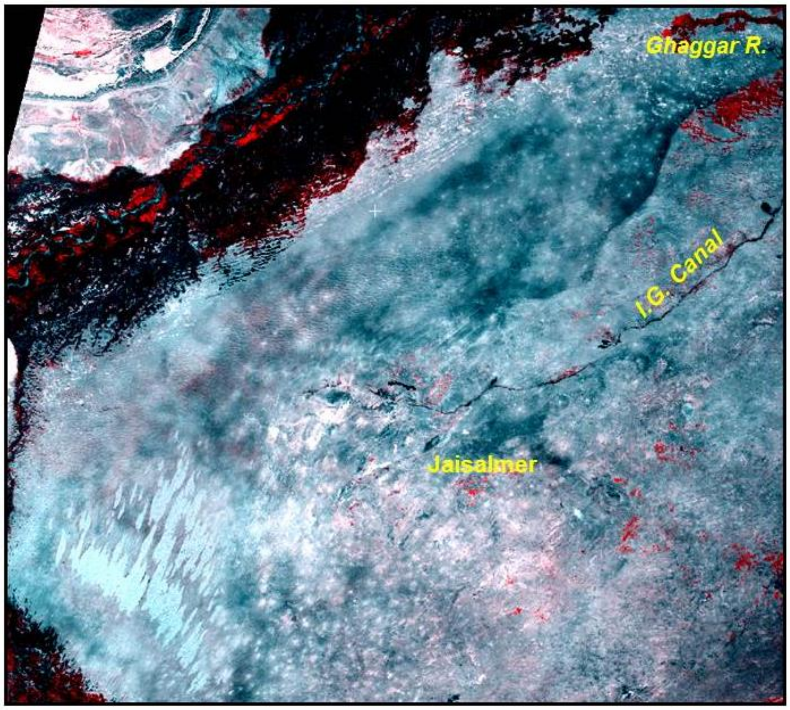


Fig.4: IRS WiFS image showing palaeochannel signature (dark tone) in Jaisalmer region of Rajasthan

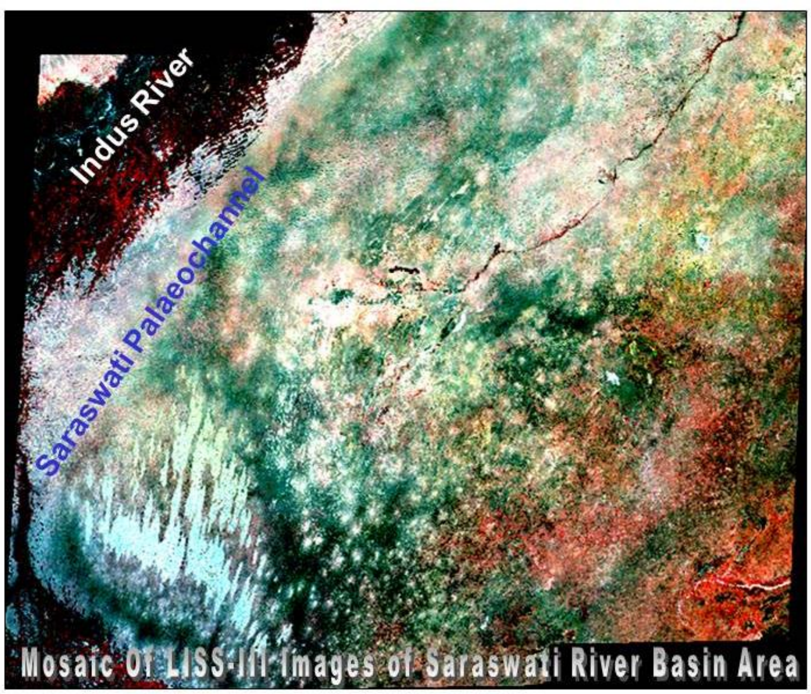


Fig.5: IRS LISS-II image showing palaeochannel signature (dark tone) in Thar Desert region of Rajasthan

They have also validated the course of Saraswati River through collateral data such as published old maps, archaeological data, geomorphic anomalies, drilling data (litholog) of tube wells and age of ground water.The drilled tube wells in Jaisalmer district of Rajasthan shows potable water with high discharge from the sub-surface fluvial palaeochannels. Isotopic dating of trapped water is correlated with the Harappan Civilisation. Thus, a palaeochannels etwork of Saraswati River in Rajasthan and parts of northern Gujarat has been established across the Thar Desert **(Fig.6 and 7)**.

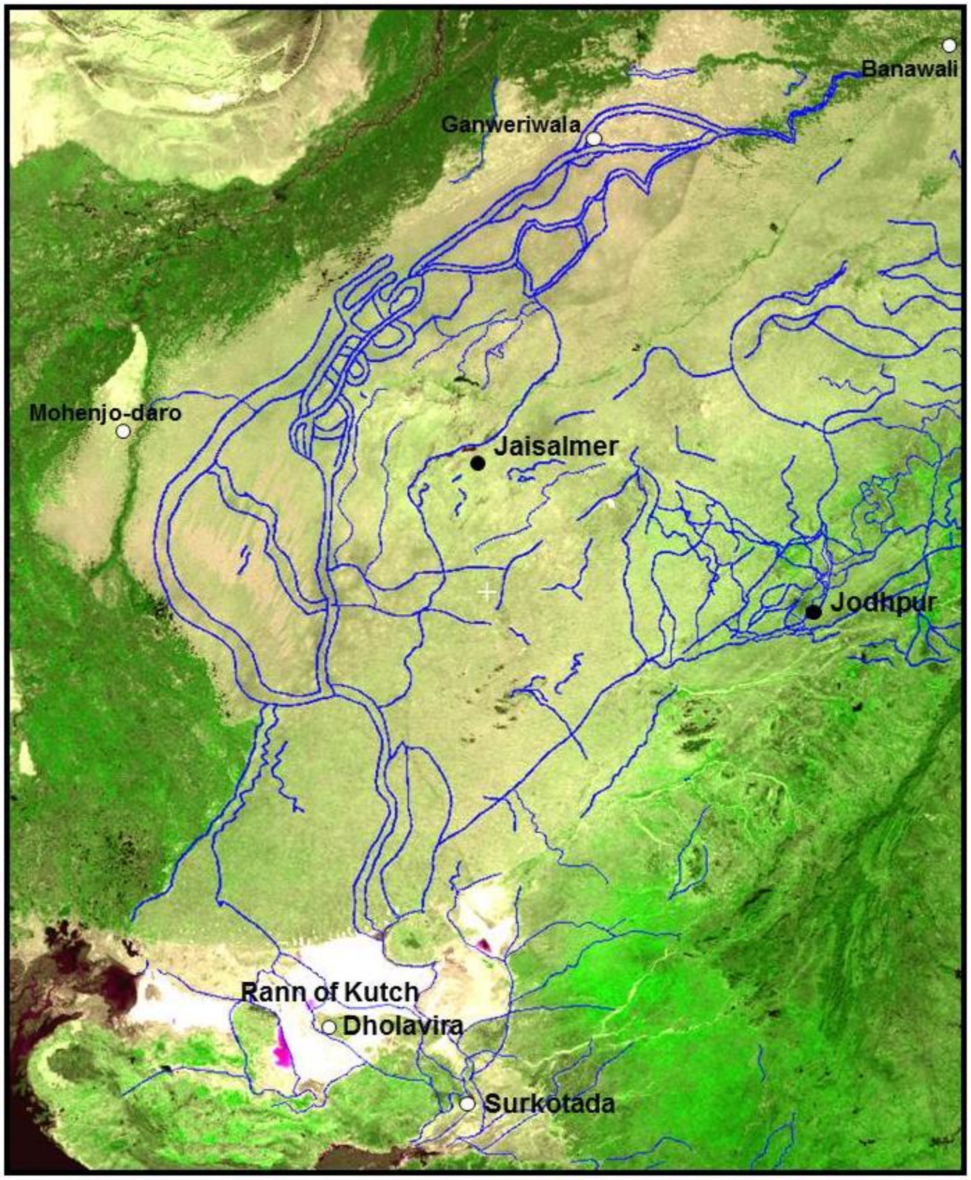


Fig.6: Palaeo-drainage map of Thar Desert Region using IRS P3 WiFS satellite Image

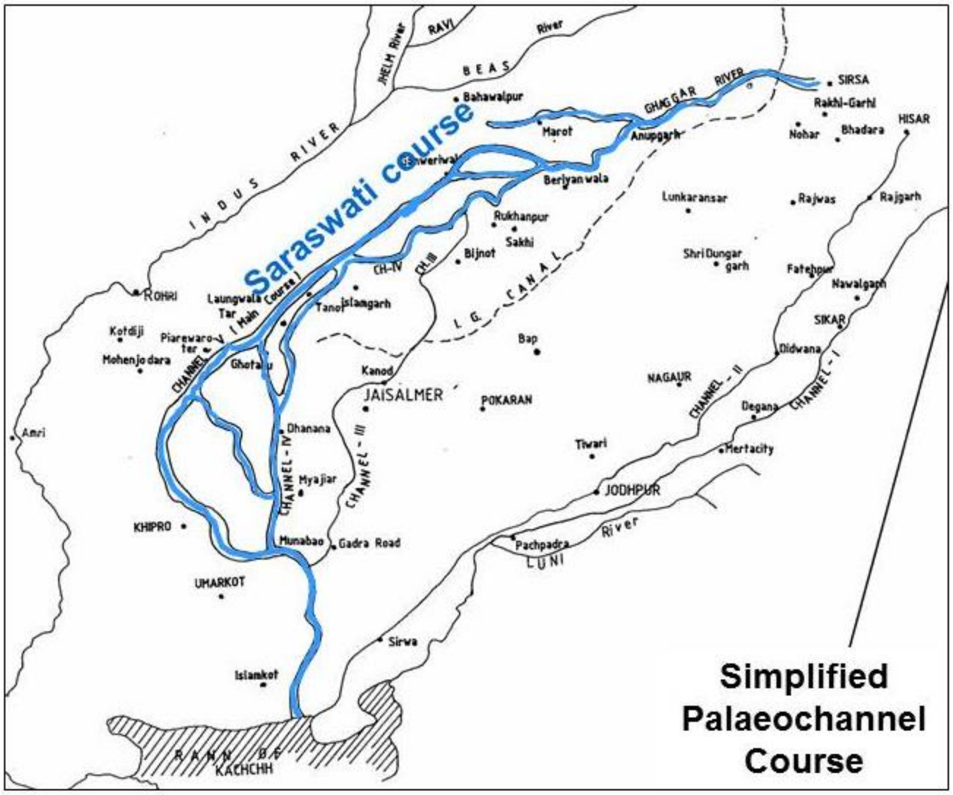


Fig.7: Simplified palaeochannel map course of NW Rajasthan

3.3 Delineation of Palaeochannels in Haryana and Punjab

The Saraswati river system (present day drainages along with palaeochannels) in Haryana and Punjab **(Fig.8 and 9)** has also been studied in detail by using IRS P6 AWiFS, LISS-III and LISS-IV satellite data (Bhadra et. al., 2006; Bhadra et al., 2009; Sharma and Bhadra, 2009; Bhadra and Sharma, 2011). Whereever necessary, Landsat ETM data also have been used for delineation of palaeochannels in Haryana, digital image processing techniques like histogram equalization, linear stretching, contrast and brightness enhancement etc. have been applied on a small area of the satellite images. Drainage features are highlighted on applying local stretching the full LISS-III scene. Using this process, the possible course of Saraswati and Drishadvati palaeochannels in Haryana are delineated. An attempt has been made to identify the continuity of Saraswati palaeochannels in eastern Punjab also. For this purpose, satellite images of IRS P6 LISS-III data (23.5m resolution) of February, 2004 and Radarsat SAR data (50m resolution) of December, 2002 have been processed to delineate palaeochannels (**Fig.10**). In this area, Radarsat SAR image could able to pick up moist zone (torquous channel with dark tone), possibly indicating a subsurface palaeochannel. The delineated palaeochannel between Ropar and Patiala is named as Sutlej palaeochannel which is an N-S trending palaeochannel extending for a length of about 75 km with having width from 1 to 6 km. The Sutlej palaeochannel is connecting the present day Sutlej River near Ropar and the Ghaggar River in the south of Patiala. The delineated palaeochannels in Haryana d

Punjab have been validated on the ground by using archaeological sites, hydrogeological and drilling data, rainfall data and stream discharge data.

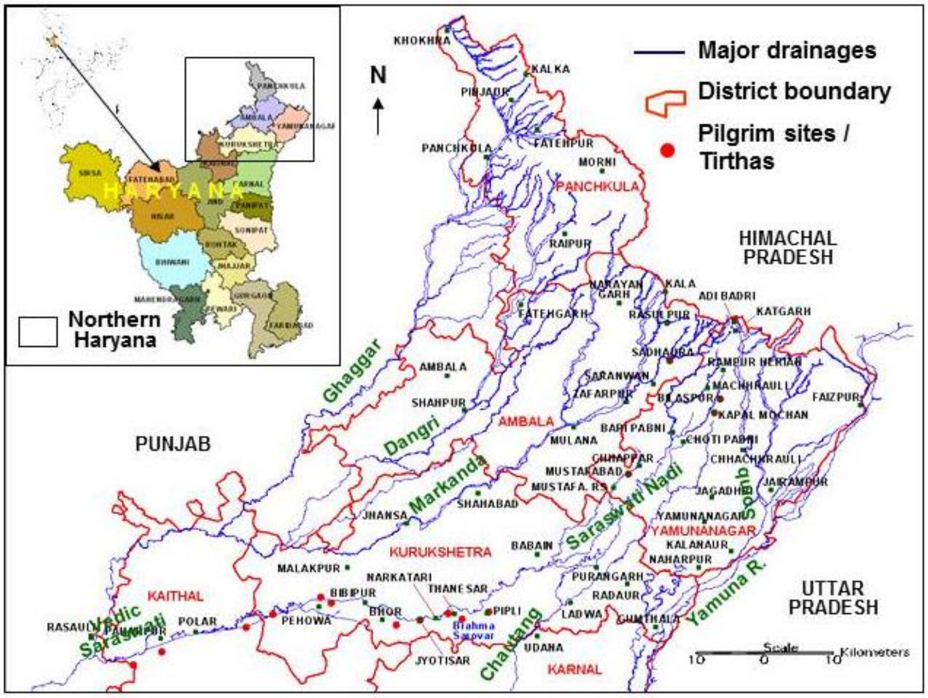


Fig.8: Saraswati drainage and its tributaries in northern Haryana

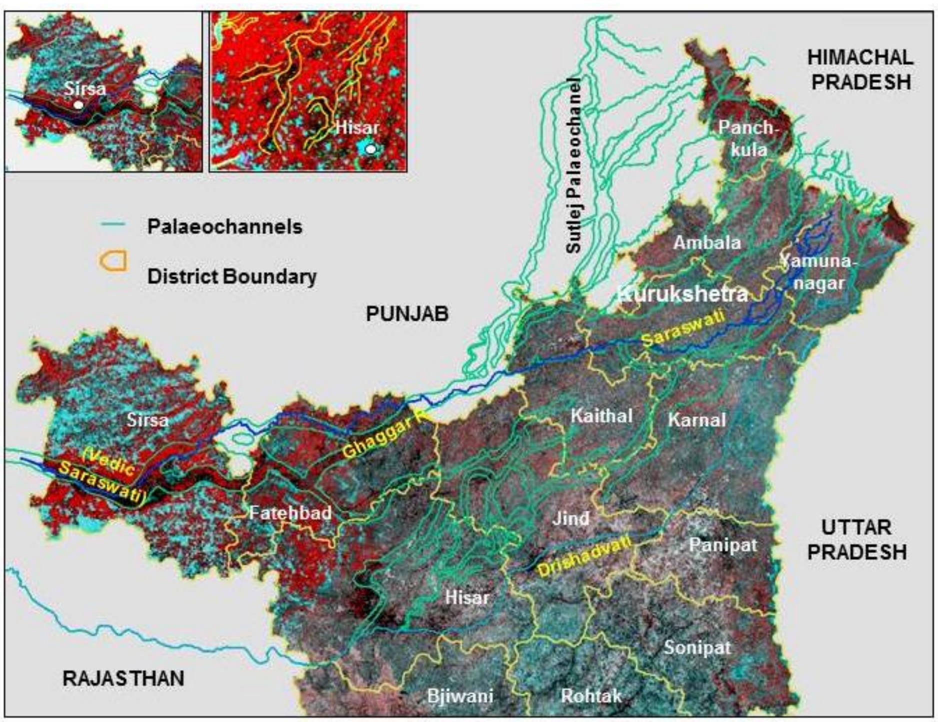


Fig.9: IRS P6 LISS-III Image with delineated palaeochannels in northern Haryana and parts of Punjab.

Sutlej Palaeochannels along Ropar-Sirhind-Rajpura section (N-S)

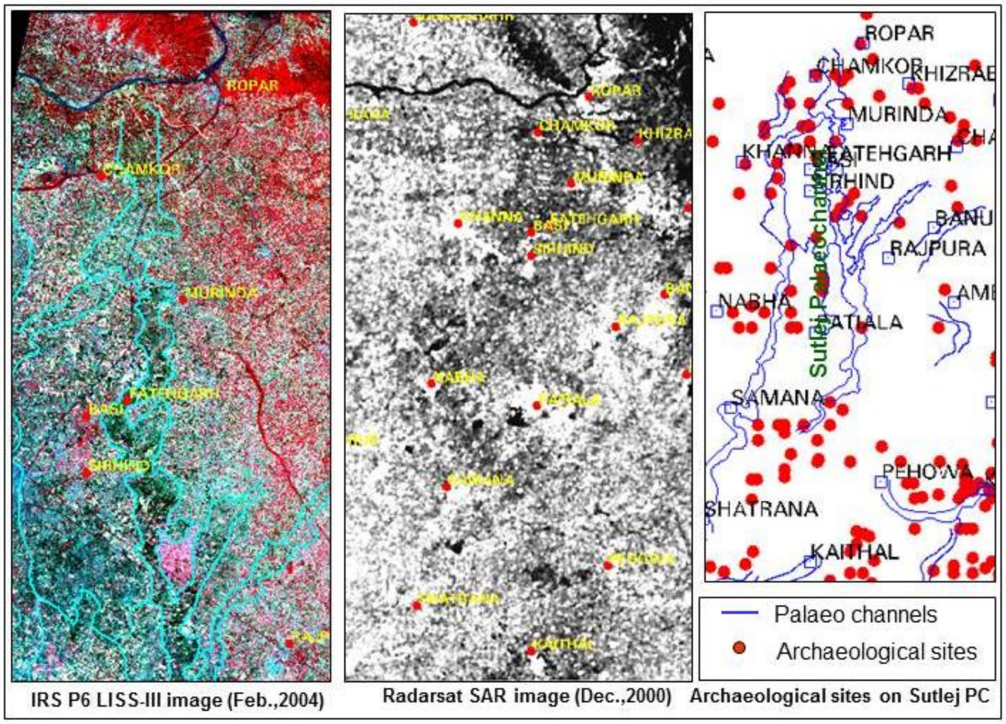


Fig.10: Optical (IRS P6) and SAR (Radarsat) images showing the delineated Sutlej palaeochannels between Ropar and Shatrana in Punjab. Note a large number of archaeological sites lie along the palaeochannels.

3.4 Saraswati Delta Structure in Rann of Kachchh (Gujarat)

The Saraswati River is supposed to be the mightiest river in the proto-historic times which might have been flown through Rann of Kachchh and finally discharged into the Gulf of Kachchh. The Rann is today a salt impregnated marshy tract, which gets flooded during the rainy session. A number of references have been made about the Saraswati River meeting the sea along the existing Kori Creek (Oldham, 1893). Recent investigations have revealed that more than one river were involved in building up the deltaic deposits in the Great Rann. According to Roy and Merh (1977) the channels represent relicts of a delta of Nara River which is a tributary of Indus River. The Saraswati delta is characterized by strikingly uneven topography, marked by areas of higher grounds (bet of river borne sandy and silty sediments) and depression or distributary channels (Malik et al., 1999). Digital image processing of IRS-P6 AWiFS and Radarsat SAR images reveals deltaic drainage pattern (Bird’s Foot type) which is made up of complex intertwined channels. This structure was formed in the past by huge sediment discharge of Saraswati River within marshy land of Great Rann of Kachchh. The delta structures are restricted by the E-W fault, known as Allah Band. However, these palaeochannels can be traced upto the Gulf of Kachchh which might have a link to the submerged Dwarka of Mahabharata times. In northern Gujarat also, a large number of Harappan settlements are found to lie near the delineated palaeochannels. Thus, a close association of Harappan civilization can be established with the delineated palaeochannels which might have a link with the Vedic Saraswati civilization. Beyond Little Rann, Saraswati channel might have continued upto Dwarka along the Gulf of Kachchh **(Fig.11)**.

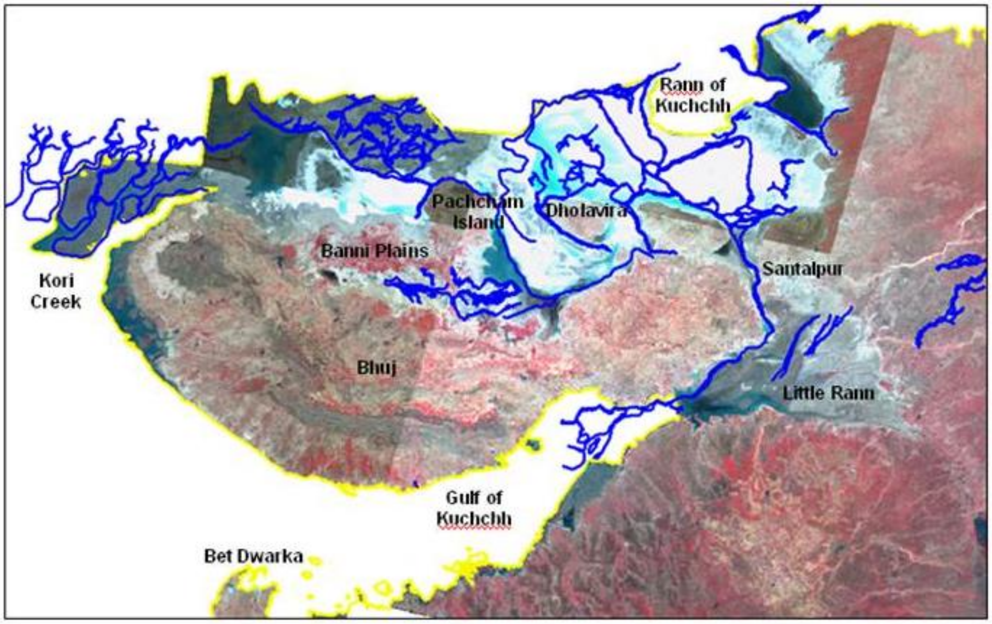


Fig.11: Satellite Image showing the Saraswati palaeo-drainage network (blue lines) in Rann of Kachchh area, Gujarat

3.4.1 Saraswati Confluence at Gulf of Kachchh: Dwarka was the capital of the Yadavas which is mentioned in Indian epic Mahabharata. It is believed that Lord Krishna has found this town by reclaiming 12 yojana land from the sea at about 3,600 years ago. After the Mahabharata War, Krishna lived for 36 years at Dwarka which was extended from Bet Dwarka in the north to Okhamadhi in the south. It is described in Mahabharata that Balaram travelled along the dry banks of Saraswati River from Dwaraka to Mathura. Hence, it is possible that Saraswati palaeochannel might have continued beyond Little Rann upto Dwarka along the Gulf of Kachchh. Archaeological excavation revealed the existence of Harappan settlements in Dwaraka as well as port city of Lothal (Gaur, et al. 2000 and 2005; Rao, 1979 and 1985).

Underwater explorations in Bet Dwarka and Poompuhar yielded a large number of potteries, stone anchors and building blocks from 5-8m water depths and have been established by thermoluminiscence tests to be 3,528 years old. Marine archaeological expeditions between 1983 and 1992 revealed the discovery of well-fortified township of Dwarka which was built in six sectors along the banks of a river. Nigam (2012) studied sea level changes along the Gujarat coast during Holocene period based on the abundance of microfossils like Foraminifera. In southwestern Gujarat, Lothal was an ancient dockyard which is presently located about 10-12 km away from the sea and few meters above the present sea level. This dockyard is believed to be of 4500 years old and is connected to the sea through a channel. Dr. R. R. Nayer proposed a theory that probably sea level was lower than today about 60-80m around 10,000 years ago because fossils in the sediments are found at that depth. Reclamation Dwarka land by Lord Krishna may be explained by lowering sea level changes after 4500 BP. In the year 2000, NIO Goa discovered Neolithic settlement of 9500 BP in Gulf of Khambat which was lost because it submerged under the sea due to the rise in water level around 7000 BP. Rise in sea level and occurrence of tsunami like phenomenon caused submergence of Dwarka in the year 3443 BP.

3.4.2 Rejuvenation of Saraswati Palaeochannels after Bhuj Earthquake (2001): As discussed in the previous section, Saraswati drainages in Thar Desert area have disappeared due to climatic changes in 5000 BP. These dry channels have been covered by aeolian sands all along the Indo-Pakistan border, leaving with a few traces as relict palaeochannels. The evidence for the confluence of araswati palaeochannels could be found in Rann of Kachchh region with obscured impression like palaeo-delta complex (Malik et. al., 1999). Most of these drainages are either submerged under tidal sea water or buried under the mud flat in the Rann area. The entire region appears bluish white on the satellite image due to development of salt encrustations after desiccation of sea water. It has been observed that the sub-surface drainages (palaeochannels) in the Rann area rejuvenated after the Bhuj earthquake of 26th January, 2001. The phenomenon of sudden spurt of the water jet in the area might have been caused due to increase in hydrostatic pressure at the sub-surface aquifer condition. Rigorous shaking of saturated soil by tectonic disturbance may result such type of oozing as an artesian well. Appearance of these drainages can be seen on the post-earthquake IRS LISS-III satellite images on both FCC (colour) as well as Infrared band image (black and white). The spectacular drainage features have been compared between pre-earthquake (10.12.2000) and post-earthquake (29.1.2001) satellite images around Khadir Island in Rann of Kachchh region **(Fig.12).** Similar spectacular drainage features can be seen on post-earthquake satellite image and may be compared with the pre-earthquake image of 1989 **(Fig.13)**. Similar phenomena like sudden spurt of sub-surface water oozing at Kalayat village in Jind district of Haryana has been observed in December, 2005 (Bhadra et al., 2006). This incidence was in concurrence with the mild earthquakes in Jind district and the earthquake event (6.8M) of 13th December, 2005 in Hindukush area. All these observations coupled with the archaeological findings (Harappan age) clearly indicate that source of oozing water at Kalayat was from the Saraswati palaeochannel.

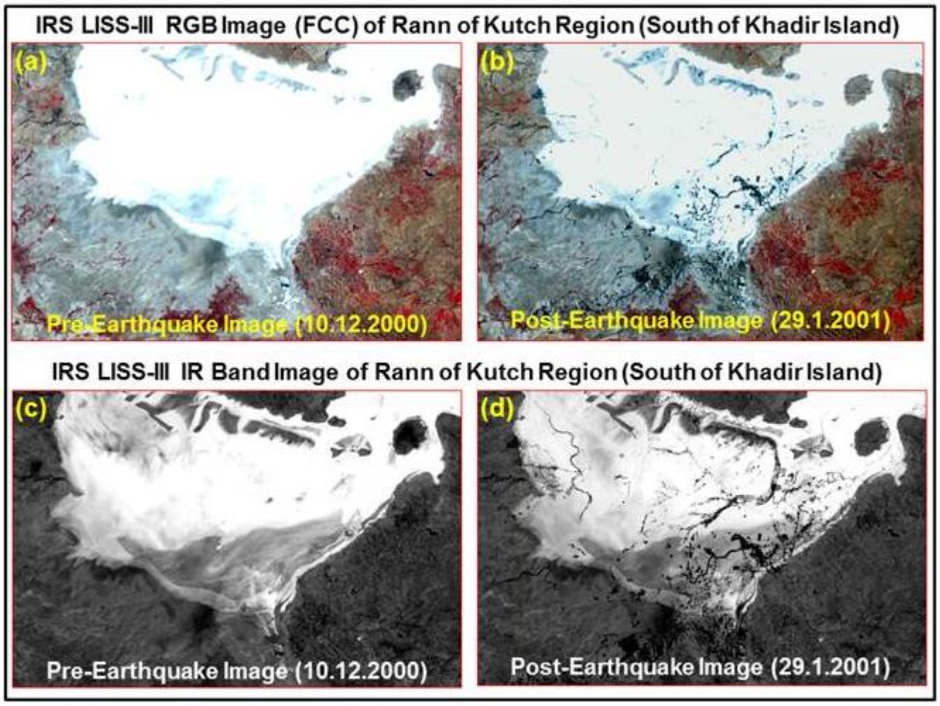


Fig.12: Rejuvenation of sub-surface drainages in Rann of Kachchh area after Bhuj earthquake on 26.1.2001, as appeared on Pre-earthquake (a and b) and Post-earthquake images (c and d)

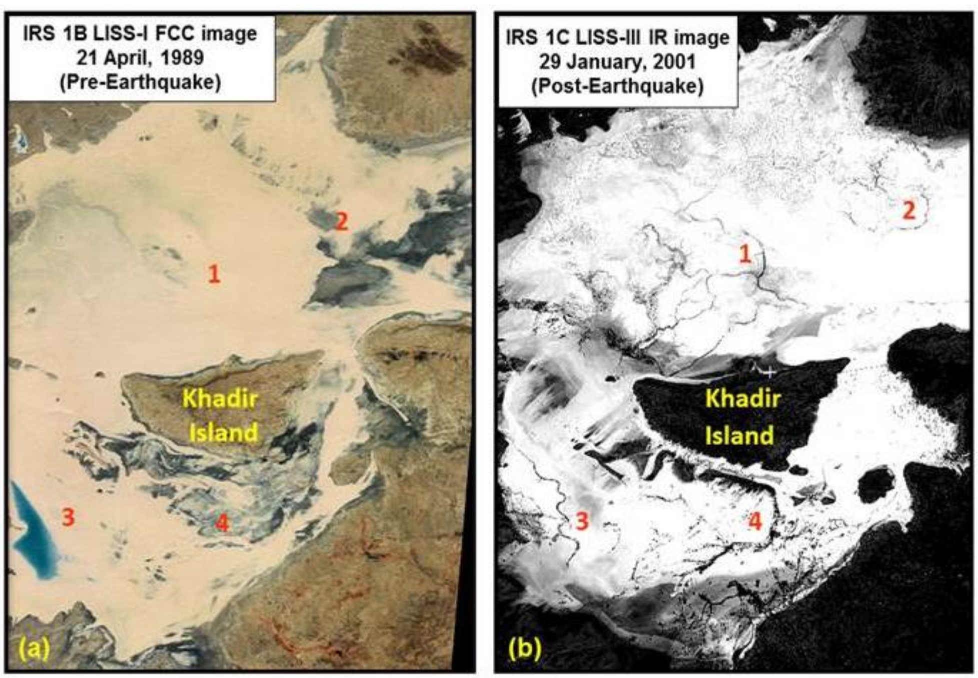


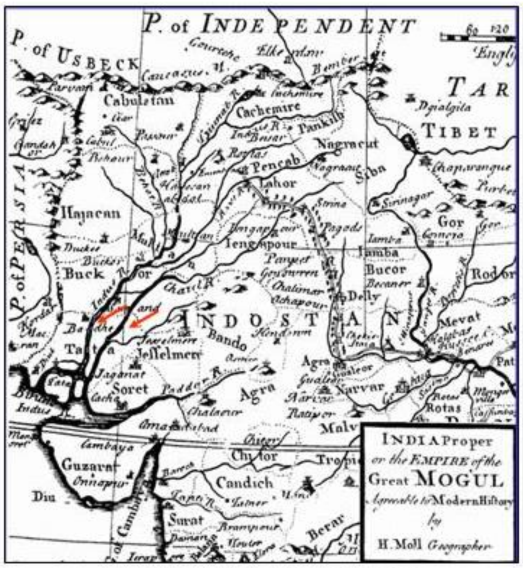
Fig.13: Emergence of new channels (1 to 4) in Rann of Kachchh area (Gujarat) after Bhuj Earthquake on 26.1.2001, as appeared on the satellite image (b) than that of image (a).

CHAPTER - 4

4.0 GROUND VALIDATION OF SARASWATI PALAEOCHANNELS

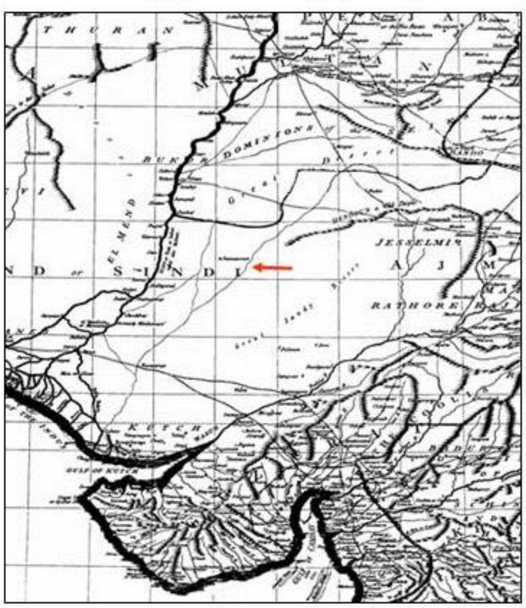
4.1 Historical maps

A number of very old maps of Indo-Pakistan region of Mughal period have been prepared by the Italians, Dutch and British authors during 14th –17th Century A.D. **(Fig.14)**. These maps have been studied as a reference to the drainage conditions, in Indo-Pakistan region during that period (Source: A series of early printed maps of India in facsimile, New Delhi, 1980).

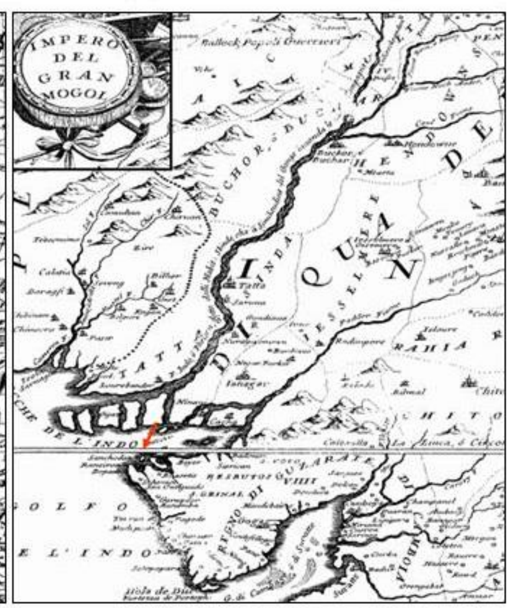


(a) Dutch Map (1746)

(b) British Period Map



(c) Italian Map



(d) Mughal Period Map

Fig.14: Saraswati River recorded in old maps (Dutch, British, Italian & Mughal)

Empire of Great Moghul published a map (sheet no. 27a) in the year 1746 A.D. which shows Indus as a parallel river system with that of in the east. Presence of a stream parallel to Indus in 17 th century map indicate towards presence of the dry channels of Saraswati along which occasionally water flowed during heavy monsoon or flood events, which continued till 13 th century and minor flows up to the end of 16th century (Wilhelmy 1969). The mapped courses of Saraswati main course runs for 80 to100 km east, parallel to the Indus river course.

4.2 Field Studies along Saraswati Nadi

Field studies in western Rajasthan have been carried out during 1998-99, 1999-2000 and 2007-08. Field photographs show vast stretch of aeolian terrain with different sand dune features **(Fig.15)**. Although the terrain is devoid of thick vegetation, but sparse vegetation such as phog, chag, ker, aak, bue, sewan, khib, khejri etc. has grown on aeolian plains. Several tube wells have been drilled on the palaeochannels which provides potable water in Tanot, Gotaru, Ranau and Ghantiyali villaves in Jaisalmer district of Rajasthan.

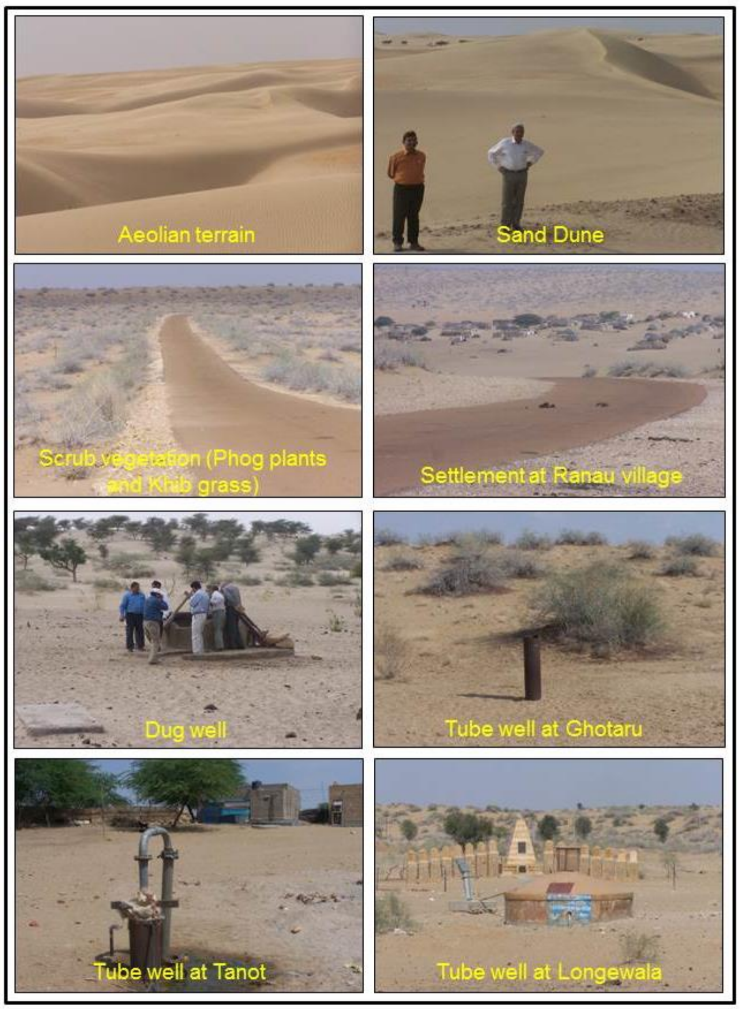


Fig.15: Field photographs showing aeolian terrain with scrub vegetation in Jaisalmer district of Rajasthan. Several tube wells have been drilled on the palaeochannel.

Field investigations in Haryana have been done during 2004-2005 and 2005-06 along the Saraswati drainage course, right from Adi Badri to Bibipur Lake till Pehowa. The presence of this drainage courses in different villages (Bari Pabni, Choti Pabni, Chhapar and Mustafabad) have been located through Global Positioning System (GPS) survey and are shown through field photographs **(Fig.16 and 17)**. The name of “Saraswati Nadi/ Nala” has been inscribed at several old rail/road bridges. In the downstream direction, this drainage becomes wider but left with stagnated water. At many places sewerage water was flowing along the Saraswati drainage course at Sadhaura and Mustafabad in Yamunanagar district and Thaneswar and Pehowa in Kurukshetra district. Ground truth in the area reveals that the drainage becomes narrow (about 10-100m wide) at several places which is the result of climatic and tectonic changes coupled with anthropogenic interventions. The holy river of the past has turned into a sewerage drain, obliterated at different places, virtually defunct and is flowing seasonally. As a result, frequent flash floods occur in the area, causing enormous damage to the crop and the property. Saraswati Nadi in this region is in the verge of obliteration and witnesses an unbearable pathetic condition.

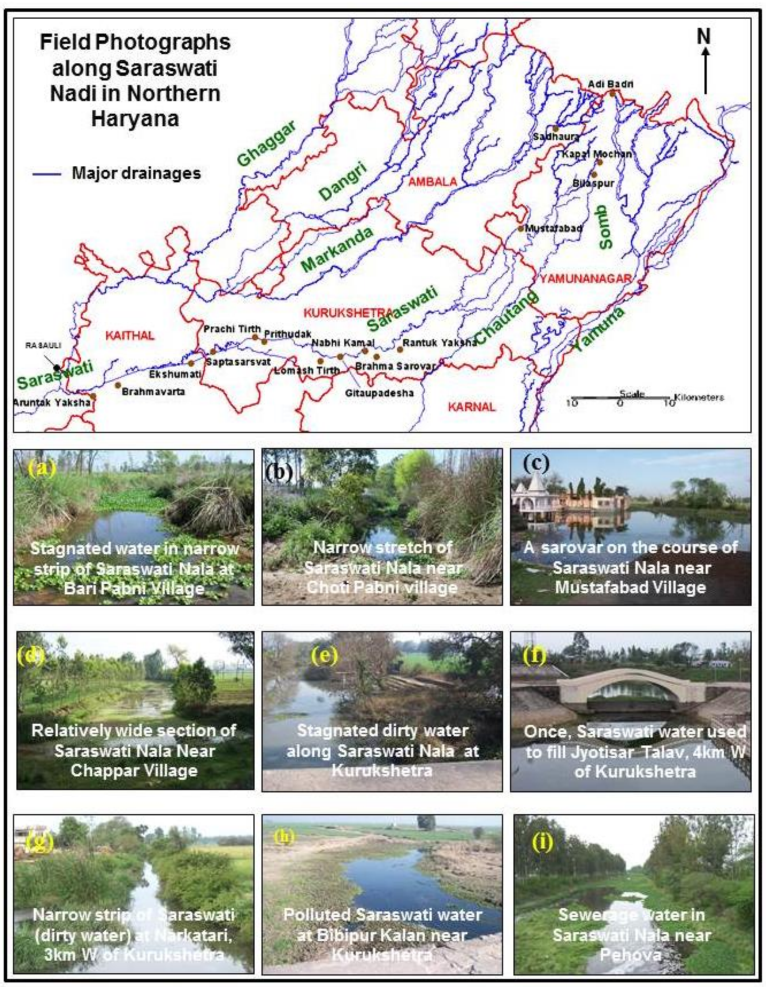


Fig.16: Field photographs showing defunct state of Saraswati Nadi at various places in the upper catchment area, south of Siwalik foothills.

Fig.17: Field photographs showing remnants of Saraswati Nadi at various places in Yamunanagar district, Haryana.

4.3 Archaeological Data Analysis

The pre-historic remains in the Saraswati basin were for the first time brought to light in the early 1940's with the investigation of Hakra valley by Stein (1942). Stein's work was further extended by Ghosh during (1950-52) during survey of the dried up course of Saraswati and Drishadvati in Ganganagar district of Rajasthan (Ghosh et al., 1979, 1980). Kar and Ghosh (1984) have carried out an intensive survey of the Saraswati basin within Haryana since 1960. In northern Haryana, important Harappan sites were discovered at Banawali, Rakhigarhi, Kunal, Bidarna, Balu and others (Chakrabarti and Saini, 2009, Kalyanraman, 1999; Lal, 2002, 2009; Valdiya, 2002). Late Harappan and Painted Grey Ware (PGW) materials were recovered from Kurukshetra, Mirzapur (Kurukshetra district) and Bhagwanpura (Hissar district). Recent excavations at Bhagwanpura and Kasithal (Kurukshetra district) have yielded evidence of a partial overlap between the late Harappan and PGW culture. The Ghaggar-Hakra palaeochannel course has been associated with extensive Bronze-age Harappan civilisation archaeological sites that are located with the channel. The abrupt abandonment of urban centres at ~3500 BP has been explained as a consequence of river diversion, although alternative explanations for cultural decline have also been offered (Sinha et al., 2013).

The explored area has been seen to be rich in archaeological sites which may be classified as Harappa, PGW and Early Historical with the addition of the well-known Pre-Harappa. The remains of the prominent PGW settlements are often overlaid by those of the succeeding early historical (Rang Mahal) culture. The Rang Mahal culture is named after the site of Rang Mahal about 3Km up Suratgarh. A general dissection followed the decay of the Rang Mahal culture as indicated by a scatter of pottery in the dry riverbed and also on the sand dunes.

A steady flow of water, followed by dessication and then utter dryness of the river is clearly indicated by the archaeological evidences. Eastward diversion of water to the Ganga system is indicated in 1750 B.C. (end of Harappa culture), resulting in a dry phase (partly coinciding with the PGW period), a recurrence of the wet phase in the early centuries A.D (Rang Mahal period) and then by another desiccation. Thus, the PGW sites are generally small and are sometimes situated in the riverbed itself indicating a scanty flow. Radiocarbon dating indicates that Kalibangan, the Mature Harappan settlement located on the bank of the ancient river Saraswati was abandoned around 1900 B.C. because of the drying up of the river.

More than 1200 settlements of the Stone Age and Harappan civilizations are found along the river course implying the availability of year-round supply of water, which only perennial rivers could have provided. Joshi et al. (1984) have compiled the data on Harappan, Early Harappan (Pre-Harappan) and Late Harappan sites in India. A summary of the sites in the Saraswati valley is given below **(Table-1)**:

Table-1: Number of archaeological sites in NW India (Joshi et al., 1984)

State	**Early Harappan (2500-2200 B.C.)**	**Harappan (2200-1700 B.C.)**	**Late Harappan (1700-1000 B.C.)**
Punjab	23	32	102
Haryana	103	44	297
Rajasthan	8	28	

The archaeological studies revel the following information: (a) No Early Harappan or Harappan sites occur along the present Sutlej or the Yamuna channel, (b) There is fairly good distribution of Early Harappan and Harappan sites along the Ghaggar – Hakra bed and (c) No Late Harappan sites are found in Rajasthan along the Saraswati bed which must have dried up during that period forcing eastward or westward migration (Joshi et al. 1984; Mughal, 1982; Rajani and Rajawat, 2011).

4.3.1 Archaeological Studies in Rajasthan: More than 1200 of the 1600 settlements, including many prosperous towns of Harappan culture (5000-3500 B.P.) have been discovered in the Saraswati river basin (Valdiya 2002, Mughal, 1981). Out of the archaeological sites discovered by the Archaeological Survey of India in the Sarasvati river basin (Possehl, 2000), 54 sites of Early-Harappan and Mature Harappan period are falling in the western Rajasthan **(Table-2)**. These have been plotted on to the palaeo channel map prepared from WiFS data, to observe if any correlation exist between the two types of data. It is observed that most of the archaeological sites of Harappan period discovered in Ganganagar and Hanumangarh districts fall along the Ghaggar River **(Fig.18)**, indicating Ghaggar to be the palaeo Sarasvati course (Gupta et al., 2001, 2003).

Table-2: Number of archaeological sites in NW Rajasthan (Possel, 2000)

Site	Site Name	Site	Site Name	Site	Site Name
1	Akalgarh	9	Chak 02	17	Chak 087
2	Bhaironura	10	Chak 03	18	Chak 088
3	Bingee	11	Chak 07	19	Jogiasson
4	Binjor One	12	Chak 043	20	Jogiason Chak One
5	Binjor Two	13	Chak 050	21	Kalibagan
6	Binjor Three	14	Chak 072.3	22	Satuki East
7	Binjor Four	15	Chak 075	23	Satuki West
8	Bugia	16	Chak 080	24	Sullewala

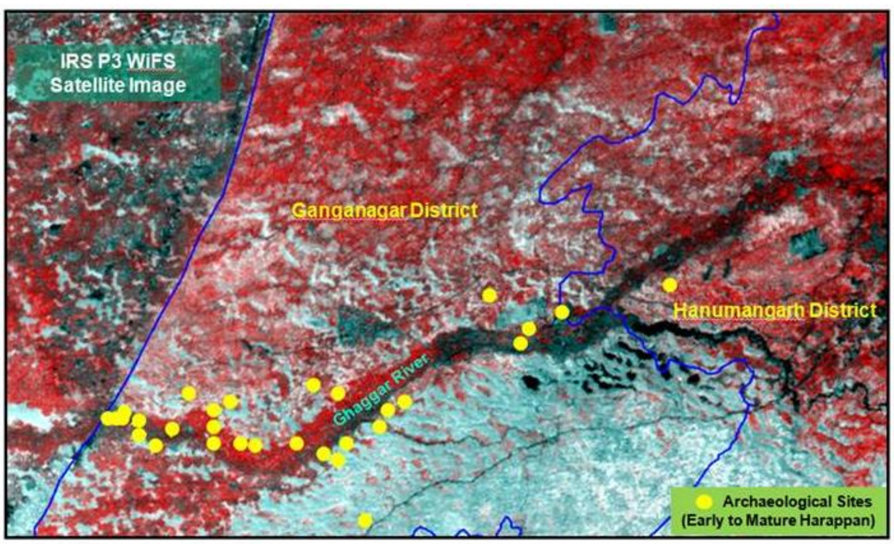


Fig.18: IRS WiFS image showing Harappan Sites along Ghaggar River in Ganganagar and Hanumangarh Districts of Rajasthan

4.3.2 Archaeological Studies in Haryana and Punjab: The locations of archaeological sites, discovered till 2000 in Haryana (Possel, 2000) and a few recently discovered archaeological sites have been plotted and overlaid on the mapped river courses for age determination. The archaeological sites are classified into four categories viz. Mature Harappan, Sothi Harappan, Late Harappan and

Post to Harappan **(Table-3)**. In northern Haryana, mostly Late Harappan sites have been found to lie in Yamunanagar, Kurukshetra and Kaithal districts **(Fig.19**). However, clustered Mature Harappan/Sothi Harappan sites are found to occur in Jind and Karnal districts, where many palaeochannels have been demarcated.

Table-3: Classification of Archaeological sites in Haryana (Valdiya, 2002, p.38)

Classes ((Period, B.P)*		**Remarks**
Post to Harappan (3500 to Medieval)		Represents all the sites which are post to Harappan period. It includes OCP, PGW, Pre-Historic, Buddhist, Medieval, etc.)
Harappan	Late Harappan (3900-3300)	Mostly Post-Urban Harappan
	Sothi-Siswal (~Mature Harappan)	Sothi-Siswal sites have distinct Hakra culture but resembles Mature Harappan culture
	Mature Harappan (4600-3900)	Exclusive Harappan sites

Criterion: The archaeological sites, reported in Possel (2000) and other sources are plotted on the map. It is observed that archaeological assemblages (cultures) of many periods are found over a single site. To plot on the map, only the oldest period out of many cultures present over a site, has been considered for a particular class. Other lower period cultures are not depicted on the maps.

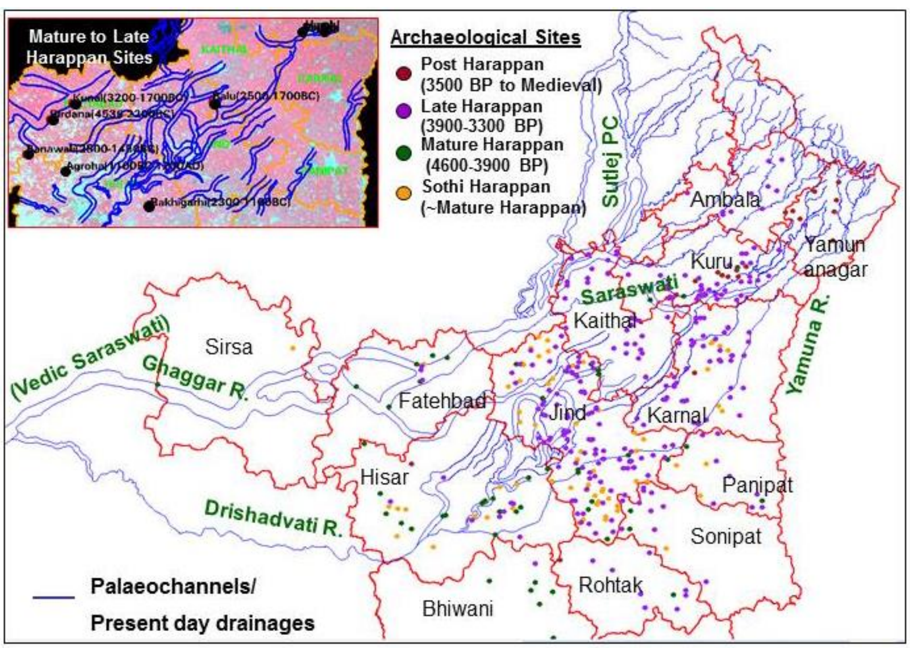


Fig.19: Archaeological Sites and the Palaeochannels in Northern Haryana

Apart from the Harappan sites, archaeological sites of Late-Harappan to Medieval period have been discovered in Adi Badri, Sandhya, Kapal Mochan, Mustafabad, Bilaspur, Sadhaura, Thanesar and Pehowa which lie mostly along the course of

Saraswati Nadi. Although catchment area of Markanda River is larger than that of Saraswati Nadi, but the number of available archaeological sites are much more along the course of Saraswati Nadi. This indicates towards higher level of historical significance of Saraswati Nadi in the region than that of Markanda River. Recently, an archaeological site (12^{th} Century old Painted Grey Ware i.e. Post-Harappan) has been discovered at Bhor Saidan village which lie on the bank of Sarraswati Nadi in the west of Kurukshetra (Purohit, 2006). All these evidence indicate flourishment of Mature Harappan to Post-Harappan culture along the Saraswati Nadi.

The delineation of the palaeochannels of Saraswati & Drishadwati in the northern parts of Haryana got a big boost by the discoveries of Harappan sites. The excavations are done by Archaeological Survey of India (ASI) & various other scholars. It provides a good evidence of the presence of an ancient civilization which is known as ‘Harappan Civilization’ or ‘Indus Valley Civilization’.

Most of the sites of this civilization have show a common characteristic like
- (a) Presence of house made of bricks,
- (b) Well planned city,
- (c) Ploughed agricultural field, etc.

The region between Saraswati River System in the north and Drishadvati River System in the south witness a rich cultural sequence from Harappan to Modern period.

1.	Birdana	- C.4000 B.C
2.	Kunal	- C.3200-1700 BC
3.	Balu	- C.2500-1700 BC
4.	Banawali	- C.2500-1450 BC
5.	Rakhigarhi	- C.2500-1450 BC
6.	Siswal	- C.2450 BC
7.	Bhagwanpura	- C.1700 BC-1300 BC
8.	Mirzapur	- C.1700 BC-1600 AD
9.	Raja Karna ka tila	- C. 800 BC-1600 AD
10.	Daulatpur	- Late Indus to Medieval period
11.	Harsh ka Tila, Thaneswar - Pre-Kushana to Late Medieval period.	

There are more than 400 archeological sites spreads all over Haryana especially in the northern part. Some of these belong to Harappan age & some to Post Harappan age. These Archeological sites are present in cluster, which are called “Economic Pockets” by Joshi et al. (1984). Most of the sites are falling on or nearby the paleochannels. Most of the green and yellow spots representing the Mature Harappan sites are found at the SW part of Haryana, i.e. Jind, Hisar, Fatehabad and Sirsa districts. But the Post-Harapppan sites represented as brown spots are present in the eastern and NE part of Haryana i.e. Kurukshetra, Kaithal, Karnal, Ambala and Yamunanagar. This probably shows the shifting of the people from W to E with loss of river. Similarly, location of a large number of archaeological sites along the Sutlej palaeochannel in eastern Punjab indicates close affinity between ancient civilizations with the Saraswati River.

4.3.3 Archaeological Study in Gujarat: Available archaeological sites of Pre, Mature and Post Harrapan ages have been plotted in Kachchh, Mehsana, Patan, Jamnagar, Rajkot and Surendranagar districs of northern Gujarat. Plots of archaeological sites of Mature Harappan period in Kachchh district (Desalpur, Dholavira, Gunthai, Kanthkot, Kerasi, kotada, Lakhpat, Luna etc.) clearly indicates close association of important civilization along the bank of Saraswati palaeochannels **(Fig.20)**.

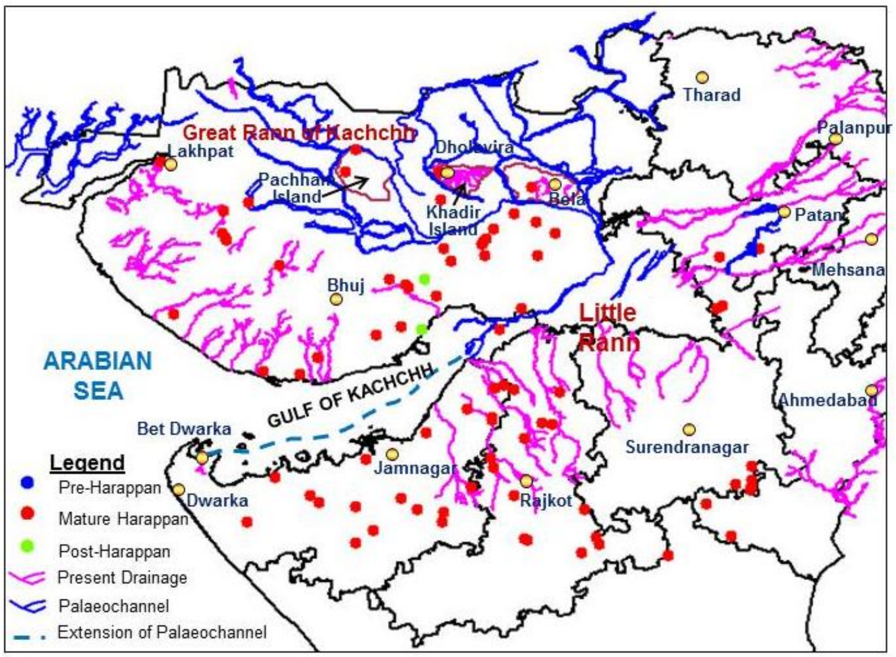


Fig.20: Archaeological Sites and the Palaeochannels in Northern Gujarat

4.4 Drilling (Litholog) Data Analysis

The geophysical (resistivity) survey was carried out for identifying potable groundwater in the desert areas. It revealed the presence of several zones of less saline and fresh water in the form of arcuate shaped aquifers. The disposition of these water pockets are correlatable with the traces of the palaeochannels found in these areas. This subsurface evidence of fresh water further adds prevalence of an earlier active drainage system in these areas. Sedimentological analysis for aquifer characteristics have been done in collaboration with Ground Water Department (GWD), Jodhpur and Central Ground Water Board (CGWB), Jaipur. The palaeochannels most often consist of the alternating layers of fine to medium and coarse grained sand and sometimes have gravel columns, indicating presence of fluvial regime. Coarser sediments are noticed at a depth ranging from 40–125m (general depth of 55-85 m) and have been encountered in 9 of the 14 tube wells drilled **(Fig.21)**. Channels are about 35 to 80m thick with depth of water level ranging from 35-60m **(Table-4)**.

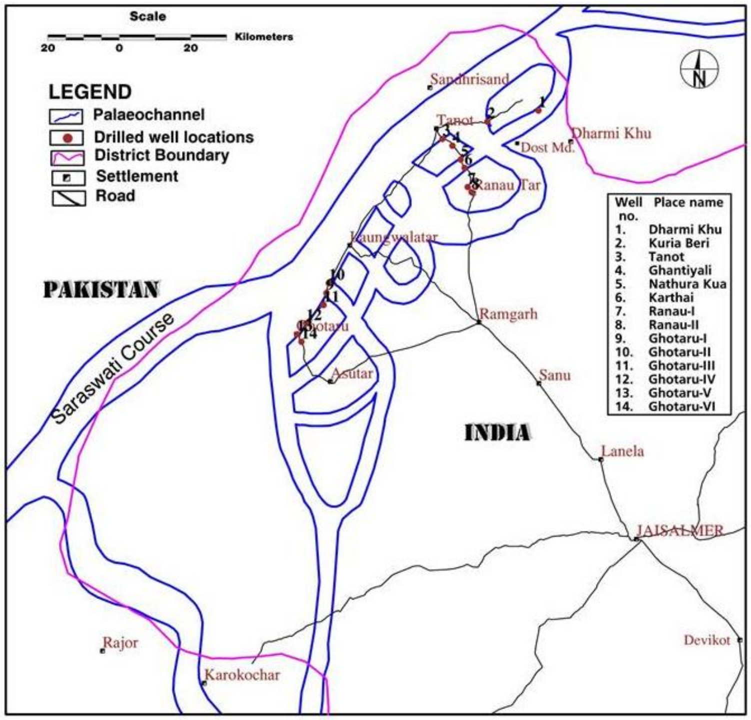


Fig.21: Location of tube wells drilled along the palaeochannels in Jaisalmer district along Tanot-Ghotaru-Longewala section.

Table-4 : Data of the tube wells drilled along the palaeochannels in the Jaisalmer district (Source : Ground Water Department, Government of Rajasthan, Jodhpur)

Sl. No.	Drilled well name/ location	Yield (lph)	Quality (TDS)	Depth Drilled (m)	Static Water Level (m)	Structure Installed	Aquifer material as observed in lithologs
1	Tanot (3.5 Km from Ghantiyali to Tanot LHS of Road)	11250**	2650	125	33	Tubewell	Mainly fine grained sand, medium grained at certain levels.
2	Ghotaru-I (12.5 Kms Ghotaru to Longewala, LHS of Road)	13500**	6506	151	43	Tubewell	Medium to coarse sand and gravel (Out of main channel).
3	Ghotaru – II (14.5 Kms Ghotaru to Longewala, RHS of road)	Not Developed	-	151	-	-	Fine grained sand –sandstone chips-fine grained S.St.-Kankar. (Out of main channel)
4	Ghotaru – III (10 Kms from Ghotaru to Longewala, RHS of road)	2250**	4337	151	48	Tubewell	Fine grained sand and very coarse grained gravelly sand
5	Ghotaru – IV (3 Kms from Ghotaru to Longewala, RHS of road)	32400#	3554	151	45	Tubewell	Medium to fine and coarse grained sands
6	Ghotaru – V (150 m NE of Fort)	33750#	1536	148	33	Tubewell	Coarse gravelly and fine to medium grained sands,
7	Ghotaru –VI (1.5 Kms from Ghotaru to Asutar, RHS of road)	22500#	934	125	46	Tubewell	Dominantly medium to coarse sands, fine grained and clayey sands at certain levels.
8	Dharmi Khu (3 Kms from Kishengarh to Dharmi Khu, RHS of road)	35100#	1024	153	40	Tubewell	Fine and medium grained sands
9	Ranau – I * (Ranau-Tanot Road. ~2 km from Ranau, LHS of road)	9120**	1010	102	42	Tubewell	Fine grained sand and silt with kankar; fine to medium sand
10	Ranau – II* (Close to Ranau village, RHS of Tanot road)	18240**	1000	120	58	Peizometer	N.A.
11	Karthai* (9.5 km from Ranau on Ranau - Tanot road, LHS of road)	12312*	1800	125	42	Peizometer	Mostly Fine sand medium at certain levels
12	Nathura Kua* (4.5 Km from Tanot, 250 m RHS of road)	12768**	2656	120	36	Peizometer	Fine grained sand and silt with kankar
13	Kuria Beri*	12768**	1295	131	32	Tubewell	Mostly Fine sand
14	Ghantiyali I* (500 m from Ghantiyali Mandir to Tanot, LHS of road)	11400**	2200	130	62	Peizometer	Fine grained sand
	Note : Yield by pumps are normally higher than the compressor yield by a factor of 1.5 to 2.0 * Wells are drilled by the CGWB ** Compressor yield # Pump test yield						

Exploration of palaeochannels (PCs) in the Jaisalmer district by the Ground Water Department (GWD), Rajasthan has proved existence of large quantities of potable quality ground water along the explored palaeochannels **(Fig.22, Table-5)**. Further, available litholog data for the wells drilled by the GWD for water supply to villages in different districts of Rajasthan has been analyzed to confirm if the mapped palaeo drainage courses conform to the fluvial regime. Data available for the study area from districts of Sri-Ganganagar, Sikar, Jhunjhunu, Churu, Bikaner, Nagaur, Jaisalmer, Jalor, Pali, Sirohi and Barmer districts was plotted on GIS layer and overlaid on to the palaeochannel map. It was observed that the wells falling along the palaeochannels mostly had encountered coarser sediments (Medium to coarse sand and gravels) during drilling.

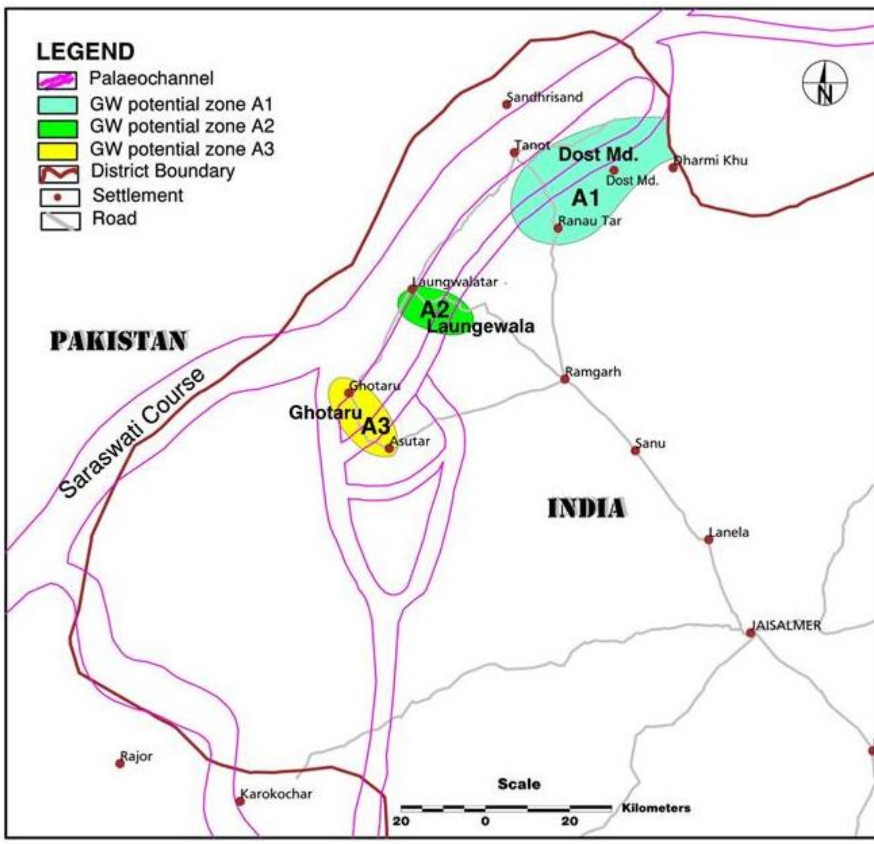


Fig.22: Groundwater potential zones, discovered in Jaisalmer district of Rajasthan (source: Ground water Department, Jodhpur)

Recently, electrical resistivity soundings were used to map the large-scale geometry and architecture of the palaeochannel system along Ghaggar River in NW India (Sinha et al., 2013). They found a thick and extensive sand body in the subsurface in parts of north-western Rajasthan, Haryana and Punjab. The dimensions of the palaeochannel bodies imply that these are the deposits of a large river system. The dimensions of the palaeochannel complex suggest a large, longlived fluvial system existed in this region.

Table-5: Hydrogeological Characters of the aquifer Zones delineated along Palaeochannels in Jaisalmer District (GWD Report)

	Zone-A1	Zone-A2	Zone-A3
Formation Material	Alluvial	Alluvial	Alluvial
Area (sq.km)	547	1100	150
Dir. Location	NE part	SW part	SW part
Water Levels(m)	31-62	45-63	39-60
WL fluctuation (m)	0.14	0.02	0.69
Av. Yield (m3ph)		136	22.6
EC (omh m)	1100-4000	2960-4000	1100-4000
Aquifer Thickness(m)	18	14	9
Static GW Reserves (mcm)	590	92	81
Recharge due to RF	Negligible	Negligible	Negligible

To investigate the charactersistics of the palaeochannels in Haryana, litholog and hydrological data from a large number of wells drilled in 9 districts of northern Haryana have been collected from Ground Water Cell, Govt. of Haryana. The locations of the individual lithologs have been plotted in different districts on the map (**Fig.23)**. Sedimentological characteristics encountered at different depths of the lithologs have also been studied. On superimposing the litholog points on the palaeochannel map of Haryana, it has been found that most of the lithologs falling near the palaeochennels have medium to coarse grained sands and associated gravel and pebbles at a depth between 10 to 100m.

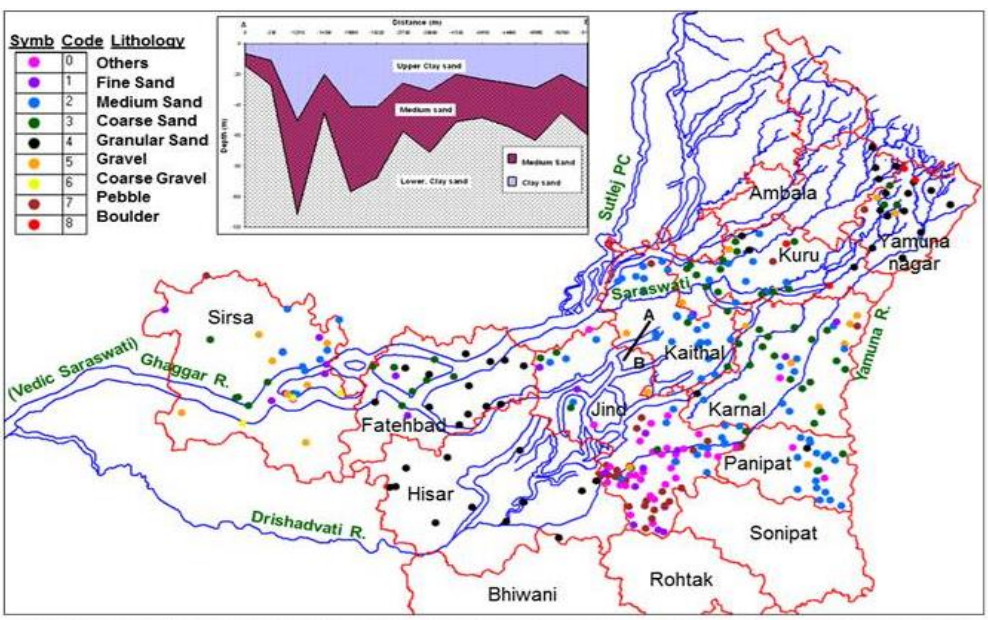


Fig.23: Spatial distribution of different size of sediments, encountered in the lithologs and the palaeochannels in northern Haryana. A section (line A-B) across the palaeochannel shows the layer of medium sand (fluvial channel).

4.5 Hydrological Data Analysis

4.5.1 Hydrogeological Study of Western Rajasthan: Analysis of sediments and water samples obtained from core drilling of 14 tube wells on the image identified palaeochannels in Tanot–Kishangarh–Longewala-Ghotaru section Jaisalmer district indicate that the water quality is quite good **(Table-4)** for most of the drilled wells, as compared to tube wells / dug wells away from the channel. As per the local Government norms, in the desert region ground waters upto EC of 4000 µs/cm are supplied to villages for drinking water purposes. The ground water away from palaeochannels is saline (non potable), EC >8,000 µs/cm at 25°C (CGWB, 2002 and GWD, 2003). The presence of vegetation even during extreme summer shows that these courses still maintain their headwater connection and form potential groundwater zones for exploitation. In spite of very low rainfall (less than 150 mm) and extreme weather conditions in the northwestern part of Jaisalmer district groundwater is available at a depth of about 50-60 m along the course. Despite being intensively used for 35-40 years there is no indication of any decline in the discharge of tube wells or of the lowering of water table. The wells in the vicinity do not dry up throughout the year.

4.5.2 Hydrogeological Study in Haryana: As a part of field validation, hydrogeological data (yield, water quality etc.) from different wells in all the northern districts of northern Haryana has been analyzed. Electrical Conductivity (EC) zoning pattern of the area shows that most of the demarcated palaeochannels lie in lower EC zone (2000-4000 µS/cm) indicating good quality water. Poor quality water (brackish to saline) is found in the central Haryana (Rohtak district) and northwest Haryana (Sirsa district) where EC values are very high (>4000 µS/cm). The analysis of water level data in some districts of Haryana also gives evidences of ground water at shallow depth. The water level contour of 4 district of northern Haryana (Kurukshetra, Karnal, Kaithal, & Panipat) shows large variation within the district. The water level contour, which are closer to any river show lower value as compared to those which are far away from rivers or palaeochannels marked e.g., northern part of Kaithal and eastern part of Karnal show shallow water level (15-25m) as compared to the central part of Kaithal and western part of Panipat (35-60m). The contour map of discharge data of the 4 districts of north Haryana also verifies the above conclusion. The discharge contour map shows the contour line with higher values in the northern part of Kaithal and western part of Karnal and Panipat (21000-39000 cusec) as compared to central part of Kaithal, Karnal and Panipat (15000-19000 cusec).

CHAPTER - 5

5.0 GEOCHRONOLOGICAL AGES OF SARASWATI RIVER BASIN

5.1 Age of Sediments in the Palaeochannels in Haryana - Based on the collection of subsurface lithofacies data from well logs, Saini et al. (2009) attempted to map the buried channel-floodplain systems of a part of the northwestern Haryana plains and provides evidence of buried major sand bodies at various depths. They have identified four lithological facies based on litholog data analysis:

(a) Brown sandy facies – Well-sorted very fine sand, deposited by eolian activity
(b) Brown silt facies – This sequence is of 20-40cm thick, formed by floodplain.
(c) Grey sandy facies – Fluvial deposit
(d) Brown clay/mud facies – Floodplain or lacustrine deposit

Further, Sediment characteristics from litholog data and Optical Stimulated Luminance (OSL) dating of sand (quartz) samples suggest the following evolutionary history of fluvial activity in western part of Haryana (**Saini et al., 2009**):

F-3 Phase (< 2.9 Ka) – Weak, piedmont-fed Ghaggar system, semi-arid climate

~~~~~~Desiccation of the channel between 4.3 Ka and 2.9 Ka~~~~~~

F-2 Phase (2.9 to 5.9 Ka) – Vedic Saraswati channel, buried as relict land, sub-humid climate

~~~~Aeolian phase with accumulation of sand dunes/sheets, arid climate during 15-20 Ka~~

F-1A Phase (~21 Ka) – Disorganization phase, weak fluvial activity, buried at 3-6m depth, terminated around Last Glacial maximum (LGM)

F-1 Phase (26-28 Ka) – Himalayan-fed channel network, including palaeochannels courses at Sirsa-Phaggu, Fatehbad-Agroha and Hisar at 6m depth, humid climate. Active channel during interglacial period (MIS-3)

Thus, OSL dates of sands at different levels suggest the existence of much older palaeochannels (~26 to 28 Ka) than the Saraswati palaeochannels (2.9 to 5.9 Ka), as estimated by most of the previous workers.

5.2 Age of Aeolian Sands in Rajasthan

Using Thermoluminescence (TL) and Optically Stimulated Lumeinisance (OSL) dating of sands, Singvi and Kar (2004) advocated that the Quaternary aeolian activity in Thar Desert is more than 150Ka old. There were four major phases of pre-LGM (Last Glacial Maximum) aeolian accumulation during the Late Pleistocene viz. 100 and 115 ka, ~75 ka, ~55 ka and between 30 and 25 ka. LGM was a period of high aridity, when the desert could have extended far beyond its present boundary. The LGM also experienced reduced fluvial activity. Maximum sand mobility and accumulation took place when the SW monsoon wind strength was sufficient during the transition period from an arid phase to a wetter phase and vice versa. Thus, the peak of aridity at ~18ka was marked by very less Aeolian activities. The Aeolian deposition following the LGM started at ~16ka, but the major activities took place roughly between 14 and 10ka, when sand spread to areas far beyond its present eastern limit.

A northward shift in dune forming climate during the Holocene was also seen. Thus the southern margin of mega-Thar in Gujarat did not experience any dune building activity after 10Ka, the north Gujarat plain experienced dune aggradation activity up to 5ka, while large parts of west Rajasthan, containing the core of the Thar experiences dune activity even after 2ka. Within the present desert boundary, the major phases of aeolian activities after the Holocene Climatic Optimum were between 5 and 3.5ka, and 2 and 0.8ka (0.6ka in the western part). The Harappan and pre-Harappan civilization in the northern part of the desert flourished during a waning phase of SW monsoon, when rainfall events were more aberrant, and Aeolian activities high.

5.3 Age of Groundwater in the Palaeochannels

The isotopic ages (H^3, O^{18} and C^{14}) of 17 groundwater samples from the existing wells along the palaeochannels in Jaisalmer district of Rajasthan were analysed by the Bhabha Atomic Research Center (BARC), Mumbai on the basis of Pearson model **(Table-6)**. The analysis indicates the variation in groundwater ages from 1340 to 18880 BP at different localities from NE to SW (Rao and Kulkarni, 1997; Nair et al., 1999). These areas lie either on the palaeochannel or very close to it viz. Kuriaberi (1340 BP), Ghantiyali (550 BP), Ranau (1930 BP), Sadewala (18800 BP), Longewala (12400 BP), Ghotaru (8910 BP), Dost Mohd. (2000 BP) etc.. Hence, age analysis of water samples indicate towards a palaeo source of water along the channels that may be linked to Ghaggar (Saraswati) palaeochannels. The shallow (>30m) and deep (>60m) groundwater along the palaeochannels have similar chemical and isotopic characteristics. The ground water do not have isotopic signature of present day Himalayan Rivers. However, the deep groundwater indicates towards origin from Himalayan source. Based on the relative radiocarbon ages, ground water movement (velocity) along the palaeochannels has been estimated as 5m/yr.

Table-6: Ages of groundwater samples from Jaisalmer district (Analyzed by BARC)

Sample ID	Location	Well Type	Age Uncorrected (Before Past)	Model Age, a (Pearson)-BP
D1	Dharmikua	DW	1900	M
T1	Kishengarh	TW	6190	M
D3	Kuriaberi	DW	4390	1340
D4	Nathurakua	DW	3000	M
T2	Ghantiyali	TW	9630	5550
D5	Ghantiyali	DW	4960	1550
T3	Ranau	TW	5930	1930
T7	Ghotaru I	TW	18700	12400
D12	Ghotaru-II	DW	3860	M
D17	Dost Md.Kua	DW	5780	2000

5.4 Palynological Evidence for Climatic Changes

Based on palynological studies on sediments derived from three salt lakes in Rajasthan, namely Sambhar, Didwana and Lunkaransar, Singh et al. (1974) postulated climatic fluctuations during the period 8000 B.C. to present day. Out of the five phases, Phase IV (3000 B.C. to 1800 B.C.) encompasses the early Harappan and Harappan culture. It was postulated to be characterized by heavy rainfall at least 50 cm more than the present rainfall in the arid zone. The decline of the Harappan culture during the period 1800- 1000 B.C. was attributed to setting in of a dry climate. This hypothesis has not been accepted by many archaeologists and palaeobotanists (Mishra, 1984). Increased rainfall during 8000-2000 B.C. should have led to farming activity in western Rajasthan. No Neolithic- chalcolithic or early Iron Age site has been reported from even the Luni basin where extensive exploration has been carried out during sixties and seventies. Mughal (1982) has reported hundreds of farming sites of Neolithic-chalocolithic period from Cholistan desert (Bahawalpur state), which is considered to be still more arid (rainfall ~100 mm/year) than the western Rajasthan Thar Desert (rainfall ~200- 250 mm/year).

5.5 Geochronological Events of Saraswati Drainage Evolution

A comprehensive table has been generated for the geochronological events of the Saraswati drainage network evolution based on the available data of isotopic (H^3, O^{18} and C^{14}) analysis, Thermo Luminescence (TL) dating, Optical Stimulated Luminance (OSL) dating, foraminifera study of sea level changes and other collateral information (**Table-7**). Sample analysis of sediments in lithologs and OSL dating of sand (quartz), Saini et al. (2009) suggested a much older palaeochannels (~26000 to 28000 BP) than the Saraswati palaeochannels (2900 to 5900 BP). Using TL and OSL dating of sands, Singvi and Kar (2004) interpreted that the Quaternary aeolian activity in Thar Desert began prior to 150,000 years before present. The Harappan and pre-Harappan civilization in the northern part of the desert flourished during a waning phase of SW monsoon, when rainfall events were more aberrant, and aeolian activities were high. Isotopic analysis (H^3, O^{18} and C^{14}) of 17 groundwater samples from the existing wells along the palaeochannels in Jaisalmer district of Rajasthan by BARC, Mumbai indicates that age of trapped groundwater varies from 1340 to 18880 BP (Rao and Kulkarni, 1997; Nair et al., 1999). Recently, groundwater samples were analysed by Reddy et al. (2011) in parts of the Jaisalmer district. The groundwater of deeper aquifer (~480m) was found to be more than 40,000 years and the age of groundwater in medium aquifer (~170m) vary from 9000 to 17,000 years. Based on the study of foraminifera along Gujarat coast, Nigam (2012) advocates that sea level was lower during 7,000-10,000 and 3,000-4,000 years. Lowering of sea level is evinced by the dissociation of an ancient dockyard like Lothal which is presently located about 10-12 km away from the sea and few meters above the present sea level. Rise in sea level was observed during 4,000-7,000 and 1,500-3,500 years which causes submergence of Neolithic settlement in Gulf of Khambat and Dwaraka in Gulf of Kachchh. All these available data indicates that the Himalayan drainage in NW India was existing more than 40,000 years ago i.e. before the Saraswati civilization. Vedic Saraswati River was in full majesty during 6,000-8,000 years (Radhakrishna, 1999; Valdiya, 2002).

Table-7: Geochronological Events Related to Saraswati Drainage Evolution in NW India during Quaternary Period (Pleistocene=10000 years to 2 m.y. and Holocene=0-10000 years)		
Duration (BP)	**Events**	**References**
1,340 to 18,880	Isotopic age (^{3}H, ^{18}O and C^{14}) by BARC. Groundwater in the palaeochannels in Jaisalmer region, Rajasthan	Rao and Kulkarni (1997) Nair et al. (1999).
1,500 – 3,500	Sea level rise (4-5m). Dwaraka submerged.	Nigam (2012)
< 2,900	Ghaggar-Saraswati drainage system become weak with the beginning of semi-arid climate	OSL dating by Saini et al. (2009)
2,900 to 4,300	Desiccation of the Saraswati channel	OSL dating by Saini et al. (2009)
2,900 to 5,900	Vedic Saraswati Channel buried with relict landform in sub-humid climate. Existence as Saraswati palaeochannels.	OSL dating by Saini et al. (2009)
3,000 to 4,000	Sea level was lower (4-5m). Lothal port dissociated from sea. Land reclamation by Lord Krishna to build Dwaraka city.	Nigam (2012)
3,500	Major river diversion of Sutlej and Yamuna	Sinha et al. (2013)
3,500 – 5,000	The major phases of aeolian activities after the Holocene Climatic Optimum	TL and OSL dating Singvi and Kar (2004)
3,528	Thermoluminiscence dating of potteries. Existence of Bet Dwaraka	Rao, S.R. (http://veda. wikidot.com/dwaraka)
3,792	Astronomical dating for Mahabharata War (1792BC)	Ashok Bhatnagar (2014)
< 4,000	Saraswati dwindled and dried up due to river shifting, river piracy, Rajasthan greenery lost with onset of arid environment.	Sankaran (1999)
4,000 – 7,000	Sea level rise (4-5m). Submergence of Neolithic settlement in Gulf of Khambat	Nigam (2012)
5,000	Continuous flow of Saraswati upto Little Rann	Sankaran (1999)
6,000 – 8,000	Saraswati was in full majesty.	Radhakrishna (1999), Valdiya (2002)
7,000 to 10,000	Sea level was lower (0-30m). First human settlement (Neolithic) near Surat in Gujarat coast.	Nigam (2012)
7,000 to 13,000	Groundwater in Indo-Pak Thar region	Geyh & Ploethner (2008)
8,670 to 17,000	Groundwater in Jaisalmer region: Medium aquifer (170m) = 9000-17000years	C^{14} dating by Reddy et al. (2011)
10,000	Mighty Himalayan rivers were flowing in western Rajasthan. Sea level was lower (60-80m) than today	Sankaran (1999); Nigam (2012)
10,000 – 18,000	Reduced fluvial activity. Major aeolian activities took place. Aeolian deposition started after LGM.	TL and OSL dating by Singvi and Kar (2004)
15,000-20,000	Aeolian phase with sand dunes and sand sheets accumulation. Prevalence of arid climate	OSL dating by Saini et al. (2009)
21,000	Fluvial activity became weak and terminated around LGM	OSL dating by Saini et al. (2009)
26,000-28,000	Existence of Himalayan-fed channel network including older palaeochannels	OSL dating by Saini et al. (2009)
40,000	Himalayan Rivers originated by melting of glaciers due to warming. Groundwater in deeper aquifer (480m) in Jaisalmer region >40,000 years	Sankaran (1999); C^{14} dating by Reddy et al. (2011)
40,000BP-1.7m.y (Pleistocene)	Major tectonic events in the Himalaya. Himalayan mountains under glacial cover. Climate was fluctuating between glacial and interglacial phases	Sankaran (1999), Mitra and Bhadu (2012)

CHAPTER - 6

6.0 DISCUSSION ON SARASWATI RIVER LINKAGES

6.1 Linkage of Saraswati Nadi with Somb River at Adi Badri

Topographical and ground survey show that Saraswati Nadi originates near Rampur Herian village, located 9 Kms south of Adi Badri area in Yamunanagar district of Haryana. However, the Somb River originates further north in the higher reaches of the Siwalik Hills. Somb River is located east of Saraswati Nadi and flows in N-S direction and finally joins River Yamuna in the southeast. Adi Badri is located on the bank of a small rivulet joining the Somb River. Topography of Adi Badri area is studied based on the satellite data of SRTM of February, 2000. SRTM derived hill shade view shows the emergence of ephemeral 1st order drainages of saraswati Nadi and Somb River from the Siwalik foothill zone **(Fig.24a)**. Close contour pattern of this area **(Fig.24b)**, generated from SRTM DEM, indicate gentle topography between Adi Badri (360m) and Rampur Herian (330m). A height difference of only 20m has been observed from the tip of Saraswati drainage line at Rampur Herian (330m) and the Somb River bed (310m) in the E-W direction. Thus, the drainage pattern of the area indicates the possibility of joining the upstream of River Somb with the Sarasawti Nadi in the past.

On high resolution satellite data (IRS LISS-IV FCC) of May, 2004, an N-S trending dark greenish red colour linear tonal anomaly can be clearly demarcated in the southwest of Adi Badri area upto the 1st order drainage from where Saraswati Nadi originates near Rampur Herian **(Fig.24c)**. This strong image anomaly indicates a possible linkage of drainages around Adi Badri area with Saraswati Nadi in the past, instead of River Somb in the present state. This gives rise towards a strong possibility that drainage originating from the upper catchment area of Somb River in the north of Adi Badri must have served as the drainage of Saraswati Nadi in the past. The configuration of tributaries of Somb River also indicates towards feasibility of river capture of previously upstream drainage of Saraswati Nadi by the Somb River at Adi Badri. All these evidences lead towards the likely origin of Saraswati Nadi at Adi Badri sometimes in the past (historic/pre-historic period), as strongly believed even today by the people of the region.

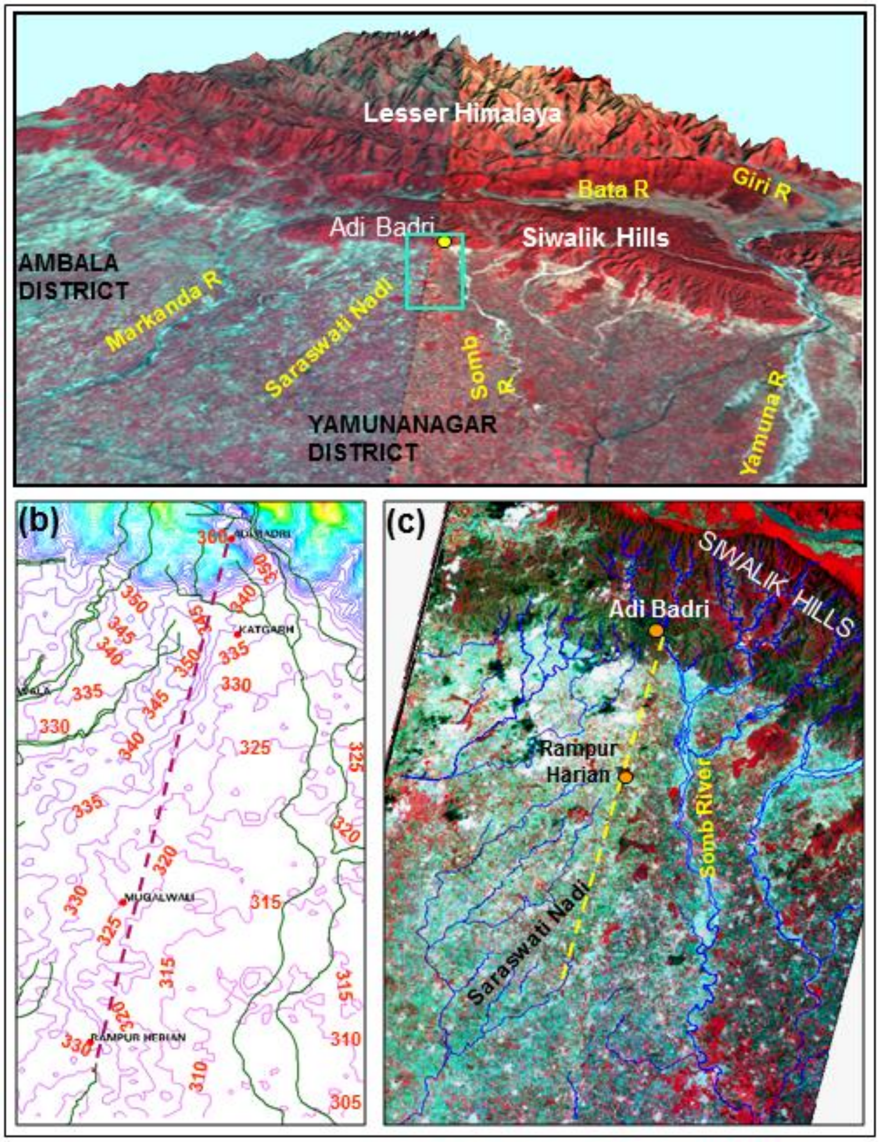


Fig.24: (a) SRTM DEM with draped Landsat ETM image showing 3D view of Siwalik foothill around Adi Badri area. (b) Elevation contour map (5m) between Adi Badri and Rampur Herian. (c) IRS-P6 LISS-IV Image showing vegetation anomaly (yellow dash line), indicating possible link between Somb River and Saraswati Nadi.

6.1.1 Archaeological Importance of Adi Badri Area: A major archaeological breakthrough has been reported from the archaeological excavation carried out during 2002-03 at Adi Badri area, north of Kathgar in Yamunanagr district (Dwivedi et. al., 2006). Archaeological Survey of India (ASI) excavated three sites viz. ABR-I and ABR-II on western bank of Saraswati-Somb River confluence and ABR-III on the eastern side of the Somb River **(Fig.25a and b)**. A rich heritage of Buddhist Civilization, right from 3rd-4th Century A.D. (Burial activity) to 10th-12th Century A.D. (Dressed stone structures) have been discovered from ABR-III**.** Stone sculpture associated with Shivling of medieval period has also been found from this site. Local people believe that the udgamsthal (origin) of Saraswati Nadi is at Adi Badri where water oozes from a cave. A large pond (Saraswati Sarovar) has been constructed here for a holy bath for the pilgrims and a large number of artifacts of Buddhist period have been excavated from ABR-I **(Fig.25c)**. Moreover, this area is known as the Haridwar of Haryana due to the existence of three old temples viz. Adi Badri, Adi Kedar and Mantra Devi. Based on the evidences of Hindu rituals sites (after death) at Adibadri stream confluence with Somb and the occurrence of several Buddhist settlements and stupa there, it may be concluded that Adi Badri has been an important historic place in the past.

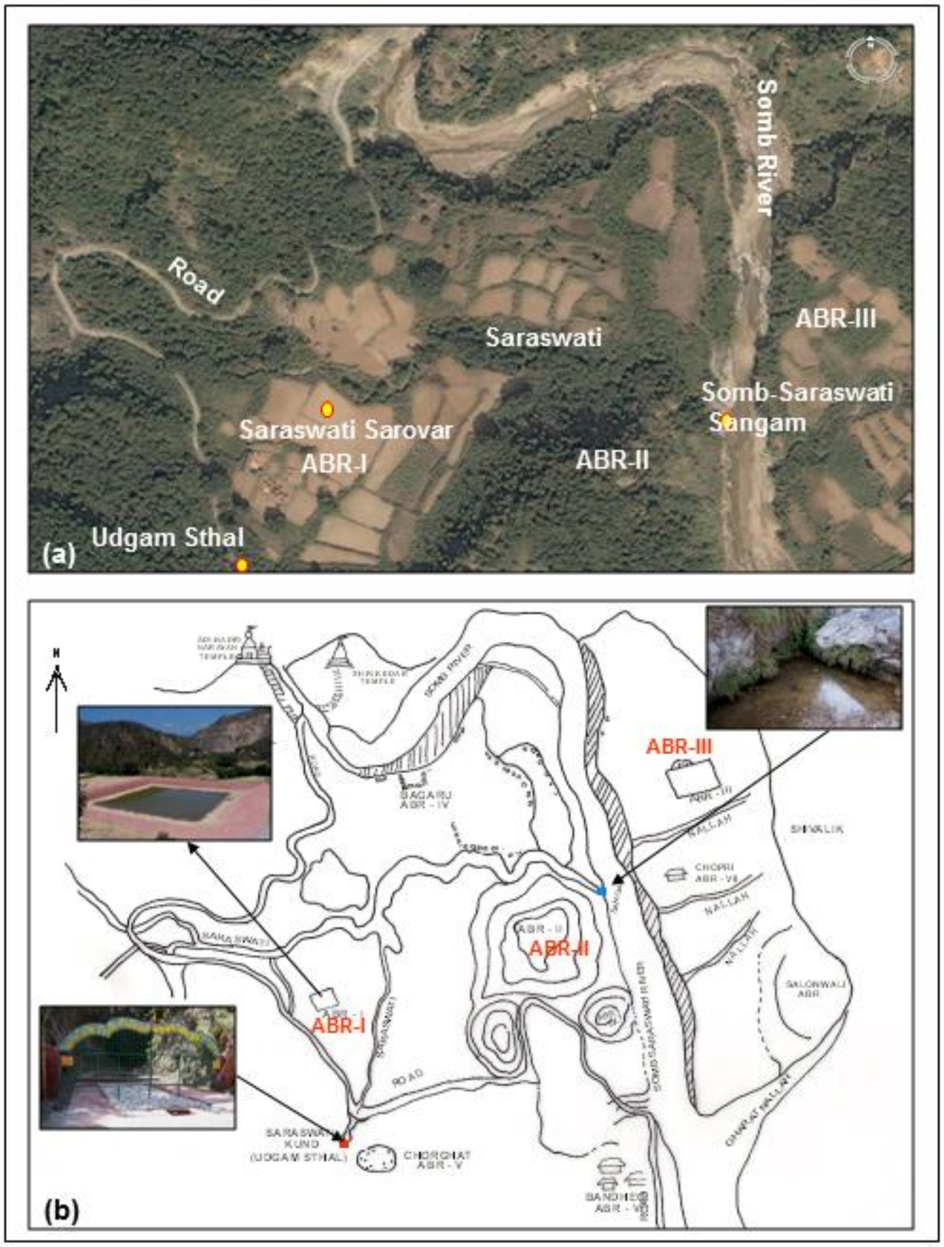


Fig.25: (a) High resolution satellite image around Adi Badri area. (b) Map showing the sites of archaeological excavations (ABR-I, ABR-II and ABR-III) around Adi Badri area (ASI, New Delhi).

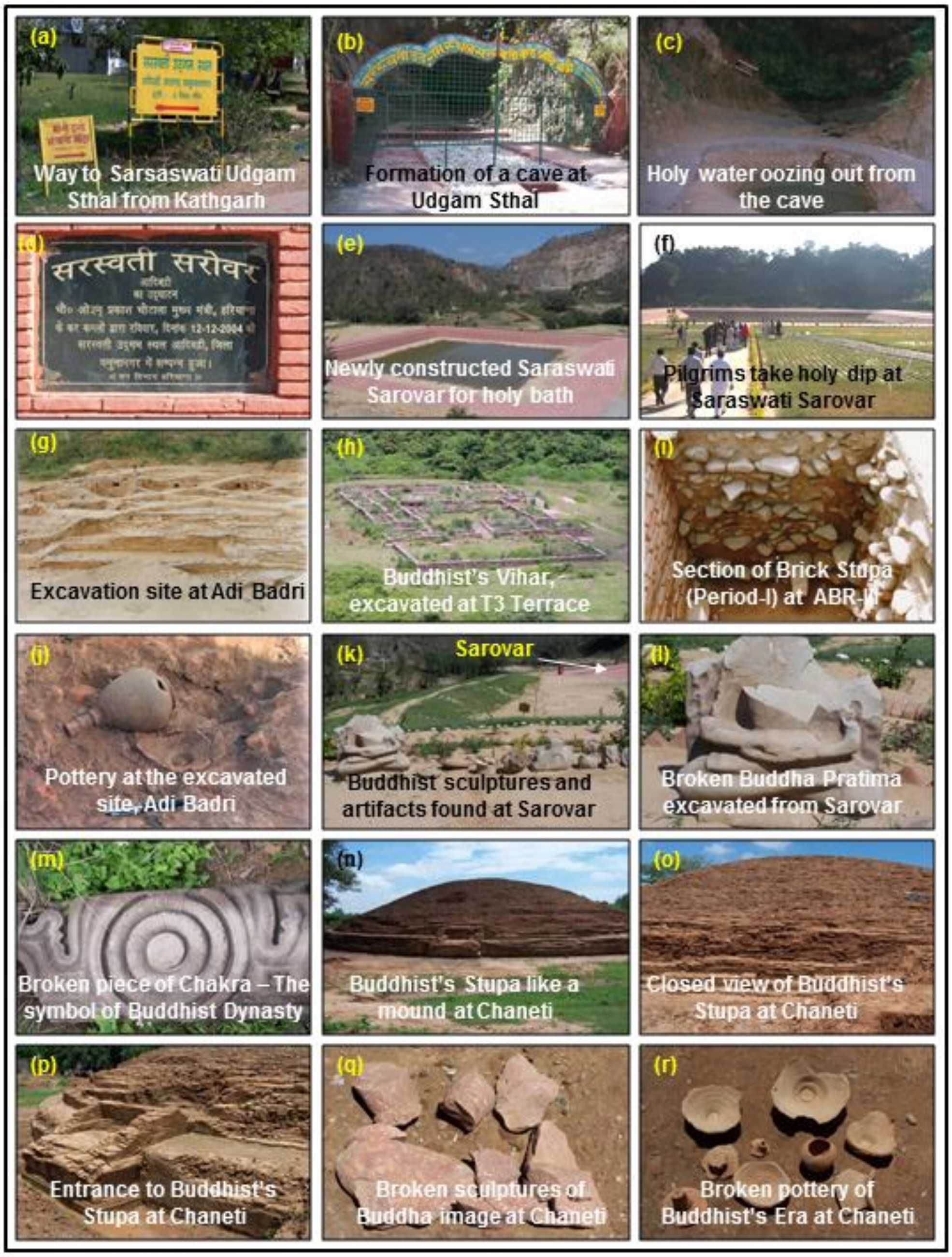


Fig.25c: Field photographs showing different artifacts of Buddhist period at Adi Badri and Chaneti in Yamunanagar district, Haryana.

6.1.2 Study of Riverine Sediments at Adi Badri: During excavation of archaeological sites (ABR-I, ABR-II and ABR-III) at Adi Badri area, the nature of riverine sediments (mostly pebbles) has been studied by Puri and Verma (1998). They inferred that these pebbles are of glacial origin and belong to Higher Himalayan metamorphic rocks. The area has been revisited by the present authors in 2005-06 for detailed study of the nature of the sediments to reveal their source / provenance. Physiographically, Adi Badri lies on an elevated region, on the southern flank of Siwalik Hills in Yamunanagar district. ABR-I and ABR-III are located at lower elevation on either side of the Somb River. But the ABR-II site is located on a ridge (locally known as Itonwali), ½ km NE of Kathgarh and it lies at a higher elevation (~70m high) from the Somb River bed **(Fig.25b).** A large number of pebbles of varying nature (colour and texture) have been found at ABR-II. These pebbles are rounded to sub-rounded, light to dark grey in colour and medium to coarse grained texture. Moreover, the pebbles are mostly sorted (more or less same size) which indicate the end phase of fluvial deposit. At ABR-II site, pebbles of both sedimentary and metamorphic rocks have been found at ridge top. But pebbles of only sedimentary origin are reported from ABR-I and ABR-III sites.

Since the Somb River is the only river flowing through this area, it is possible that in the past, these pebbles might have been transported by Somb/ Saraswati which was perhaps more energetic and must have had higher carrying capacity than the present day flow. Occurrence of large number of pebbles at such a higher elevation at ABR-II indicates that possibly Somb River might have been flowing at 70m high above the present river bed. In other words, present day physiography is the result of deep river cutting across the Siwalik Hill range.

Detailed field observation in two pits of ABR-II excavation site shows sub-rounded pebbles which are aligned almost parallel to the valley configuration. It reveals that this ridge constitutes the basal part of T3 terrace which is the oldest terrace in outer Himalaya during Holocene period (Puri, 2001; Puri and Verma, 1998). They have reported pebbles of high grade metamorphic rocks like mica schist, quartzite and metabasite along with the pebbles of Siwalik rocks. Similar assemblages of sedimentary and metamorphic pebbles are also reported near Sudanwala T3 terrace, NE of Adi Badri, on other side of Siwalik Hill slope. Occurrence of high grade metamorphic rocks are very uncommon all along the Siwalik Hills rather they have an affinity with the rocks of Central Crystallines / Jutogh Group in Higher Himalaya.

6.2 Linkage of Saraswati Nadi with Yamuna River

Pebbles of metamorphic rock have been found at several places viz. Adi Badri, Sudanwala, Garibnath etc. between Tons-Yamuna River confluence (Paonta Sahib) and Bata-Markanda River divide **(Fig.26).** Puri and Verma (1998) postulate that these pebbles might have been transported by a river like Tons which originate from Higher Himalaya in the north. Transportation of these pebbles for such a long distance and their deposition on river terraces of Siwalik foothills clearly indicates towards the existence of an ancient powerful drainage system. Since this drainage course follows the Bata valley, it is possible that Tons River might have flowed through Bata River in the past and joined either with Markanda or Saraswati Nadi in aryana. In such a case, the present day Yamuna flow was not to the south rather it flowed westward along Bata River. Puri and Verma (1998) also postulated that the Vedic Saraswati might have drained through the Adi Badri site and dumped the metamorphic pebbles at ABR-II. Petrographic studies indicate occurrence of pebbles of calcareous sandstone and quartzite of metamorphic origin at Adi Badri area. However, the catchment area of Saraswati Nadi is confined to the southern slope of the Siwalik Hills and the river receives only seasonal flow due to low precipitation. Hence, no linkage of Saraswati Nadi with any major perennial river systems like Yamuna could be found out based on the available data and evidences. It remains doubt that Saraswati Nadi could have formed a powerful drainage system in the past and served as the main channel of Vedic Saraswati River. The present day topography, rainfall and drainages of the region, does not support the hypothesis provided by the Puri & Verma (1998). However, study of neotectonic activity along major and active faults like Yamuna Tear Faults shows upliftment or subsidence of the terrain. As a result, drainages have been shifted eastward and capture by other stream (river piracy) due to accelerated headward erosion (Virdi and Philip, 2006).

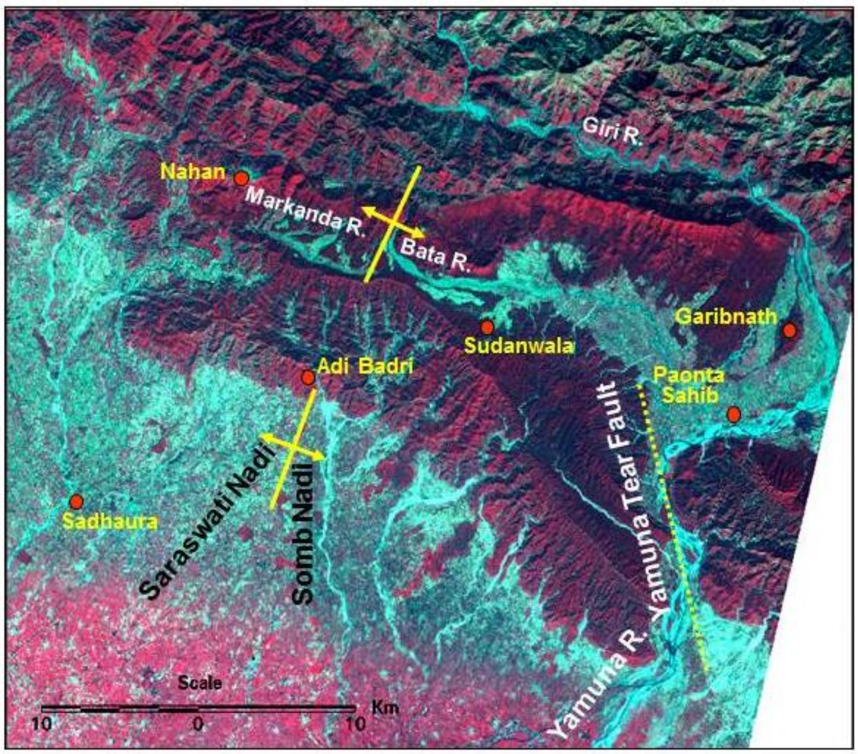


Fig.26: IRS P6 LISS-III image showing Markanda-Bata divide and its mis-fit wide valley around Paonta Sahib. The NNW–SSE trending Yamuna Tear Fault, possibly responsible for the diversion of Yamuna towards south.

6.3 Linkage of Saraswati Nadi with Vedic Saraswati

As observed from Satellite data and the SOI topomaps, Saraswati Nadi has been a tributary to the Vedic Saraswati River. Saraswati Nadi presently originates from a place `Rampur Herian' which is located south of Adi Badri in Yamunanagar district. The river passes through Yamunanagar (Bari Pabni, Choti Pabni, Chhapar, Sadhaura and Mustafabad), Kurukshetra (Pipli, Thanesar, Jyotisar, Bhor-Saidon, Bibipur and Pehowa), Kaithal and Fatehabad districts and joins with River Ghaggar at Rasauli village near Shatrana in Patiala district of Punjab.

The catchment area of Saraswati Nadi is found to be confined to Yamunanagar and Kurukshera disricts. Since the catchment area of Saraswati Nadi is confined to the southern slope of the Siwalik Hills, the river receives only seasonal flow. Hence, this stream (Saraswati nadi) in its present form does not seem to be a powerful drainage system in the past. However, sites of Late-Harappan to Early Historic period like Sandhaya, Kapal Mochan, Sadhaura, Mustafabad, Bilaspur, Thanesar and Pehowa etc. and also the sites of Mature/Sothi Harappan period viz. Bhagwanpura, Garhi Rodan and Nandu Khera in Kurukshetra district are found to lie along the course of Saraswati Nadi and its tributaries. Relics of a large number of old temples and ashramas (hermitages) of Rishis like Parasara, Ved Vyas, Dadhichi, Parsurama etc., described in ancient texts of Mahabharata and Puranas and several sacred ponds and sites of Vedic rituals are present along the banks of the obliterated Saraswati drainage course. All these indicate Saraswati Nadi to be a historically important and perhaps perennial stream of the past and served as the main powerful channel of Vedic Saraswati River.

6.4 Linkage of Sutlej Palaeochannel with Vedic Saraswati

In previous section, it has described that optical data as well as SAR images could able to pick up a subsurface palaeochanne between Ropar and Patiala and is known as Sutlej palaeochannel. It is a N-S trending palaeochannel of nearly 75 km length and 1-6 kn width. The Sutlej palaeochannel is connecting the present day Sutlej River near Ropar and the Ghaggar River (Vedic Saraswati) in the south of Patiala. Thus, Sutlej palaeochannel possibly acted as a major link between the Himalayayan glacier and the Vedic Saraswati.

6.5 Linkage of Vedic Saraswati from Mannsarovar to Dwaraka

Rising in the Himalayas from the holy lake of Mansarovar in Tibet, the Satluj river enters the plains near Ropar (Punjab), when it takes a sharp right–angled turn and flows westward a distance of 150 km before being joined by the Beas river. The Ghaggar River rises in the Siwalik from the Morni Hills and enters the plains near Ambala (Haryana). After covering a distance of 175 km it joins the Saraswati at Rasula (Patiala district). The combined rivers now know as Ghaggar flows through Sirsa (Haryana), Hanumangarh and Ganganagar district (Rajasthan) and through the Bahawalpur state (Pakistan). The Saraswati rises in the Sirmaur region of the Siwalik and enter the plains at Adi Badri (Yamunanagar). After flowing through Karnal in Haryana it joins the Ghaggar near Rasula in Patiala. The Ghaggar bed dries up near Sirsa.

To be a vibrant mighty river, the Sarasvati in Vedic Period must have been contributed by any major river system of the Himalaya. Presently, Sutlej and Yamuna are the two perennial rivers which are likely to be the feeder channels of Vedic Sarasvati River in the past. Beyond the range of Siwalik and Lesser Himalaya, these two rivers are fed with the permanent glaciers in the Higher Himalaya. It has been observed from the satellite images that the size of the glacier of Sutlej River is much larger than the size of the Yamunotri and Bandarpunch glaciers. But, due to tectonic changes in the past, these two perennial rivers shift their courses viz. Satluj to the west to join river Indus and Yamuna to east to join

River Ganges near Allahabad. Based on the analysis of several satellite images coupled with the Remote Sensing techniques, the entire course of Sarasvati palaeochannels have been delineated from the Himalayan foothills to the Rann of Kachchh, passing through the Thar Desert in NW India **(Fig.27)**.

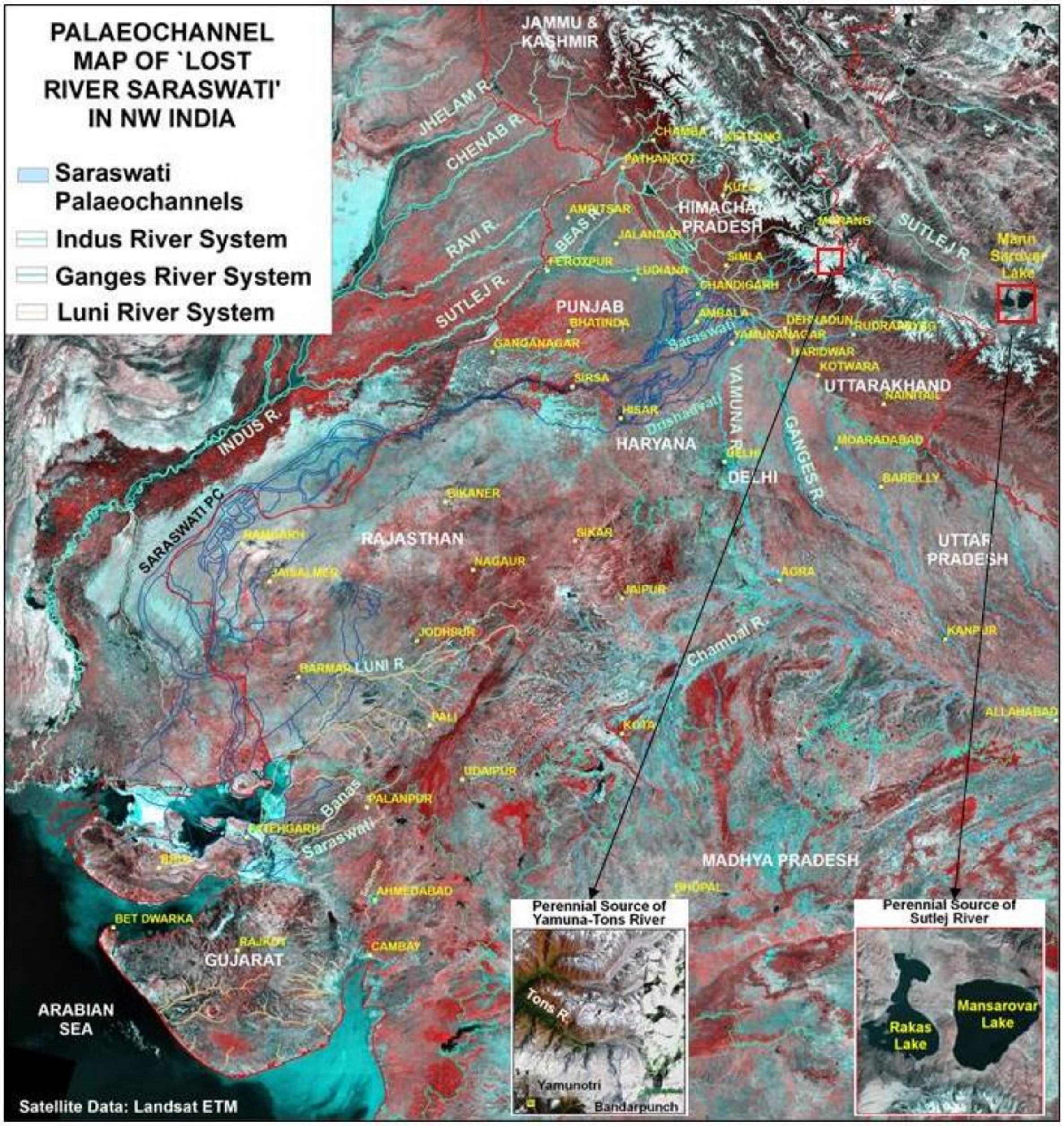


Fig.27: Saraswati Palaeochannel network with major drainage system in northwest India.

As mentioned earlier, Vedic Saraswati River met the Arabian Sea at the Rann of Kachchh. In Late Vedic period, Saraswati lost her major tributaries, Yamuna and Sutlej. Sutlej turns west and joined Beas-Sindhu system and Yamuna started migrating east to join Ganga (Valdiya, 2002). During Mahabharata times, the volume of water flowing down the Saraswati had reduced and did not flow upto the sea. At the time of Krishna's birth Yamuna has not as mighty as it is today. Hence, it must have been possible for Basudev to cross the river with the new born Krishna in his arm. It is described in Mahabharata that Balaram travelled along the most dry banks of Saraswati and then along the banks of Yamuna from Prabhas (Somnath) to Mathura. Dwaraka city was in existence during Mahabharata period whose northern extension ends at Bet Dwarka. Based on all these scientific evidence, the course of Saraswati River may be linked from Mansarovar in Higher Himalaya to Dwaraka in Arabian Sea coast during late Quaternary period **(Fig.28)**.

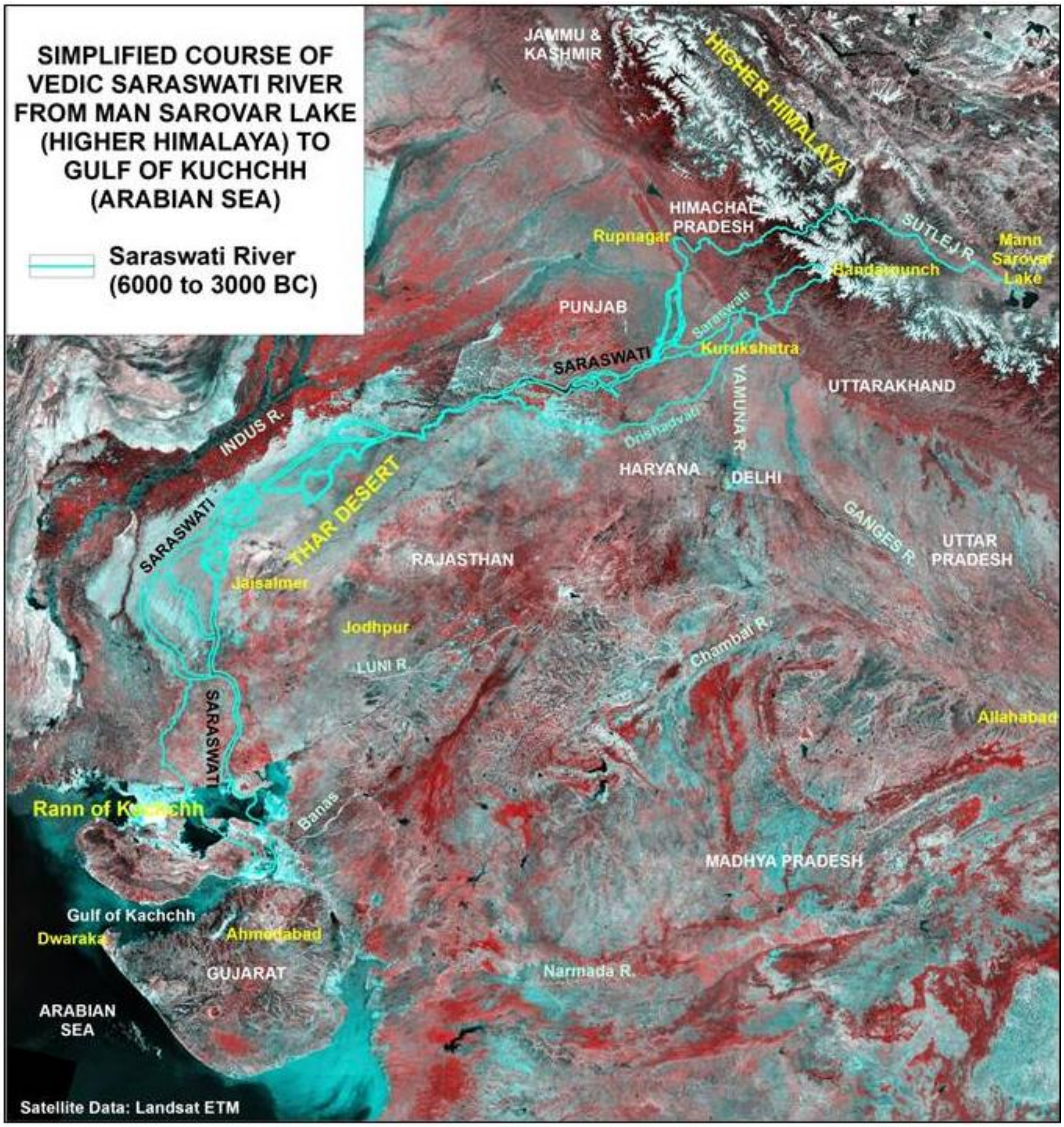


Fig.28: Simplified map of Vedic Saraswati River from Mansarovar to Dwarka in northwest India

CHAPTER - 7

7.0 CONCLUSIONS AND SUGGESTIONS

7.1 Conclusions

The entire course of Vedic Sarasvati River has been delineated using latest satellite images. The mapped course is validated with a variety of ground data such as archaeological sites, drilling and hydrogeological data. Radiometric ages of river sediments suggests that the age of Vedic Saraswati River (older palaeochannels) may be as old as 28,000 years and flourished during 8000 to 5000 years ago which may be represented by younger palaeochannels in Haryana. However, the age of trapped ground water in the palaeochannels in Rajasthan shows contemporary age of Saraswati (1340-8910 BP) and as old as 18800BP. Present day perennial sources of Sutlej and Yamuna/Tons rivers upto the Siwalik foot hills have been considered as part of Vedic Sarasvati River. Available sources with the present scientific evidence leads to the conclusion that Saraswati River network might have been in existence as old as 28,000 years BP and ceased to be a dry channel during 3792 years BP. Integrated study with multi-disciplinary approach leads to the following conclusions:

- The northwestern region of Indian sub-continent witnessed a number of mighty flowing rivers in the past. Like present day Indus River system, a sub-parallel river system known as `Vedic Saraswati River' was flowing with full majesty around 6000 B.C. The river dried up subsequently and disappeared around 3000 B.C. due to climatic and tectonic changes in Himalayan region. The relict of this lost river is still found as palaeochannels in the above states.
- River Saraswati originated in the Higher Himalayas and flowed through the western part of Indo-Gangetic alluvial plains along several tributaries like Satluj, Yamuna, Chautang and Drishadvati. The Saraswati river system passed through the states of Himanchal Pradesh, Punjab, Haryana and Rajasthan and finally discharged into Rann of Kachchh in Gujarat.
- Close association of contemporary Vedic composers all along the River Saraswati indicates that the Rig Vedic tradition might have been prevailed during 8000-5000 BP. Rishi Veda Vyasa composed Mahabharata with the observation of sky inscriptions on the banks of River Saraswati. Recent astronomical dating indicates that Mahabharata War was fought around 3792 BP. Thus, civilization grown along the Saraswati River possibly links between Vedic and Mahabharata period (8000-3792 BP).
- The course of Vedic Saraswati is mapped using modern tools like Remote Sensing and GIS. The satellite image interpretation shows the obscured signature of `palaeo-rivers' below the aeolian sands in the Thar Desert. An attempt has been made to trace the entire drainage network of the `Lost Vedic Saraswati' from the Siwalik foothills to Arabian sea and its possible link to the perennial source in higher Himalaya.

- Multi-spectral and multi-resolution satellite images like optical satellite data (Landsat ETM and IRS P3 WiFS and IRS P6 AWiFS, LISS-3 and LISS-4) as well as microwave (Radarsat SAR) data have been used to delineate the palaeochannels.
- The mapped courses have been validated with a variety of ground information like archaeology, sedimentology, hydrogeology and drilling data.
- The relative ages of the discovered archaeological sites and the radiocarbon dating of ground water and sediment samples all along the palaeochannels are highlighted in the present study.
- Radiometric ages of river sediments suggests that the age of Vedic Saraswati River (older palaeochannels) may be as old as 28,000 years and flourished during 8000 to 5000 years ago which may be represented by younger palaeochannels in Haryana. However, the age of trapped ground water in the palaeochannels in Rajasthan shows contemporary age of Saraswati (1340-8910 BP) and as old as 18800BP.
- Present day perennial sources of Sutlej and Yamuna/Tons rivers upto the Siwalik foot hills have been considered as part of Vedic Sarasvati River. Available sources with the present scientific evidence leads to the conclusion that Saraswati River network might have been in existence as old as 28,000 years BP and ceased to be a dry channel during 3792 years BP.
- Sutlej palaeochannel in Punjab links Vedic Saraswati River to the major source at Mansarovar Lake. A linkage of the entire drainage network has been established from Mansarovar (Tibetan Himalaya) to Dwarka (Arabian Sea coast) during late Quaternary period.

7.2 Suggestions for Reviving Saraswati River

7.2.1 Safeguarding Saraswati Nadi at Adi Badri: There is a need to safeguard and revive the Saraswati Nadi which is historically and archaeologically important drainage in Haryana. This could be done by diverting water (through canals) from existing Rivers (Markanda, Somb or Yamuna) which are close to the Saraswati Nadi. The effort may benefit the people of the region to meet their religious needs and perform rituals along the banks of flowing River Saraswati. At the same time, water can also be used for irrigation along the Saraswati River.

7.2.2 Action Plan to Revive Saraswati Nadi in Haryana: Based on the present study and assessment of the actual ground situation, the following action plan is suggested for revival of Saraswati Nadi, restoring the heritage and keep with the people’s sentiments.

1. Silt removal / deepening of Saraswati Nadi in blocked areas for free flow of water and routing of flash floods.
2. Legislation to avoid dumping of sewerage / industrial water into Saraswati Nadi by way of providing alternative disposal mechanism.

3. Legislation and movement for freeing the encroached river land belonging to Saraswati Nadi from private possession.
4. Revival of Saraswati Nadi to restore the heritage by way of River linking with Somb, Markanda or Yamuna Canal.
   (a) Linking of Saraswati Nadi with Somb River by constructing artificial channel near Rampur Herian for about 1.5-2.0 km distance. Also construction of reservoirs in upstream of Somb River area to augment and divert the flow of water in Saraswati Nadi in dry periods.
   (b) Linking of Saraswati Nadi with Markanda River by constructing artificial channel for about 3-4 km distance near Saranwan village.
   (c) As a permanent solution, construction of a feeder canal to supply water from Western Yamuna Canal into Saraswati Nadi (between Radaur and Purangarh village in Kurukshetra district) for a distance of 6-7 km to make it perennial.
5. Usage of ground water available along the Saraswati palaeochannels for supplemental irrigation. Palaeochannels form storehouse for good quality ground water.

7.2.3 Revival of Vedic Saraswati: Vedic Saraswati River is believed to be the holiest in India by the local people of Haryana, Punjab, Rajasthan and Gujarat. Projects have been already started for the revival of the 'Lost Saraswati'. 'Saraswati Sarovar' has been constructed in Adi Badri region recently as part of the project. The water from the pretty stream is collected at the 'Saraswati Udhgam Sthal' known as the Saraswati kund. In the region, a small stream exists which is known as Saraswati Nadi. It is now represented by a drain called Sarsuti. The lower parts of this stream are also dissected and cannot be traced downstream. Numerous temples and Sarovars are constructed along the course of the Vedic Saraswati. The Saraswati Sarovar at Mustafabad village is filled by the present Saraswati nala. The Kapal mochan Sarovar near Bilaspur and the Jyotisar Talab near Kurukshetra were all once fed by the Saraswati River. The dimensions of these water bodies also indicate the mighty of the river Saraswati in the past. The religious, sentimental and emotional attachment of the people of the Saraswati basin is the main cause behind reviving the Saraswati River. The objective of the project includes tracing of the entire course of the river as well as construction of channels wherever required to make the Saraswati water flow through the recent course of the river. The old courses of the river will also be utilized for the purposes of inter-linking of rivers.

7.2.4 Public Utility of Saraswati Palaeochannels: Finally, the delineated course of Saraswati palaeochannels can be utilized for the benefit of the region and the country in the following three sectors:

1. Ground Water Resources:
   (a) Groundwater Exploration
   (b) Groundwater Recharge
2. Tourism Sector:
   (a) Renovation of Temples / Tirtha Sites

(b) Reconstruction of Ritual Sites along the Saraswati Channels to perform Pind Dan, Asthi Visharjan, Mundan etc.

3. Vedic Cultural Heritage:
   (a) Restoration of Historical sites
   (b) Excavation of New Archaeological Sites

REFERENCES

Bakliwal, P.C. and Grover, A.K. (1988) Signature and migration of Saraswati River in Thar Desert western India, Records Geol. Survey of India, V.116, Parts 3-8, pp.77-86.

Bakliwal, P.C. and Sharma, S.B. (1980) On the migration of river Yamuna. Jour. Geol. Soc. of India, V.21, pp.461-463.

Bhadra, B.K. and Sharma, J.R. (2013) Efficacy of EO Satellite Data to Unearth sub-surface Drainages: Potential of Groundwater Source in Arid Region of NW India. NNRMS Spl. Bulletin No.38, pp.67-74.

Bhadra, B.K. and Sharma, J.R. (2012) Saraswati River – The source of Quenching Thirst of Thar Desert. In: Book `Remote Sensing Application for Dryland Natural Resources Management in India', Mahesh Gaur (Eds). Publisher - New India Publishing Agency, New Delhi, pp.53-72.

Bhadra, B.K. and Sharma, J.R. (2011) Satellite Images as Scientific Tool for Sarasvati Palaeochannel and its Archaeological Affinity in NW India. In: Proceedings of Int. Seminar `How Deep are the Roots of Indian Civilization' by Draupadi Trust, New Delhi, pp.30-49.

Bhadra, B.K. Gupta, A.K. and Sharma, J.R. (2009) Saraswati Nadi in Haryana and its linkage with the Vedic Saraswati River – Integrated study based on satellite images and ground based information. Jour. Geol. Society of India (Springer Co-Publ.), V.73, pp.273-288.

Bhadra, B.K. Gupta, A.K. and Sharma, J.R. (2006) Sub-surface water oozing at Kalayat village, Jind district, Haryana in December, 2005: Possible connection with Saraswati Palaeochannel. Jour. Geol. Society of India, V.68, No.6, pp.946-948.

Bhadra, B.K., Sharma, J.R. and Bharadwaj Trilok (2005) Delineation of Sutlej Palaeo Channel using IRS LISS-III and Radarsat SAR data in parts of Punjab: Its possible linkage with "Lost River Saraswati" in Northwest India. In: Abstract in Indian Geological Congress (IGC) National Conference at Delhi University during 2-4 Dec., 2005, pp.8-9.

Bharadwaj, O.P. (1999) The Vedic Sarasvati. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No..42, pp.15-24.

Chakrabarti, D.K. and Saini, Sukhdev (2009) The problem of the Saraswati River and notes on the Archaeological geography of Haryana and Indian Punjab. Publ. Aryan Books International, New Delhi, 302p.

Chauhan, D.S. (1999) Mythological observations and scientific evaluation of the Lost Saraswati River. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No.42, pp.35-45.

Dwivedi, I. D., Kesarvani, A., Manjul, S. and Bhosle, R. (2006) Archaeological investigation in and around Adi Badri in Yamuna Nagar district of haryana. Jour. of History and Historical Archaeology, Delhi, No.6, 2005-06, pp.54-63.

Gaur, A.S., Sundaresh, Gudigar, P., Tripati, Sila, Vora, K.H. and Bandodker, S.N. (2000) Recent Underwater Explorations at Dwarka and Surroundings of Okha Mandal. Man and Environment XXV (I), pp.67-74.

Gaur, A.S., Sundaresh, Vora, K.H. (2005) Archaeology of bet Dwarka Island: An excavation report. National Institute of Oceanography, http://drs.nio.org/drs/handle/2264/1005

Ghose, B., Kar, A. and Hussain, Z. (1979) The lost courses of the Saraswati river in the great Indian desert – New evidence from Landsat Imagery. The Geographical Jour., London, V.45, Part 3, pp.446-451.

Ghose, B., Kar, A. and Hussain, Z. (1980) Comparative role of Aravalli and Himalayan river systems in the fluvial sedimentation of Rajasthan desert. Man and Environment, V.4, pp.8-12.

Gupta, S.P. (1996) Indus - Saraswati Civilization: Origins, problems and Issues. Pratibha Prakashan, Delhi.

Gupta, A.K., Bhadra, B.K. and Sharma, J.R. (2008) Saraswati Drainage system of Haryana - Satellite based study. In: Kalyanraman, S. (Ed.) Vedic River Saraswati and Hindu Civilization. Publ. Aryan Book International, New Delhi, pp.46-64.

Gupta, A.K., Sharma, J.R. and Sreenivasan, G. (2011) Using satellite imagery to reveal the course of an extinct river below the Thar Desert in the Indo-Pak region. Int. Jour. of Remote Sensing, v.32(18), pp.5197-5216.

Gupta, A.K., Sreenivasan, G. and Sharma, J.R. (2001) An attempt towards establishing inter relationship between Palaeo drainage courses and the archaeological sites found in the Sarasvati River Basin, Western Rajasthan. NNRMS Bulletin, No. 26, pp.14-23.

Gupta. A.K., Sharma, J.R. Sreenivasan, G. and Srivastava, K.S. (2004) New findings on the course of River Sarasvati. Jour. Ind. Soc. Remote Sensing, v.32, No.1, pp.1-24.

Kalyanraman, S. (1999) Saraswati River, Goddess and Civilization. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, v.42, pp.25-34.

Kar A (1995) Geomorphology of arid western India. Memoirs Geological Society of India, No. 32, pp.168-190.

Kar, A. and Ghose, B. (1984) The Drishadvati River System of India: An assessment and new Findings. The Geographical Journal, V.150, No.2, pp. 221-229.

Kochhar, R. (2000) The Vedic People: Their History and Geography. Orient Longman, Hyderabad, 259p.

Krishnan, M.S. (1952). Geological history of Rajasthan and its relation to present day conditions. Proc. Symp. Raj. Des. Bull., Nat. Inst. Sci. India. No.1.

Krishnaswamy, V.S., Jalote, S.P. and Shome, S.K. (1970) Recent crustal movements in northwest Himalaya and the Gangetic foredeep and related pattern of seismicity. Proc. 4th Symp. Earthquake Engineering, Roorkee University, Roorkee, pp.419-439.

Lal, B.B. (2002) The Saraswati flows on: The continuity of Indian culture. Publ. Aryan Books International, New Delhi.

Lal, B.B. (2009) How deep are the roots of Indian Civilization? Publ. Aryan Books International, New Delhi, 150p.

Malik, J.N., Merh, S.S. and Sridhar, V. (1999) Palaeodelta complex of vedic saraswati and other ancient rivers of northwestern India. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No.42, pp.35-45.

Mishra, V.N (1984) Climate, a factor in the rise and fall of the Indus civilization – evidence from rajasthan and beyond. In: Lal, B.B. and Gupta, S.P. (Eds) Frintiers of the Indus Civilisation, Books & Books, New Delhi, pp.461-489.

Misra, V.N. (1995) Geoarchaeology of Thar Desert, North-West India. in: S. Wadia et al. (Eds.) Quaternary Environments and Geoarchaeology of India, Geological Society of India, pp.210-250.

Mughal, M.R. (1982) Recent archaeological research in the Cholistan desert, in Harappan Civilisation. A contemporary Perspective (Ed. Possehl Gregory, L.), pp.85-95.

Mughal, M.R. (1992) The consequences of river changes for the Harappan settlements in Cholistan. Eastern Anthropologist, Special Number on Indus Civilization, V.45(1 & 2), pp.105-116.

Nair, A.S., Navada, S.V. and Rao, S.M. (1999) Isotope study to investigate the origin and the age of ground water along the palaeo channels in Jaisalmer and Ganganagar districts of Rajasthan. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No.42, pp.315-321.

Nigam Rajiv (2012) Sea Level fluctuations during last 15000 years and their impact on Human settlements. In: Book `Historicity of Vedic and Ramayan Eras: Scientific Evidence from the Depths of Oceans to the Heights of Skies', Eds. Saroj Bala and Kulbhusan Mishra, Publ. Institute of Scientific Research on Vedas (I-SERVE), New Delhi, pp.193-210

Oldham, C.F. (1893) The Saraswati and the lost river of the Indian desert. Jour. Royal Asiatic Soc. London, v.34, pp.49-76.

Pilgrim, G.E. (1919) Suggestions concerning the history of the drainage of northern India, A rising out of the study of the Siwalik boulder conglomerate. Jour. and Proc. Roy. Asiatic Soc. of Bengal, N.S., v. XV, pp.81-99.

Possehl, G.L. (2000) Indus Age – The Beginnings. IBH & Oxford Publication Co., Delhi.

Puri, V.M.K. (2001) Orogin and course of Vedic Saraswati River in Himalaya - Its secular desiccation episodes as deciphered from palaeo-glaciation and geomorphological signatures. Geol. Surv. Ind. Spl. Publ. No.53, pp.175-191.

Puri, V.M.K. and Verma, B.C. (1998) Glaciological and geological source of Vedic Saraswati in the Himalayas. Itihas Darpan, IV (2), pp.7-36.

Purohit R. (2006) Mythical river fllowed off Pehowa: New light on Saraswati. Tribune, Chandigarh, December 13, 2006.

Raghav, K.S. (1999) Evolution of drainage basins in parts of northern and western Rajasthan Thar Desert, India. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No.42, pp.175-185.

Raghav, K.S. and Grover, A.K. (1991) major sub-recent changes in the upper reaches of Kantli river course and related environmental implications, Rajasthan. Proc. Quaternary Landscape of Indian subcontinent. M.S. University of Baroda, pp.147-152.

Rajal, B.S., Virdi, N.S. and Hasija, N.L. (1986) Recent crustal uplift in the Doon valley. Proc. Int. Symp. Neotectonics in South Asia, Survey of India, Dehradun, pp.146-159.

Rajani, M.B. and Rajawat, A.S. (2011) Potential of satellite based sensors for studying distribution of archaeological sites along palaeo channels: Harappan sites a case study. Jour. Archaeological Science, V.38, Issue 9, pp.2010–2016.

Rajaram, N.S. (1994) Saraswati River in Science, History and Myth. Quat. Jour. Mythic Society, Bangalore. V.85, pp.75-107.

Rajawat, A.S. and Narain, A. (1996) Reconstruction of palaeodrainage network of Northwest India – A review of remote sensing based studies. SAC Scientific note No. SAC/RSA/RSAG/MWRD/SN/01/96.

Rajesh, Kochhar (1997) The Vedic People: Their history and Geography. Orient Longman, Hyderabad. 259p.

Ramasamy, S.M., Bakliwal, P.C. and Verma, R.P. (1991) Remote Sensing and river migration in western India. Jour. Ind. Soc. of Remote Sensing, V.12, pp.2597-2609.

Rao, S.R. (1979, 1985) Lothal: A Harappan Port Town (1955 - 1962), Vols. I and II, Memoirs of the Archaeological Survey of India, no.78, New Delhi.

Rao, D.P. (1999) Role of remote sensing in understanding of palaeo drainage evolution. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No.42, pp.237-244.

Rao, S.M. and Kulkarni, K.M. (1997) Isotope hydrology studies on water resources in western Rajasthan. Current Science, V.72, No.1, pp.55-61.

Reddy, D.V., Nagabhusanam, P., Rao, M.R., Mitra, D.S. Tripathi, Sinha, S.K. and Bhadu, B. (2011) Radiocarbon evidence of palaeo-recharge (pre-Saraswati period) of potential deep aquifer in Thar Desert. Jour. Geol. Soc. India, v.77, pp.239-242.

Roy, B. and Merh, S.S. (1977) The Great Rann of Kutch: An intriguing Quaternary terrain. Rec. Res. Geol., Hindustan Publ., Delhi, v.9, pp.100-108.

Sahai, Baldev (1999) Unraveling the ‘Lost’ Vedic Sarasvati. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No.42, pp.121-142.

Saini, H.S., Tandon, S.K., Mujtaba, S.A.I., Pant, N.C. and Khorana, R.K. (2009) Reconstruction of buried channel-floodplain system of the northwestern Haryana plains and their relation to the `Vedic Saraswati’. Current Science, V.97, No.11, pp.1635-1643.

Sharma, J.R. and Bhadra, B.K. (2009) Satellite Imagery and Saraswati: Tracing the Lost River. Geospatial Today, April, 2009, pp.18-20.

Sharma, J.R. and Bhadra, B.K. (2012) Signatures of Palaeo Rivers Network in Northwest India Using Satellite Remote Sensing. In: Historicity of Vedic and Ramayan Eras: Scientific Evidence from the Depths of Oceans to the Heights of Skies’, Book Eds. - Saroj Bala and Kulbhusan Mishra, Publ. Institute of Scientific Research on Vedas (I-SERVE), New Delhi, pp.171-192.

Sharma, J.R., Gupta A.K. and Bhadra B.K. (2006) Course of Vedic River Saraswati as deciphered from latest Satellite data. `Puratatwa', Bulletin of Indian Archaeological Society, New Delhi, No.36, pp.187-195.

Singh, G., Joshi, R.D., Chopra, S.K. and Singh, A.B. (1974) Late Quaternary history of vegetation and climate of the Rajasthan Desert, India. Philos. Trans. Royal Soc. London, v.267B, pp.467-501.

Singhvi S K, and Kar, Amal (2004) The aeolian sedimentation record of the Thar Desert. Proc. Indian Acad. Sci. (Earth Planet. Sci.), v.113, No.3, pp.371-401.

Sinha, Rajiv, Yadav, G.S., Gupta Sanjeev, Singh, Ajit, Lahiri S.K. (2013) Geo-electric resistivity evidence for subsurface palaeochannel systems adjacent to Harappan sites in northwest India. Quaternary International, v.308-309, pp.66-75. http://dx.doi.org/ 10.1016/j.quaint.2012.08.002

Sood, R.K. and Sahai, B. (1983) Hydrographic changes in northwest India. Man and Environment, VII, pp.166-169

Sridhar, V., Merh, S. S. and Malik, J. N. (1999) Late Quaternary drainage disruption in northwest India: A geoarchaeological enigma. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No.42, pp.187-204.

Stein, A. (1942) A survey of ancient sites along the lost Saraswati river. The Geographical Journal., v.99, pp.173-182.

Thussu (1999) Role of tectonics in drainage migration in Punjab-Haryana plains in Recent times. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No.42, pp.175-185.

Valdiya, K.S. (1996) River Piracy – Saraswati that Disappeared. "Resonance" Jour. of Academy of Sciences, Bangalore, V.1, No.5, pp.19-28.

Valdiya, K.S. (2002) Saraswati – The River That Disappeared. University Press (India), Hyderabad, 116p.

Virdi, N.S. and Philip, G. (2006) Neotectonic activity and its control on drainage changes in the northwestern Frontal Himalaya between the Rivers Satluj and Yamuna. Himalayan Geology, v.27(2), pp.129-143.

Wilhelmy, H. (1999) The ancient river valley on the eastern border of the Indus plain and the Saraswati problem. In: Vedic Saraswati (Eds. B.P. Radhakrishna and S.S.Merh). Mem. Geol. Soc. India, No.42, pp.95-112.

Willhelmy, H. (1969) The ancient river valley on the eastern boarder of the Indus plain and the Sarasvati problem. Z. Geomorphologie N.F.Suppl., v.8, pp.76-93.

Yashpal, Sahai, B., Sood, R.K. and Agarwal, D.P. (1980) Remote Sensing of the `Lost' Saraswati River. Proc. Ind. Acad. Science (Earth and Planetary Sciences), v.89, pp.317-331.