

PALAEOCHANNELS OF NORTH WEST INDIA: REVIEW AND ASSESSMENT

**REPORT OF THE EXPERT COMMITTEE TO REVIEW
AVAILABLE INFORMATION ON PALAEOCHANNELS**

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Summary

Remnants of once active rivers or streams are described as palaeochannels. Some of the channels lie buried under the cover of younger sediments. They are parts of misfit rivers and streams representing channels abandoned by migrating rivers as they shift their courses and cut new ones. In the context of prevalent dryness over larger swathes of our country and the exponentially growing need of water for a variety of purpose, the palaeochannels hold good promise as rich repositories of ground water. For, they are proven as a dependable source of supply in many parts of the world.

In the dry western part of the Indian sub-continent encompassing Haryana, southern Punjab, Rajasthan and Gujarat, numerous palaeochannels have been identified and comprehensively investigated since early nineteenth century by geomorphologists, geologists, geophysists, geohydrologists, archaeologists and remote-sensing specialists using high-end techniques. Large number of exploratory wells dug along the palaeochannels in these states to establish extensive networks of surface and buried palaeochannels constituting potential water-bearing aquifers in multiple groups covering the entire plain of the drainage system. The quality of groundwater in these palaeochannels is generally good. The aggregate length of the palaeochannels of all - in parts of Haryana, Rajasthan and Gujarat - is of the order of more than 2200 km. Water is available in quite many of them. More importantly, almost all of them can be artificially recharged and replenished with water. The palaeochannels promising to hold substantial amount of water thus act as storage reservoirs augmenting groundwater resources.

The banks of one of the misfit rivers, the Ghaggar-Hakra-Saraswati-Drishadvati, is intimately, associated with multiplicity of palaeochannels dotted densely with ruins of settlements, including the largest ones such as Ganweriwala (>100 ha) in Cholistan (Pakistan) and Rakhigarhi (>150 ha) in Haryana and such medium to large cities as Kalibangan, Farmana, Karanpura, Baror, Banawali, Bhirrana, Farmana and Mitathal. These settlements belong to the Hakra, Pre/ Early Harappan, Harappan, Late Harappan, Painted Grey Ware and Rangmahal cultures. The middle course of the Ghaggar-Hakra palaeochannels (Saraswati) is thus related with archeological sites from the fourth millennium BCE to the historical period. However, there was perceptible dwindling both quantitatively and qualitatively in the settlement pattern during the second millennium BCE, which is attributed to the changing water regime. The river that supported these settlements finally disappeared in the late Holocene period.

Applying various geophysical methods of underground mapping, analyzing hundreds of well logs and pertinent data and interpreting satellite imageries, recent workers have demonstrated existence of under-surface sand bodies of palaeochannel systems (adjacent to the Harappan sites). These aquifer bodies represent the past courses of large rivers originating in the Himalaya – one flowing in the period 20 to 15 ka and the other 6 to 3 ka in northern Haryana. The Ghaggar of this region occupies the former course of the Satluj River and the hydraulically related Markanda and Sarsuti rivulets etc. were connected to the palaeo-Yamuna River. Recent studies have identified sediments deposited in the Ghaggar-Hakra palaeochannel that were sourced from the Yamuna and Satluj catchments. The strontium ratios and neodymium ratios of the constituents of the Ghaggar sediments in the northern Haryana and in the Sirsa-Kalibangan reach in the west unequivocally demonstrate that the sediments of the buried channels were derived from the Great (Higher) Himalaya as well as from the Lesser Himalaya.

In the Hakra reach, where among hundreds of settlements, the largest city of the Harappan civilization, Ganweriwala was located, the buried palaeochannel yielded potable water dated 12,900 years BP to 4700 BP. Likewise the palaeochannels in the Jaisalmer area have been supplying potable water.,The water in the depth range of 30 to 50 m being 1800 to 5000 years old and in the 60 to 250 m deep aquifers 6000 to 22000 years old.

In the lowermost reach, the Ghaggar-Hakra-Nara formed a delta characterized by a network of distributaries. Some of the channels of which have yield heavy minerals of Himalayan origin.

The facts presented in the pages of this report lead to the conclusion that in the northern Haryana, the Ghaggar-Patialwali rivulets provided pathways to the western branch of the Himalayan born river (palaeo Satluj) and through the former courses of the Markanda and hydraulically connected Sarsuti rivulets flowed the eastern branch of the Himalayan river (palaeo Yamuna). The two branches combined 25 km south of Patiala, then flowed through the extraordinarily wide channel of the Ghaggar-Hakra-Nara and emptied itself into the Gulf of what is today know as the Arabian Sea.

On the banks of this Ghaggar at Sirsa stands an ancient fort named **Sarsuti**, the name recalling the rivulet **Sarsuti** that joins the Ghaggar at Pehowa in Kurukshetra district. Presumably, the fort represents a tribute to the importance of the rivulet Sarsuti, a corruption of the name, Saraswati. The name Saraswati is ingrained in the perception of the people and the Government revenue records show the river Saraswati extending from Adibadri in the Siwalik foothills to Pehowa and beyond.

A few recommendations for implementation have been made. These relate to launching of Missions on Establishment of Databank on Palaeochannel, Aquifer Delineation and Development, Palaeochannel Recharge, Heritage Development, Framing of Law and Regulation for withdrawal of water from palaeochannel aquifers and Formation of a dedicated cell on Palaeochannels in CGWB.

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Preface

Remnant of once an active river or stream, a palaeochannel is now bereft of flowing water. It may be presently filled up with loose unconsolidated sediments or be buried under the pile or sheet of the later deposited sediments. Palaeochannels are indeed parts of misfit rivers and streams representing channels abandoned by migrating rivers as they shifted their courses and carve new water courses.

The most common type of palaeochannels contain fining-upward, often laterally accreting sediments. There are also palaeochannels containing only gravels and very coarse grained sediments.

In the context of prevalent dryness over larger swathes of our country and the exponentially growing need of water for a variety of purpose, the palaeochannels hold great promise as rich repositories of groundwater. For, they have been proven as a dependable source of water supply in many parts of our world, including in Agra district along the Yamuna River (Liaqat A.K. Rao, S. Rehan Ali, Zia Ur Rahman, Ruby Siddqui, Harit Priyadarshi, M. Sadique, Zahoor Ul Islam), in the Ganga basin between Haridwar and Roorkee (R.K. Samadder, R.P. Gupta, Sudhir Kumar), in the coastal belt in South India (S. Suganthi, L. Elango and S.K. Subramanian) and in the Chennai area (T.N. Narasimhan). They have proven values of being reservoirs of stored water that seep down by recharge — natural or artificial.

In one more respect the palaeochannels have been found to be of tremendous importance. They help reconstruct the saga of the once large rivers in historical and

geological past and the peopling of land in relation to changes in the river regimes or their channels (B.B. Lal; K.S. Valdiya; Victor N. Karmanov, Alexey V. Chernov, Nataliya Engenievna, Zaretskaya and Aleksandr Vasil'evich Volokitin).

Among the many individuals or groups of individuals (B. Ghose, A. Kar, Z. Husain, A. K. Gupta, J. R. Sharma, G. Sreenivasan, K. S. Srivastava, J. P. Shukla, K. S. Kshetrimayum, V. N. Bajpai, H.S. Saini, S.K. Tandon, S.A.T. Mujtaba, N.C. Pant, R.K. Khorana, R. Sinha, G.S. Yadav, S. Gupta, A. Singh, S.K. Lahiri, W. van Dijk, A. Densmore, A. Singh, P. Mason, S. Joshi, N. Nayak, M. Kumar and S. Shekhar) and among the organizations the Central Ground Water Board has identified a large number of palaeochannels in Haryana and Rajasthan. The CGWB carried out comprehensive investigation particularly in context of the ground water potential and the scope for artificial recharge.

How important the palaeochannels can be would be obvious from an example of three palaeochannels identified in the Ganga basin between Haridwar and Roorkee. Encompassing a very limited area of approximately 396 km², the three palaeochannels alone hold 4.65 billion cubic metres of freshwater (R.K. Samadder, R.P. Gupta, Sudhir Kumar). Combined with interpretation of satellite imagery if bore hole data are analysed, the areal extent, the thickness, the volume, the boundaries of sand bodies, and the interconnection with adjacent aquifer bodies can be precisely worked out. In other words, the geometry of the water-bearing bodies can be reconstructed for practical purposes. In the Ganga palaeochannel the hydraulic conductivity is appreciable — 20 to 70 metres per day, implying that the underground water moves with ease and therefore

the rate of recharge of the palaeochannel sand body is appreciably higher than those of the adjoining floodplain aquifers (R.K. Samadder, R.P. Gupta, Sudhir Kumar).

It would therefore be rewarding to undertake measures to recharge the multitude of palaeochannels of the Sarsuti–Ghaggar–Hakra domain in Haryana and adjoining Rajasthan. These efforts would also sustain the continued flow of underground currents that flow slowly but surely (K. S. Valdiya).

Keeping in view the vision outlined above, the Ministry of Water Resources constituted an expert committee (vide Order No. T-40015/1/2016-GW) (Appendix A and B) to critically review the available information on palaeochannels and to give recommendations on various issues related to water resource development vis-à-vis the palaeochannels. The main objectives of the committee are to review available information on palaeochannels in India with particular reference to northwestern part of the country, their archaeological linkages, geological origin and ground-water potentiality.

The Committee comprises of :

Prof. K.S. Valdiya, FNA, FASc, FNASc, FTWAS, Honorary Professor of Geodynamics, Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru
(Chairman)

Dr. R.S. Bisht, Former Joint Director-General, Archaeological Survey of India

Prof. S.K. Tandon, FNA, FASc, FNASc, FTWAS, J.C. Bose Chair Professor, Indian Institute of Science Education and Research, Bhopal

Prof. Rajiv Sinha, FNASc, Head of the Department, Department of Geoscience, Indian Institute of Technology, Kanpur

Dr B.K. Bhadra, Scientist/Engineer, SF, RRSC-W, Indian Space Research Organization, Jodhpur

Dr Amal Kar, Formerly Principal Scientist & Head of Natural Resources and Environment, Central Arid Zone Research Institute, Jodhpur

Dr V.N. Prabhakar, Visiting Assistant Professor, Indian Institute of Technology, Gandhinagar, and

Shree Rana Chatterjee, Scientist D, Central Ground Water Board (Member Secretary)

Apart from the above-mentioned members, several experts were invited to the deliberations of the meetings of the Committee and they helped in the finalization of the Committee's report. These experts include —

Shree K.B. Biswas, Chairman, Central Ground Water Board

Dr Dipankar Saha, Member (SAM), Central Ground Water Board

Dr S.K. Jain, Regional Director, CGWB, Northwest Region, Chandigarh

Required to submit the draft report within six months of the constitution of the Expert Committee on March 1, 2016, we realized the limited time we had to obtain and analyze relevant information from a staggering mass of data on palaeochannels dispersed in diverse reports — some published but mostly unpublished — prepared by scientists of disparate organizations, research institutions and academia. It was therefore decided to confine our attention just to the plains of the rivers Yamuna, Ghaggar–Hakra, Satluj and some others in northwestern and western and western India. Luckily, we have had the benefits of comprehensive reports submitted by the

Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation and Regional Remote Sensing Centre (ISRO) at Jodhpur.

In addition to all members and invitees meeting together thrice (on April 13, 2016; July 7, 2016 and October 4, 2016) at New Delhi, there was a good deal of exchanges of information, observations and writings amongst members.

It has been my great pleasure to work with very experienced erudite and perceptive members of the Committee.

We all are grateful to the Chairman and scientists of the Central Ground Water Board for warm and comfortable hospitality and for many unstinted help.



K.S. Valdiya

CHAPTER 1

Definition and Studies on Palaeochannels in India

Definition of Palaeochannels

A channel that is no longer part of an active river system and has ceased to be a conduit of water is commonly referred to as a palaeochannel (Goudie, 2012). Despite remaining cut off from the active river flow, except perhaps during episodes of flood inundation, these features remain part of the flow regime of the active river. However, depending upon the age of the palaeochannel in large alluvial landscapes, some ancient palaeochannels may be the products of different flow regimes of the past. They may thus provide evidence for river transformation, following significant changes in flow regimes, implying river adjustments to development outside their catchment.

Palaeochannels are commonly occurring landforms in alluvial landscapes, and have an economic significance because of their use in the exploration for freshwater resources, artificial recharge and storage of ground water; additionally, they are of importance in the location and assessment of mineral deposits such as uraniferous ores, gold, silver and other placer deposits hosted in them. The scale on which these features form is highly variable, from small meander cut-offs to entire channels/channel belts extending over tens to hundreds of kilometres. Almost inevitably, when they are preserved as large-scale elements in fluvial/alluvial landscapes, concerns arise regarding continuity, connectivity and the variations in palaeochannel patterns and dimensions. Therefore, the study and mapping of palaeochannels has to be pursued using inter-disciplinary approaches that draw upon landscape analysis and remote sensing, sedimentology, geohydrology, tectonics and geophysical exploration.

Abandoned channel is a closely related term which also implies “a former stream channel through which water no longer flows”. Such abandoned channels as opposed to some ancient buried palaeochannel deposits constitute a landscape element, thus allowing their relationship and association with other landscape elements to be analysed and evaluated.

Buried channels, abandoned channels and palaeochannels are preserved as morphological sedimentary entities in the alluvial landscapes; they may subsequently be buried, and long-term preservation of these features occurs in areas of net high sediment accumulation and accompanying subsidence. The short-term preservation of palaeochannels may take place in areas of no-net-depositional floodplains. However, reoccupation of these palaeochannels results in the reworking and erosion of channel

deposits, thereby reducing their potential for preservation over the long term. Table 1.1 lists the different terminologies related to palaeochannels as discussed above.

Table 1.1: Terminologies related to palaeochannels

Serial Number	Term	Definition	Remarks	Sources
1)	Avulsion	Diversion of flow out of an established into a new permanent channel on the floodplain or fan surface	Feature of aggrading floodplains; wide range in recurrence interval	Slingerland and Smith (2004)
2)	Abandoned Channel	A former stream channel in which water does not flow any longer	Channel form, filled or partially filled, preserved in the riverscape as a landform element	
3)	Buried Channel	A former stream channel buried by younger geological materials, mostly sediments corresponding to younger sediment depositional events, and rarely by lava flows in regions of active volcanism	Following burial, the buried channel form is disconnected with the active processes in the landscape; in some cases buried channel forms may be exhumed	
4)	Palaeochannel	A channel that is no longer part of an active river system; generally remains scaled to the flow of the channel	Could be the products of past flow regimes and if so indicative of river metamorphosis; vary in scale from small wavelength meander cut offs to channel belts extending over tens of kilometres	

A Palaeochannel is thus an abandoned, old segment of a stream that may or may not carry water, depending on its proximity and linkage to an active stream system, and also depending on the characteristics of its valley form that allows it to perform as a

conduit of flowing water. It is therefore, recognised generally by (1) a wide valley with or without a narrow stream that may not get sufficient upstream discharge to maintain its course and to fill up a significant part of the valley cross section, (2) a valley with some pools of water (as lakes) that often dry up due to poor upstream flow, and/or evaporates, or (3) in some extreme cases, a stream segment that is completely buried under later deposits of sand and silt, as is sometimes found in a desert and its margin, but which can be identified from the soil texture, soil moisture, vegetation status, sediment characteristics and aquifer condition along the buried course. The occurrence of palaeochannels in a region provides enough hints of an active stream system through the area sometime in the past.

Review of Palaeochannel Studies in India

In India palaeochannels have been widely studied, particularly in the context of tracing geological history of the ancient rivers and their hydrogeological significance. Way back in 1874, C.F. Oldham identified a major palaeochannel along the dry bed of the Gagghar river (Anon, 1874, Oldham, 1893). C.F. Oldham (1893) and R.D. Oldham (1886) also described a number of other similar palaeochannels in the Punjab plain. Since then lots of studies on palaeochannels have been carried out in the North West India and other parts of India using various techniques like aerial photography, remote sensing, geophysical studies, isotope studies and hydrogeological studies. Some of the eminent early works on the palaeochannels of northwest India are of Ghose et. al. (1979, 1980), Yaspal et. al. (1980), Kar and Ghose (1984) etc. In the Gangetic plain of eastern India, the surface impressions on the satellite images, combined with field investigations and subsurface data have been used to infer the palaeohydrologic conditions in parts of the world's largest tract of Quaternary sedimentation in North Bihar plains (Sinha, 1996). The palaeochannel traces seen on the satellite images as well as in the field bear testimony to the migration trends and palaeohydrogeologic conditions of the region. The study drew important inferences about the channel pattern changes, channel belt migration trends, palaeoflow conditions and depositional history of the Quaternary sediments in the north Bihar plains. Nair et. al. (1999) carried out isotope study to investigate the origin and age of ground water along palaeochannels in Jaisalmer and Ganganagar districts of Rajasthan. From the advent of Twenty First Century, extensive studies have been carried out by Prof. K.S. Valdiya (2002, 2013, and 2016) on the palaeochannels of vedic river Saraswati. According to K.S. Valdiya (2013), the geological, geophysical, geomorphological, remote sensing evidence leads to the postulation that Saraswati was a large glacier fed river, greatly influenced by neotectonic activities as borne out by existence of several tectonic lineaments including faults and seismic zones. Other path breaking works are of Gupta et. al. (2004), Bhadra et. al. (2009) etc. Saini et. al. (2009) mapped the buried channel-floodplains systems of a part of north-western Haryana and reconstructed the geological history of the past

fluvial activity based on sub-surface lithofacies data from well-logs and their dating by Optically Stimulated Luminescence (OSL) technique. The recognition of major palaeochannel belts in the study area provides definite proof of the presence of a strong fluvial regime sometimes in the past. The older palaeochannels date back to interglacial period (i.e. MIS 3) and the younger palaeochannels are interpreted to be of Last Glacial Maximum (LGM). Usefulness of remote sensing techniques for mapping of palaeochannels and delineation of ground water prospect zones for water resources development plan has been demonstrated in the Yamuna flood plain in Uttar Pradesh (Rao et. al. 2009). These studies indicate that palaeochannels have good prospects of being potential aquifers. Samadder et al. (2011) emphasized on palaeochannels and their potential for artificial groundwater recharge in the western Ganga plains. According to the study, three major palaeochannels occur in the Western Ganga plain, which are in unconfined condition and composed of coarse grained sandy material well interconnected with the adjacent alluvial aquifers. The hydraulic characteristics of the palaeochannel aquifers indicates that these aquifers hold good promise for the artificial recharge to ground water. Sinha et. al. (2013) used geophysical investigation and drill cores to confirm the presence of buried palaeochannels in the Ghaggar plains and to establish its upstream connectivity. The coastal parts of Arani and Koratalai river basin, Tamil Nadu mostly comprises alluvial plains with palaeochannels which were mapped using IRS LISS-III imagery based on the tonal difference. The study indicated that palaeochannels are expected to be zones with rich groundwater potential (Suganthi et. al. 2013). Palaeochannels are identified on IRS-1D, LISS-III images by their contrasting dark tone in a characteristic winding fashion in association with cropping pattern. In a recent study carried out by Dijk et. al. (2016) in the alluvial plains of the Ghaggar river between the Satluj and Yamuna rivers, a palaeochannel was identified in the region of the current Ghaggar river.

Various institutes like Central Arid Zone Research Institute (CAZRI), National Remote Sensing Centre (NRSC), Regional Remote Sensing Centre (RRSC-W)/ ISRO, Central Ground Water Board (CGWB), Oil and Natural Gas Commission (ONGC), State Ground Water Departments of Rajasthan, Bhabha Atomic Research Centre (BARC), Geological Survey of India (GSI) etc. have also carried out voluminous works on palaeochannels of river Saraswati.

CHAPTER 2

Delineation and Characterization of Palaeochannels in the Satluj, Ghaggar and Yamuna Plains

Pioneering Endeavours

Palaeochannels are numerous in the dry western part of the Indian subcontinent, especially in the alluvial plains of the sub-Himalayan Punjab between the Satluj River in the Punjab, the Yamuna River in the east, and the Sindhu River in the west and in the vast sandy Thar Desert south of the Punjab Plains, and in the Great Rann of Kachchh. The high density of palaeochannels in this region is because a large number of streams from the Himalayas, many of them snow-fed, tend to shift frequently on reaching the plains due to a variety of reasons. This is also the region that witnessed the birth and flourishing of a great civilization that survived on availability of water, both surface and subsurface. This is also a region richly endowed with numerous natural resources, some exposed on the surface for humans to gainfully use and manage, but many others hidden under variable thickness of sand. This makes the identification, mapping and characterization of palaeochannels still more relevant.

During the 19th century, when a few canals were constructed in the plains of the Punjab and in northern Rajasthan, early researchers were able to identify several wide and abandoned beds of major streams. C.F. Oldham first identified in 1874 a major palaeochannel along the dry bed of the Ghaggar River, roughly through Bhatner (now Hanumangarh), Suratgarh and Anupgarh in Rajasthan, and then traced it through the vicinity of Marot, Mojarh, Derawar Fort, Rajarwala, Kachelo, and then along the surviving course of the Raini River from near Kandahu to Phararo, and along the Nara-Hakra River further downstream to the Great Rann of Kachchh. This he identified as the Saraswati River (Anon., 1874; Oldham, 1893). C.F. Oldham (1893) and R.D. Oldham (Oldham, 1886) also described a number of other similar dry valleys (palaeochannels) in the Punjab Plains, most characterized by a wide shallow valley, flanked by short, degraded banks that were sometimes topped by low sand dunes and with dense green vegetation (Figure 2.1). Many such courses were identified as the abandoned courses of the Satluj River, also mentioned in old maps as the “Sotar”, the “Setledge”, and the “Ghara” or the “Garrah”. C.F. Oldham mentions in his 1874 paper, “the Satlej, instead of turning nearly due west from Rupar to join the Biyas, as at present, originally flowed in a much more southerly direction; and that the Sotra or Hakra is its ancient bed.....Between the Saraswati and the Garrah is a series of broad channels, most of them a mile or more in width, of which those to the east terminate in the valley of the latter river, while those towards the west, which are the most ancient, are continuous with the Sotra or Hakra. All diverge from the direction of the point at which the Satluj

leaves the hills” (Anon., 1874, p.4-5). The river was called in the Sanskrit literature as the “Shatadru” (i.e., a stream, whose courses are divided into hundreds of channels). According to Oldham (1893) it is the older courses of the Satluj, which used to meet the Ghaggar, were in the east, and the oldest identified was along a small stream called the “Wah or the Sirhind Nadi” whose upstream end was traced near Ropar, and which used to meet the Ghaggar between Sirsa and Bhatner. The course was converted into a canal by Firoz Shah Tughlaq in the 14th Century. C.F. Oldham (1893, p.55) suggested “that the Jumna may at some very remote period have taken a westerly instead of an easterly course and joined the Hakra; observed by Mr. R.D. Oldham, of the Indian Geological Survey, this old river-bed lies between the fan or talus of the Jumna, and the Satluj”. He also suggested the likelihood of the Saraswati once flowing south into the Chautang (Figure 2.1).

After the above discoveries, many of the abandoned stream courses and other palaeochannels have been mapped in details by Survey of India, which can be appreciated from the old editions of their topographical sheets.

Field recognition of palaeochannels from observation of the abandoned valleys became gradually difficult when canal construction started along the dry valleys. The progressive conversion of many palaeochannels into canals has been described in the literature since 18th century. For example, Rennell’s (1788) describes how Feroze Shah Tughlaq took keen interest in agricultural development and, after reaching Debalpur in 1355, “made a canal 100 miles in length, from Suttuliz to the Jidger”. He then cut a channel from the Yamuna, divided it into seven branches, and brought one to Hansi, and then to the modern-day Hisar, the city he founded. That canal remained largely disused after the reign of Feroz Shah’s, mainly due to squabbles and wars. C.F. Oldham (Anon., 1874; Oldham, 1893) found the canal to be along the dry valley of the Chautang River, a Himalayan river that he identified with the Drishadvati River of the *Rig Veda* and the *Mahabharata*, the Drishadvadi been a major tributary of the Saraswati River. Canal construction received a major boost during the British Period and during the post-Independence era, when not only the palaeochannels were converted into canals and quite many new branch canals were also dug through the alluvial plains. These activities changed much of the natural landscape in the region for ever, and made it extremely difficult to identify palaeochannels from observation of ground features.

The setback has been partly offset by the availability of satellite remote sensing products from the late-1970s, especially as the satellite sensors in different wavelength bands are capable of capturing the signatures of high soil moisture content, variations in soil texture (coarse, fine, etc.), and evaporites (surface layers of calcrete, gypsum, etc.), and the relative density and health of vegetation along the shallow palaeochannels as some linear, or winding features. The capabilities of the sensors to ‘see’ features in a

much wider area than by the conventional aerial photographs, and the amenability of the images to digital processing (whereby one can convert the signatures of different land features in a specific wavelength band into some numbers, for assessing their relative dominance, etc.), with precise grid coordinates, were also helpful. Remote sensing, therefore, became a standard research tool for identification and characterization of palaeochannels, and it led to the mapping of several hitherto unknown palaeochannels, especially in the Thar Desert (Figure 2.1).

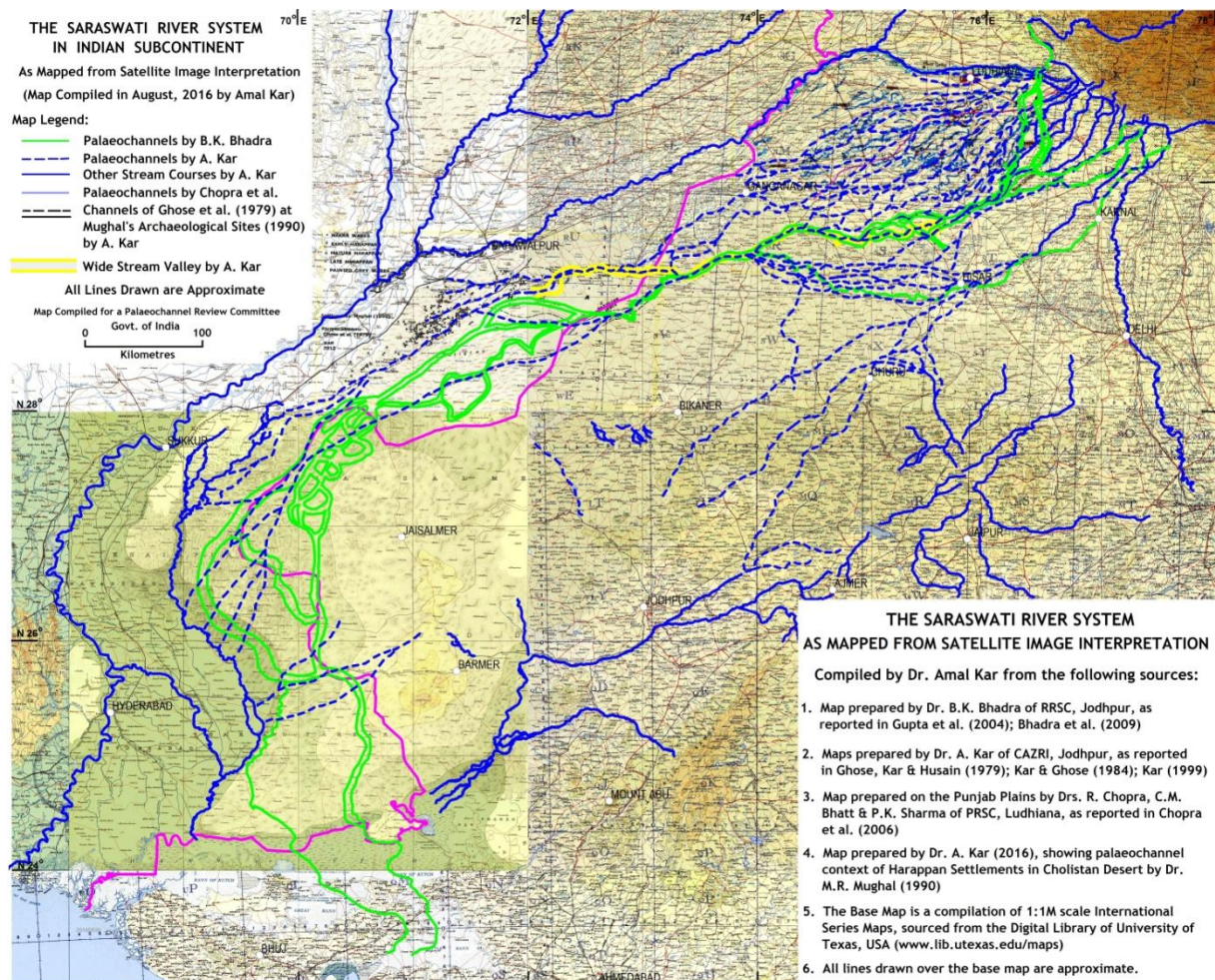


Figure 2.1. Palaeochannels recognised in the Ghaggar-Hakra-Nara, at the both basins, West of Aravalli Range (after A. Kar)

In a study of tremendous impact Yaspal et. al. (1980) used satellite Landsat imagery pertaining the period 1972-1977 and identified several traces of buried channel that runs southwest-northeast in the Yamuna plains. Based on visual interpretation they proposed three palaeochannels on the Yamuna namely Y1, Y2 and Y3 (Figure 2.2) which represents the course of ancient river which flowed south-east of the river Markanda. They also suggested that palaeochannels Y1 joined the ancient bed of the River Ghaggar whereas palaeochannels Y2 flowed into the Chautang (Drishadvati) and

palaeochannel Y3 flowed in the present course of the Yamuna down to Delhi and finally joined the River Ganga through the Chambal at Allahabad.

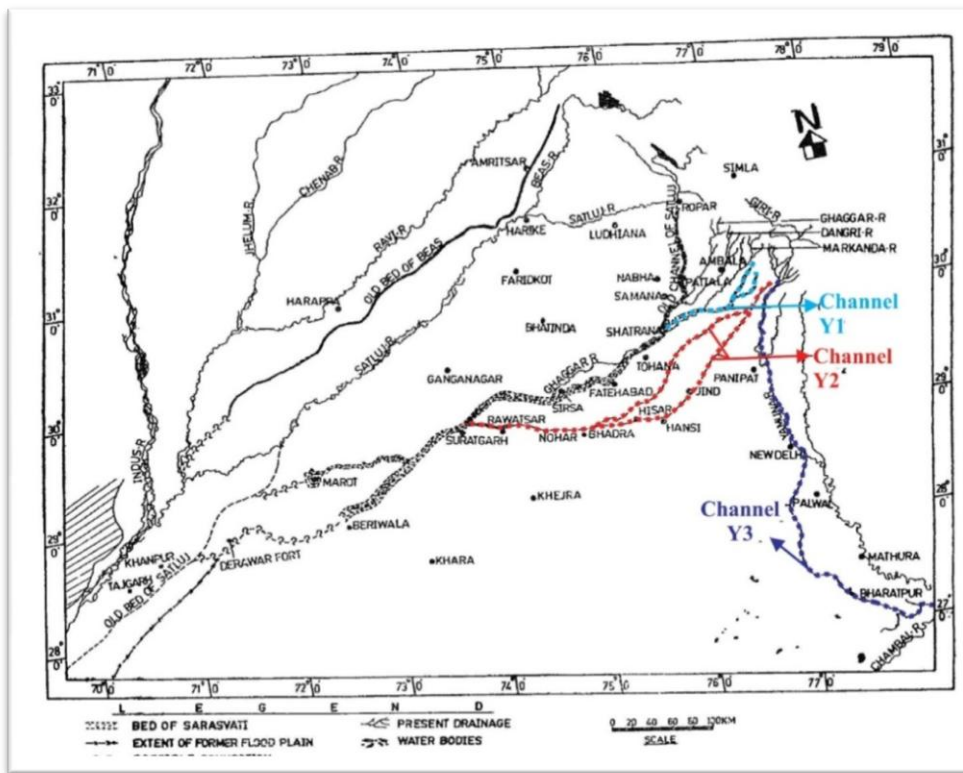


Figure 2.2 Present drainage system and palaeo-drainage system in the plains of Haryana, Punjab and Rajasthan (from Yashpal et al., 1980).

This landmark study inspired many workers to embark on investigation of the palaeochannels in India. In recent years the Jodhpur based Regional Remote Sensing Centre of Indian Space Research Organization has carried out comprehensive and extensive integration of the palaeochannel including that of the Ghaggar-Hakra-Nara studies in Haryana, Punjab and Rajasthan (Gupta et. al. 2004, 2008, 2011, Bhadra et. al., 2009, Sharma & Bhadra, 2012). They identified these palaeochannel system with the River Saraswati.

Indo-Gangetic Plain

The Indo-Gangetic Plain, is one of the largest alluvial plains in the Satluj, Ghaggar and Yamuna basins, encompassing most of northern and eastern India. It is broadly divided into two drainage basins by northwest-southeast running Aravalli-Delhi Ridge (Singh, 1996). The western part consists of the Punjab-Haryana plains fed mainly by the Sindh, Satluj, Beas, Ravi, Jhelam and Chenab, whereas the eastern part consists of the interfluvies of the Ganga-Brahmaputra drainage system. This foreland drainage

basin has been continuously receiving sediments from the Himalaya at least for the past 20 million years similar to the present day river systems (Derry and France-Lanord, 1996; Sinha et al., 2005). The Sindhu and the Saraswati were the two major river systems with their network of their tributaries of northwestern India during the ancient period. Some of those are known to have deviated from their initial courses or become non-existent today. Sridhar et al., (1999) have classified the rivers of Indo-Gangetic plains into four main groups (i) Indus (Sindhu) and its tributaries Vitasta (Jhelum) and Askini (Chenab), (ii) Shatadru (Satluj) and its two major tributaries Vipasa (Beas) and Parasuni or Iravati (Ravi), (iii) Saraswati and its three tributaries Markanda, Ghaggar and Patialewali in its upper reaches and a major tributary in its middle course, (iv) Drishadvati and Lavanavati. Sindhu shifted westwards up to 160 km, primarily as a consequence of the northward drifting Indian plate, which must have caused subsidence of the belt adjacent to the Kirthar-Sulaiman mountain front. The Sindhu also flowed through its many channels in different time periods as testified by its multiple palaeochannels.

The Indo-Gangetic Plain since long has been a focus of Quaternary studies pertaining to classification of river system and estimation of sediment flux (Sinha and Friend, 1994), identification of different geomorphic surfaces (Singh, 1996), mapping of spatial inhomogeneity (Sinha et al., 2005), reconstruction of sedimentary succession and identification of regional scale discontinuity (Gibling et al., 2005), understanding the controls of incision (Tandon et al., 2006), and testing of fluvial responses to climate forcing (Roy et al., 2012). Consequently, it has been suggested that this area was once drained by a large river system and was the center of cultural growth and sustainability of the Harappan Civilization of northwestern South Asia, 2500–1900 BC (Madella and Fuller 2006). It is suggested that the Harappan Civilization was evolved during an Early Phase 5200-4500 year ago and reached its urban peak (Mature Phase) approximately 4500 and 3900 years ago (Giosan et. al., 2012; Madella and Fuller 2006; Wright, 2010). It has been proposed that the Ghaggar River occupies the palaeochannel of a major river (palaeo-Saraswati) in the Himalaya and provided water resources to sustain the extensive Harappan sites located along its course (e.g., Oldham 1893; Kar and Ghosh, 1984; Valdiya, 2002; Saini et al., 2009). The abrupt abandonment of urban centers in this terrain at ~3500 BP has been explained as a consequence of river diversion (tectonic?) or its drying (climatic?), although alternative explanation for cultural decline have also been entertained in some previous studies. These hypotheses have remained untested because the sub-surface evidence of the postulated palaeochannel has never been determined. As a result, the very existence of this large river remains unresolved. The prevailing opinion is that the palaeo Saraswati-River was originally fed by the Yamuna and Satluj Rivers and that it dried due to a combination of tectonic activity and river capture (e.g. Valdiya, 2002; Sinha et al., 2009).

Mention may be made of a few comprehensive investigations that helped understanding the problem and prospects.

Upper Reaches of the Ghaggar Plain

1. Sinha et al. (2013) utilized resistivity surveys and drill cores to confirm the presence of the buried palaeochannel in the Ghaggar plains and to establish its upstream connectivity. Two transects for resistivity soundings mapped the sub-surface lithology of the region close to Kalibangan and Kunal across the large valley partially occupied by the Ghaggar river channel at present (Figure 2.3). The third transect, SRH, was located across the trace of a palaeochannel near Sirhd in Punjab close to the Himalayan front. This palaeochannel was originally identified by Yashpal et al. (1980) as a possible former course of the Satluj River. Although this area lies in the semi-humid region with an average annual rainfall of 690 mm per year, there is no major surface drainage in this region. The modern Satluj flows ~150 km west and the Yamuna flows ~150 km east of this transect. It has been suggested that the Satluj flowed through this region before moving west (Yashpal et al., 1980).

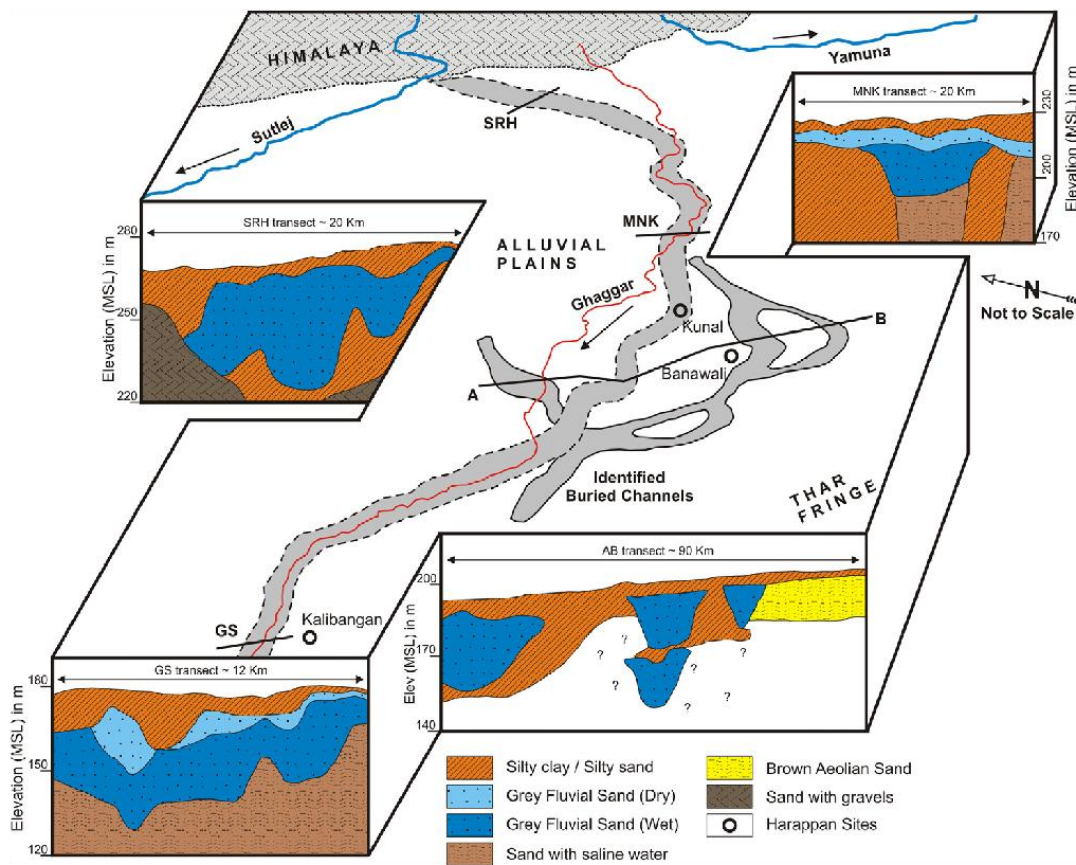


Figure 2.3. Sub-surface stratigraphy of the Ghaggar and palaeo-Satluj valley portrayal by Sinha et al., (2013)

2. In a comprehensive study carried out by Saini et al. , 2009 and Sinha et al. 2013, sub-surface stratigraphy of this region, resistivity sounding data along the GS and MNK transects indicate a large composite sand body (L3 and L4) in the subsurface with complex internal architecture buried beneath aeolian cover. While the lower sand body L4 is saturated with fresh groundwater, the upper one (L3) is finer-grained and dry with dispersed kankars resulting in high resistivity values. The cores obtained from several locations confirm the presence of a sand body and also indicate an overall fining-upward trend. The transects L3 and L4 together show a composite sand body (>12 km wide and 30 m thick) that is an order of magnitude larger than the modern Ghaggar river channel which is >500 m wide and >5 m deep. This composite sand body likely represents the localised amalgamation of multiple individual fluvial channel bodies. The amalgamated channel complex represents a river system that either formed in a more humid phase, or represents the palaeo-course of a large river that now flows elsewhere due to river diversion. In the GS and MNK (Figure 2.3) transects, there is a layer of silty sand (L2) overlying the buried sand body which is fairly continuous and has a distinct channel cross sectional geometry. With a maximum thickness of ~10 m in the GS transect, this sandy layer appears to have incised the lower sand body (L3), and therefore, likely represents a younger phase of fluvial activity. The muddy layers encased in this sand body may represent channel fill deposits, which are in turn covered by modern deposits of the Ghaggar River and aeolian deposits. Both edges of the palaeochannel complex are very well marked by sharp changes in the resistivity values, both laterally and vertically, suggesting transition to aeolian sands or floodplain deposits. This is confirmed by the presence of aeolian mounds on either side of the palaeochannel complex around Kalibangan.

The SRH transect was primarily designed to track the sub-surface existence of a palaeochannel complex in northern Punjab originally identified by Yashpal et al. (1980) as a possible tributary to the Ghaggar-Hakra palaeochannel. Resistivity data confirms a large sand body, 40-50 m thick, although there is no surface expression of this large valley. This sand body is covered with a hard and compact layer reflected by very high resistivity values. The sand body has a distinct channel-form geometry that is thickest in the centre of the transect and tapers on both sides. Unlike the GS and MNK transects, no layer with saline water was encountered along this transect in the upper 70 m of the strata represented by the resistivity data. A layer with very high resistivity value at the base is interpreted as a gravelly bed. This is attributed to the proximal position of this transect based on limited field observations.

Stratigraphic data from the GS and MNK transects in Figure 2.3 compare well with that of the AB transect recognized and illustrated by Saini et al. (2009) on the basis of groundwater borehole data. The sand body thickness of the buried channel complex in all of these transects ranges between 25 and 30 m. This body is underlain by aeolian

sand and covered with floodplain muds and aeolian silts. However, the buried channel separated by wide interfluvies mapped along the AB transect is ~25 km south of the valley margin of the main channel complex. They also point out toward the existence of subsurface multilateral channel systems on the basis of apparent high widths and presence of silty clay and mixed sand layer fluvial bodies and later suggested three phases of fluvial activity (F-1, F-2 and F-3) as given in Figure 2.4.

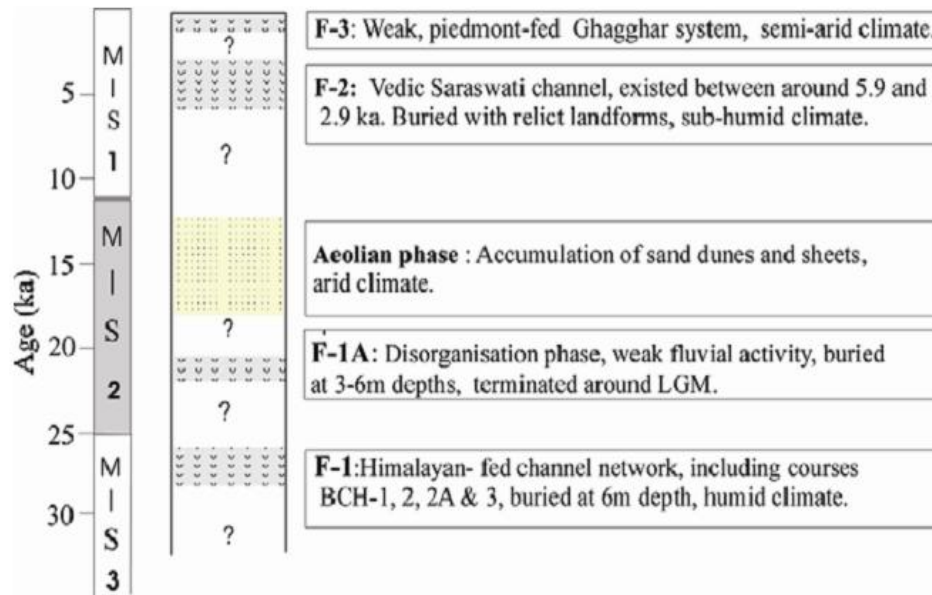


Figure 2.4. Summary diagram of the area showing three phases of fluvial activity (F-1 to F-3). F-1 and F-1A are buried, the F-2 is mappable as a relict landform on aerial photos and imagery and has subtle expression on the ground. The F-3 is represented by the present day Ghaggar River (From Saini et al., 2009).

In the absence of intensive chronological data, it is difficult to state if these buried channels co-existed or are time-separated. However, there are several examples in the Gangetic basin from where large-scale avulsions of large rivers and valley migration have been reported over time scales of 1000 to 10,000 years (Gibling et al., 2005; Tandon et al., 2006; Sinha et al., 2007; Sinha, 2009). It has been suggested that the valley prominence may change with time and space as a function of tectonics (Gupta, 1997) or climate and hydrological regime (Tandon et al., 2006). It is likely that the buried channels discovered so far are a part of a much large drainage network which has varied in time and space. The resistivity results represented the definitive stratigraphic evidence that a palaeochannel exists in the sub-surface alluvium both in the Ghaggar valley. The fact that the major urban sites of Kalibangan and Kunal lie adjacent to the newly discovered sub-surface fluvial channel body along the GS and MNK transects suggests that there may be a spatial relationship between the Ghaggar-Hakra palaeochannel and Harappan site distribution.

3. In Northern Haryana, Kshetrimayum and Bajpai (2011) recognized missing stream link between the River Markanda and River Vedic Saraswati in Haryana using VES with the aid of remote sensing technique (Figure 2.5). Based on resistivity values (23-148 Ωm) authors identified the presence of subsurface buried sand bodies (~100m thick) connecting two rivers (Markanda into the Saraswati) composed of fine, medium and coarse sand with gravel (Figure 2.5).

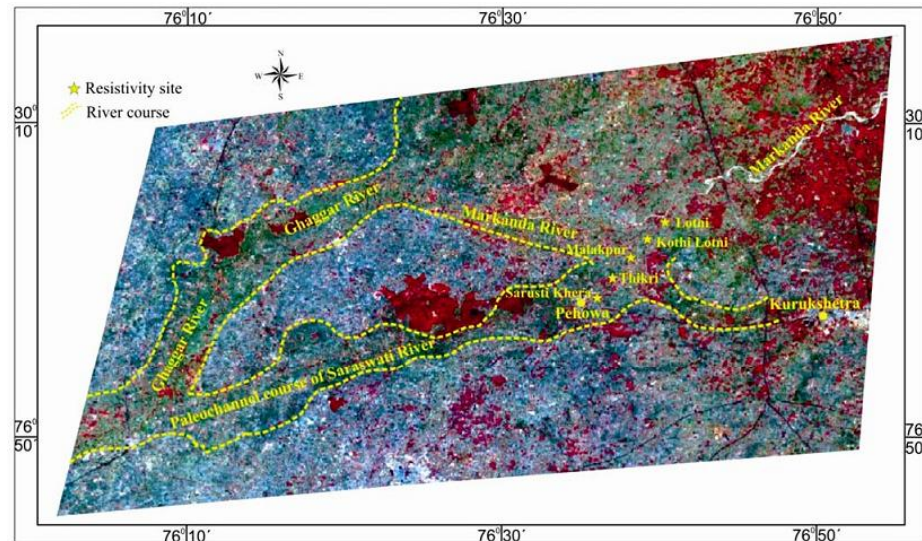


Figure. 2.5 False colour composite of IRS 1D LISS IV image of lower portion of the Markanda river and palaeochannel course of the Vedic Saraswati in the northern Haryana plains (from Kshetrimayum and Bajpai, 2011).

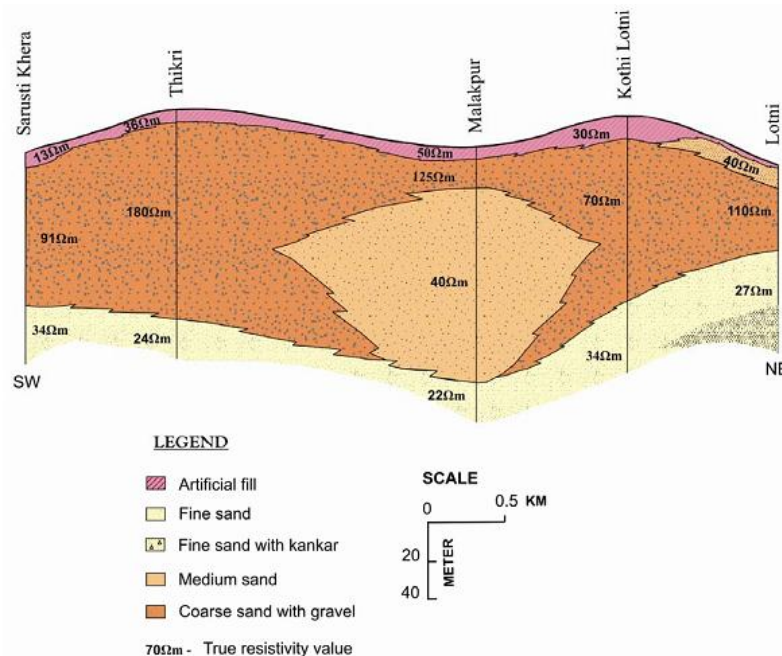


Figure 2.6. Resistivity log section between the Markanda River and Vedic Saraswati River (from Kshetrimayum and Bajpai, 2011).

4. In a recent study carried out by van Dijk et al. (2016) in the alluvial plains of the Ghaggar river between the Satluj and Yamuna rivers, a palaeochannel was identified on the location of the current Ghaggar River, and was interpreted as a former course of the Satluj, with the underfit Ghaggar having occupied the Satluj palaeochannel. It is also known as the Ghaggar-Hakra palaeochannel. The observations, and the fact that the modern Satluj and Yamuna rivers are confined to narrow incised valleys, provide evidence of a complex late Quaternary history of channel avulsion and incision.

To illustrate the variability in aquifer body thickness and depth, van Dijk et al. (2016) compiled two representative transects of aquifer thickness logs at medial and distal positions down fan. Analysis of lithology data made available from CGWB showed that the mean percentage of aquifer bodies across all logs is 39%, but values for individual logs range from 0% to 80% with major variations between adjacent wells. The percentage of aquifer bodies within each fan body does not noticeably vary laterally, although a general down fan decrease in aquifer percentage is observed in both fans (Figure 2.7a). In contrast, the interfan area and the fan marginal area at the boundary between the Satluj and Yamuna fans both show lower percentages of aquifer bodies (Figure 2.7b) compared to the fans themselves especially in the deeper parts of the section.

There is no clear relationship discernable between aquifer body thickness and depth for adjacent logs and no evidence that aquifer bodies are laterally connected or correlatable at the length scale of the log spacing (median ~7000 m). This result is perhaps not surprising, as this median log spacing is larger than the widths of the channel features identified on the Satluj and Yamuna fan surfaces. Along the medial transect, the percentage of aquifer bodies decreases slightly toward the eastern margins of both the Satluj and Yamuna fans (Figure 2.7a). Logs in the distal transect show fewer aquifer bodies compared to the medial transect (Figure 2.7b), in concert with the observed decrease in bulk aquifer body percentage with distance downstream from the apex on both the Satluj and Yamuna fans. Aquifer body thickness varies across both transects, but most aquifer bodies are less than 10 m thick.

It may be mentioned that several recent studies have identified sediment deposits in the Ghaggar-Hakra palaeochannel that were sourced from the Yamuna and Satluj catchments (Clift et al., 2012). The geophysical profiles have verified the existence of a large palaeochannel within the subsurface (Sinha et al., 2013).

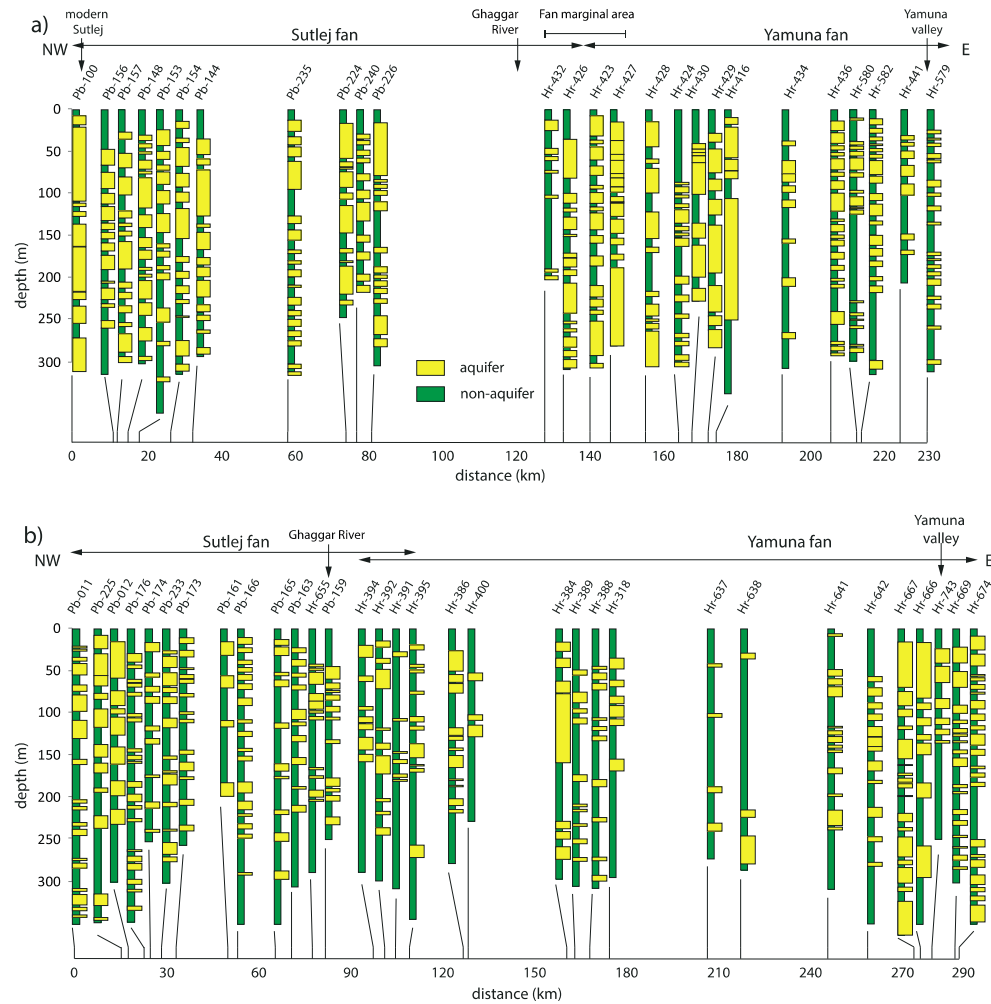


Figure 2.7. Aquifer body thickness transects across the study area. (a) Medial transect of aquifer thickness logs. Geomorphic setting relative to the Satluj and Yamuna fans and river channels is shown at the top of the panel, while distance from the northwestern end of the transect is shown below the logs. Note the overall decrease in the proportion of aquifer material toward the eastern margin of both the Satluj and Yamuna fans. There is no systematic change in the proportion of aquifer material with depth below the surface. (b) Distal transect of aquifer thickness logs. Compared to the medial transect, the distal transect shows a lower overall proportion of aquifer material. Both the Satluj and Yamuna fans are characterized by aquifer-rich and aquifer-poor zones. In both panels, the lack of correlation between adjacent wells in both transects, even where they are closely spaced, argues for limited lateral dimensions of channel bodies, as expected in a fan sediment routing system (after van Dijk et al., 2016).

5.. The Ghaggar basin in Haryana and Punjab has also been studied in detail by using IRS P6 AWiFS, LISS-III and LISS-IV satellite data (Gupta et. al. 2004, 2008, 2011, Bhadra et. al., 2006; Bhadra et al., 2009; Sharma and Bhadra, 2009; Bhadra and Sharma, 2011). Landsat ETM data were used for delineation of palaeochannels. These drainage features are highlighted on applying local stretching the full LISS-III scene. Using this process, the possible course of Saraswati and Drishadwati palaeochannels have been delineated (Figure 2.8). Satellite images of IRS P6 LISS-III data (23.5m resolution) of February, 2004 and Radarsat SAR data (50m resolution) of December, 2002 were specially processed to delineate palaeochannels (Figure 2.8). The delineated palaeochannel between Ropar and Patiala is named as Satluj palaeochannel which is an N-S trending palaeochannel extending 75 km in length with having width of 1 to 6 km. The Satluj palaeochannel is connects the present day Satluj River near Ropar to the Ghaggar River, south of Patiala. The delineated palaeochannels in Haryana and Punjab have been validated on the ground by using archaeological sites, hydrogeological and drilling data, rainfall data and stream discharge data.

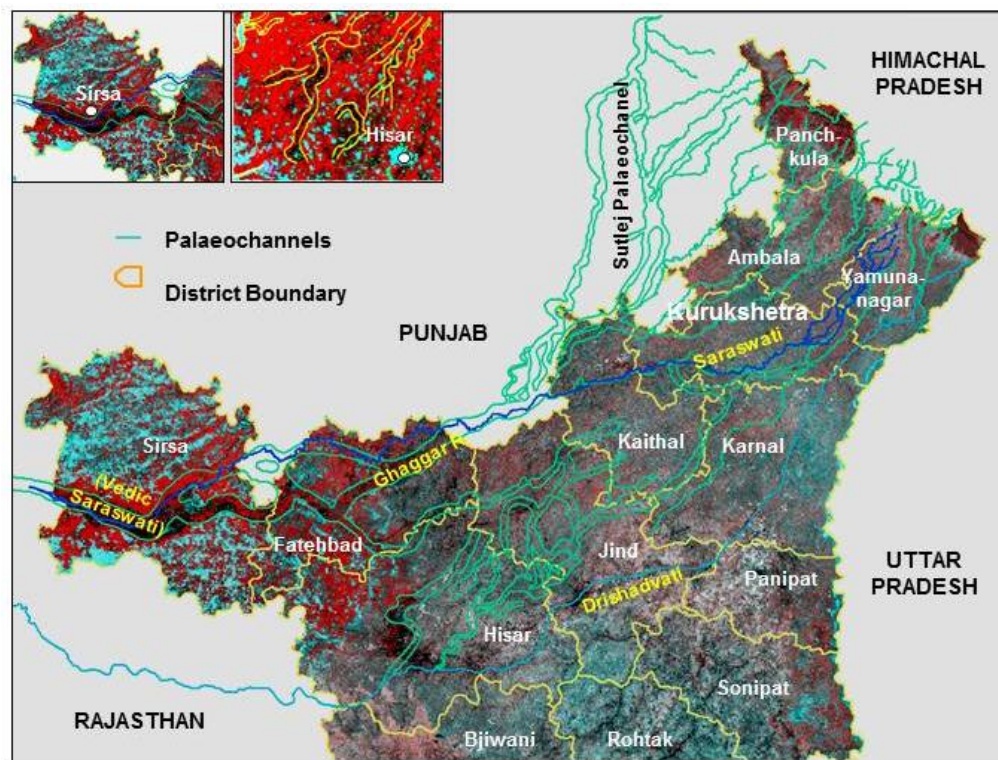


Figure 2.8. IRS P6 LISS-III image with delineated palaeochannels in northern Haryana and eastern Punjab (Bhadra et al. 2009)

Middle reaches of Ghaggar Plain

Central Ground Water Board has long been carrying out geophysical investigation and exploratory drilling at locations of some of the palaeo-channel in the Ghaggar basin. The locations of the VES and exploratory drilling are given as Figure 2.9.

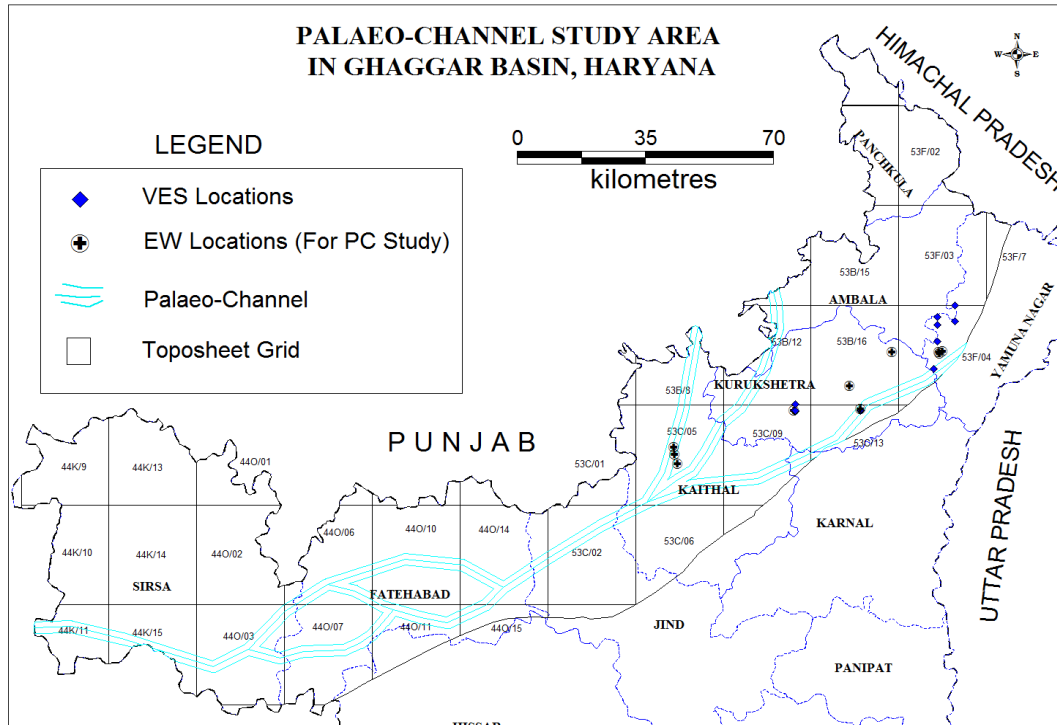


Figure 2.9. Locations of the VES and exploratory drilling along the palaeochannels

Under the aquifer mapping programme, at few locations, multiple wells (well field) have been constructed for the generation of aquifer specific data. The data from such locations have been critically analysed to infer the depth and width of the palaeo-channels. It may be mentioned that for the understanding of the fluvial deposition principles and processes and reconstruction of past deposition history, the basic premise is the - (i) presence of gravel and sand formations is construed as presence of the river channel, (ii) deposition of clay is construed as the presence of the flood plain, and (iii) occurrences of fine sand or medium sand are construed as presence of the river banks/terraces. Accordingly, analysis of the well field data has been carried out for different sites. A few of them are described below.

1.. Site close to the existing creek of the Sarswati river at Masana Jatta-Sahabpura well field in Yamunanagar district (Figure 2.10).



Figure 2.10. Location of well field sites and its spatial distribution along Palaeochannels in Yamunanagar district.

There is presence of the sands and gravels at various depth ranges in all the three locations with variable thickness (Figure 2.11 & Table 2.1). A cross-section shows correlation of the contemporary strata related to the infurred channel characteristics (Figure 2.12).

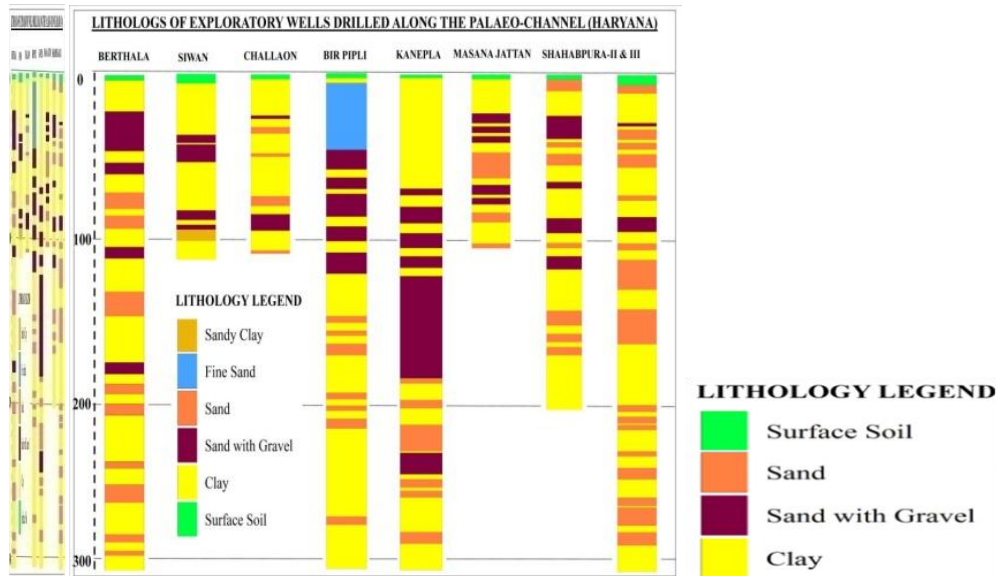


Figure 2.11. Lithological logs of exploratory wells drilled by CGWB in Yamunanagar district.

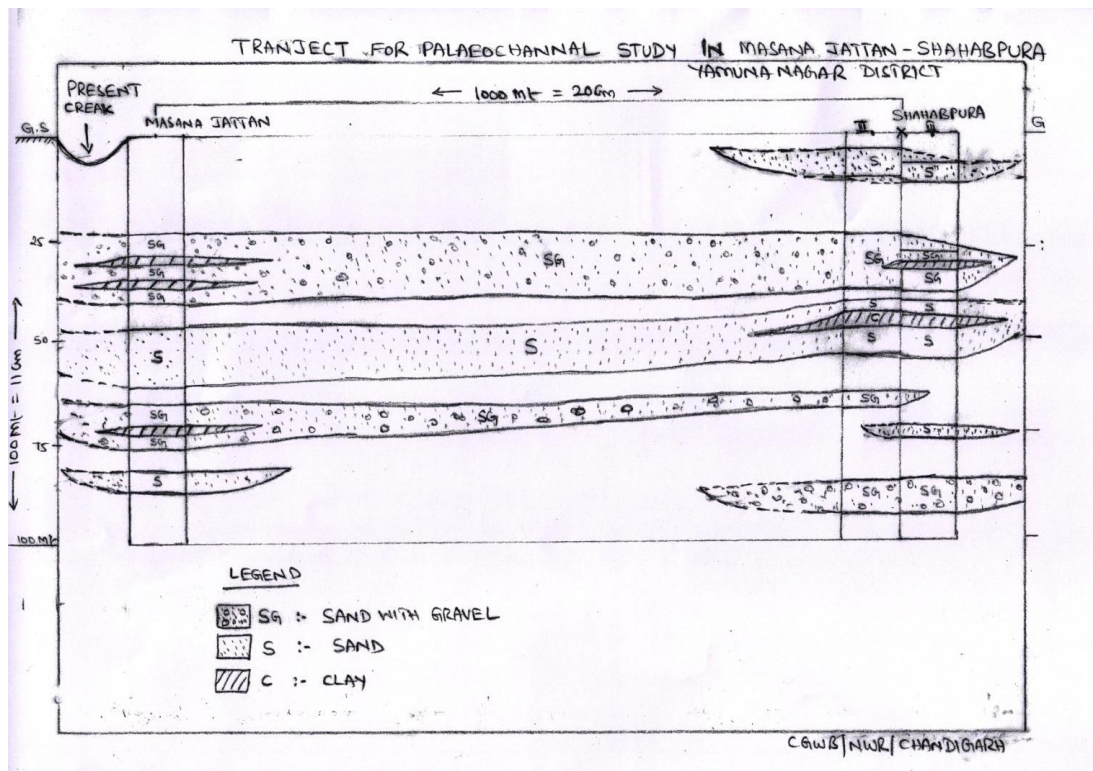


Figure 2.12: Lithological Cross-section of exploratory wells drilled adjacent to a palaeo-channel in Yamunanagar district.

Table: 2.1: The lithologs of wells drilled near the river creaks of the Saraswati palaeo-channel at Masana Jattan-Shahabpura site

Site-1 (Masana Jattan)	Depth of palaeo-channel (m)	Site-2 (Shahabpura-II)	Depth of palaeo-channel (m)	Site-3 (Shahabpura-III)	Depth of palaeo-channel (m)
Sand with Gravel	24-30 (6 m) 32-36 (4 m) 38-42 (4 m)	Sand with Gravel	25-39 (14 m)	Sand with Gravel	29-31 (2 m)
Sand	48-64 (16 m)	Sand	41-44 (3 m) 48-55 (7 m)	Sand	33-39 (6 m) 41-45 (4 m) 48-56 (8 m)
Sand with Gravel	68-74 (6 m) 76-80 (4 m)	Sand with Gravel	65-69 (4 m)	Sand with Gravel	73-76 (3 m Sand only)
Sand with Gravel	--	Sand with Gravel	87-96 (9 m)	Sand with Gravel	86-95 (9 m)

Based on the above cited information, it is inferred that a prominent but shallow palaeochannel occurs at the depth range of 24-38 m below the ground level and it has thickness of about 14 m at sites 1 and 2. It is followed by thin clay deposit and there is second palaeochannel at 48 to 64 m depth, the thickness being 16m. The third palaeochannel of about 6 m thickness is located at 68-74 m depth at site 1 and another at 65-69 m depth is 4 m thick. It is separated by thick clay deposit. The above sequence indicates that the river channel in the past had a tendency of shifting as indicated by the layered sequences of channel deposits (sand and gravels) and flood-plain deposits (clay). The shallowest palaeochannel became extinct in the historical past for it is now buried under the clay layer of around 24 m thickness.

It is inferred that there was a prominent river present in the immediate geological past which shifted for a brief period and again appeared over this area. Finally the topmost clay deposition indicates that the river has disappeared from this site at present leaving a number of water deficient creeks.

2. Analysis of the well field data at Bir Pipli - Kanepla - Berthala close to the existing creek of the Sarsuti river site brings out the lithlog of the exploratory well as represented in Figure 2.13.

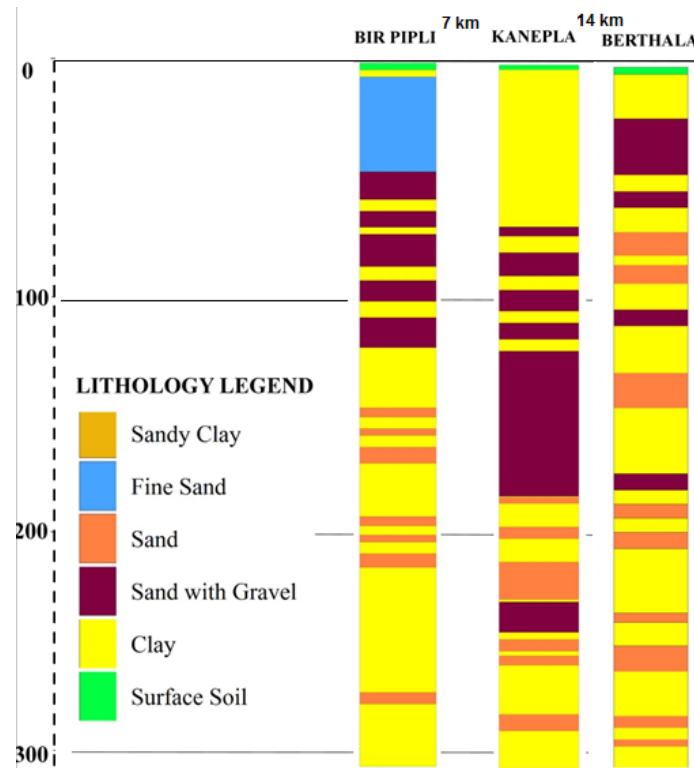


Figure 2.13. Lithological logs of exploratory wells drilled by CGWB in Kurukshetra district

Five layered bodies of sand and gravels below the thick top sand deposit indicates presence of past channel of a river that shifted a number of times. Birpipli site located on the youngest palaeochannel represents a prominent river existing for long years. The depth of channel is 53 m. The bottom part of channel is filled with 12 m thick sand and gravel.

The contemporary buried channel at the nearby Kanepla and Berthala sites are not evident due to presence of thick clay below the ground surface. However a deeper buried channel of a prominent river system existed in the past earlier than the Birpipli river system, as evident from the presence of significant channel deposits (sand and gravel) (Figure 2.13).

Site close to the existing creek of the Saraswati (Sarsuti) river at Challaon village in Kurukshetra district is shown in Figure 2.14.

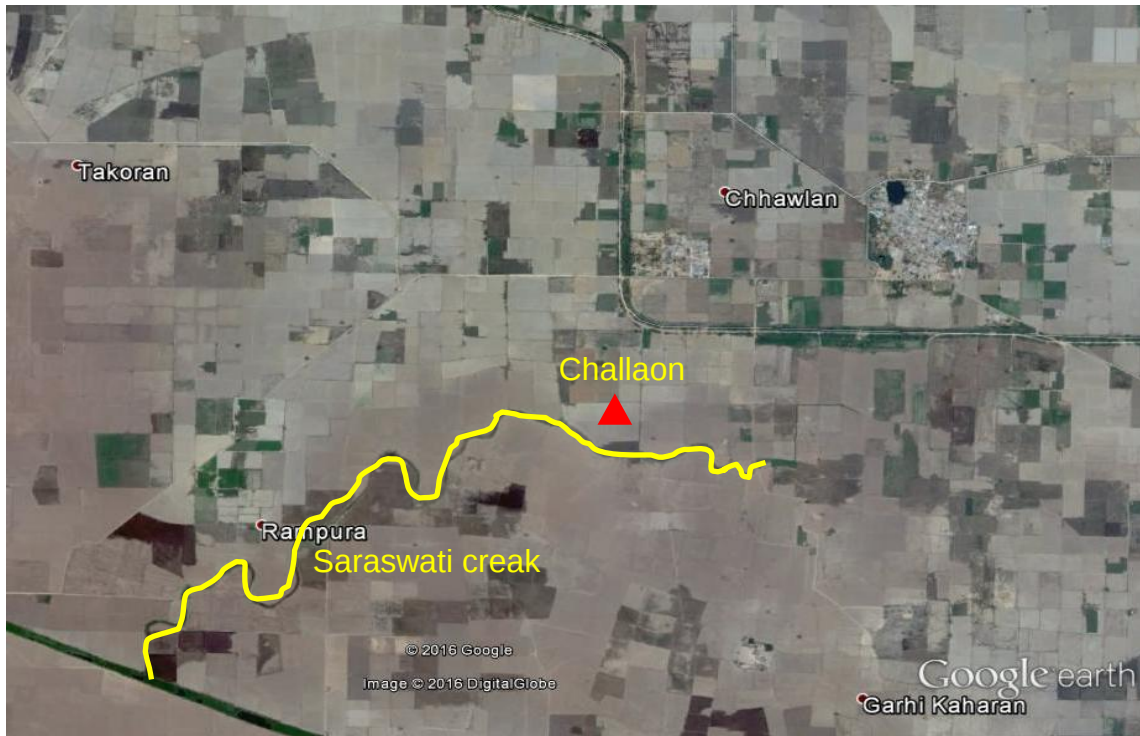


Figure 2.14. CGWB drilling site at Challaon near the Sarsuti, now known as Saraswati Creek

Geophysical investigations were carried out using VES in the area near the existing creek areas. It was followed by the Electrical and Natural Gamma logging done in the exploratory well drilled close to the creek by CGWB. The composite litholog of the site is shown as Figure 2.15.

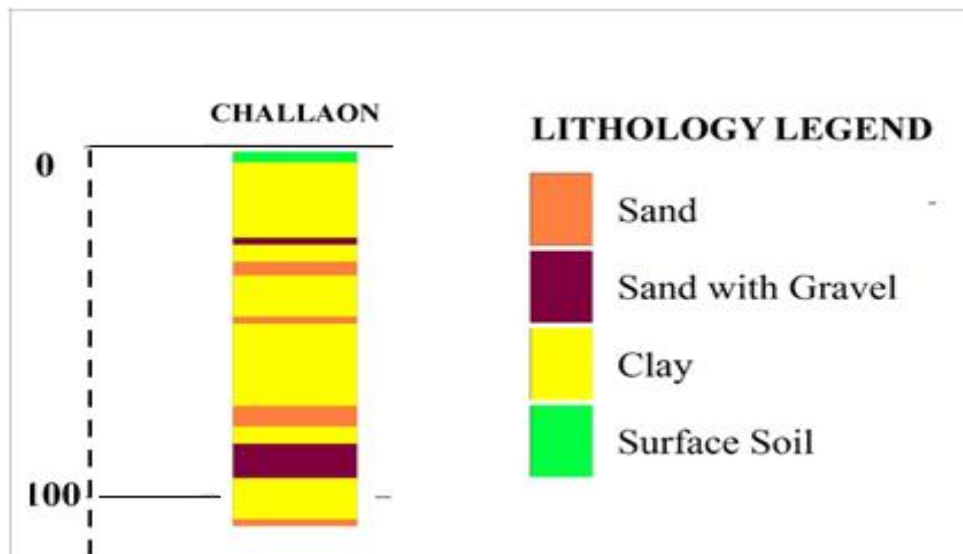


Figure 2.15. Composite litholog of the Challaon site

The geophysical surveys and the exploratory well data do not confirm presence of any prominent historic river system in this area.

An overall satellite-based map showing all relevant locations of the exploratory well sites and VES surveys is given as Figure 2.16. The lithologs of these wells are also arranged in sequence from west to east in order to understand the overall correlation of the subsurface and surface palaeochannel characteristics (Figure 2.17). The depth ranges by and large are definable but there are limitations to define the width of the palaeo-channels.



Figure 2.16. Spatial distribution of exploration wells drilled along the palaeo-channel.

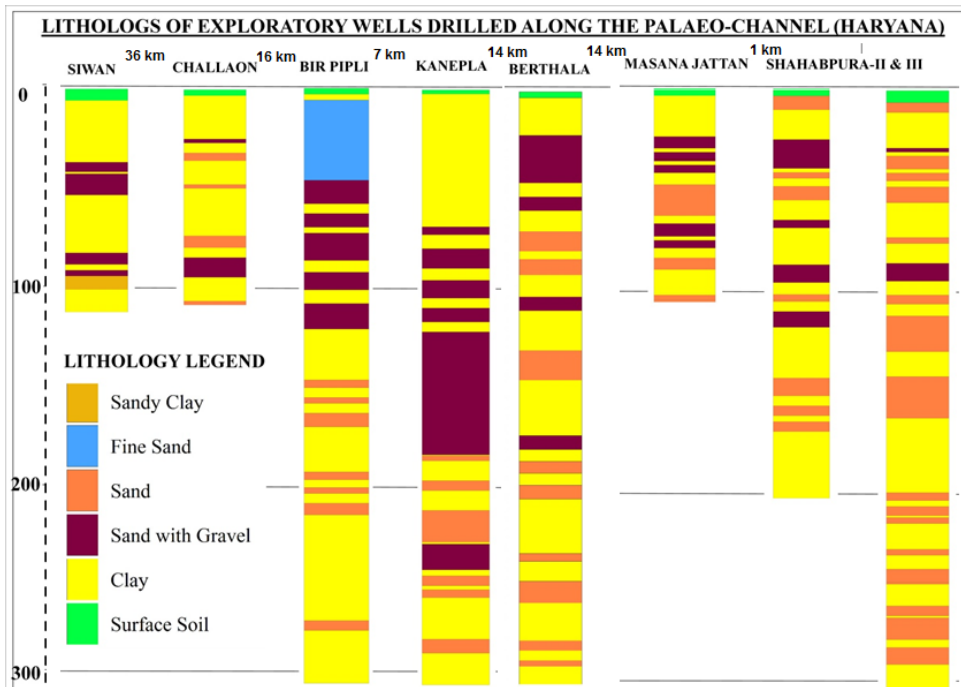


Figure 2.17. Lithologs of the Exploratory wells drilled by CGWB in the Ghaggar Basin, Haryana state

Desert Terrain

Identification of palaeochannels in a desert terrain with high and closely-spaced sand dunes is difficult indeed, especially because the remnants of old channels and dry valleys become buried under moving sand and sand dunes. Despite this, the subsurface configuration below the loose sand cover tries to follow faithfully the pre-sand topographical configuration of ridge and valley. Under such circumstance, the erstwhile major stream valleys become the sites of accumulation of surface or subsurface water during the rainy seasons, and become a good host for trees and shrubs. Under a natural situation, therefore, such valley-fill areas become the sites of dense growth of many deep-rooted tree and shrub species, although all such densely vegetated areas can not be construed as having palaeochannels.

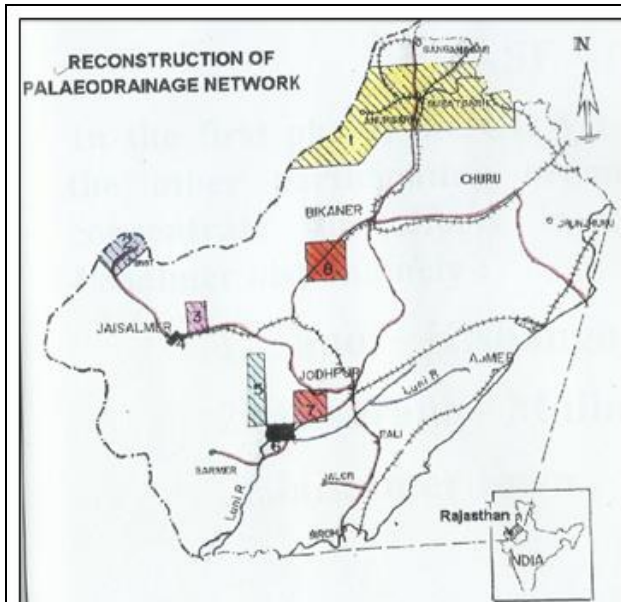
The linearly arranged patches of such evaporates as gypsum and calcretes in the interdune plains, and also beneath the tall flanking sand dunes, have been noticed in different parts of the desert. The formation of gypsum and calcrete layers in the soil suggests ponding of water and strong evaporation in a cyclic manner and over a long period of time, especially under an arid climate with improper leaching of minerals that leads to gradual accumulation of calcium, sodium, etc., as carbonates and sulphates in the surface layers. While such deposition in isolated small pockets could be the result of some local ponding in enclosed basins, the occurrence of such features in narrow strips for appreciable distance, and the presence of finer soils along the strips than in the

surroundings, as well as few other diagnostic features, like availability of potable, shallow subsurface water, suggest the likely presence of a major palaeochannel through that strip of land (see e.g., Ghose et al., 1979, Yashpal et al., 1980; Kar and Ghose, 1984; Kar, 1999; Gupta et al., 2004; Chopra et al., 2006; Bhadra et al., 2009).

(1) The central part of Thar Desert, especially in Hanumangarh, Churu, Bikaner and Nagaur districts, bear the signatures of above features, roughly in a NNE-to-SSW alignment. In the southern part of Hanumangarh district the signatures are found to blende with the signatures of the Ghaggar and Chautang valleys, suggesting the likelihood of a major palaeochannel system flowing into the desert proper (Ghose et al., 1979; Kar and Ghose, 1984). Chance observation of a few sediment sequences along some deep dug-wells, roughly between Nohar, Sardarshaahr and Dungargarh revealed a thick layer of greyish and micaceous fine sand and silt at a depth of ~20-25 m, the type of which one notices along the Ghaggar valley. Some recent studies in connection with uranium exploration in valley-calcretes in the area reported some enrichment along the palaeochannel in Churu district, which has been explained as the mineral getting washed down from the Himalayan sources and deposited in the area as a placer deposit (Rao et al., 2015).

(2) One of the first detailed stratigraphic analyses across the palaeochannels in the northern Rajasthan was by a Swedish research group, working at Rangmahal near Suratgarh (Rydh, 1958), who analysed sediment samples from 5-7 m deep profiles at 17 sites along an 8-km-wide stretch across the Ghaggar valley between Lakha Dhora and Karnisar. This helped them to understand the sedimentary environment of the river during the last pluvial phase, and the stronger aeolian environment before and after this phase. The Himalayan stream was identified from the grey, micaceous fine sand deposit in the profile.

(3) Three palaeochannels of the Kantlil River in parts of Jhunjhunu and Sikar districts were delineated using Landsat TM imagery and aerial photographs (Raghav and Grover, 1991). Tectonic lineaments observed in the area seem to have controlled shifting of the channels (Sharma, Mathur and Punia, 1999). Using satellite images, palaeochannels in different parts of the Thar Desert were mapped (Fig 2.18). This was followed by detailed geological, geophysical and drilling investigations were also done in eight target areas.



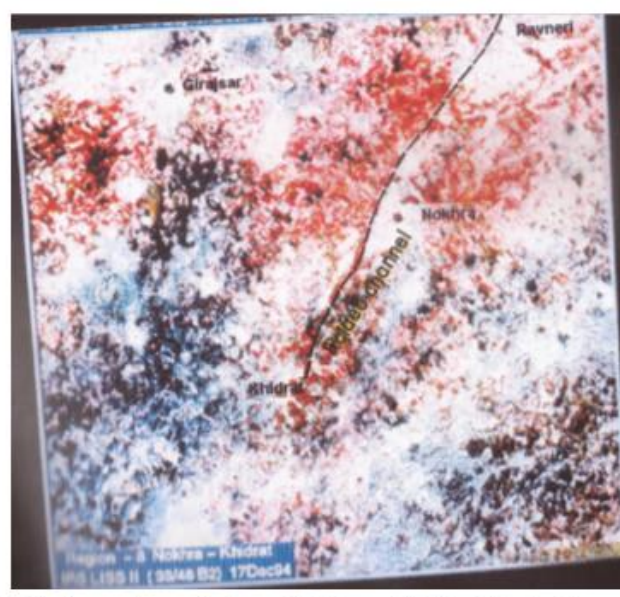
(b) Location map of Target areas in Rajasthan



(b) Palaeochannel near Kalyanpur, Rajasthan.



(c) Palaeochannel near Agolai-Korna, Rajasthan



(d) Palaeochannel along Nokhra-Khidrat, Rajasthan

Figure 2.18. Satellite images depicting palaeochannel segments of the Saraswati River along Kalyanpur, Agolai-Korna and Nokhra-Khidrat area, Rajasthan (CGWB 1999).

(4) With the advent of Remote Sensing technology and the availability of high resolution satellite images, it is possible to trace the drainage course in the form of buried palaeochannels. Recently the entire course of a large palaeochannel system recognized as the River Saraswati has been traced from satellite images (Bhadra et al., 2005, 2006, 2009), Bhadra and Sharma (2011), Bhadra and Sharma (2012, 2013),

Gupta et al. (2001, 2004, 2011), Sharma et al. (2006), Sharma and Bhadra (2009, 2012). With synoptic viewing capability in 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 different digital image processing techniques were applied on the satellite images. 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 or abandoned channels as well with dry lakes and Rann.

Using IRS P3 WiFS and IRS 1C LISS-III satellite data, Gupta et al. (2004, 2008, 2011) have mapped the course of a large river they recognized as the Saraswati, buried below the sands of Thar Desert. Through collateral such data as published old maps, archaeological sites, geomorphic anomalies, drilling data (litholog) of tube wells and age of ground water, they have validated the course of the Saraswati River. Litholog of 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 network of Saraswati River in Rajasthan and parts of northern Gujarat has been established across the Thar Desert (Figure 2.19).

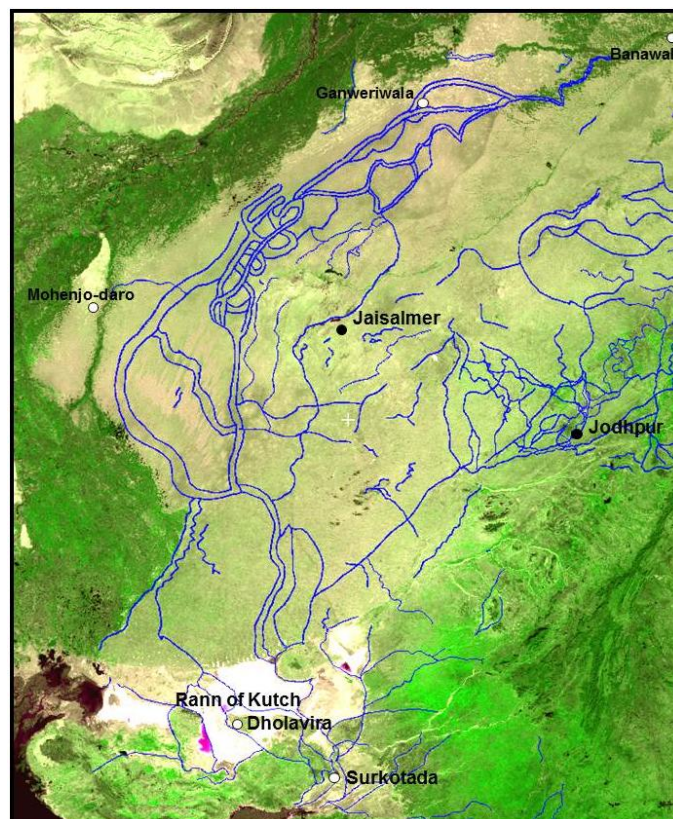


Figure 2.19: Palaeo-drainage map of the Thar Desert using IRS P3 WiFS satellite image (Gupta et al., 2004)

Rann of Kachchh

Investigations have revealed that more than one river were involved in building up the deltaic deposits in the Great Rann. This 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). The digital image processing of IRS-P6 AWiFS and Radarsat SAR images reveals a pattern of deltaic drainage pattern called the Bird's Foot type comprising complex intertwined channels (Figure 2.20). This structure was formed in the past by huge sediment discharge of what is believed to be the Saraswati River within marshy land of Great Rann of Kachchh. The delta structures are restricted by the E-W fault, represented by the Allah Band. Significantly, these palaeochannels can be traced upto the Gulf of Kachchh.

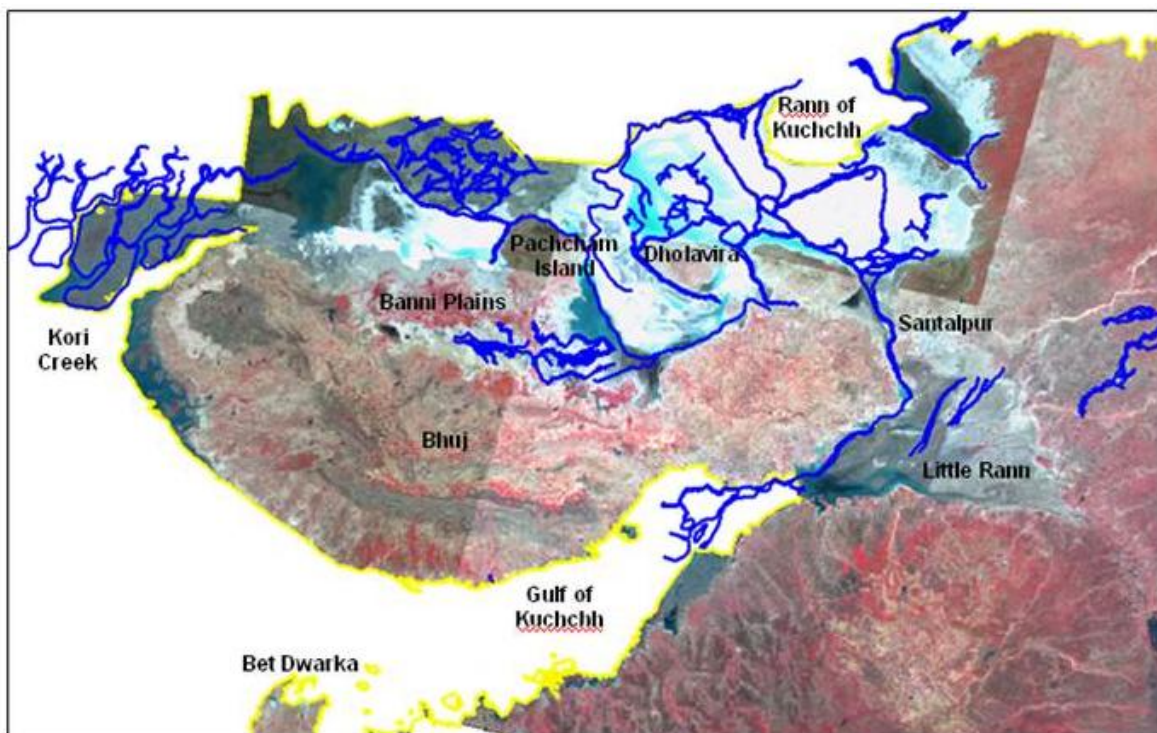


Figure 2.20. Satellite image showing Sarasvati palaeochannel network in Rann of Kachchh area, Gujarat (RRSC-W Report, 2014)

CHAPTER 3

Geological Evolution of Palaeochannels of the Satluj, Ghaggar and Yamuna Plains

The earliest record of analysis of subsurface sediment in this study area was reported by Raikes (1968) in the form of cross-section through Ghaggar river near Kalibangan. The cross-section was based on four boreholes and shows coarse greyish sand below 11 m deep deposit of silty clay and silt. Raikes (1968) interpreted the coarse sand to be similar to the present day Yamuna on the basis of mineralogical similarity with grey granite derived materials occurring in the Yamuna while the overlying finer silty sediment as floodplain deposits possibly of Ghaggar river. However, this was a brief description and was not followed up in detail by any publication later on. But recently in their study, Saini et al., (2009) mapped the buried channel-floodplain systems in the part of north-western Haryana plains on the basis of subsurface lithofacies data from well logs available from groundwater agencies. The authors used ~250 km cross section to show the presence of 10–30 m thick semi lensoidal grey micaceous sand surrounded by fine silty clay deposits 4–10m below the ground. They identified grey sand as channel deposits separated by (silty clay) floodplain sediments which in some parts show interlayering with aeolian sand. The dates of these channel sands are 26 ± 2 to 21 ± 1 ka that suggested that these buried channels were active around MIS-3 and went through a disorganization phase during the LGM as suggested by the overlying aeolian sand that are dated to be between 20 and 15 ka (Saini et al., 2009) and (Saini and Mujtaba 2010). Saini et al., (2009) also mapped a small patch of grey sand deposit was dated around 5.9 ± 0.3 and 2.9 ± 0.2 ka BP which was considered to be part of the 'lost' Saraswati river by previous workers (Yashpal et al., 1980; Sahai, 1991). The study by Saini et al. (2009) clearly suggests presence of a buried channel network in Haryana plains; however, they also indicated that detailed stratigraphic mapping at regional scale is needed to establish its upstream connectivity. More importantly, detailed stratigraphy of the buried channel is needed to understand the depositional history and fluvial responses to climatic changes in the NW Indo Gangetic plains.

Singh (2014, unpublished PhD thesis) used drill cores across the buried Ghaggar valley, aided by optically stimulated luminescence (OSL) chronology, to reconstruct the alluvial stratigraphy of this buried valley fill. A total of 11 drill cores (35–50m deep) were raised from the Ghaggar plains; five cores along a transect near Kalibangan in Rajasthan, and two cores each near Kunal in Haryana, and Moonak and Sirhind in Punjab, NW India. Based on the detailed analysis of five drill cores penetrating down to a depth of ~40–45 m, five major stratigraphic units are identified covering a time span of 70 ka of fluvial sedimentation with an aeolian base dating ~155 ka.

In a recent study carried out by van Dijk et al. (2016) in the alluvial plains of the Ghaggar river between the Satluj and Yamuna rivers, a palaeochannel was identified in the region of the of the current Ghaggar River, and was interpreted as a former course of the Satluj, with the underfitGhaggar having occupied the Satluj palaeochannel, also known as the Ghaggar-Hakra palaeochannel. Several recent studies have identified sediment deposits in the Ghaggar-Hakra palaeochannel that were sourced from the Yamuna and Satluj catchments (Clift et al., 2012), and geophysical profiles have verified the existence of a large palaeochannel within the subsurface (Sinha et al., 2013). These observations, and the fact that the modern Satluj and Yamuna Rivers are confined to narrow incised valleys, provide evidence of a complex late Quaternary history of channel avulsion and incision in the Indo-Gangetic plain (Gibling et al., 2005; Tandon et al., 2006; Sinha et al., 2005, 2007; Roy et al., 2012).

Sinha et al. (2009) addressed a key question whether the Yamuna River has followed its present course since antiquity or not. Based on stratigraphic and petrographic evidences, they postulated that >120 Ka ago, Yamuna was flowing westward and it avulsed eastward to its present position during the Late Quaternary (Figure 3.1).

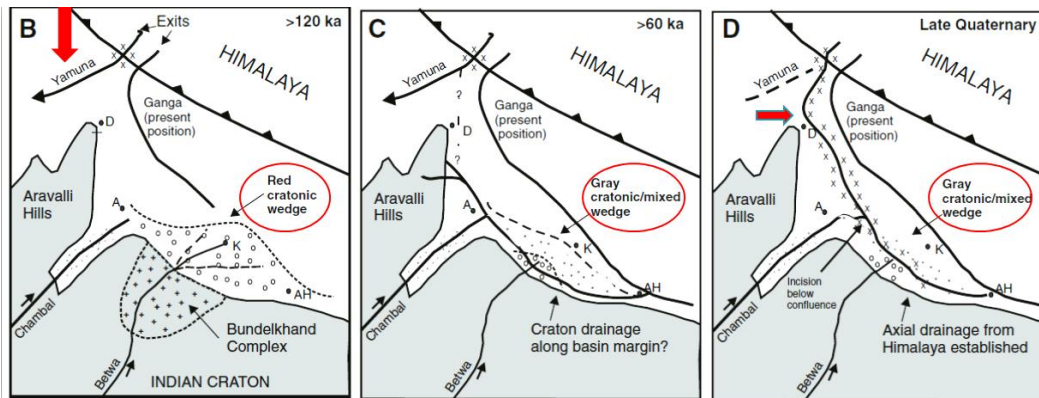


Figure 3.1. Possible evolution of drainage systems in southern Ganga Plains over the past 120 ka and beyond.

Furthermore, Clift et al. (2012), studied subsurface channel sand bodies (4.0 ka) and used zircon sand sized grains to obtained U-Pb dating for provenance analysis and compared them with the established character of modern river sands. The authors concluded that Yamuna was flowing to west, not east as its present position. However they did not clearly explain the reason of diversion of the Yamuna from the Sindhu as this occurred as early as 49 ka and no later than 10 ka, but it could be cumulative effect of an avulsion event driven by auto-cyclic processes as seen by the 120 km shift of the Kosi River in 2008.

Although the hypothesis of the eastward avulsion of the Yamuna River to its present course has been in the literature for quite some time, the exact cause and timing of avulsion has not been established. Similarly, although three palaeochannels of the Yamuna (Y1, Y2 and Y3) west of the Aravalli hills (e.g., Yash Pal et al., 1980; Sharma et al., 2004) have been identified from satellite images (Figure 1), no evidence about their subsurface existence has been provided so far.

CHAPTER 4

Archaeological Sites on and Related to Palaeochannels of the Satluj, Ghaggar-Hakra and Yamuna Plains

Introduction

The sprawling alluvial landscape, trapezoidal in shape, and lying between the Himalayan Rivers, Yamuna and Satluj, delimited by the Siwaliks in the north and the Aravalli outliers and the Thar Desert in the south is much discussed but sporadically investigated. It indeed poses a great enigma as there are no perennial rivers and yet it is configured with a multitude of channels and palaeochannels; it was home to phenomenally rich archaeological heritage of different ages; it is eloquently spoken of in the most ancient literature, particularly the *Rigveda* and the Mahabharata and some other works; and, it hosts Kurukshetra, which is one of the most revered regions in India even to this day.

Administratively, this region falls in the states of Haryana, Panjab and north Rajasthan in India and Cholistan desert in the Pakistani Punjab, although the lower part of the trunk palaeochannel lies in Sindh right up to the Rann of Kachchh in Gujarat.

Drainage Systems

The area is formed of the following two drainage systems:

- (i) The much larger drainage is marked by southwestern slope configured with numerous palaeochannels all of which merge with an arterial palaeochannel that runs markedly from the Siwaliks to the Cholistan in Pakistan.
- (ii) The much smaller southeastern is drained by monsoon channels of the Sahibi, Kasavati (Krishnavati), Kantali, and others, which emanate from the Aravallis in Jaipur area and flow into Haryana. In older times, Kasavati joined the Sahibi, which took an abrupt turn to the east and passed through traceless swaths including Najafgarh and Bhindawas lakes before it meets the Yamuna. The Kantali, disappears in the sand near Rajgarh (Rajasthan).
- (iii) All channels and palaeochannels of Haryana and cis-Satluj Panjab (Malwa) meet a trunk channel, different segments of which are known by different names such as the Sarsuti, Ghaggar, Sottar, Ghaggar again, Hakra, Wahinda in the order it runs from the Siwaliks to some distance beyond Derawar Fort (Pakistan), beyond which it is now covered by a thick pile of sand accumulated over three millennia.

(iv) During its onward march, the above palaeochannel is met by the long palaeochannel of Chautang (Chatang, Chitrang) near Rangmahal near Suratgarh.

(v) Outside the above geomorphic zone, the lower course of the palaeochannel reappears near about Alor and Rohri (Pakistan) as the Raini and further on runs as Nara, almost parallel to the tortuous Sindhu to its west. It finally meets the Great Rann of Kachchh in Gujarat. Most interestingly, the lower course of the Nara is still called 'Hakro' which lends its name to local inhabitants as well. The Nara had cut a clear channel into the mud flat of the Rann through the mouth of Kori Creek when the sea was considerably lower during LGM.

It is this trunk channel, which has been widely identified with the Vedic Saraswati, while the Chautang is the Drishadvati by a majority of scholars from the 18th century onwards (James Rennel: 1788, 71; Vivien de Saint-Martin: 1860: i; Henry Beveridge: 1867; Alexander Cunningham: 1871: 282-3 and 1882: 86-106: 282-3; C.F. Oldham 1893 (Figure 4.1): 49-76; R.D. Oldham: 1886: 322-43 and several others), including archaeologists, historians, geologists, environmentalists, etc. There are, however, some dissenting voices too, mostly of the present times, based on no empirical knowledge and evidence.

There are few remarkable features of drainage of the Ghaggar basin.

Northward flowing Sahibi and the westward flowing palaeochannels makes some abrupt turns almost at 90°, not in a straight line, parallel running step like fashion. For example:

- (i) The west-east turn of Sahibi,
- (ii) Similarly, it is observed in the palaeo-Drishadvati and palaeo-Saraswati, in east-west fashion.
- (iii) In case of the Chautang, the abrupt east-west turns may be noticed from Safidon to Ramrai (first step), from Hansi to Siswal (second step), from Bhadra to Rawatsar (third step), and along the Ghaggar-Hakra from Rangmahal to Marot through the Sindhu (fourth step). It seems that a segmented subsurface geological lineaments make the southern boundary of the Chautang-Ghaggar-Hakra palaeochannel, incidentally making the limit of trapezoidal Yamuna-Satluj divide
- (iv) Possibly, there lies a subsurface Aravalli wedge running between the Yamuna fault and the Chautang channel that determines the course of eastward and westward flowing rivers / channels.

The Palaeochannels

This arterial river is rightly identified with the Rigvedic Saraswati.

Six small hill streams issuing from the outer flanks of Siwaliks, combined together to make the famous Saraswati. Interestingly, four of the six, are locally called Saraswati: the easternmost one, which is still celebrated to be the most sacred Saraswati, now joins the River Somb (Rigvedic Sushuma), which has since turned to the Yamuna, whereas the westernmost one has turned to the Markanda. The combined waters of the remaining streams run past the famous site of Bhagwanpura which has yielded interlocking the Bara (late Harappan) and Painted Grey Ware (PGW) cultures, with a separate underlying cultural horizon of the former. Nearby, there is another multicultural site of Kasital at the base of which lies the PGW deposit. The same channel goes on and passes the G.T. Road at Pipli, and close by is the northeastern doorway to the holy region of Kurukshetra. It then passes through a large number of sacred *tirthas*, each containing antiquarian remains. Some important ones are: Kurukshetara-Thaneswar, Svastipura, Jyotisar, Arnai (Aruna-Saraswati-sangam), Pehowa, Beharjachha (the northwestern doorway of Kurukshetra region), and in between the Beton (Vaitarni of the *Mahabharata*), and the Markanda through several channels meets the Saraswati. Thereabouts, the Tangri meets beyond which the Saraswati is captured now by the Ghaggar, although there are several palaeochannels of both the rivers, running into each other from time to time. The combined waters anciently flowed through a valley which is about 2 km broad near Tohana and runs past the famous archaeological sites of Kunal, Bhirrana, Banawali and many historical sites and further to the south of Sirsa, Ellenabad (where it formed a huge lake now completely reclaimed for building activities). It is, however, interesting to note that, possibly sometime in the 14th century CE, the Ghaggar cut an avulsion, by leaving the course of the combined waters, to the north-northeast of Tohana, to run past Ratia, Sardulgarh, Hanspur (far north of) Sirsa and Otu beyond which it rejoins the palaeochannel of the Saraswati (all within Haryana). The abandoned channel is now known as the Sottar valley.

The Ghaggar, then passes through Hanumangarh (Bhatner - a multicultural site), Kalibangan (pre-urban and urban Harappan site), Pilibangan (a Rangmahal site), and meets the ancient Drishadvati (Chautang) near Rangmahal. It then passes through the famous pre-urban and urban Harappan sites of Baror, Tarkhanwala Dhera, Binjor, besides a number of PGW and historical sites. It then enters the Cholistan desert in Pakistan, which is also replete with numerous sites ranging from the 4th to 1st millennium BCE.

The Drishadvati (Chautang), a dry bed present at Jagadhari railway station and passing through Damla, Radaud, Indri, and further on to the east of Karnal comes to

Safidon (ancient Sarpadaman or Sarpadevi) whereabouts the Yaksha guarding southeastern gateway to the holy region of Kurukshetra. It then runs past the sacred spots Hat (Panchanada), Asan (Ashwini), Barah (Varaha), Jind (Jayanti), and through others to the Yakshini near Ramrai (Ramahradas), which is the southwestern doorway to the holy land of Kurukshetra. Further on it passes through Narnaund (near Rakhigarhi, one of the five largest Harappan cities, and it was even during the pre or early Harappan times a sizeable settlement), Hansi, Hissar, Matarsyam, Siswal, Sothi, Ramgarh, Jhansal, Bhadra-Karanpura, Nohar, Rawatsar and further to join the Ghaggar (Saraswati) near Rangmahal. Further, historical *tirtha* of Karoti is located on this course.

The third important river in *Rigveda* is **Apaya** (Apaga of *Mahabharata*), which flows traversely through the Kurukshetra region between the Saraswati and the Drishadvati. It is in fact branched off from the Saraswati and runs passing through the sacred *tirthas* like Brahma Sarovar, Karna Sarovar, Pundari, Kaithal, Sajuma, Kalayat (all within Kurukshetra). It then runs past to the east of Narwana, and ancient historical sites of Ukhana and Bhuna and possibly joined the Saraswati at Fatehabad where both made a huge lake (remains of which still be seen), possibly the ancient Kamyaka, where Pandavas intermittently spent many seasons of their stay during their exile. According to Mahabharata, Kamyak is said to be located at the head of Maru, that is the Thar Desert, which fits well with the description. As per the Puranas, the Kurukshetra had many rivers and at least seven sacred forests and as many as 360 holy places.

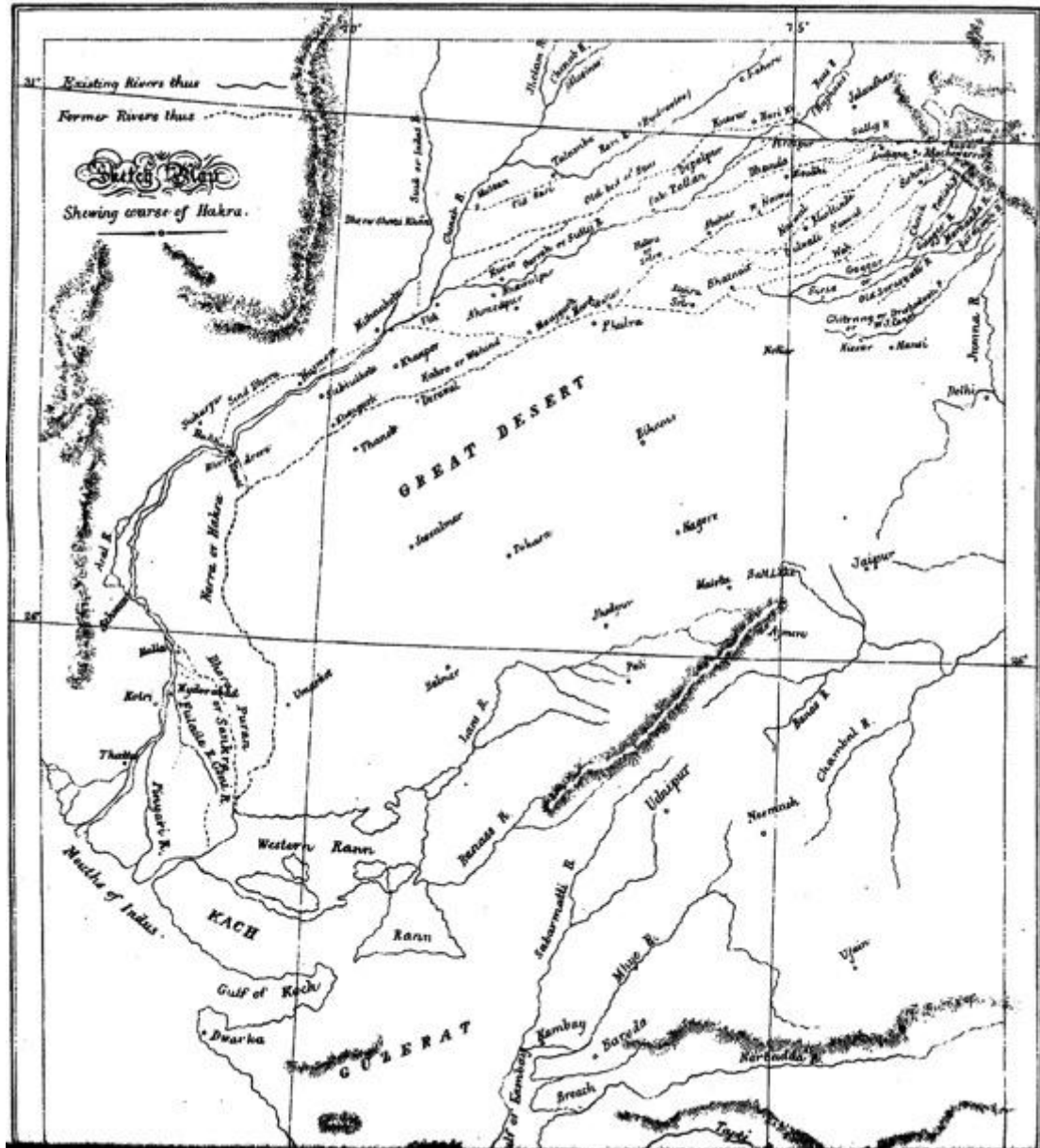


Figure 4.1: Classical Map C.F. Oldham showing the course of River Saraswati and Drisadvati

Kurukshetra is named after king Kuru, who ploughed it, possibly indicating towards introduction of agriculture in this part of Haryana. That perhaps occurred during the post-urban phase of the Harappan civilization. The entire land is practically dotted with huge mounds and many sacred ponds, sometime more than one or two at some places. The rivers, which are mentioned, are not readily identifiable. However, the Kaushiki could be the Rakshi palaeochannel, which may be identified with the *Rigvedic* Raka.

The Ghaggar may be the *Rigvedic* Anshumati and the Iskshumati of the *Mahabharata* and the *Ramayana*. At a place called Ghuram (Panjab), it is called as Sarayu, which may be the same referred to as the one flowing between the Sindhu and the Saraswati in the *Rigveda*. In the *Ramayana*, it is called Pitripaitamahi River meaning to belong to the family of Rama of Ikshavaku clan.

There are many other palaeochannels in Punjab. In local tradition, many of the palaeochannels have names which are alive even now in public memory or folklore. Even the villagers speak of ancient ferry points where boats were tied. The ancient literature is not much vocal about these channels. The Sirhindi Var or Choa was possibly the Sairandhari that is named after the region of Sairandhra, which is mentioned as one of the regions in the northwest of India according to *Parasharatantra* (recently edited and published for the first time; Iyengar 2013). Some of the channels are known to the geographers as Wah, eastern Naiwal, middle Naiwal and western Naiwal. The western Naiwal and all the channels to the west of it were very plausibly the old courses of the Satluj, testifying what Yashpal *et al.* have recorded that why and how the Shatadru (Satluj) was split into hundred channels.

Over some centuries, the Satluj has shifted considerably to the north between Ropar and Ludhiana, and further west in the remaining course and that is why many ancient settlements now represented by huge mounds like one that at Ludhiana and another at Janer are much away from the present course of the river. In a curious hymn in the *Rigveda*, the Satluj and the Beas coming differently from the hills started flowing in a common bed, possibly indicating that both were flowing independently of each other. Most significantly, the old course of the Beas has yielded as many as 18 protohistoric sites of the Hakra, the Kot Diji and the Harappan cultures. That old course seems to have joined the Chenab and not the Satluj as it does now.

Literary Evidence

The *Rigveda* praises Saraswati eloquently as ‘the best of the mothers’, ‘the best of the rivers’, and ‘best of the goddesses’ (*ambitamenaditamedevitame* RV. II. 41.16), ‘moving pure from the hills to the Sea’ (*suchiryati giribhya a samudrat*: RV. VII. 92.2); and also that it could be the seventh Sindhu mother (*Saraswati saptathi sindhumata*, RV VII. 36. 6) which, together with the five rivers of Panjab and the Sindhu, drained the land that was the *terra firma* of *Rigvedic* Aryans, that they occupied it by defeating their foes by breaking asunder numerous forts of the latter (RV. I.130.7; III. 12.6, IV. 30.20, VII. 31.4, etc.). Since the Saraswati is addressed as the destroyer of Paravata tribe or of Pani community, and some other kings, who were adversaries of the *Rigvedic* Aryans, it indicates that the valley should yield the evidence prior to and contemporary of the

Aryans, both of whom had fortified settlements belonging to a high level of civilization. During the later *Rigvedic* times, it seems that the whole land of seven rivers was experiencing droughts as well. That is why Devapi performed sacrifice for King Shantanu for rains during a period of drought. A large number of tribes ruled by their respective kings (names given) inhabited the land of the Saraswati as mentioned by the several sages of *Rigveda*. It may be emphasized that the Saraswati under discussion should be the *Rigvedic* Saraswati as the *Nadisukta* (RV X. 75) clearly mentions Saraswati after Yamuna and before Shutudri (*imam me gange yamune Saraswati shutudri sachata parushnya: RV.X.75.5 & 6*). Therefore, there is no necessity at all to take Saraswati to Afghanistan to identify it with the river Helmand, which is actually Heoitumati (i.e. Setumati-a land of dams and bridges, *Avesta*), in fact, the Zend form of the Saraswati is Haraqueti, the modern Argandab. The latter is mentioned in the *Rigveda* as inauspicious Harasvati.

The Saraswati is invoked to be a 'strong fort' (*ayasipuh: RV. VII 95.1*), as such 'a prosperor of five tribes' (*RV.VI. 61.12*), and it is why there was one king (*Chitraas rajan*) while there were many princelings (*rajakas*) in its land (*RV.VIII. 21. 18*). The Bharata princes lit sacred fire on the banks of the Saraswati and its sister rivers the Drishadvati and the Apaya (*drishadvatyam manusha apayayam sarasvatyam revadagne didihi RV. III. 23.4*) and the Puru people were living on its banks (*RV. VII. 96.2*), and many such references.

If the Saraswati was flowing strong from the hills to the sea (*RV. VII. 95.1 & 2*), during the *Rigvedic* times, the later literature clearly mentions about the drying up of the Saraswati. Vinashana is the place where it disappeared in the sand as mentioned in *Panchavimsa Brahmana* (*RV. XXX. 10.1*) and *Latyayana Srauta Sutra* (*RV. X. 15.1*). Vinashana is said to be the western limit of Madhyadesa as testified in the *Manava Dharma Sastra* (II. 21). Vinashana occurs repeatedly in the *Mahabharata* and other works as a point of disappearance of the Saraswati.

The most important account is found in the *Mahabharata* (*SalyaXXXV-CIV*) in which the upstream journey of Balarama from Prabhasa on the sea to the source of the Saraswati in the (Siwalik) hill is mentioned and different stations of pilgrimage are geographically enumerated, with only one exception that might be prevailing at that point of time about its meeting the sea at Prabhasa in Saurashtra. In the whole journey, Vinashana is an important station of the disappearance of the Saraswati. From this point, the upstream was the route where the Saraswati was running and the downstream, where it had become desiccated. The downstream places are Chamsodhbheda, Shashayana, Kumarakoti, Rudrakoti and Saraswati-sangams (*Mbh. Vana. 82. 1-27*). Chamsodhbheda should be the place where Saraswati reappears, possibly in form of three springs, namely, Chamsodbheda, Shivodbheda and Nagodbheda which can be located somewhere near Alor / Rohri area in

Pakistan; Sashaying, where Saraswati was in the form of several ponds, which can still be seen on the map either between Mithrau and Lund, or between Bakar and Chor, where numerous water bodies along the Nara can still be seen. Kumarakoti may be somewhere around Kuar Bet in the Great Rann of Kachchh. Rudrakoti was certainly, Kotesar (Kotesvara, Kotishvara) which is still very sacred to Rudra-Siva, and is located at the mouth of Kori Creek, where still pilgrims throng; and Saraswati-sangama is traditionally said to be west of Narayana Sarovar, another pilgrim place which in Mahabharata is said to be sacred to Keshava (another name of Narayana).

Upstream of Vinashana, there are several places right up to the Plakshaprasavana (which is now held to be at Adibadri) as mentioned in the *Mahabharata*. Interestingly, one of the places is Gargasraota, which is perhaps the present day Gargaji in Cholistan, now lying a little distance away from the Saraswati now. Among other places further upstream are many, important of which may be Dvaitavana (from where Balarama started to travel along the southern bank of the Saraswati), which is tentatively identifiable with Ellenabad lake; Naimisheya and Sapta Sarasvata (Mangna), both of which fall in the sacred land of Kurukshetra. Further upstream, a great number of holy places are mentioned such as Pehowa (Prithudaka), Arnai (Aruna-Saraswati sangam), Jyotisar, Svastipura, Kurukshetra-Thanesar, Kapalmochana and so on. Most interestingly, all these places are multicultural sites of archaeological importance and some of them contain the vestiges of Harappan, post-urban Harappan and PGW cultures.

The most interesting piece of evidence from *Mahabharata*, is that about nature of the desiccated lower course of the Saraswati (in Sindh), where it was not physically present but the experts recognized its course by examining the stickiness of the soil and lushness of vegetation (*snigdhatyadoshdhinama cha bhumeshcha janamejaya, jananti siddhah rajendra nashtamapi Saraswatim: Salya XXXV: 90*). In the present context, it may be applicable to the whole middle course of Saraswati, where it is not flowing, yet can be identifiable by similar conditions. These accounts on the Saraswati seem to be written around a couple of centuries before and after the beginning of Common Era, during which the expanded edition of *Mahabharata* was finalised. This also coincided with the post-Mauryan period during which a revival of ancient literary traditions and belief systems is noticed.

The course of the Saraswati in Haryana is represented by a broad belt of silty clay and clayey silt (Jaspir Singh 1976: Figure 49). The same is more emphatically applicable to the remaining middle course right Derawar Fort and beyond. Possehl holds that there could be an inland delta in Cholistan, which have produced phenomenally large number of archaeological sites. It may hold through when the encroaching sand fields completely choked the flow of the river.

Evidence of Human habitation

The evidence of human habitation all along and peripheral region of Sindhu-Ghaggar-Saraswati-Drisadvati is available since the Palaeolithic period onwards as witnessed from several sites in Rajasthan, Sindh, and the Siwalik region. Even though the plains of Sindhu and its tributaries are devoid of the Mesolithic / Microlithic remains, the peripheral regions in Rajasthan, Gujarat yield enough evidence of human occupation during this period. The most important evidence for human occupation in the Sindhu-Saraswati basin is from pre-urban / proto-urban / mature urban and late / decadent urban phases of the Sindhu Valley Civilization of Copper-Bronze Age, cultures of early Iron Age, early historical through different historical phases down to late medieval times - all ranging from 4th millennium BCE onwards to the first millennium BCE.

The entire middle course of the palaeo-Saraswati is replete with archaeological sites from fourth millennium BCE to the historical periods, the former much more stronger. The premise is upheld owing to the archaeological richness. It is, however, another enigma that no ancient literature ever speaks of either the Yamuna or the Satluj ever joined the Saraswati. So far archaeology is concerned, work on the ground is not at all adequate in upper Haryana or the cis-Satluj Malwa to prove the point. There is little doubt that one or both may have contributed their waters to the Saraswati but that happened in the Holocene or the Pleistocene while the scenario of the former would be the most relevant because all those ancient sites belong to mid-Holocene onwards. There is observed a perceptible dwindling both quantitatively and qualitatively in the settlement pattern during second millennium BCE, which must be due to the changing water regime in the river which remained variable that is even vouched for in the ancient literature itself.

A brief outline of successive cultural periods of human habitation in Greater Sindhu-Saraswati plains is given below:

Sl. No.	Cultural Period	App. date	Region	Remarks
1.	Prehistoric Palaeolithic Mesolithic	> 0.5 Ma 7 – 5 Ka	All along the periphery of Greater Sindhu-Saraswati plains	Stone tools, hunterer gatherer communities
2.	Copper-Bronze Age 1. Hakra 2. Pre - / EH 3. Harappan	>5.5Ka 5 Ka 4.5 Ka	Entire Greater Sindhu-Saraswati plains and Ganga-Yamuna	Settled life, cities, towns and villages, agriculture and trade, technologies

Sl. No.	Cultural Period	App. date	Region	Remarks
	(I Urbanization) 4. Late Harappan, OCP, CH	3.9 – 3.2 Ka	doab	including metal and ceramics
3.	Iron Age 1. PGW 2. NBPW (II Urbanization)	> 3 Ka 700 BCE	Western U.P. to Upper Cholistan North Indian plains	Settled life, emergence of iron technology and consolidated, emergence of city states and later empires

Protohistoric Period

The protohistoric period is the transition between the prehistoric and historic periods when the human started to settle down, leading a sedentary lifestyle and also domesticated plants and animals. This period marks the Neolithic, Chalcolithic and Bronze Age cultures of South Asia. Ever since the discovery of Sindhu Valley Civilization in 1924 from the excavations at Harappa (1921 onwards) and Mohenjo-daro (1922 onwards), investigations at several locations in the Greater Sindhu Valley have led to a better understanding of development of cultures starting from the Neolithic period (Figure 4.2) onwards. In the Sindhu basin, the combined evidence from the sites of Mehargarh, Nausharo, Pirak and Sibri indicates the settling of humans domesticating plants and animals from around 8th millennium BCE, then passing through several technological innovations including pyrotechnology, smelting of copper, ushered into the Bronze Age coinciding with the Harappan Civilization. In particular, the evidence from Mehrgarh, located on River Bolan starting from around 8th millennium BCE onwards is very significant. A complete evolution of settled life, domestication of plants and animals, emergence of various technologies like ceramic, metal, aided through the control of fire, ornaments and jewelry, long distance trade contacts, all are witnessed here, which laid the foundation of later period emergence of towns and cities.

However, in the Satluj, Ghaggar and Yamuna basins, such evidence is lacking so far for the Neolithic and Early Chalcolithic cultures dating from around 8th to mid 4th millennium BCE excepting the Rohri hills evidence from Sindh region of Pakistan located between the Sindhu and Hakra Rivers, wherein evidence for prehistoric human occupation is noticed.

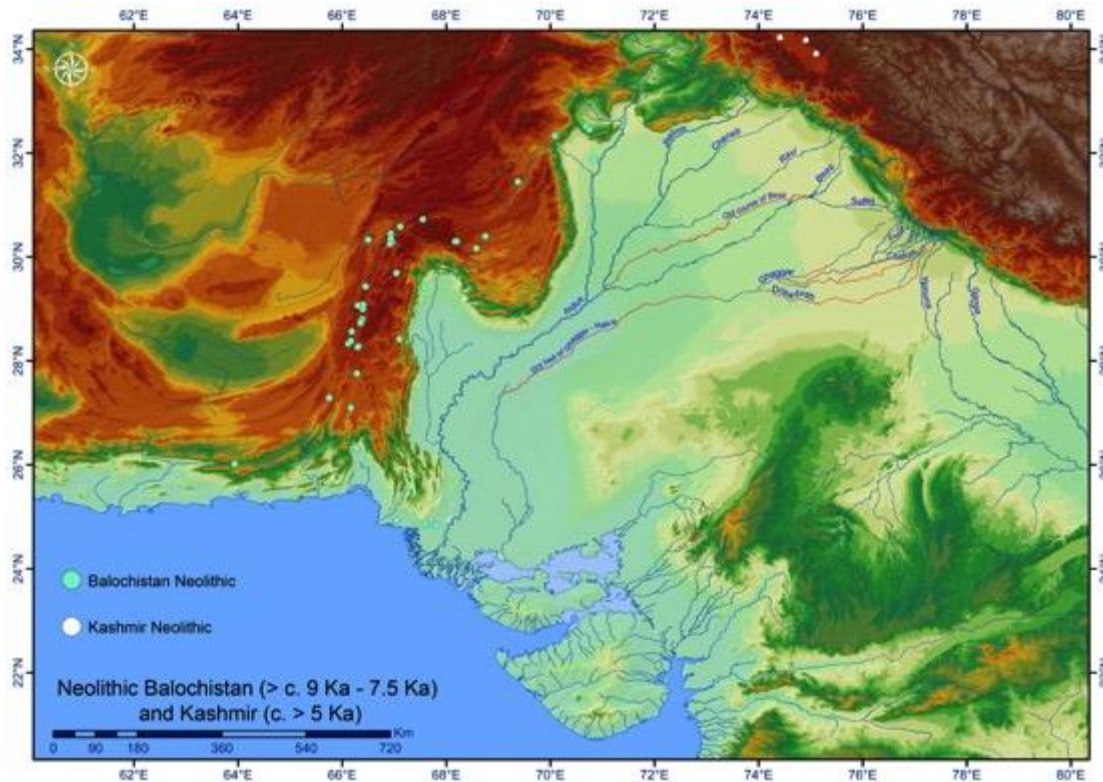


Figure 4.2: Map showing sites of Neolithic Balochistan and Kashmir

From the 4th millennium BCE onwards, evidence for human occupation in the Ghaggar-Hakra-Saraswati-Drishadvati river basins is noticed which can be categorized into Hakra, Pre-/Early Harappan, Harappan, late Harappan, Painted Grey Ware and Rangmahal (early Historic) cultures. While Hakra, Pre-/Early Harappan, Harappan and late Harappan falls under the Chalcolithic Age, Painted Grey Ware and Rangmahal belongs to Iron Age.

Hakra Cultural Phase

The Hakra Culture (Figure 4.3) marks the occupation of the Ghaggar-Hakra basins with the largest concentration in the Cholistan region of Pakistan. A total of 103 sites belonging to this culture have been discovered so far with a total settled area of 655.65 ha (Possehl 1999). Mughal (1982), who carried out an extensive survey in the Cholistan area characterizes the settlements as ‘...*low mounds in lesser Cholistan (Bahawalnagar and Bahawalpur Districts) and are located to close to, or in, the idahars (mud flats). In greater Cholistan (Rahimyar Khan District), they also occur on sand dunes.*’ The Hara culture settlements are datable to mid-fourth millennium BCE based on radiocarbon dates and stratigraphic correlations from other sites. This culture is identified based on a distinct ceramic complex, which among others consisted of “mud applique” and “Hakra incised” wares (Mughal 1982).

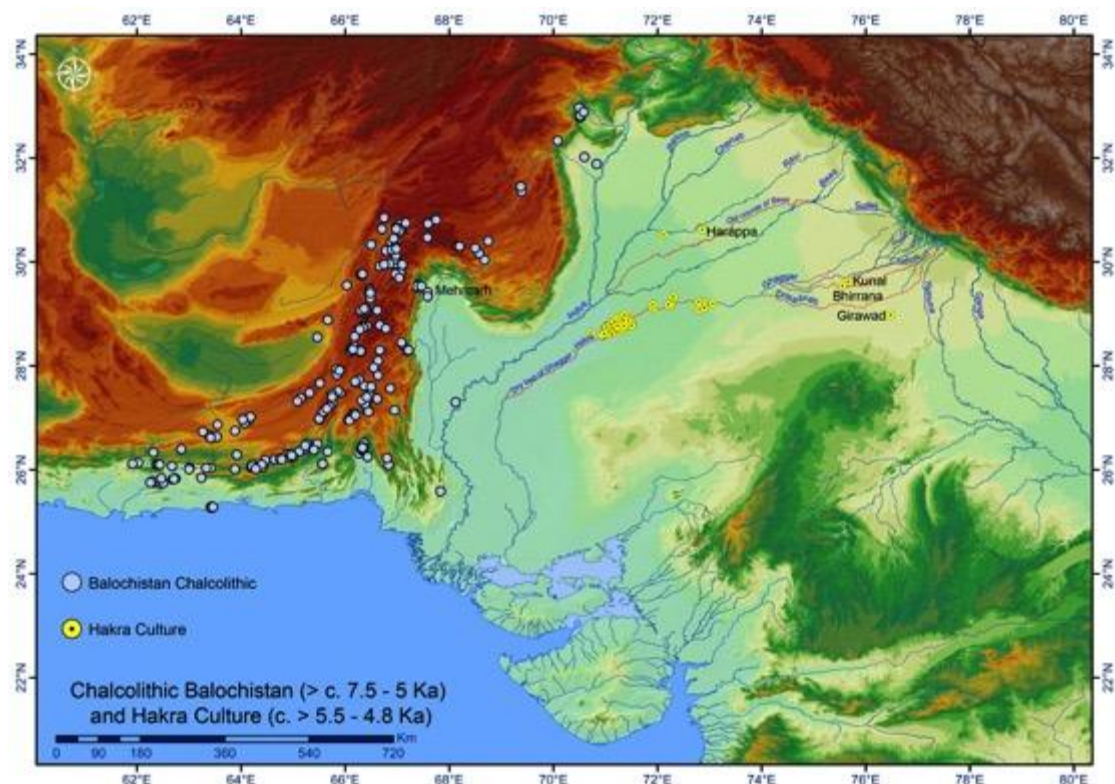


Figure 4.3. Map showing sites of Chalcolithic Balochistan and Hakra Culture

A majority (54 in number) of the 103 reported sites has been identified as campsites used by pastoralists, which has been attributed to the role of pastoralists during the early formative phases of Harappan Civilization. Among the Hakra culture sites, only two, i.e. Jalilpur and Harappa have been excavated and the latter yielded a stratigraphic occurrence of this culture below the early Harappan ones which is also dated from 3700-2800 BCE (Kenoyer 2013). The nature of human occupation from Harappa consisted of several working floors along with hearths (Kenoyer 2000), while at Jalilpur evidence of mud brick and earthen floors were encountered (Possehl 1999). The artefact assemblage from this culture consists of animal figurines of bulls and cows; bangles of shell and terracotta; grinding stone fragments; copper bits and pieces; stone tools like blades, borers, arrowheads, scrapers, cores.

On the Indian side, three sites, namely Kunal, Bharrana and Girawad belong to Hakra culture as identified by the excavators (Shinde *et al* 2011). The radiocarbon dates from Girawad dates the site to late fourth millennium BCE (Shinde *et al* 2011), while for Bharrana some very early dates have been proposed, which, however are not consistent with fourth millennium BCE dates. Thus, the earliest phase of human occupation in the Ghaggar-Hakra basin can be traced to fourth millennium BCE.

The Hakra phase on the middle and upper reaches of Ghaggar-Hakra is contemporary with the Balochistan Chalcolithic sites marked by several type sites like Kechi Beg, Shahi Tump, Quetta, Anjira, Damb Sadaat, Kulli. Thus, it can be observed that the presence of settled and developed human habitation co-existed from at least fourth millennium BCE onwards in Balochistan and Ghaggar-Hakra plains.

Early Harappan / Pre-Harappan Cultural Phase

The early Harappan or pre-Harappan cultures (Figure 4.4) represent the formative stages of Harappan civilization and just preceding the urban phase. These are Chalcolithic cultures, slightly advanced when compared to the Hakra culture in terms of sophisticated architecture, which at some sites like Kalibangan, Harappa have a fortification surrounding the settlement. The early / pre-Harappan cultures are dated to the first half of third millennium BCE, or more precisely from *circa* 2800 – 2600 BCE, when several of these regional chalcolithic cultures flourished in the Greater Sindhu valley which ultimately ushered into their integration around 2600 BCE.

These early / pre-Harappan cultures are distinguished based on material culture and geography and named variously as Amri-Nal (South Sindh, Makran, Kachchh Gujarat), Kot Dijian (North Sindh, Cholistan, Pakistan Punjab), Sothi-Siswal (Rajasthan, Haryana, Indian Punjab), Anarta (North Gujarat), Damb Sadaat (Central Balochistan). On the Ghaggar-Hakra basin, the Kot Dijian sites are found on the lower course, while Sothi-Siswal sites are found along the central and upper courses including Ghaggar, Saraswati and Drisadvati basins. The Kot Dijian culture gets its name from the type site of Kot Diji in North Sindh, while Sothi-Siswal takes its name from two type sites, namely Sothi and Siswal, both on the River Drisadvati, the former in Hanumangarh district of Rajasthan and latter in Hissar district of Haryana.

An estimated 166 Sothi-Siswal sites have been discovered and out of these 19 are excavated. The average size of these settlements is 4.28 ha with two sites more than twenty ha. Some of the important excavated sites are Kalibangan, Sothi, Nohar, Karanpura, Tarkhanawala Dhera (all in Rajasthan), Banawali, Siswal, Bhirrana, Rakhigarhi (all in Haryana). The number of Kot Dijian sites discovered is around 111, with an average settlement size of 6.31 ha. The Kot Dijian sites have a distribution largely in the central and lower part of Saraswati basin, Bannu and Gomul valley and as far as north in Taxila valley. Harappa is the largest Kot Dijian site with an estimated size of around 40 ha.

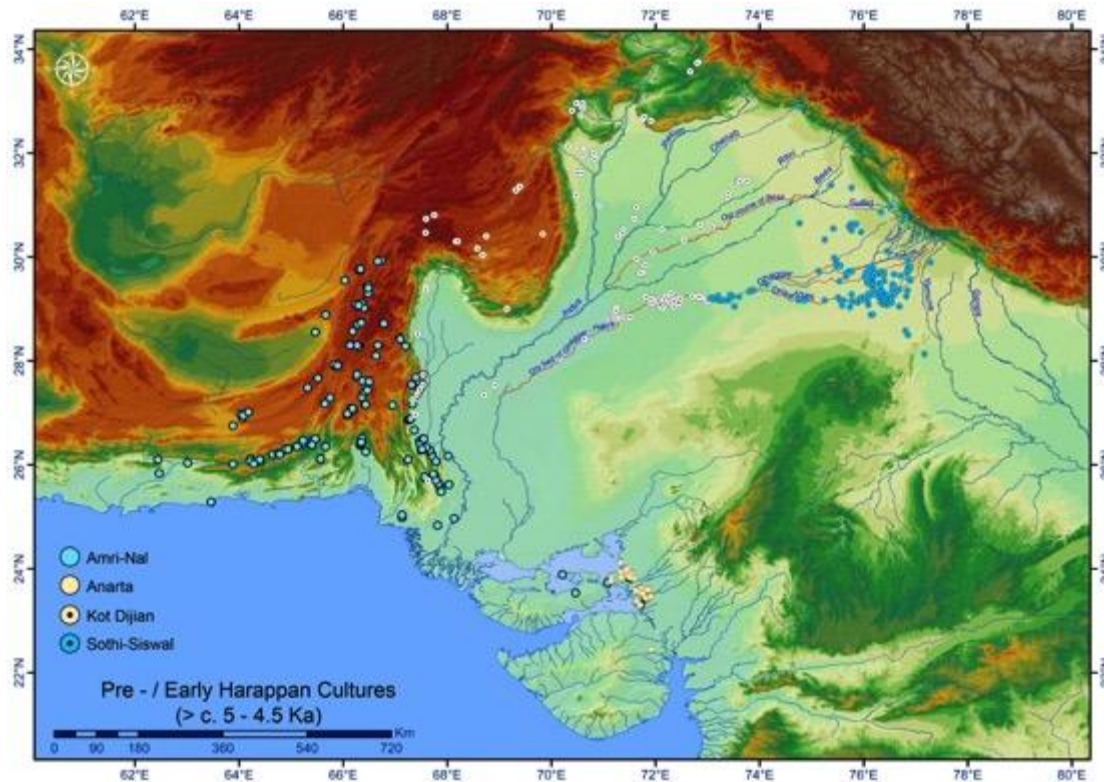


Figure 4.4. Map showing sites of Pre-/Early Harappan Cultures

As mentioned elsewhere, both Sothi-Siswal and Kot Dijian cultures form an important phase during which advancements in architecture, trade, procurement of raw materials, technology are noticed. The excavations at Kalibangan on Ghaggar and Banawali on Saraswati indicate separate fortified settlements. Evidence for a ploughed field from Kalibangan is an important finding from this period. The palaeobotanical investigations of Kalibangan remains indicate the presence of wheat, barley, chickpea, field pea. Wood remains include *Acacia* sp, teak, heartwood, axelwood. It has been estimated that except teak, the other species would have been easily found along Saraswati River in gallery forests (Possehl 1999). The presence of rhino bones from Kalibangan and Karanpura is an interesting finding which may indicate a different eco-system from today.

Harappan Phase

The integration of the regional Chalcolithic cultures found during second half of fourth and early third millennium BCE is witnessed in several regions of the Greater Sindhu Valley (Figure 4.5). This integration was necessitated due to several reasons like a common ideology, expansion of trade networks for procuring exotic products from often distant lands, pooling of resources from one region to another, external trade with Mesopotamia, to name a few. Several of the medium and large sized towns of Kot

Dijian and Sothi-Siswal cultures saw great prosperity and expanded into small and large cities. Two of the five largest Harappan sites of over 100 ha size is noticed on the Saraswati River, namely Ganweriwala (>100 ha) in Cholistan, Pakistan and Rakhigarhi (>150 ha) in Haryana, India. The other medium to larger cities of this period on the Saraswati is Kalibangan, Karanpura, Baror (all in Rajasthan), Banawali, Bhirrana, Farmana, Mitathal (all in Haryana). An estimated 1500 sites of Harappan phase have been identified so far (Kenoyer 1999), which can be classified into small villages or hamlets (<1 to 10 ha), few larger towns and small cities (10 – 50 ha).

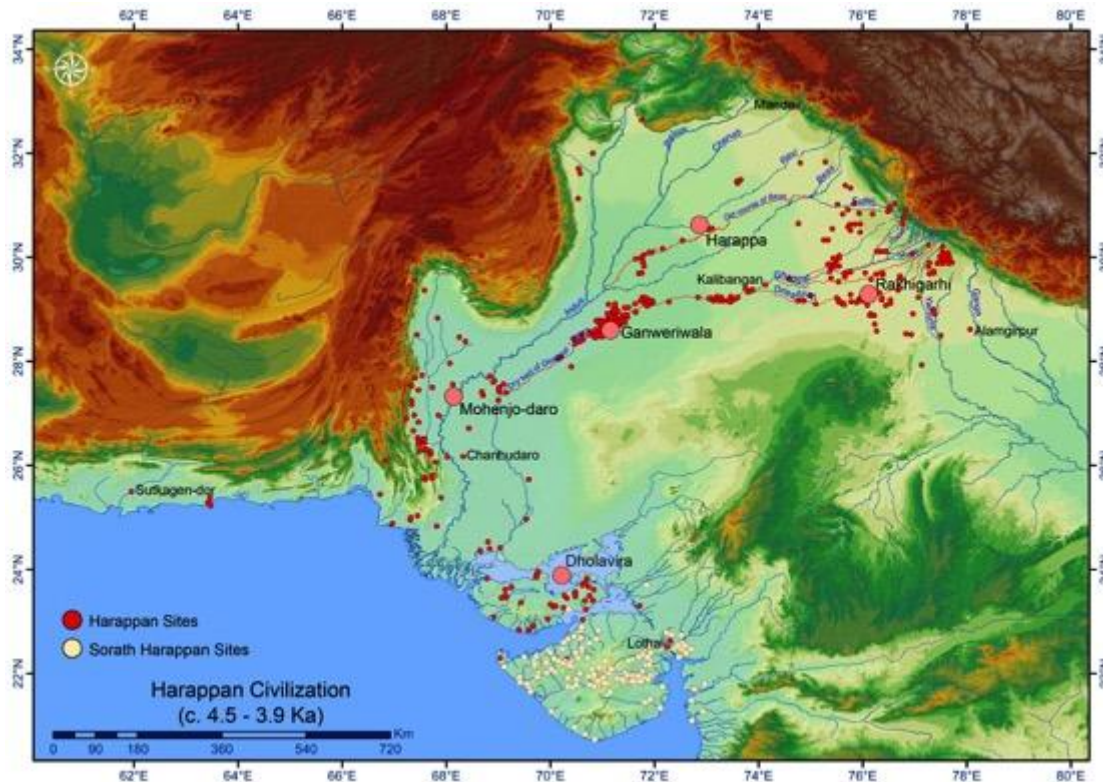


Figure 4.5. Map showing sites of Harappan Civilization

Of these the number of mature Harappan settlements in Cholistan is around 174 and in the eastern region (i.e. Rajasthan, Punjab, Haryana and Uttar Pradesh) there are 218 sites. It is also estimated that around 80% of the total Harappan phase sites are located on the '*vast plain between Sindhu and Ganga*' (Mishra 1994). The number of sites in Haryana and Rajasthan put together is 74 (modified after Mishra 1994), of which many of them are located on the narrow southwest-northeast belt along the dry bed of Ghaggar-Saraswati basins (Figure 4.5) and also along the several tributaries which emanate from the Siwaliks.

The characteristic features of Harappan settlements are well known which are found in these settlements, including multiple divisions in settlements each surrounded by massive fortifications, standardization in bricks in the 1:2:4 ratio, seals and sealings,

weighing system, pyrotechnology, copper and bronze tools, evidence of long distance trade, to name a few. The chronology of the Harappan Civilization has been radiocarbon dates from several excavated sites, which is c. 2600-1900 BCE. This chronology is the overall time bracket for the civilization and individual sites may have a different date for their origin and abandonment. Thus, it may be seen that a large number of settlements were supported by the Ghaggar-Hakra river systems during second half of third millennium BCE, which otherwise could not have been possible if a river system with considerable flow of water all the year round. This is also marked by another crucial evidence in the form of lack of wells within the settlements like Kalibangan, Banawali, Bhirrana, Karanpura, to name a few. This implies that the inhabitants were still depending upon the water from the river directly.

Late Harappan / Post-Urban Harappan phase

The early understanding of the Harappan Civilization was a sudden abandonment and vanishing after the peaking urban phase. The evidence from the urban centres like Mohenjo-daro was cited as an example for this theory. Possehl (1977) aptly summarizes the earlier understanding of this civilization as, *“.....the civilization arose quickly from whatever formative base might have been present, and that it ended with equal rapidity.”*

Possehl in 1977 also observes that a clear evidence for the presence of ‘late Harappan’ phase of Indus Civilization was always there but largely ignored by the archaeologists due to the *‘.....distinctiveness of the Mature Harappan material culture’* and less understanding of the transformations preserved in the habitation of different settlements. Kenoyer (1998) observes that there was a gradual shift which marked the fading of first urban civilization into the background as many new cultures emerged at the eastern, southern and northern edges of Indus valley. Kenoyer (1998) further states that it took nearly a thousand years for the shift in cultural and political centre from Indus Valley to the middle Ganga region. The transformation marked the end of urban phase of Sindhu Civilization which was sustained for nearly seven hundred years. The beginnings of this transformation have been documented at sites like Harappa and Dholavira during the last phase of Harappa phase itself.

This transformed late Harappan / post-urban cultures (Figure 4.6) are variously known in different parts of the Greater Sindhu Valley such as Cemetery H (Pakistan Punjab and Cholistan), late Harappan / Bara (Haryana Punjab and West Uttar Pradesh), Jhukar and Jhankar (Sindh). The settlement pattern of the sites datable from c. 1900-1300 BCE clearly indicates abandonment of several settlements along the central and lower Ghaggar, including larger settlements like Kalibangan and Ganweriwala.

This decrease in number of settlements in the Bahawalpur (Pakistan) and Ganganagar & Hanumangarh (Rajasthan) can be clearly seen in comparison with the preceding mature Harappan phase (c. 2600-1900 BCE) along with a sharp increase in the number of settlements in Haryana, Punjab and Uttar Pradesh. In Haryana, a dramatic increase in number of settlements is noticed in the districts of Jind, Kurukshetra, Karnal, Hissar and Ambala districts, while in Mahendragarh and Gurgaon districts the first Harappan settlements were found. While the number of sites increased from 44 (Harappan) to 297 (late Harappan) in Haryana, all the Harappan sites in Rajasthan were abandoned.

The important excavated late Harappan settlements are Harappa, Mitathal, Bara, Sanghol, Alamgirpur. Sanauli, a large cemetery site of late Harappan period was also excavated which helped in understanding the contacts of the Harappans with another culture characterised by Copper Hoards and Ochre Coloured Pottery in the Ganga-Yamuna *doab*.

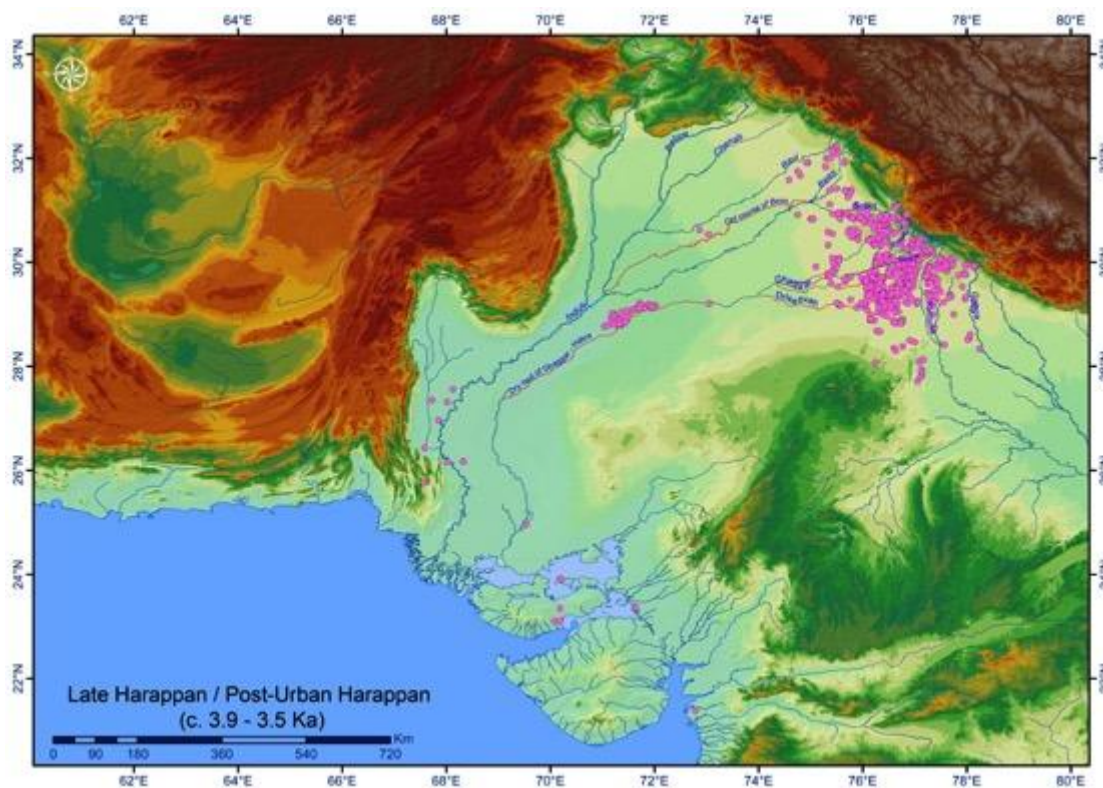


Figure 4.6. Map showing sites of late Harappan / post-urban Harappan sites

Several hypotheses were put forth for the end of Harappan Civilization and abandonment of settlements along the Ghaggar-Hakra river system and one among them is the drying of River Saraswati around 1900 BCE, and the capture of Satluj River by Sindhu River. C.F. Oldham (1874) discusses the pattern of shifting of Satluj River.

Oldham proposes that Satluj joined the Hakra River through the present dry beds known as Eastern and Western Naiwal, downstream of Bhatnair. The shifting took place gradually and during the intervening period of *Rig Veda* and *Mahabharata*, Satluj flowed into the western arm of the Hakra and the final change in its course took place in 13th century CE to join Beas River. Thus, the Satluj played a crucial role in the sustenance of the River Saraswati and its shifting might have caused the abandonment of settlements towards the east.

Ochre Coloured Pottery Culture and Copper Hoards

A distinct ceramic tradition represented by a pottery known as Ochre Coloured Pottery (OCP) marks the transformation and cultural assimilation of late Harappans into the Ganga-Yamuna *doab* during the second millennium BCE (Figure 4.7). The ceramic was first identified from stratigraphic contexts at Hastinapura by B.B. Lal (1955) and later from many sites in the Ganga-Yamuna *doab* like Bahadarabad, Ambkheri, Atranjikhhera, Lal Qila, Saipai, Madarpur. The ceramic tradition is also found in association with the enigmatic Copper Hoards from excavations at Saipai, and at Madarpur, it was found at the same stratigraphic horizon wherein copper anthropomorphic Figures were discovered. The copper hoards have been reported ever since the first specimen was discovered in 1822, albeit most of them are chance finds and not from regular excavations. However, there is a remarkable uniformity in the typology of the specimen found which now include a variety of tools and weapons. They include flat celts, hatchets, shouldered celts, bar celts, rings, antennae swords, harpoons, lugged spearheads and anthropomorphic Figures. These hoards are even though found in a wide geographical area, is concentrated in the Ganga-Yamuna *doab* from where OCP is also found. The chronological time bracket for this culture based on the investigations at several sites is c. 2000-1200 BCE.

The discovery of a copper antenna sword of the Copper Hoard tool typology from an *in situ* condition from Burial 14, Sanauli in Western Uttar Pradesh is a remarkable find in terms of understanding the cultural contacts between late Harappans and OCP / Copper Hoard people.

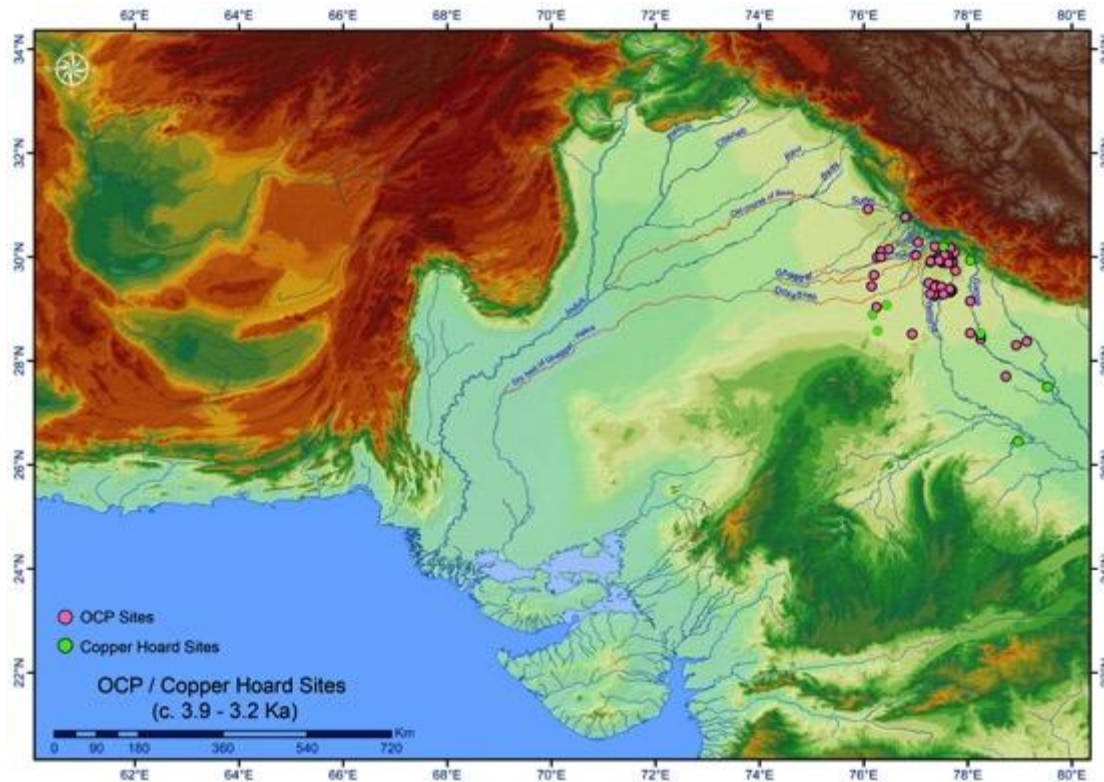


Figure 4.7. Map showing sites of OCP and Copper Hoard

Painted Grey Ware Culture

After a gap of nearly 700 years, the central course of Ghaggar-Hakra basin is re-occupied by a new culture distinguishable by a distinct ceramic known as Painted Grey Ware (PGW) (Figure 5.8). This culture also marks the beginning of iron in Indian sub-continent. The ceramic is grey in colour, fired in reducing conditions to achieve a uniform grey colour.

They are also decorated with various designs like dots and dashes, vertical, oblique and criss-cross lines, concentric circles and semicircles, a chain of short spirals, sigmas, *svastikas*. The PGW culture is characterised by a rural economy with an agricultural-cum-pastoral way of living. Three distinct regions based on the settlement pattern can be delineated, viz., western zone (Cholistan in Pakistan and Ganganagar in India) on the central course of Ghaggar-Hakra; upper courses of Drisadvati, Saraswati and Ghaggar in Haryana and Punjab and Western Uttar Pradesh. The settlement pattern also indicates the complete absence of PGW sites beyond Ganganagar up to Hissar district. The important settlements of this culture are Bhagwanpura wherein an overlap between late Harappan and PGW culture is noticed; Ahichchhatra, which may be the largest PGW settlement; Atranjikhhera, Hastinapur, Mathura. One important aspect emerging on the basis of settlement pattern is that the Ghaggar-Hakra basin is

re-occupied which may be due to return of favourable conditions including availability of water in the river for a considerable part of the year.

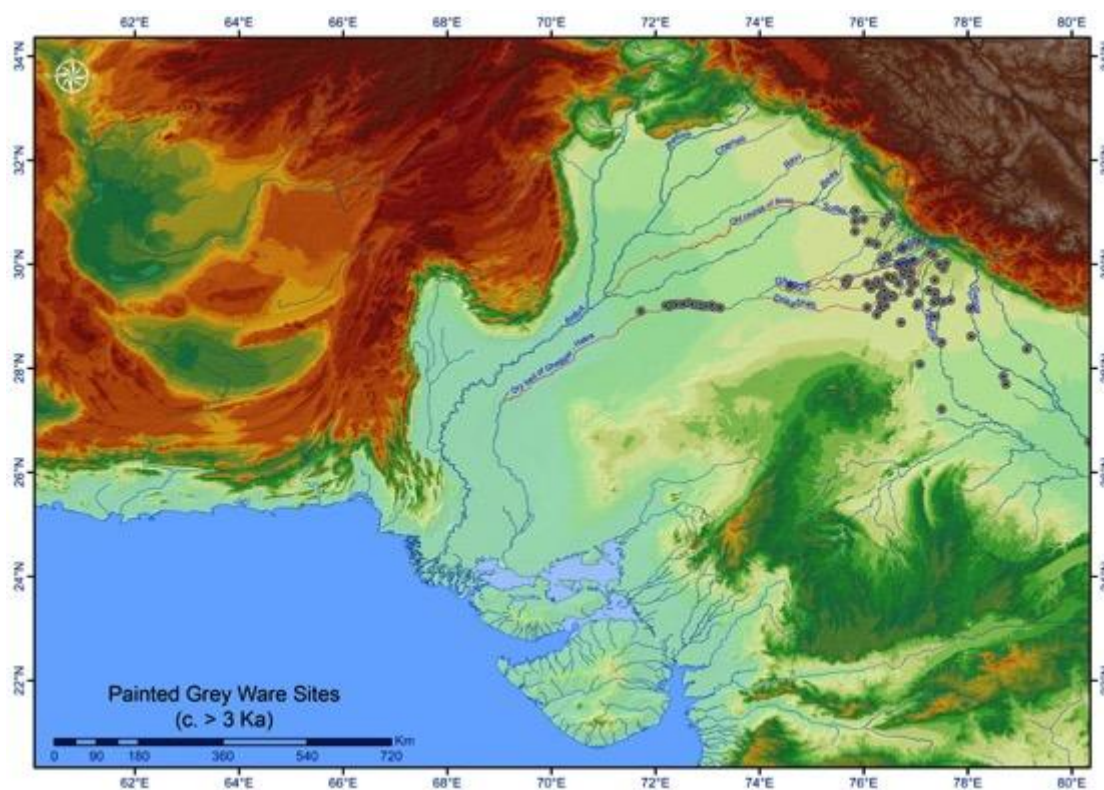


Figure 4.8. Map showing sites of Painted Grey Ware culture

Early Historic Period

The formative phases of emergence of kingdoms and empires in north India and elsewhere is known as Early Historic Period which extends to a few centuries of the current era as well. In the Ghaggar-Hakra basin, the emergence of a culture marked by a distinct pottery known from the type site of Rangmahal is noticed during the few centuries of current era and preceding it.

This culture is also contemporaneous with the Kushana dynasty, which ruled the northwestern part of the Indian sub-continent from 2nd century BCE to 3rd century CE. The ceramics of the Rang Mahal is distinguished by red coloured pottery with beautiful black coloured decorative motifs consisting of geometrical and animal motifs. A number of sites belonging to this culture can be noticed along the central course of Ghaggar-Hakra river. The settlement pattern of this culture indicates a dense concentration of sites along the Ghaggar-Hakra river, while many others spread in eastern part of Rajasthan and a few sites in Punjab as well. The presence of sites along the Ghaggar-Hakra river is an indication of renewed water availability which

supported human occupation, while the entire middle lower middle portion was completely depopulated and that is reflected in the accounts of James Todd.

Archaeological Evidence in Yamuna Plains

A continuous human occupation in the form of settlements is noticeable in the upper Yamuna basin from the Harappan phase onwards (c. 2600-1900 BCE). The number of Harappan sites in Uttar Pradesh is 31 and Alamgirpur is an important site. The radiocarbon dates from this site indicate its earliest occupation around 2600 to 2200 BCE indicating the expansion of Harappan civilization in this area during second half of third millennium BCE (Singh *et al* 2013).

The settlements in the Yamuna basin increased dramatically during the late Harappan / post-urban Harappan phase from c. 1900 BCE onwards and nearly 132 settlements have been reported from this area. Among them a few chance discoveries have led to a complete new understanding of late Harappans in this region. One among them is Mandi, district Muzaffarnagar which brought to light a large hoard of gold objects consisting of bangles, beads and silver ornaments indicating the holding of wealth by the Harappans for generations together and ultimately deposited in hoard form. Similarly, the large cemetery site of Sanauli, district Baghpat, not only contained several burials with exotic funerary offerings in the form of gold bangles, necklace and beads of agate-carnelian, faience, steatite, but also indicates the connections with Copper Hoard people. A third site known as Chandayan, district Baghpat is another burial site of late Harappans similar to Sanauli, wherein a copper headgear adorned with carnelian beads is found.

The Ganga-Yamuna *doab* witnessed cultures which were contemporary to the late Harappans like the OCP / Copper Hoard and then after a continuous succession of human occupation during the Painted Grey Ware culture and early Historical period. This region witnessed the Iron Age stage, which was also instrumental in the ushering of urbanization, leading to establishment of kingdoms and empires. The settlement pattern of various cultures from Harappan Civilization onwards is shown in Figs. 4.5-4.8.

Archaeological evidence in Satluj Plains

Geographers, geologists and enthusiasts who have dealt with the various river systems including the Saraswati and Satluj discuss in detail the various prospects related to the shifting of channels of River Satluj. In particular, C.F. Oldham (1893) deals in detail regarding how River Satluj joined the Ghaggar-Hakra system through the channels identified with Eastern and Western Naiwal and there have been a gradual

shifting until it joined the River Beas. Oldham (1893) also points out that the united stream of Beas and Satluj was not known as Sutudri, Satadru or Satludra and instead as Vipas, Vipasi, Vipasa, Beas and Beah. Further, the present combined stream of Beas and Satluj was not known with the name Satluj in the old writings, either Hindu or Islamic. Oldham opines that this application of name of Satluj to combined stream is a modern innovation and not an ancient one.

Mishra (1994) points out the existence of local traditions, which indicate that the Satluj flowed into the Hakra channel until the arrival of Islamic rule. The absence of the Harappan settlements on the Satluj just before it meets Beas is an indication for this new course. Mishra (1994) further points out to the presence of several Harappan settlements on the western part of Punjab, which may indicate that the Satluj might have flowed eastwards. Similarly, Harappan or and after the late Harappan settlements are not found along the combined streams of the Beas and the Satluj and rather on the old course of River Beas. This clearly shows that the River Beas was flowing in a different course westwards different from the present only during the third millennium BCE.

The presence of protohistoric sites, starting from the Harappan phase onwards could be noticed in the upper course of the River Satluj, when it leaves the Siwaliks and enters the plains. The settlements like Rupnagar, Bara, Sanghol, Kotla Nihang Khan are examples in this regard. Of these, Rupnagar is particularly important as it preserves a long and continuous history of human occupation starting from Harappan phase (c. 2300 BCE), followed by Painted Grey Ware to Early Historic Periods and after. Even now, Rupnagar is a district headquarters and occupies an important position in terms of exploitation of raw materials sources.

The settlement pattern and distribution maps have been shown in Figures 4.5 - 4.8.

CHAPTER 5

Hydrogeological Significance of Palaeochannels

Palaeochannels consists of channel-lag deposits which are coarse grained sediments having good permeability. Hence palaeochannels in general are rich repository of ground water which and can act as a dependable source of water supply (Andreasen & Smith, 1997, CGWB, 2002, Pucillo, 2005, Rao et.al. 2009, Suganthi et. al. 2013). For example, in Ghaggar basin, North-West India, the extensive network of surface and deep palaeochannels constitute potential aquifers in multiple groups covering the entire plain land. Ground water abstractions from these aquifers have boosted the irrigation in agriculture sector in these areas. The quality of ground water in palaeochannels is generally good, because they often belong to the active recharge system. The unsaturated part of the palaeochannel deposits can act as storage reservoir for artificial recharge for augmenting the ground water resources. A study carried out in the Upper Ganga Plain around Muzaffarnagar area for identification of sites for artificial ground water recharge using remote sensing-GIS techniques concluded that in the foothill zones of mountains and adjoining plains, the upper reaches of palaeochannels where ground water may occur at deeper levels, can be considered as potential sites for artificial ground water recharge (Gupta et. al., 2011). Thus palaeochannels are potential reservoirs for ground water and also favourable zones for artificial recharge.

Hydrogeological Scenario in Palaeochannel

As delineated from the satellite map, the palaeochannels of Ghaggar-Hakra extents from Great Himalayas to Rann of Kachchh, passing through the states of Himachal Pradesh, Haryana, Punjab, Rajasthan, Gujarat. The total length of the said palaeochannels is nearly 4800 km. out of which the stretch within India is around 3200 km. The parts of the palaeochannels in the upper reaches may not hold significant ground water or artificial recharge potential. However, the palaeochannels in Haryana, Punjab and Rajasthan are underlain by unconsolidated alluvial deposits which usually make potential aquifers.

Aquifer Disposition in Palaeochannel

Central Ground Water Board has constructed more than 30 exploratory wells along the palaeochannels of Ghaggar-Hakra extending over the states of Hyarana, Rajasthan and Gujarat in order to map and characterize the aquifers existing within the palaeochannels. Ground water exploration has confirmed the presence of coarse grained unconsolidated sediments with high groundwater potential possibly representing palaeochannels in Ghaggar basin. Geophysical studies and ground water exploratory drilling have confirmed the presence of alternating layers of fine to medium

and coarse-grained sand and locally gravel columns, indicating presence of fluvial regime. Resistivity surveys carried out in desert areas of Rajasthan 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. Coarser sediments are noticed at a depth ranging from 40 to 125 m (general depth of 55 to 85 m). Channels are about 35 to 80 m thick with depth to water level ranging from 35 to 60m. In the Kishangarh-Tanot track forming north-western parts of Jaisalmer district, it was found that fine to medium grained sand mixed with gravels, kankar etc. having a thickness from 6 m to 22 m were encountered at the depth zones from 25 m to 125 m. The sediments encountered here are well sorted with low uniformity coefficient.

Aquifer Characteristics in the Palaeochannel

In the palaeochannels of Ghaggar basin, Haryana, the results of aquifer performance tests show that the discharge of the wells drilled varies from 350 litre per minute (lpm) to 1900 lpm, Transmissivities of the aquifers range from 446 m²/day to 1939 m²/day with Storativities ranging from 3.6×10^{-5} to 2×10^{-3} , which represent highly potential aquifers. Such high values of aquifer parameters indicate possible presence of unconsolidated coarse sediments representing the palaeochannels.



Figure 5.1. Exploratory Drilling by CGWB at Sarswati River Creek/ Channel Reminiscence site at Kurukshetra, Haryana

Ground water exploration carried out in the palaeochannels of Rajasthan recorded high discharge of upto 1000 lpm with comparatively good quality ground water (Figure 5.2). The ground water quality deteriorates with depth and also laterally away from demarcated palaeochannels.



Figure 5.2 A tubewell in the palaeochannels near Tanot, Jaisalmer district, Rajasthan with good quality groundwater (source:<http://indianexpress.com/article/india/india-others/finding-an-extinct-river-as-rajasthan-pushes-saraswati-plan-water-marks-all-along-course/>)

Ground Water level in Palaeochannel

The information on ground water level along the palaeochannels is obtained from exploratory wells drilled by CGWB. The water level ranges from 15 to 37 m below ground level (bgl) in parts of Haryana, 30 m bgl to 60 m bgl in palaeochannels of Rajasthan and more than 90 m bgl in parts of Gujarat. However, these are the water level data at the time of construction of Exploratory Tubewells. The depth to water level during Pre-monsoon season (May), 2016, (Figure 5.2a) in major parts of the area covered by palaeochannels more than 10 m below ground level (bgl). Shallower ground water level (less than 10 m bgl) are observed in the in parts of Patiala district, Punjab, Yamunanagar, Mansa, Hissar, Fatehabad, Bhiwani, Sonapat, Panipat, Rohtak, Faridabad and Sirsa districts of Haryana, Sri Ganganagar and Hanumangarh district of Rajasthan and Banaskantha, Patan, Kachchh, Surendranagar and Rajkot districts of Gujarat.

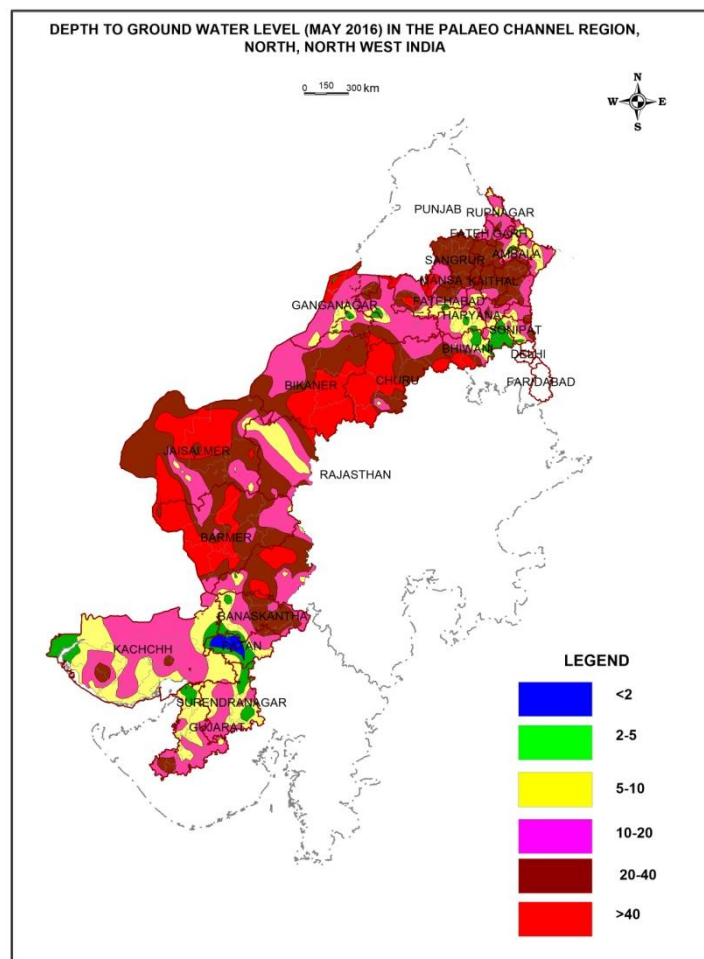


Figure 5.2a. Depth to Ground Water level Map (Premonsoon - May, 2016)

The depth to water level during post-monsoon season (November, 2015) (Figure 5.2b) in major part of Rajasthan, Punjab and Haryana is more than 10 mbgl. However, in southeastern Rajasthan including parts of the districts of Pratapgarh, Dungarhpur, Sawai Madhopur, Bundi, Kota, Baran, Chittorgarh, Jhalawar, Udaipur as also in Sri Ganganagar and Hanumangarh districts in the north Rajasthan, the water level is mostly within 10 m bgl. Similarly, in parts of Patiwala district in Punjab, Yamunanagar, Kaithal, Hissar, Fatehabad, Jind, Panipat, Sonopath, Rohtak, Bhiwani and Sirsa districts of Haryana and Banaskanta, Patan, Mehsana, Surendranagar, Rajkot and Kachch districts of Gujarat, the water level is generally within 10 mbgl.

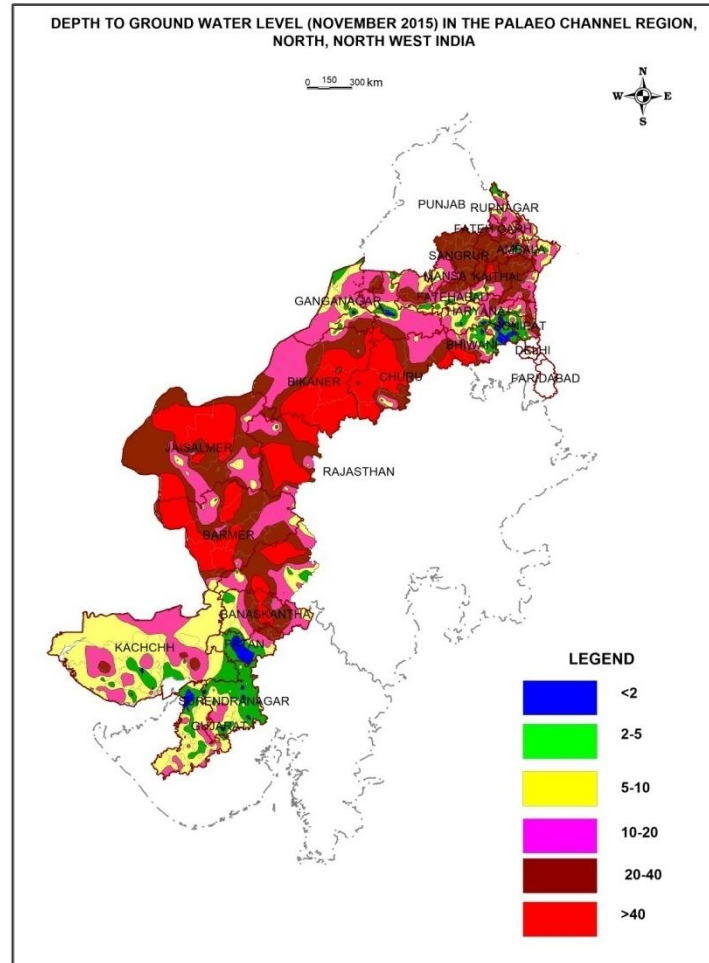


Figure 5.2b Depth to Ground Water level Map (Post monsoon - November, 2016)

Ground water Quality along palaeochannels

Hydrogeological data (yield, water quality etc.) obtained from different wells in northern Haryana have been analyzed. Electrical Conductivity (EC) zoning pattern of the area shows that most of the demarcated palaeochannels lie in lower EC zone (2000-4000 $\mu\text{S}/\text{cm}$), 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 ($>4000 \mu\text{S}/\text{cm}$).

Isotopic studies of ground water in Kurukshetra region were carried out for Oxygen-18 and Deuterium isotopes. Except one sample, most of the samples have $\delta^{18}\text{O}$ in the order of $6.5 \pm 0.75\text{‰}$. One deep well sample showed highly depleted isotope value, $\delta^{18}\text{O} : -9.0 \text{‰}$ indicating probable origin from higher altitudes.

Ground water Exploration carried out in the palaeochannels in western Rajasthan reveals the presence of fresh groundwater in a linear NE-SW extension surrounded by

comparatively saline water on either side. Also, it has been observed that groundwater quality starts deteriorating beyond the depth of 100m. The RRSSC, Jodhpur has demarcated eight areas where signature of palaeochannels exists in Western Rajasthan. The Dhamri Khu, Kishangarh, Kuria Beri and Ranau area represents fresh water zone. In southwestern part, a small area in Ghotaru-Asutar zone, the ground water quality is good but restricted upto a depth of around 100m.

The isotopic composition (H^3 , O^{18} and C^{14}) of 17 ground water samples from the existing wells along the palaeochannels in Jaisalmer district of Rajasthan were analysed by the Bhabha Atomic Research Center (BARC), Mumbai follows Pearson model. The analysis indicates the variation in ground water ages from 1340 to 18880 BC at different localities from NE to SW (Rao and Kulkarni, 1997; Nair et al., 1999). Hence, the age analysis of water samples indicate towards a palaeo source of water along the channels that may be linked to Ghaggar (Saraswati) palaeochannels (Figure 5.3). The shallow (>30m) and deep (>60m) groundwater along the palaeochannels have similar chemical and isotopic characteristics and do not have isotopic signature of the present day Himalayan Rivers. Based on the relative radiocarbon ages, the ground water movement (velocity) along the palaeochannels has been estimated at 5m/yr.

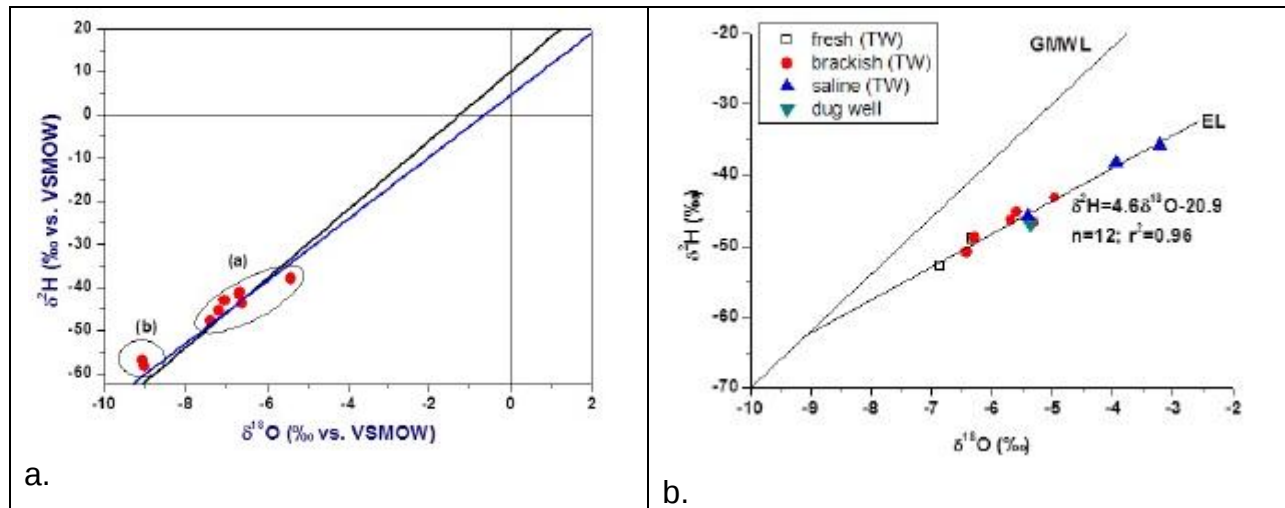


Figure 5.3. δ^2H vs $\delta^{18}O$ plot of ground water samples,
(a) Kurukshetra palaeochannels, Haryana and
(b) Jaisalmer Palaeochannels, Rajasthan

Availability of Ground Water in the Palaeochannels

As per the estimate given in the interim report of the Committee on 'Exploration of Alternate Source of Water in Arid Areas of Country including Palaeochannels', 2016, the average cross sectional area of the stretch of the palaeochannel in Haryana is approximated as 3000 m². Based on the disposition of the average water level, water

available in the channel fills has been estimated as 143 mcm. Out of this, 108 mcm is dynamic (annually replenishable) resource and the remaining 35 mcm is In-storage ground water resource.

Average of width of the channel in Rajasthan has been taken as 300m. Depth of the palaeochannel as deduced from exploratory drilling and geophysical soundings is nearly 45m. Average cross sectional area of the stretch of the palaeochannel in Rajasthan is approximated as 6750 m². Water available in the palaeochannel in the Northern part of Rajasthan is approximated as 204 mcm, of which 153 mcm is estimated as dynamic (annually replenishable) resource and the remaining 51 mcm as static resource.

Regional ground water resources assessment in palaeochannel region, North West India

Since the entire area under reference is underlain by unconsolidated alluvium, which forms potential aquifers, there is significant exploitation of ground water as is amply reflected in the assessment of dynamic ground water resources carried out jointly by CGWB and State Departments. Moreover, because of paucity of rainfall, ground water recharge is also less in the Western part of the area covering the States of Rajasthan and Gujarat and Western Part of Haryana. This has resulted in stress on the replenishable ground water resources of many places and long term decline of ground water level in the region (Figure 5.4).

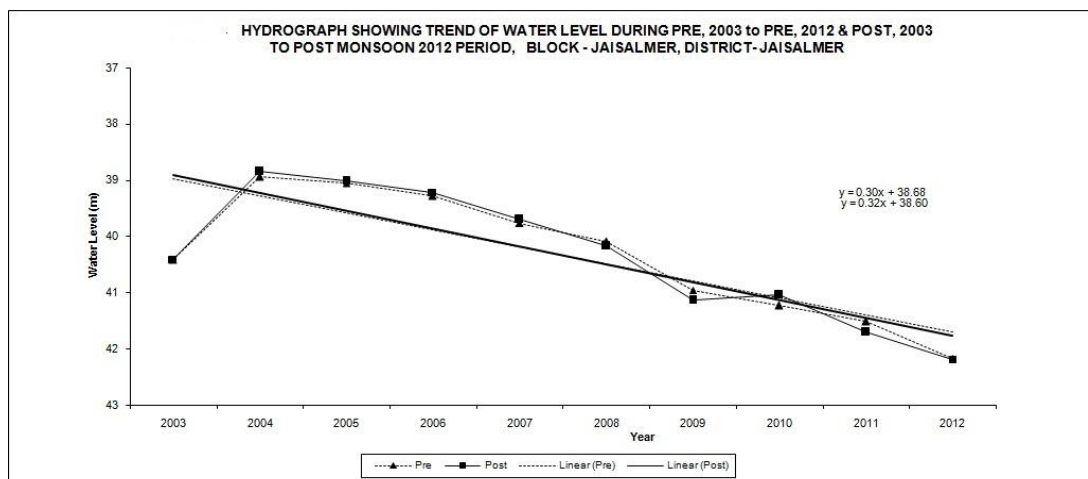


Figure 5.4 Average long term water level trend, Jaisalmer block, Jaisalmer district, Rajasthan

Categorization of ground water assessment units carried out jointly by State Ground Water Department and Central Ground Water Board (Figure 5.5), amply reflects the ground water stressed condition in North West India. Most of the blocks in the region are either 'Over-exploited' where annual ground water withdrawal has exceeded the

annual ground water recharge or 'Critical' where annual ground water withdrawal is more than 90% of annual ground water recharge.

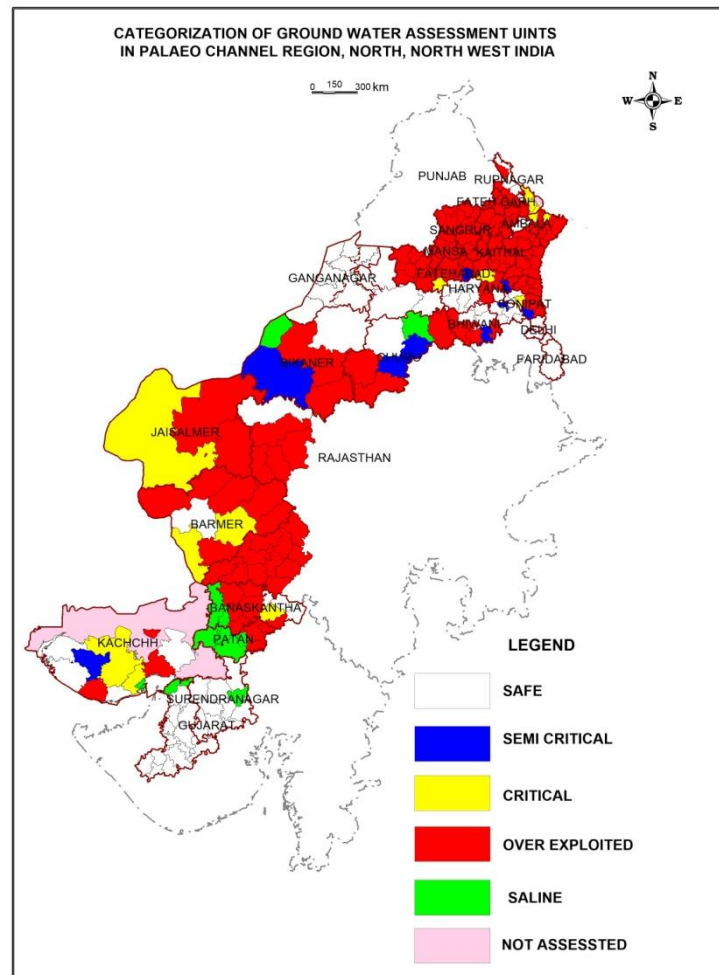


Figure 5.5. Categorization of Ground Water Assessment units in the palaeochannel region, North-West India

Palaeochannels as Storage Reservoir for Artificial Recharge

As is evident from the discussions in the previous paragraphs, the major part of North West India suffers from over-exploitation of ground water resources and as a result the ground water level is declining at a significant rate in these regions. It is therefore imperative that the ground water resources of the region need to be augmented through artificial recharge to ground water.

The committee on Exploration of Alternate Source of Water in Arid Areas of country including palaeochannels in its interim report, 2016 has given a preliminary estimate of the artificial recharge potential in the palaeochannel region in North West India. The state-wise estimate is enumerated in the following paragraphs.

The volume of water that can be artificially recharged is 177 mcm in Haryana. Non-committed surface water resources can be utilized for artificial recharge in these areas. In the Jaislamer area of Rajasthan the water levels are very deep and the entire channel-fills in the palaeochannel remain perennially unsaturated. While, a total volume of 256 mcm can be artificially recharged in the northern stretch, in the western stretch, 580 mcm can be recharged. This area being part of the arid region, surplus surface water availability is either non-existent or very limited. The total length of the probable palaeochannel in two stretches in Gujarat is 494 km. The average cross sectional area of the stretch is approximated as 3500 m². Since the water levels are deep, the channel fills remain perennially desaturated. A volume of 45 mcm can be artificially recharged.

CGWB in an initial assessment has estimated that considering the volume of unsaturated zone available in the palaeochannels and the aquifer characteristics of palaeochannel deposits in Haryana, Rajasthan and Gujarat, about 1058 million cubic meter of water can be recharged artificially in those identified palaeochannels (CGWB, 2015). The details are given in table 5.1.

Table 5.1 Estimated availability of ground water and potential for artificial recharge of the palaeochannels in parts of Haryana, Rajasthan and Gujarat in India (Report of the Committee on Exploration of Alternate Source of Water in Arid Areas of Country including Palaeochannels – Interim Report, 2016)

Sl. No.	State	Artificial Recharge Potential (million cubic metre)
1	Haryana	177
2	Rajasthan	836
3	Gujarat	45
	TOTAL	1058

The preliminary assessment presented in table 5.1 needs to be further refined based on detailed field studies.

CHAPTER 6

Linkage of Palaeochannels with An Ancient River of Significance:

The Palaeochannels through which Flowed a Large Himalayan River

A Misfit River

Through Haryana, southern Panjab and Rajasthan passes a misfit river having an anomalously wide valley but with little or negligible water. Called Ghaggar in Haryana and Rajasthan and Hakra in Bahawalpur (Cholistan) across the border in Pakistan (Figure 6.1A), the channel of the misfit river all through the vast spread of the floodplain is 6 to 8 km wide on the average and as much as 10 km in some reaches (Figure 6.1B).

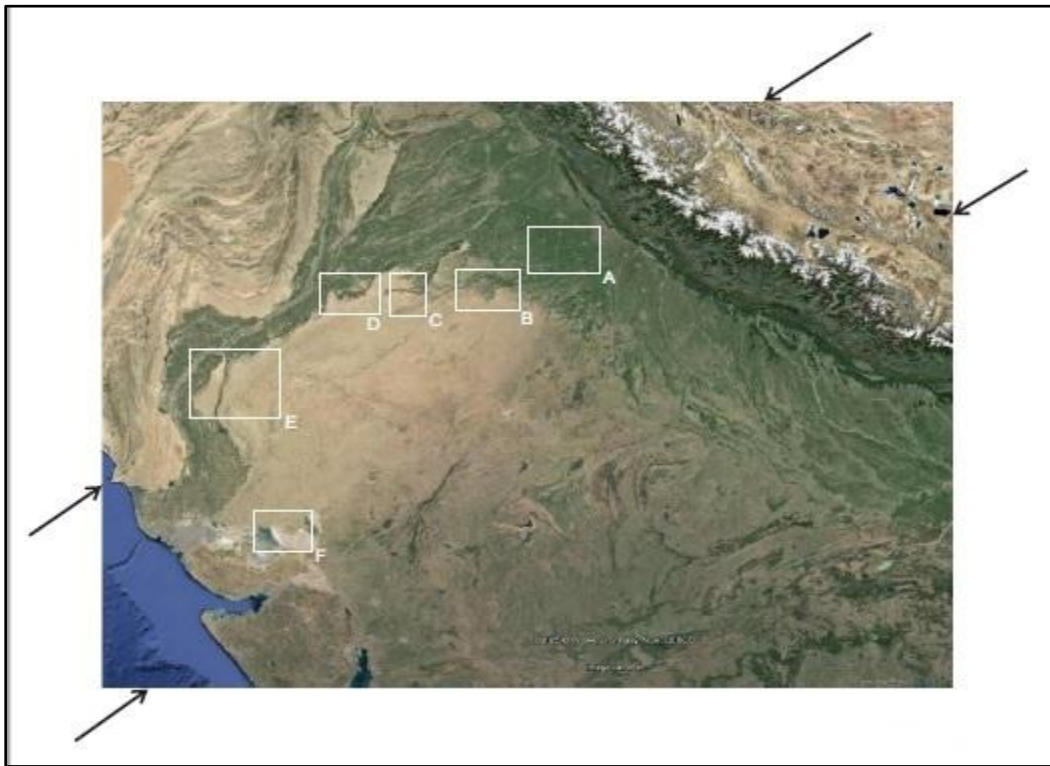


Figure 6.1A. Map shows the location of areas along the Ghaggar–Hakra–Nara water course where convincing evidence of a large river flowing through it in the ancient times have been found. Rectangles show the locations of the figures discussed. A – Figure 6.3, 6.4, 6.5 and 6.6, B – Figure 6.7, C – Figure 6.8, D – Figure 6.9, E – Figure 6.10 & 6.11 and F – Figure 6.12



Figure 6.1B. What are petty streams in the foothills of the Siwalik Hills (such as the Sarsuti, Markanda, Ghaggar, Patiali, etc.) join to become an extraordinarily wide water course marked by moist sediment supporting vegetation of the Ghaggar as this satellite image brings out. Notice that the Ghaggar breaks up into two channels before disappearing into the sands of the Thar Desert. The northern channel gives way to the Hakra in Bahawalpur (Cholistan, Pakistan) [Landsat ETM + FCC mosaic].

The banks of this practically waterless channel are dotted densely with ruins of settlements of the Harappan Civilization ~ 5000 yr B.P. to 3300 yr B.P. ago (Figure 6.2).

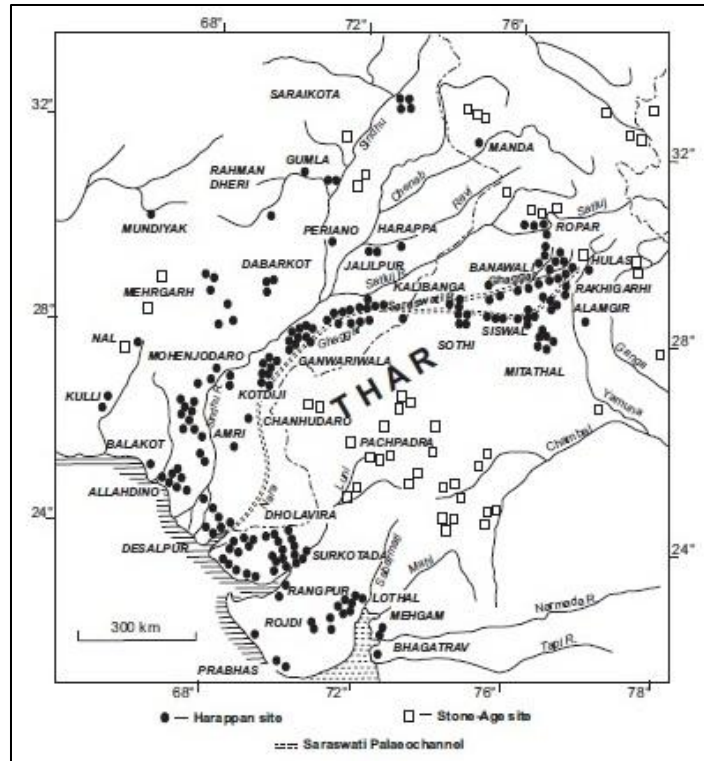


Figure 6.2. The broadly linear pattern of the distribution of the Harappan settlements (older than 5500 yr B.P. to about 3300 yr B.P.) coincides with the now waterless, sand-choked, extraordinarily wide channel of the Ghaggar–Hakra–Nara [From Valdiya, 2002].

Detailed and extensive studies of archaeologists (Ghosh, A., 1952; Bhan, 1972; Lal, 1979, 1997, 2002; Thapar, 1971, 1975; Bisht, 1978, 1982, 1984, 1991, 1997, 2000, 2013; Mughal, 1974, 1984, 1995; Shinde, 2008) on the pattern and density of distribution of these settlements numbering nearly 2378 and including large cities such as Bhirrana, Banawali, Kalibangan, Ganweriwala, Dholavira (and also Rakhigarhi) on the banks of the uncommonly broad channels as well as others associated with it, lead to the unequivocal surmise that these channels were once the water course of a large river having discharge enough to meet the needs of the very progressive and vibrant Harappans who lived with a style (Figure 6.2). Amazingly, these people chose to cling to these banks for over four thousand years. Unless water coursed adequately through these channels round the year, the people would not have preferred to live there. For, the rainfall drastically diminished since ~4800 yr B.P. (Enzel et al., 1999) and the people had only the river water or the ground water to depend. The implication is that there was a large river flowing through its extraordinarily wide channel in the time (~ 5000 to 3300 yr B.P.) the Harappan lived and prospered.

That river disappeared in the later Holocene time. The wide channel of the Ghaggar-Hakra and its tributaries, the many palaeochannels, abandoned channels and

buried channels in the floodplain need to be studied to find clue to the question what caused the disappearance of this large river.

Testimony of Fluvial Fans in Foothills

In the belt of the upper reaches of the Ghaggar-Hakra, thick pile of fluvial (riverine) sediments spreading 25 km down south from the Siwalik Hills front (Figure 6.3).

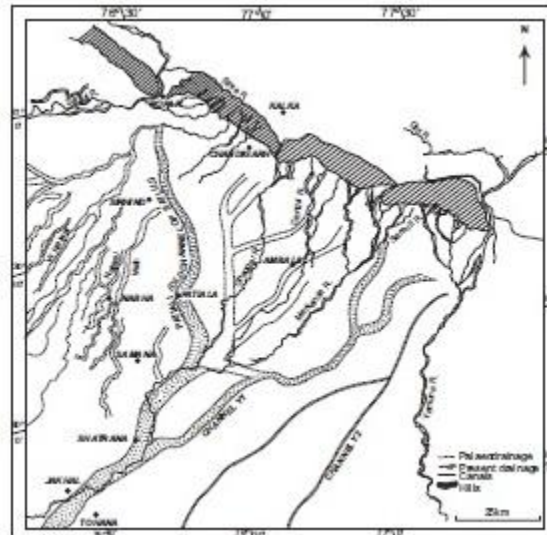


Figure 6.3. The misfit rivers or rivulets having very wide channels but little flowing water, and the palaeochannels in northern swathe of the western Indo-Gangetic Plains, just south of the foothills of the Siwalik Hills. [After Yashpal et al., 1980]

A digital elevation model reconstructed from SRTM and ASTER satellite data followed by detailed fieldwork in the domains of the present-day Wah, Patiali, Ghaggar, Markanda and Sarsuti rivulets between the rivers Yamuna in the east and the Satluj in the west revealed a large sediment pile described by Mukerjee (1971) as Terminal Fan. Sloping southwards, this geomorphological feature is characterized by diverging palaeochannels abandoned by rivers. Remarkably, this area exhibits highest drainage density anywhere in the basin (Srivastava et al., 2006). Analysis of data from 243 wells spread over the area formed in front of the points of entry onto the plains of the rivers Satluj and Yamuna demonstrates features that indicate the past geomorphology (Figure 6.4A) and past condition of sediment deposition remained consistent all through the long time from at least 150 ± 11 ka B.P. to about 6.4 ± 0.4 ka, when nearly 200 m of sediments were laid down (Djik et al., 2016). Not only that, the sediments of the palaeofan of the ancient Satluj down to the depth of 40 to 50 m contains silicates characterized by strontium ratio $^{87}\text{Sr}/^{86}\text{Sr}$ varying from 0.7365 to 0.7783 and neodymium ratio $\epsilon^{144}\text{Nd}/^{143}\text{Nd}$ -14.6 to -19.07, indicating that the sediments were derived from the

rocks that make up the snowy (Figure 6.4B) Great (Highest) Himalaya as well as the Lesser Himalaya — far north of the Siwalik Hills (Singh et al., 2016). The implication is clear — the river that laid down this subsurface deposit originated in the Himalaya.

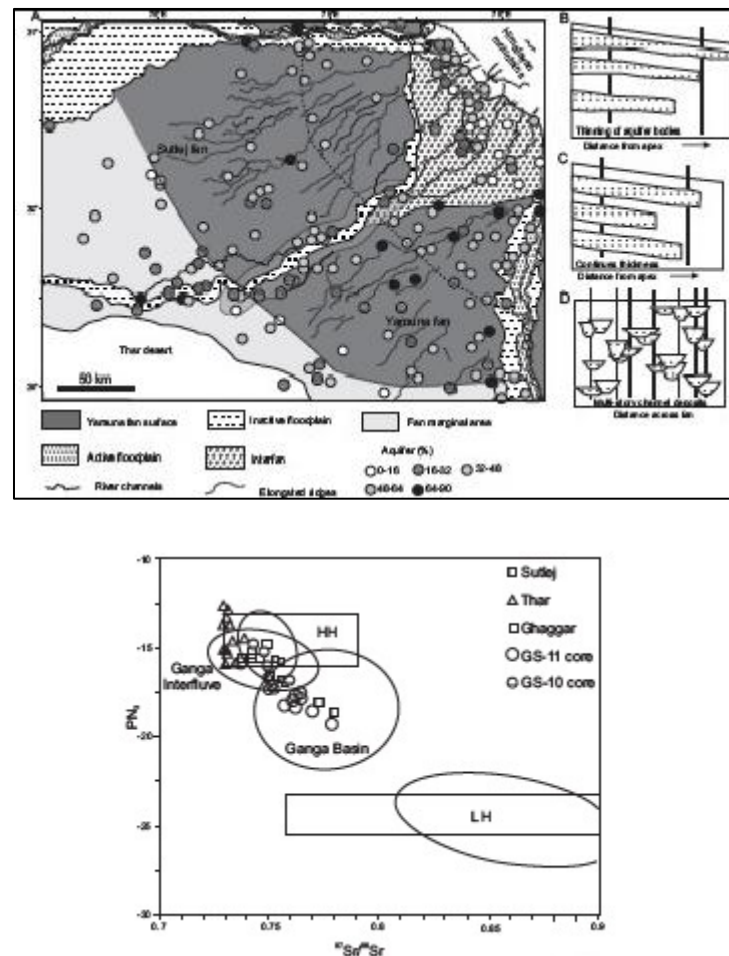


Figure 6.4 (A) Recent comprehensive studies revealed that the foothill belt of Figure 6.3 represents the coalescing fluvial fans of two Himalayan rivers — the Satluk and the Yamuna. [Dijk et al., 2016]

(B) Isotopic studies of the sediments of the Satluj Fan indicates derivation of the silicates in the sediments from the Great Himalayan and Lesser Himalayan rocks lying far north of the Siwalik Hills [Singh, Ajit et al., 2016].

An earlier very comprehensive geo-electrical study across the very crucial segment of the Satluj Fan, embracing the Patiali and the Ghaggar rivulets had revealed large-scale geometry of a palaeochannel system adjacent to the Harappan sites (Figure 6.5) (Sinha et al., 2012).

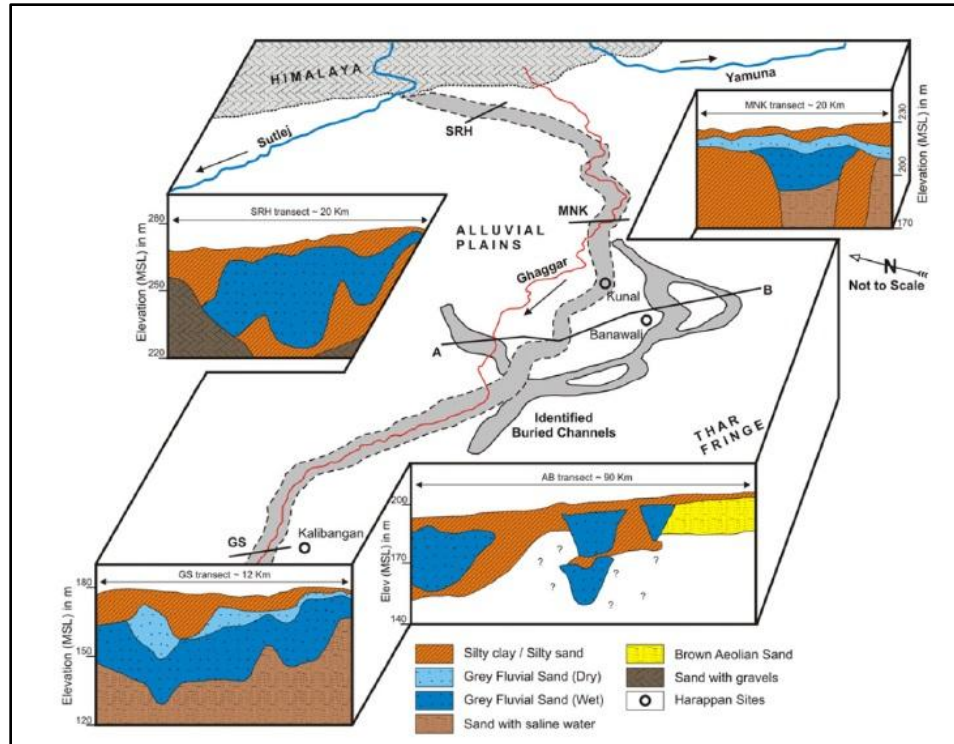


Figure 6.5. The western fluvial fan designated as the Satluj fan by Dijk et al. (2015) comprises abandoned and buried channels filled with thick and extensive deposits of sediments that only a large river could have emplaced [From Sinha et al., 2012].

This system is represented by a thick subsurface sand body more than 12 km long and 30 m thick, obviously **“the deposit of a large river”** (Sinha et al., 2012). The abandoned palaeochannel that descends southwards from the spectacular knee-bend of the Satluj at Ropar is filled with 40 to 50 m thick column of sediments overlying gravel beds. The river that deposited the voluminous amount of sediments must have been large (Sinha et al., 2012). That large river could not but have been the Satluj, springing from the Kailas–Mansarovar region in Tibet and flowing through the Great Himalayan and the Lesser Himalayan terranes (Valdiya, 2002, 2013, 2016). Interestingly, in the satellite image this palaeochannel belt is unmistakably related to the subsurface sand body. This fact establishes beyond doubt that the palaeochannel complex is indeed the work of “a long-lived fluvial system” (Sinha et al., 2012).

East of the Satluj Palaeo fan, and coalescing with it is the sedimentary deposits in the larger Yamuna domain (van Dijk et al., 2011) formed in front of the points of entry onto the plains of rivers Yamuna and Markanda (Figure 6.4A).

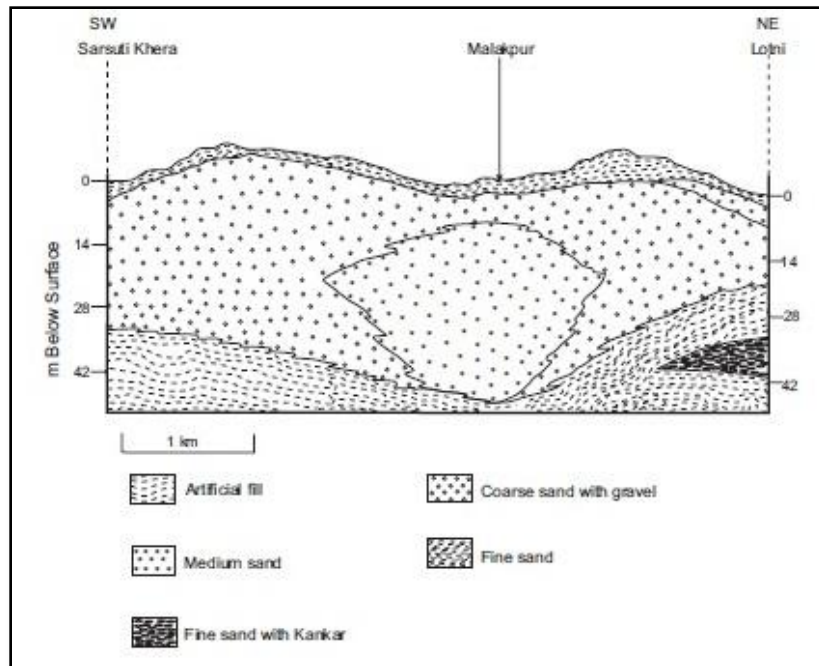


Figure 6.6. The eastern fluvial fan designated by Dijk et al., (2011) as the Yamuna fan and encompassing the domains of the Markanda and the Sarsuti rivulets is represented by a thick sand body of wide lateral extent [From Kshetrimayum and Bajpai, 2011]

From the study of the geomorphological architecture and sand bodies (aquifer), vertical resistivity sounding together with interpretation of satellite IRS-1D LISS-IV imagery, it is apparent that the water-bearing sand bodies at the depth of 10 to 100 m with average thickness of 90 m, and extending 12 km laterally and another sand body (aquifer) at the depth of 45 to 148 m, hydraulically connected the buried channels of the Markanda and the Sarsuti rivulets (Figure 6.6). implying intimate affinity of the two rivulets (Kshetrimayum and Bajpai, 2011) This belt of buried channels and misfit streams is also associated with the Late Harappan settlements (3900–3300 yr B.P.). In other words, the Markanda–Sarsuti domain was a populated tract in the later Holocene time.

The large volume of sediments in the domains of the Markanda and Sarsuti rivulets could not have been built by the presently petty river Markanda originating in the Nahan area within the Siwalik terrane and/or by the much smaller stream Sarsuti springing near Adibadri in the foothill of the Siwalik. A large river deposited the sediments making what van Dijk et al. (2016) call the Yamuna Fan (Figure 6.4A).

The finding of pebble-size rounded clasts of such metamorphic rocks as quartzites, sericitic quartzites, phyllites, schistose phyllites, etc. in the fluvial terrace near Adibadri in the Sarsuti catchment (Puri, 2008) and very similar rounded clasts of

metamorphic rocks at Sudanwala and Garibnath in the anomalously wide valley of the stream, the Bata (Puri and Verma, 1998) **connects the Sarsuti to the Bata that meets the Yamuna River near Paonta Sahab**. The Yamuna River originates at the foot of the Bandarpunch mountain in the Great (Higher) Himalaya largely made up of metamorphic rocks. The Yamuna's larger branch with higher water discharge is the Tons River springing from the Harkidun Glacier in the Great Himalayan domain (Valdiya, 2002, 2013, 2016). It seems logical to surmise that once the Yamuna (with water from the Tons) flowed through the wide channel now represented by the Bata and descended onto the plains at Kala Amb to take the courses represented by the Sarsuti and the Markanda (Valdiya, 2002, 2013). The thick and extensive subsurface sand bodies at the depths of 10 to 100 m and 45 to 148 m — the deeper ones hydraulically connected to the Markanda and the Sarsuti channels Fig.6.6 (Kshetrimayum and Bajpai, 2011) — provide evidence in support of this surmise.

If the above surmise is correct — it does seem plausible — the southwest-flowing *ancient* Yamuna met the then southward descending *ancient* Satluj at Shatrana 25 km south of Patiala where the Ghaggar channel abruptly becomes 6 to 8 km wide — and remain as wide or even wider all though its middle reaches upto the margin of the Thar Desert.

Imprints in Floodplains of Middle Reaches

The channel of the Sarsuti River at Bhor Sayidan, 13 km west of Kurukshetra, is more than 2 km wide. The upper sequence of very thick fluvial sand body, made up of seven cycles of sediments exhibiting fining upwards sequence over a range of 90 to 110 m contains 3375 year-old fragments of Painted Grey Ware Pottery (Chaudhuri et al., 2008).

Analysis of a number of subsurface lithological data collected from exploratory bore holes and dug wells by Central Ground Water Board, coupled with geophysical investigation and extensive fieldwork in the Ghaggar floodplain between Tohana and Ellenabad (Figure 6.7) revealed existence of multi-channel multilateral systems of a **strong fluvial regime** (Saini et al., 2009).

(Singh et al., 1988). Significantly, a 5 to 15 m thick **column of micaceous sands of Himalayan origin** occurs below the silty-clayey sediments (Saini and Mujtabad, 2011). Heavy minerals such as tourmaline, ilmenite, greenish brown amphibole, garnet, kyanite and sillimanite (Saini et al., 2009) in this sand corroborates the inference that the sediments were brought by a river that originated in the Himalaya. The OSL dating of sandy unit shows the age varying from 26 ± 2 ka — 21 ± 12 ka to 5.9 ± 0.3 — 2.9 ± 0.2 ka (Saini et al., 2009). While the major fluvial activity lasted until about 15 ka, the younger phase (6 to 3 ka) of the river flow was related to a smaller drainage identified by Yashpal et al. (1980). The obvious deduction is that there were rivers still flowing and depositing sediments until the Late Harappan time (3900 – 3300 yr B.P.).

The more than 20 m thick channel-fill between Kaithal and Sirsa (Figure 6.8) deposited in six stages, beginning prior to 40,000 yr upto 2,500 yr (Courty, 1995).

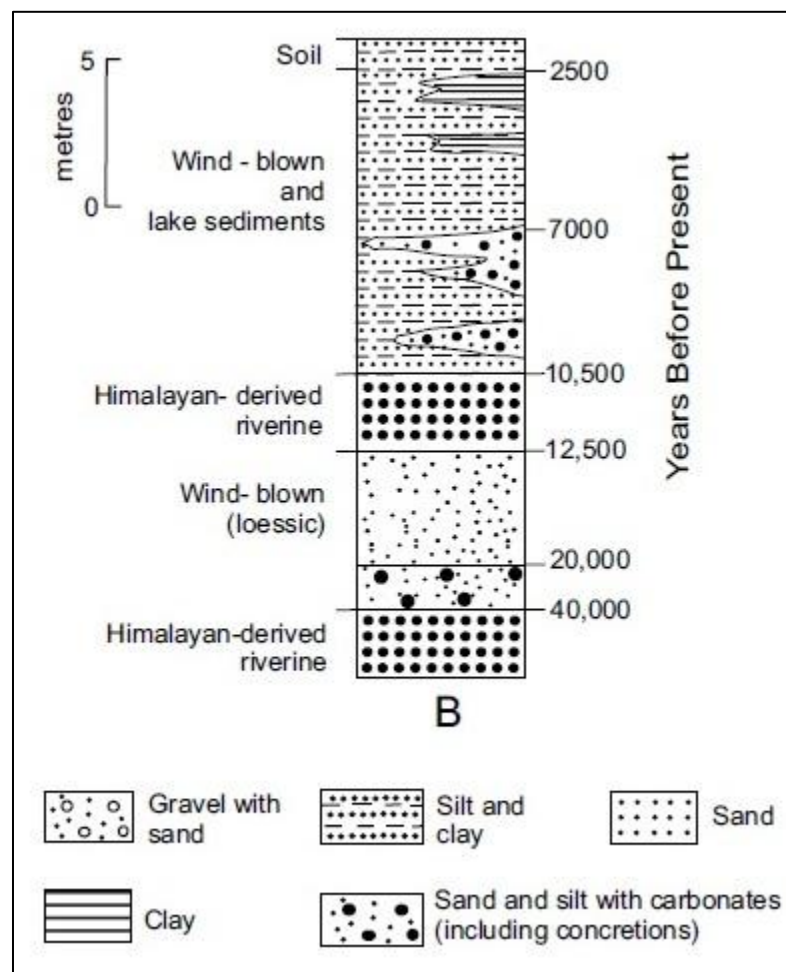


Figure 6.8. Column of sediment succession in the palaeochannel at an area between Kaithan and Sirsa shows presence of Himalayan-derived sediments deposited 10,500 to 12,500 years ago [After Country, 1995]

The column in the Sirsa area includes more than 10 m thick band of grey *sands derived from the Himalayan source* (Courty, 1995). This column is capped in the last 5 ka to 2.5 ka period by wind-borne loessic deposit. In the desert these sediments have been reworked to sand dunes.

Further downstream near Kalibangan about 10 m below the horizon of mud and silt, the carbonate-bearing micaceous sand dated 9.7 ka to 5 ka by OSL method, is characterized by $^{87}\text{Sr}/^{86}\text{Sr}$ value more than 0.76 and the ϵNd value -19 to -17 **implying derivation of the sediments from the Great (Higher) Himalayan rocks**, the river depositing its load until about 5000 years ago.

Signatures in the Desert Terrain

Further downstream in the west the Ghaggar disappears under the sands of the Thar Desert. However, across the India–Pakistan border in Cholistan (Bahawalpur region) a 2 to 6 km wide channel in floodplain river is recognizable amidst desert sands. They call it by the name of Hakra. This tract is dotted with dense settlements of the Harappan Civilization (Mughal, 1974, 1984, 1995).

Among the settlements is Ganweriwal, (Fig.6.2) the second biggest metropolis of the time. About 5 m below the Hakra bed the 100 m thick sand body in the Fort Abbas reach point to its **deposition by a large perennial river** (Mughal, 1995). The U-Pb zircon dating demonstrates that the channel was active until about 4500 years B.P. (Clift et al., 2012). Samples of sediments close to the archaeological sites show **similarities with the sediments of both the Beas and the Satluj rivers in the west and the Yamuna River in the east** (Clift et al., 2012). Giosan et al., (2012) concede that **the Yamuna may have contributed sediments to the Hakra before the Mature Harappan time**, for they recovered 5300-year old sandy flood deposit at Fort Abbas. In other words, there are tell-tale evidence of the Himalayan rivers Satluj and the Yamuna flowing through the channel of the Ghaggar–Hakra until the Harappan times (Valdiya, 2016).

There is yet another legacy of a large river having ample discharge. Between Fort Abbas and Fort Mojgarh a number of tubewells have brought out potable water from the subsurface 100 m-thick aquifer (Figure 6.9), the water giving the radiocarbon dates from 12,900 yr B.P., to 4700 yr B.P. (Geyh and Ploethner, 1995).

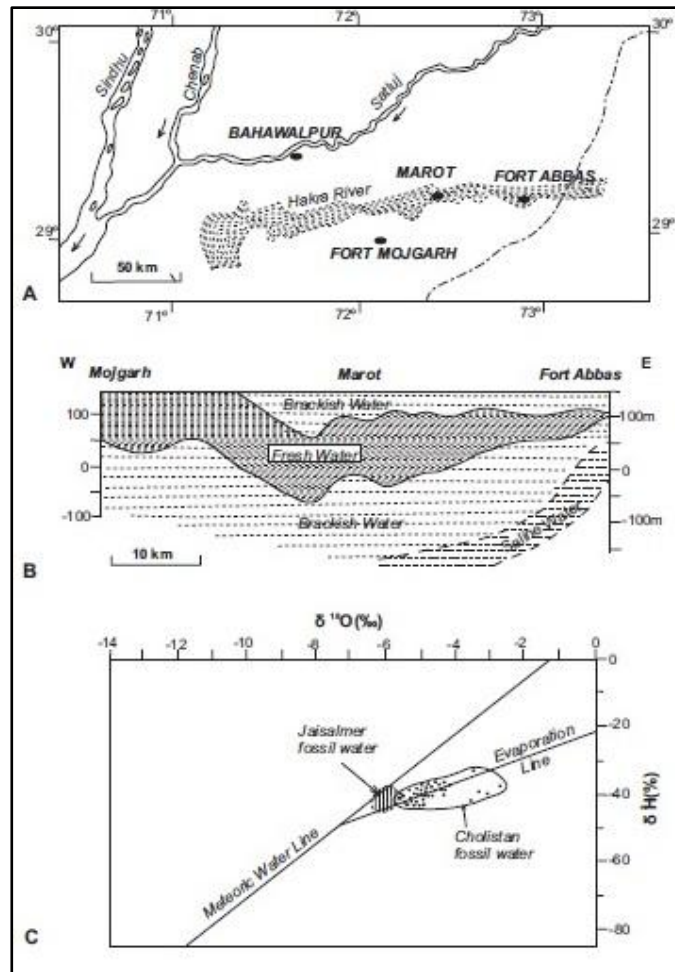


Figure 6.9. (A) Across the India–Pakistan border the Hakra channel in Bahawalpur (Cholistan)

(B) Cross section shows a thick and wide sand body replete with potable fossil water characterized by absence of tritium

(C) Geochemistry of palaeochannel water [After Geyh and Ploethner, 1995].

Importantly, this sweet water is devoid of tritium, an isotope of hydrogen. This implies that the subsurface sweet water is not a rainwater that seeped down through recharge. It is indeed a fossil water lying trapped within the confines of the 100 m-thick sand body in the palaeochannel of the river that flowed through it until about 4700 years ago.

Interpretation of satellite images of the Jaisalmer terrain in the heart of the Thar Desert reveals interlinking palaeochannels (Kar and Ghose, 1984; Kar, 1988; Ramasamy et al., 1991; Sahai, 1999; Gupta et al., 2004, 2008, 2011). Radar penetration of dry sands showed sensitivities of subsurface moisture that characterize these channels, and suggest underground active flow in this rather disorganized drainage system (Rajawat et al., 1999). Electrical-conductivity surveys for the search of

underground water established presence of palaeochannels replete with water (Kar, 1999; Kar and Shukla, 2000) (Figure 6.10). These channels are parts of the Ghaggar-Hakra system of water courses. Deep tube wells in this belt struck remarkably sweet water at depths of 30 to 50 m and 60 to 250 m below surface. Hydrogen-oxygen isotope chemistry of the underground water shows negligible presence of tritium, implying that it is not the recharge-related rainwater that seeped down and got trapped. On the contrary it is the water that lay in the palaeochannels (Figure 6.11) (Nair et al., 1999; Rao and Kulkarni, 1997). Radiocarbon dating showed that the water at the depth 30 to 50 m is 1800 to 5000 years old and at 60 to 250 depth 6000 to 22,000 years old (Nair et al., 1999). Elsewhere, the palaeochannel body at the depth of 50–60 m water gave the age of 1340 to 1850 years (Rao and Kulkarni, 1997).

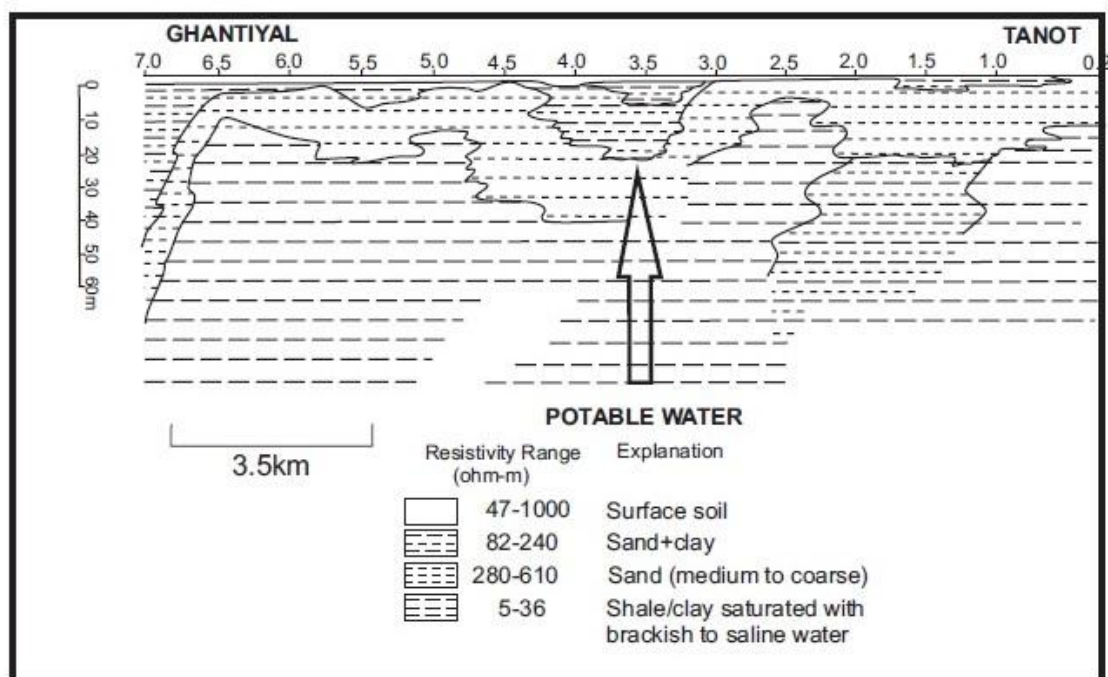


Figure 6.10. Geophysical investigation using Geo-electrical sounding reveals presence of large sand bodies within palaeochannels and containing sweet water in the western Jaisalmer – in the heart of Thar desert (from Kar and Shukla 2000)

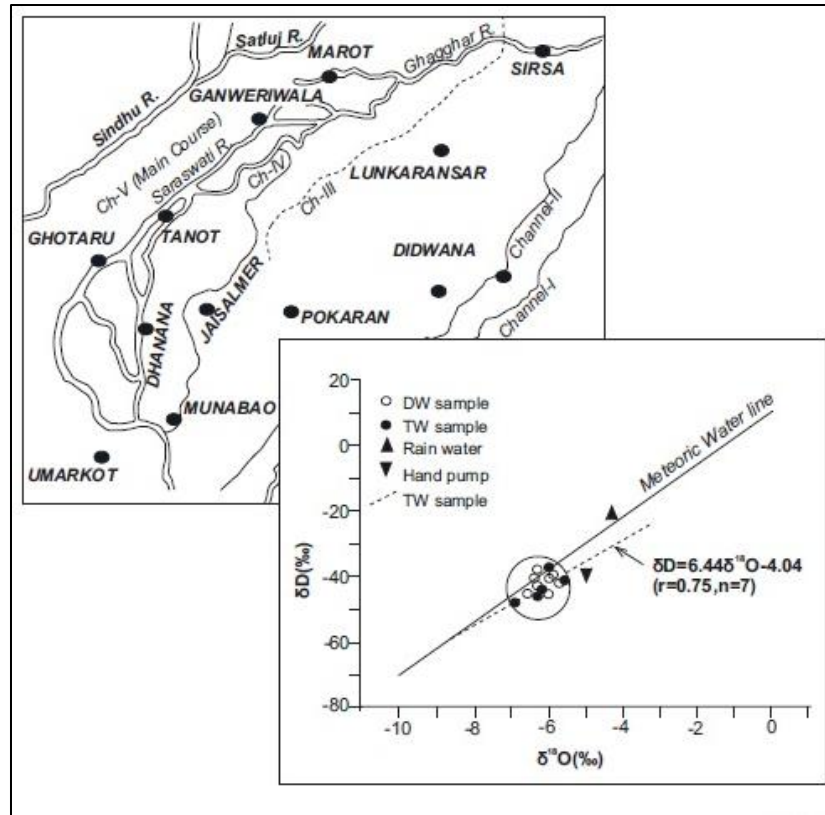


Figure 6.11. (A) Interpretation of IRS imagery revealed presence of a number of palaeochannels downstream (south) of the Hakra [After Gupta et al., 2008].

(B) Hydrogen-oxygen isotope chemistry of the underground sweet water in the palaeochannels shown above gives dates as old as 22,000 yr B.P. to 1,800 yr B.P. The negligible content of tritium suggests that is not the rainwater that seeped down and was trapped [After Nair et al., 1999].

It is evident that a large river flowed through the interlinking channels along the western border of the Jaisalmer division.

Features at the Terminus

The lower reaches of the Ghaggar–Hakra system of water courses is known as the Nara River. The Nara used to have flowing water even after 2200 yr B.P. and also in the interval 1200–1000 yr B.P. (Ngangom et al., 2012). The Nara ends against the flat expanse of the salt-encrusted tidal-flat deposits of the Great Rann of Kachchh which was once a part of a gulf of the Arabian Sea. This Rann gulf was navigable until the Arab conquest (Sivewright, 1907).

Satellite imagery clearly brings out a delta stretching southwards from the mouth of the Nara and characterized by a network of channels representing distributories now

filled with tidal clay and covered by vegetation (Figure 6.12) (Malik et al., 1999; Maurya et al., 2013). Digital processing of IRS P-6 AW IFS and Radarsat and SAR images of the Rann shows birds-foot pattern of drainage made up of inter-twined channels (Sharma and Bhadra, 2012). Presence of heavy minerals like rutile, zircon and hornblende besides biotite in the sediments of the belts (interfluvial between distributaries) suggest that a river coming from the Himalaya mountain laid them down before emptying itself in the gulf (Malik et al., 1999).

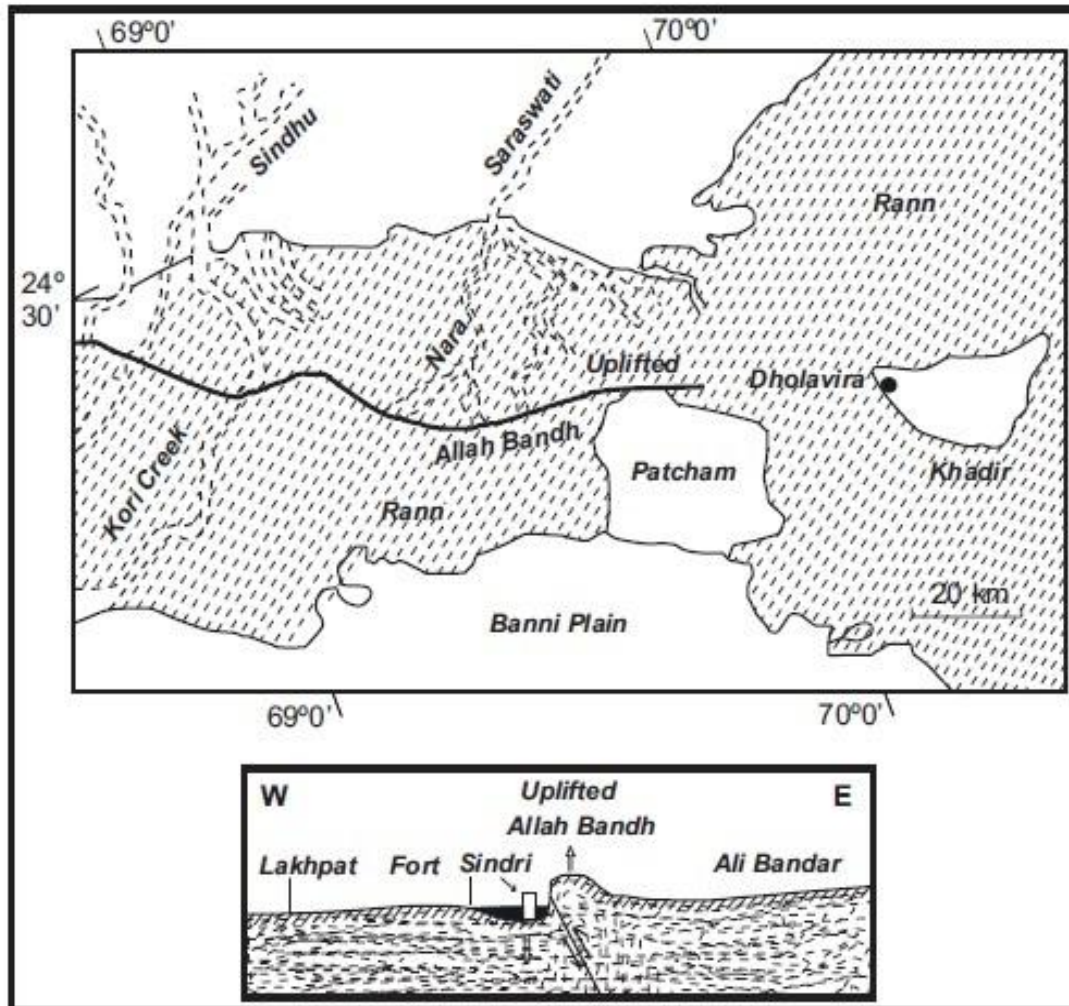


Figure 6.12. At its terminus, the Nara broke into a network of channels representing distributaries in a delta. The interfluvial-sediments between the distributaries contain heavy minerals, believed to have come from the Himalaya [After Malik et al., 1999].

Satellite Imagery:

Delineation of a System of Water Courses

Interpretation of satellite imagery processed by advanced digital enhancing techniques has vividly brought out a network of channels rather a system of water courses of a large river between the foothills of the Siwalik Hills and the Rann of Kachchh, the latter representing an arm of sea. Remote sensing specialists have used a variety of satellite images — Landsat MSS, TM and ETM, IRS P3 MW, FS, IRS P6 MW FS LISS-3 and LISS-IV, as well as Radarsat SAR (Ghose et al., 1979; Yashpal et al., 1980; Sood and Sahai, 1983; Kar and Ghose 1984; Kar, 1988, Bakliwal and Grover, 1988; Ramasamy et al., 1991; Sahai, 1999; Gupta, 2004, 2008 (Figure 6.13), 2011; Sharma et al., 2006; Bhadra et al., 2009; Sharma and Bhadra, 2012).

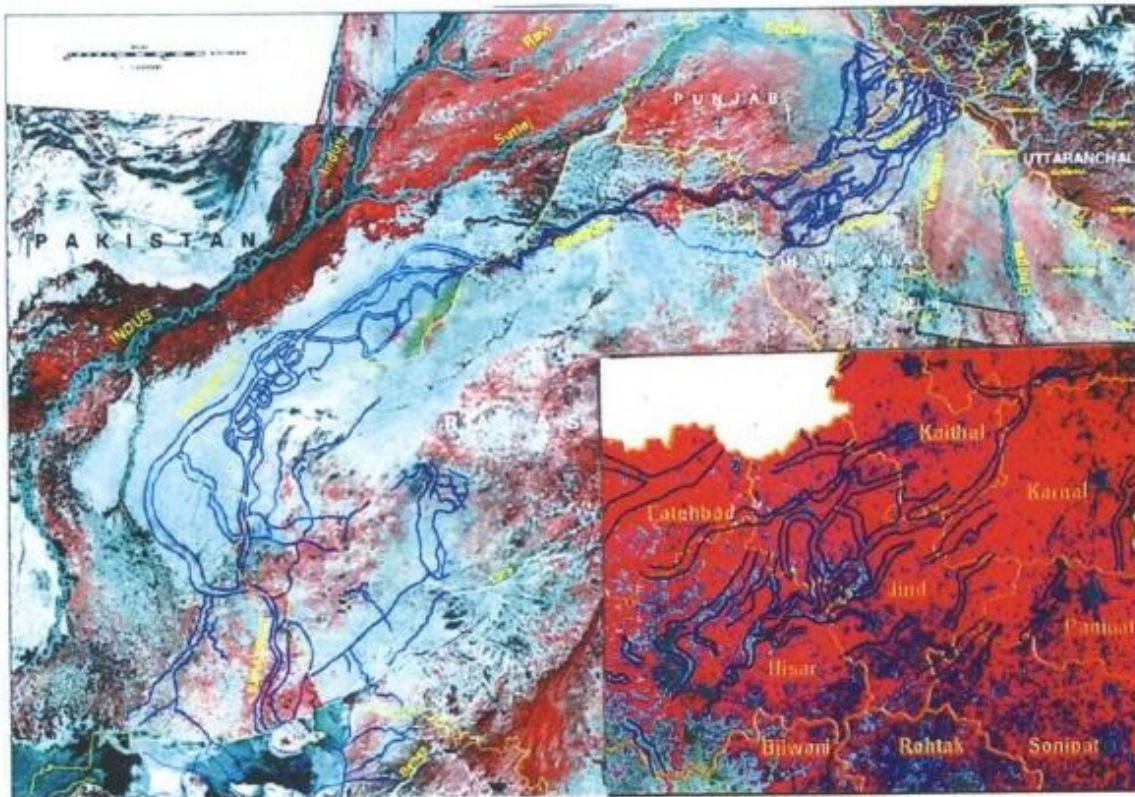


Figure 6.13. On the basis of interpretation of multi-resolution and multi-temporal satellite imagery, Gupta et al., (2004) reconstructed this picture of the large river between the foothills of the Himalaya and the Rann of Kachchh, the latter representing a gulf of the Arabian Sea now practically filled up by sediments [From Gupta et al., 2008]

As already pointed out, the channels thus delineated are associated with the Harappan settlements dated from about 9000 yr B.P. (Sarkar et al., 2016) to 3300 yr B.P. This intimate association implies that water flowed through these channels.

Identity of the Large Himalayan River

One of the oldest maps published in A.D. 1760 by Bryce, Collier and Schmitz — *Library Atlas* — depicts the river **Soorsuti** joining the **Guggur** in what was then the Punjab province (Danino, 2010). Needless to state, these are respectively the **Sarsuti** and the **Ghaggar** of today, spelt that way by the Britishers of yesteryears. The *Map of Hindoostan* published in 1788 by the Surveyor General of India, James Rennel, delineated by dotted lines the **Hankra**, the **Gaggur** and the **Sursooti**. It was the French geographer Vivien Saint-Martin (1860) who first stated unequivocally that the Sarsuti, the Markanda, the Ghaggar, the Chautang in Haryana, were the tributaries of the Vedic Saraswati. H.G. Raverty (1892), who had done extensive survey of the eastern Sindh and Kachchh, connected the Nara river to the Ghaggar and to the Sarsuti. Later, the geographer S.I. Siddique (1944) traced fairly continuously the Eastern Nara in Sindh to the Ghaggar upto Jakhar in Hisar district in Haryana. Another geographer Gurudev Singh (1952) identified the wide channel that stretches north from the Ghaggar to Ropar at the spectacular Satluj bend as the palaeochannel of this Himalayan river.

The explorer M.A. Stein (1942), who recognized clusters of prehistoric settlements on the bank of the 5–6 km wide dry channel of the Hakra in the Bikaner–Bahawalpur region, endorsed the popular belief of the local people that in the past there were ferry crossings across the 5 km wide river at Mathula in Bikaner and Minar Pattanmunara in Bahawalpur. Stein regarded the Hakra channel as the true Saraswati and the Walhar channel as the Satluj (Danino, 2010).

The British archaeologists Mortimer Wheeler (1968) and Bridget Allchin and Raymond Allchin (1993, 1996), the American archaeologists Gregory Possehl (1999) and J.M. Kenoyer (1998), the French archaeologist Jean Marrie Casel (1969), the Pakistani archaeologist A.H. Dani and the German archaeologist H. Wilhelmy (1969) all described the Ghaggar–Hakra channel as representing the water course of the Vedic Saraswati. Wilhelmy (1969) pointedly stated that the Vedic Saraswati of the Himalayan origin flowed through the Ghaggar and was met with the Vedic Satluj at Bhatner in the Hanumangarh district, and that its other tributary was Proto-Yamuna that flowed through the Chautang Nala and joined the Saraswati near Suratgarh.

Geologists R.D. Oldham (1886) of the Geological Survey of India, and C.F. Oldham (1893) in the British Army asserted that the lost river of the Indian desert was none other than the Sarsuti, whose one branch was the Yamuna and the other the Satluj. C.F. Oldham (1893) emphatically stated that the river marked as **Gaggur** in

maps was formerly called Saraswati, and that this name is still known amongst the people. This river flowed through the Jaisalmer–Bahawalpur region and then through the Nara channel.

Earth scientist R. Raikes (1964, 1969) found in the Ghaggar floodplain at the depth of 10 to 30 m, minerals very similar to those present in the Yamuna floodplains. Geologist K.S. Valdiya (1968, 1996, 2002, 2013, 2016) marshaled a wealth of information generated by geomorphologists, sedimentologists, geohydrologists, geochronologists, archaeologists and remote-sensing specialists to reconstruct the saga of the River Saraswati made up of two branches — the western branch being the Satluj and the eastern branch the Tons (Yamuna's bigger associate). **In recent years, earth scientists** Amal Kar and B. Ghose (1984), M.A. Courty (1995), V.M. Puri and B.C. Verma (1998, 2008), J.L. Thussu (1999), J.N. Malik et al., (1999), H.S. Saini et al., (2009), V.S. Kshetrimayum and V.N. Bajpai (2011), Sinha et al., (2012), A.R. Choudhury (2012), V.M. van Dijk et al., (2015), and Singh, Ajit et al., (2016) **found one or the other pieces of very convincing evidence of a large Himalayan river flowing through the palaeochannels of the Markanda and the Sarsuti** (Kshetrimayum and Bajpai, 2011), **the upper and middle reaches of Ghaggar** (Saini et al., 2009; Sinha et al., 2012; van Dijk et al., 2015; Singh et al., 2016), **the lower reaches of the Ghaggar, the Hakra** (Cliff et al., 2012) **and the Nara** (Figure 6.14).

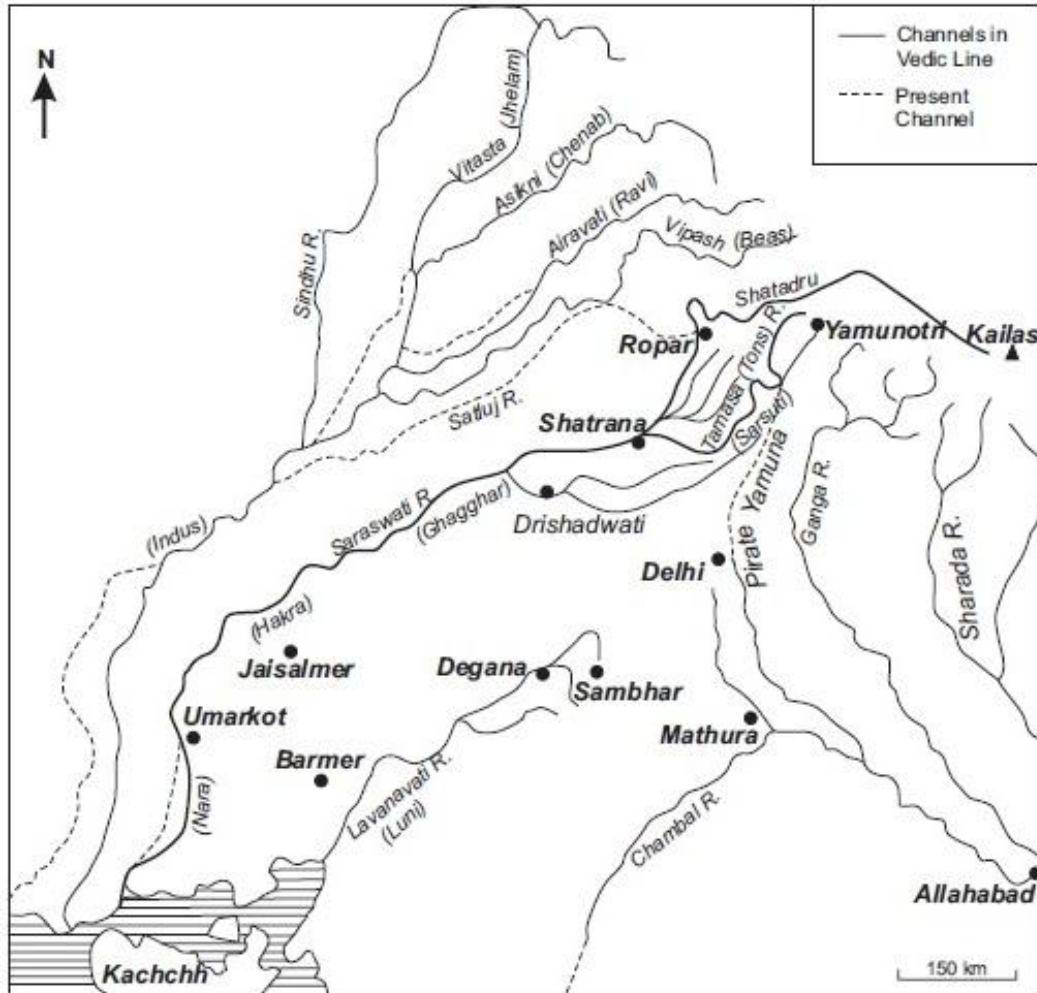


Figure 6.14. From piecing together deduction of geomorphologists, sedimentologists, geohydrologists, geochemists, archaeologists and remote sensing specialists, emerges this portrait of a large river originating in the Himalaya and emptying itself into the Sea, and on the way supporting vibrant progressive people in the prehistoric time. This river was known as the Saraswati [From Valdiya, 2016].

In sum, all facts and all postulations presented in these pages lead to the conclusion that the present-day Sarsuti–Markanda rivulets traversing the tract south of the foothills of the Siwalik Hills in northern Haryana were the water courses of the eastern branch of a Himalayan river; and the Ghaggar–Patiali channels provided the pathways to the western branch of the Himalayan river. The two branches combined near Shatrana and flowed through the extraordinarily wide channel of the Ghaggar–Hakra and discharged into the gulf of the western sea.

It is interesting to note that on the bank of the wide channel of the Ghaggar near Sirsa stands in derelict condition an ancient fort named *Sarsuti* — the name recalling the rivulet **Sarsuti** in the upper reaches of the Ghaggar drainage and traversing the

fluvial fan which van Dijk et al., (2016) described as **Yamuna Fan**. Does this fort 'Sarsuti' represents a tribute to the rivulet Sarsuti that joins the Ghaggar near Pehowa? Was that **Sarsuti** large and bountiful enough to be so honoured ? This does seem plausible. For, there are a number of road- and railway bridges built and named more than a hundred years ago in the British time that bear the name 'Saraswati'. This name is ingrained in the perception of the people. The Government revenue records also show the Saraswati river extending from Adibadri in the Siwalik foothills to Pehowa in the Kurukshetra district.

Now, the word 'Sarsuti' is a corruption of the name, "**Saraswati**". If this is the case, then the Ghaggar River in the past was known as the Saraswati River (Figure 6.14).

Post script

What Happened to that Himalayan-born River?

The OSL dating of sediments in the Tohana–Ellenabad reach of the river that flowed through the Ghaggar basin, demonstrates that it became sluggish in the period 4300 yr B.P. to 2900 yr B.P. (Saini et al., 2009). Further downstream in the Hakra reach this happened a little earlier where the river was active only until about 4500 yr B.P. as inferred from testimony of the U-Pb zircon dates (Clift et al., 2012). In this tract the fluvial sediments were covered by aeolian sediments dated 3356 yr B.P. (Giosan et al., 2012).

It is obvious that the discharge of the river had declined in the Later Holocene time. It is not without significance that there was a large-scale upstream exodus around 3750 yr B.P. of the Harappans (Thapar, 1975) as borne out by sudden appearance of a large number of Late Harappan (3900–3300 yr B.P) settlements in the upper reaches of the river in the belt south of the Siwalik Hills, and also in the northwestern parts of the Yamuna–Ganga interfluves in Uttar Pradesh (Dixit, 1981, 1993) (According to R.S. Bisht, *per.com.*, 2015, the exodus happened much earlier around 4000 yr B.P). This development corroborates the inference that there was substantial decline in the discharge of the river, forcing the people to leave their hearths and homes.

The decline of the river discharge is attributed to (i) dramatic avulsion (Sinha et al., 2012; van Dijk et al., 2016), (ii) weakening of Southwest Summer Monsoon (Giosan et al., 2012), or (iii) tectonically triggered deflection of the two branches in upper reaches of the river (C.F. Oldam, 1893; Valdiya, 1998, 2002, 2016).

Formation or reactivation of a NNW–SSE trending Yamuna Tear Fault that passes by Paonta Sahab in the terrane frequently convulsed by severe tectonic

upheavals (Wesnousky et al., 1999; Thussu, 1999; Senthil Kumar et al., 2001, 2006; Joshi et al., 2005) tore apart the Siwalik Hills, displaced the western fault block southwards relative to the eastern block, simultaneously raising the western block up 20–30 m (Valdiya, 1998, 2002, 2016). The uplifted western block caused blockage of the eastern branch of the Himalayan river, which then swung southwards finding its way out through the greatly weakened fault zone and then descended on to the plains. On the plains it eventually joined the Yamuna — the tributary of the River Chambal that was and continues to be the southern branch of the Ganga River. Thus, through the channels of the Yamuna the water of the eastern branch of the great Himalayan river mingled with the waters of the Ganga at the Prayag and made it Triveni.

Later there was another exodus of the Harappan people (Mughal, 1995). This time downstream towards southwest and south. This is attributed to the abrupt westward swerving at Ropar of the western branch of the Himalayan river, due presumably to the sinking of the ground between the Satluj and the Beas (Figure 6.15) (Valdiya, 1998, 2002, 2016).

Deprived of the waters of both the eastern (Tons) branch, and the western (Satluj) branch, the Himalayan-born river was reduced to a misfit river described as the Sarsuti and the Ghaggar in Haryana, the Hakra in Cholistan, and the Nara in eastern Sindh.

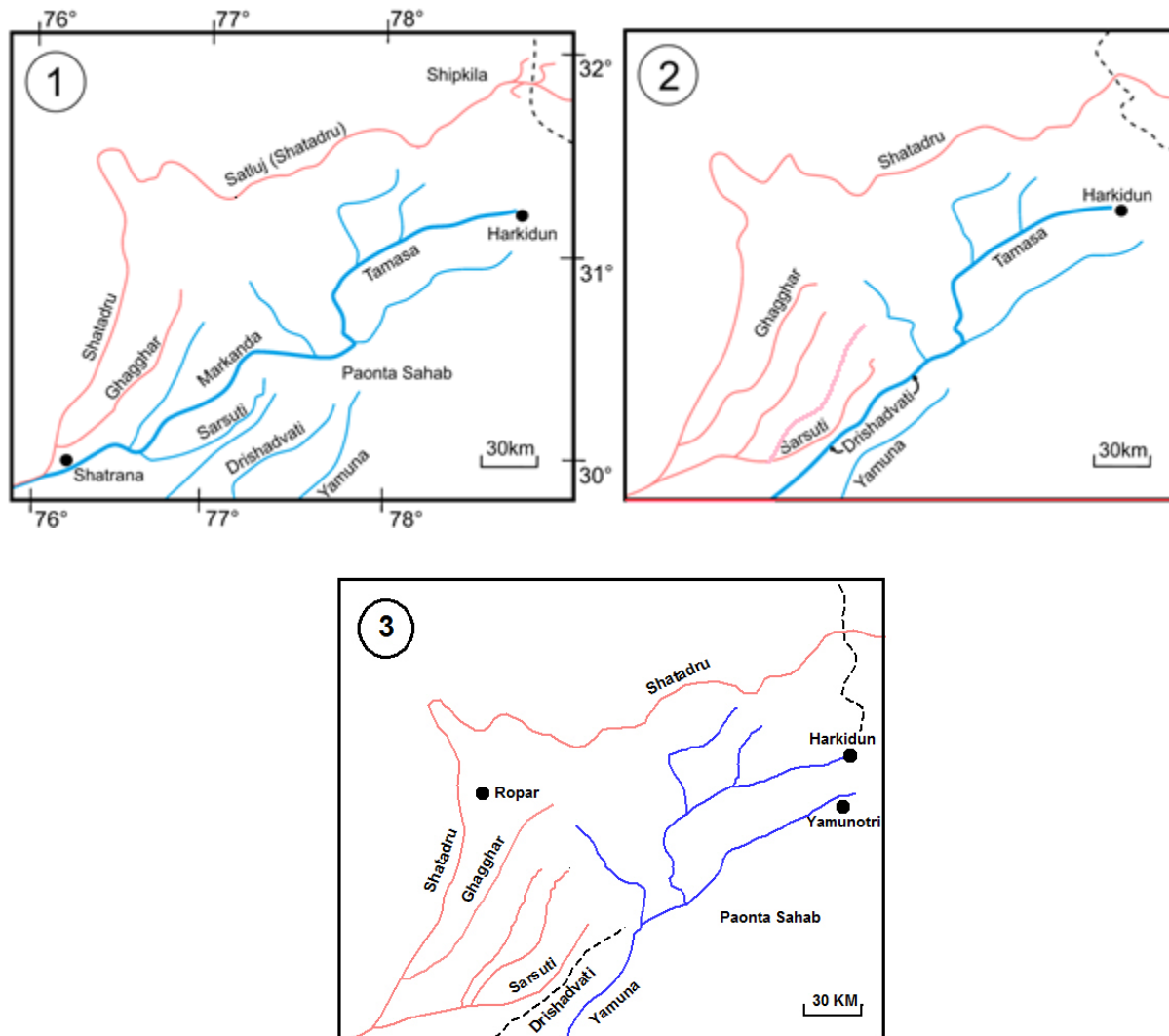


Figure 6.15. How the two branches of the large Himalayan-born river were deflected from their original courses, abandoning channels they flowed through for several thousand years [From Valdiya, 2016].

CHAPTER 7

Recommendations

This report has compiled all available information on palaeochannels in NW India in the form of maps and satellite images as well as the subsurface stratigraphic data. It is important to note that the available information is an outcome of several decades of research in this region using various sources of remotely sensed data as well as field based investigations. The development of technology with time has enabled the improvements in resolution and scale of mapping. At the same time, the changes in landuse and landcover have obliterated the manifestations of palaeochannels on the surface. Therefore, it is important to appreciate the integration of various generations of maps presented in this report. The apparent differences in the trend and distribution of palaeochannels mapped at different times by different workers is primarily because of different resolution of dataset used and not necessarily a mismatch or misinterpretation.

On the basis of detailed geological, geomorphological, geohydrological and archaeological studies backed strongly by comprehensive remote-sensing investigations using latest technology, carried out in the last six decades, it is concluded that the Himalayan-born Satluj of the PAST that flowed through the channels of the present-day Ghaggar-Patialwali rivulets represent the western branch of the ancient River Saraswati. The palaeochannel of the same ancient rivers is shown in the map. Further, the Markanda and the Sarsuti nadis provided pathways to the eastern branch of the Saraswati River, now known as the Tons-Yamuna Rivers. These two branches joined at Shatrana, 25 km south of Patiala, and flowed as a large river through the wide channel of the Ghaggar-Hakra-Nara before emptying itself in a gulf of the western sea, now represented by the Rann of Kachchh. The palaeochannels of ancient mighty river Saraswati from Himalaya to Rann of Kachchh have been compiled and presented in the map.

From groundwater development point of view, it would be ideal to first target those areas where the trends and distribution of the palaeochannels in the integrated maps are converging. For other areas, it may be necessary to generate strategic sub-surface data in well-defined transects to confirm their existence in the stratigraphy. Keeping these issues in view and the compiled information presented in this report, the Committee recommends the following set of action points for CGWB.

1. Mission Databank on Palaeochannels

Developing a systematic database of all surface maps of palaeochannels and sub-surface stratigraphic data including geophysical surveys, borehole data, chemical

quality of ground water and isotopic composition of ground water in and around the palaeochannels is of prime importance. Such database needs to be arranged and filtered using a common protocol for further use by researchers as well as planners. A map depicting all available data points linked to detailed lithologs in a GIS framework could be extremely beneficial for planning and development of groundwater resources from the palaeochannels.

2. Mission Aquifer Delineation and Development:

A detailed sub-surface stratigraphy including their chronological framework needs to be developed for understanding their geological evolution. For this, apart from using the available database on stratigraphy, new data may be necessary to fill the gaps and to confirm the sub-surface existence of several palaeochannels. The compilation of all available data on chronology as well as generation of new data are essential to understand the long-term development of these palaeochannels. Detailed stratigraphic framework will allow us to understand the geometry better and would facilitate more accurate estimation of our groundwater reserves.

3. Mission Palaeochannel Recharge:

Recharging as many well-identified palaeochannels as possible need to be an agenda of top priority. It is indeed a part of the mission to replenish our fast-depleting underground water reserves based on well-thought scientific methods. The recharge measures typically require (a) precise delineation in large-scale topographical map of a palaeochannel, (b) determination of the geometry of aquifer and its capacity to hold interstitial water, and (c) hydraulic conductivity of the aquifer system.

In general, the recharge procedure induces surface water (rainwater, wastewater, floodwater) on a large scale, to percolate down to the aquifer bodies of palaeochannels through tanks, trenches, pits and wells (including deep dug wells). Construction of check dams that hold water from going waste, would accomplish much the same objective. A much simpler way of recharging would be to allow floodwater and excess water overflowing channels/drains to spread on the fields through which the palaeochannel passes, and let fill depressions and furrows. Impoundment of flood water behind dams would likewise induce infiltration and resultantly replenish the underground water.

Taking into consideration the aggregate length of all palaeochannels in the basins of the Yamuna, the Ghaggar–Hakra, the Satluj and other rivers would be of the order of hundreds of kilometres, and therefore, the volume of water that can be stored and be available would be enormous. It is also desirable that ground water resource availability, both fresh and brackish/saline should be assessed at regular intervals. The vedose zone volume should be worked out and source water requirement should be

assessed. Considering low rainfall in the area, availability of non-committed runoff should be worked out and plan of action for recharge, along with the artificial recharge structure should be ascertained.

4. Mission Heritage Development:

The rivers carrying life-supporting-sustaining water and the cultural creations located on their banks must be regarded as prized heritages of tremendous importance. The archaeological heritage along the palaeochannels of once great ancient river known as river Saraswati needs to be protected, preserved and properly safeguarded from modern developments. The most important among this heritage, such as Kalibangan, Banawali, Bhirrana, Baror, Binjor, to name a few, may be developed as centres of academic activities and research, facilitating people from all walks of life to visit all along the palaeochannel of ancient river Saraswati from Adibadri to Dholavira.

Those spots where subsurface water has made spontaneous appearance, can then be developed the way the Sabarmati River Front in Ahmadabad has been developed — with gardens, orchards (or sylvan patches) public conveniences and museums. The museums would trace the history and archaeology of the region, house archaeological artefacts from nearby excavated sites, historical documents, virtual walk through and have galleries of photographs and maps portraying the history of the river, of the people and their culture of the place. Souvenir shops at these places will display replicas of most important artefacts, ornaments, jewelry, ceramics, handicrafts, to spread the information of long bustling activity on these rivers.

It may be emphasized that the palaeochannels should not be dredged to remove the sediments that fill them or widened to make very smooth facile passage for very slowly moving underground water, as is being done in some places in the name of revival of a legendary river. Apart from causing great loss of the scarce water due to evaporation in the hot, dry land, the exposure of under-surface flowing water would lead to the kind of pollution that has converted the Yamuna and the Ganga into veritable gutters.

5. Framing Law and Regulations:

Considering the low rainfall in the area and reckless exploitation of fresh water from the palaeochannels for irrigation and other uses, possibilities of regulating ground water extraction in the palaeochannel region should be looked into by the Central Ground Water Authority by framing law and regulations. An accurate estimation of ground water extraction should be ascertained prior to that.

6. Formation of Specific Cell:

It is strongly recommended that a separate cell be created in CGWB for handling the activities mentioned above in mission mode headed by a Regional Director. Dedicated officers may be involved in the study of palaeochannels for developing the plans for development of groundwater resources, and for regulating the groundwater development.

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No. T-40015/1/2016-GW
Government of India
Ministry of Water Resources, River Development
& Ganga Rejuvenation

Shrami Shakti Bhawan, New Delhi
Dated: 1st March, 2016

ORDER

Subject:- Expert Committee to review the available information on Palaeo-channels – Reg.

The Government has prioritized development of ground water resources in problem areas which requires a systematic study to understand and address the problem in totality. With this objective in view, a Committee under the Chairmanship of Prof. K S Valdiya, Honorary Professor of Geodynamics, Jawaharlal Nehru Centre for Advance Scientific Research (JNCASR) has been constituted to critically review the available information on Paleo-channels and to give recommendations on various issues related to water resource development vis-à-vis the paleo-channels. The composition of the committee is as under:

1. Prof. K. S. Valdiya, Honorary Professor of Geodynamics, Jawaharlal Nehru Centre for Advance Scientific Research (JNCASR), Bangalore –**Chairman**
2. Dr R. S. Bisht, Former Joint Director General, Archeological Survey of India – Member
3. Prof S. K. Tandon, D N Wadia Chair Professor: Professor Emeritus, University of Delhi, Distinguished Visiting Professor, IIT Mumbai - Member
4. Professor Rajiv Sinha, Head, Department of Geoscience, IIT, Kanpur- Member
5. Dr. B. K. Bhadra, RRSC, Jodhpur – Member
6. Professor Nayanjot Lahiri, Professor, Deptt of History, Delhi University, New Delhi- Member
7. Shri Rana Chatterjee, Scientist 'D', CGWB, Jamnagar House, New Delhi – Member Secretary

The Committee may co-opt experts from the field of archeology, history, etc. provided that the number of such experts does not exceed two.

Contd.....

Terms and References of the Committee are as follows:

- i. Compilation of all existing information, research output, reference in ancient and modern literature on ancient rivers.
- ii. Geology and tectonic aspects that influenced development and course of the palaeo-channels during the Holocene period.
- iii. Possible climatic, geological and other causes for disappearance of the ancient rivers and turning them into palaeo-channels.
- iv. Assessing the recharge potential of identified palaeo-channels.

The ToRs can be further modified if the Committee so feels and proposes.

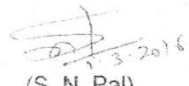
The Committee would utilize the available resources/data from Central Water Commission, Central Ground Water Board and any other organizations.

Secretarial and Logistics support would be provided by CGWB.

Non official Member(s) of the Committee will be paid TA/DA and Sitting Fee as applicable from the appropriate Head under the Scheme of Ground Water Management Regulation operated by CGWB

The Committee shall submit its Draft Report within a period of six months and the final report within a period of one year.

This issues with the approval of the competent authority.


(S. N. Pal)

Under Secretary to the Govt of India

Tel: 23766 907

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copy to:

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8. Chairman, CGWB
9. Chairman, CWC

Copy also to:

1. PS to Hon'ble Minister WR, RD&GR
2. Sr. PPS to Secretary, MoWR, RD&GR
3. PPS to Special Secretary, MoWR, RD&GR
4. PS to JS(A&GW), MoWR, RD&GR
5. PS to JS(PP)
6. PS to JS(RKG)
7. PS to JS&FA, MoWR, RD&GR

No. T-40015/1/2016-GW
Government of India
Ministry of Water Resources, River Development
& Ganga Rejuvenation

Shram Shakti Bhawan, New Delhi
Dated: 31st March, 2015

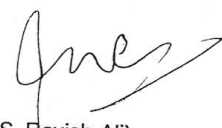
ORDER

Subject: Expert Committee to review the available information on Palaeo-channels

In continuation of this Ministry's order of even no. dated 01.03.2016 vide which an Expert Committee has been constituted under the chairmanship of Prof. K S Valdiya, Honorary Professor of Geodynamics, Jawaharlal Nehru Centre for Advance Scientific Research (JNCASR), Bangalore to review the available information on Paleo-channels, it has been decided to supplement the existing Terms of References of the Committee by the following:

- i. The Committee shall also endeavor to consolidate Archaeological findings along the palaeo-channels and the relationship between the palaeo-rivers and civilization.
 - ii. The Committee shall also endeavor to co-relate the continuity of the palaeo-channel system observed in the Northern, North-Western and Western part of India and its relation with the old prominent rivers, also described in ancient texts and mentioned in history.
 - iii. The Committee shall attempt the course of prominent old rivers (which might have disappeared now) on the basis of palaeo-channels investigated so far on scientific, historical, anthropological and others aspects.
2. Other provisions/conditions of the Committee will remain unchanged.

This has the approval of the competent authority.


(S. Ravish Ali)

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5. Dr. B. K. Bhadra, Scientist/Engr. SF, Regional Remote Sensing Centre- West, NRSC, ISRO, Dept. of Space, CAZRI Campus, Jodhpur-342003, Rajasthan (instead of Vivek Vihar Yojana, Rajasthan-342005 (E-mail- bkbhadra63@gmail.com)

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9. Member (SAM), CGWB,

Copy to:

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Ministry of Water Resources, River Development
& Ganga Rejuvenation

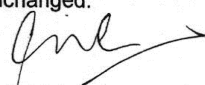
Shram Shakti Bhawan, New Delhi
Dated: 16th May, 2016

ORDER

Subject: Expert Committee to review the available information on Palaeo-channels.

In continuation to this Ministry's Order of even no. dated 01.03.2016 and subsequent modification dated 31.03.2016 on the subject cited above, the undersigned is directed to convey the approval of the Competent Authority for co-opting the following Members in the Committee:

1. **Dr. Amal Kar**, Former Principal Scientist & Head of Natural Resources and Environment, Central Arid Zone Research Institute, Jodhpur **Member**
 2. **Sh. V.N. Prabhakar**, Superintending Archaeologist, Archaeological Survey of India, New Delhi and visiting Assistant Professor, Indian Institute of Technology, Gandhinagar **Member**
- 2) All other terms and conditions of the above mentioned order will remain unchanged.


(S. Ravish Ali)
Under Secretary to the Govt of India
Tel: 23766 907
e-mail: gwdesk-mowr@nic.in

1. Prof. K S Valdiya, Honorary Professor of Geodynamics, Jawaharlal Nehru Centre for Advance Scientific Research (JNCASR), Jakkur, Bangalore-560064 (E-mail - ksvaldiya@gmail.com)
2. Dr. R. S. Bisht, Former Joint Director General, Archeological Survey of India, 9/19, Sector-3, Rajendra Nagar, Shahibabad, Ghaziabad- 201005 (E-mail-rsbishtarch@gmail.com)
3. Prof. S. K. Tandon, J.C. Bose Chair Professor, Indian Institute of Science Education and Research, Bhopal, Bhopal Bypass Road, Bhauri, Bhopal- 462066, Madhya Pradesh (E-mail sktand@rediffmail.com, sktand@iiserb.ac.in)
4. Prof Rajiv Sinha, Head. Department, Department of Geoscience, IIT- Kanpur (E-mail- rsinha@iitk.ac.in)
5. Dr. B. K. Bhadra, Scientist/Engr. SF, Regional Remote Sensing Centre- West, NRSC, ISRO, Dept. of Space, CAZRI Campus, Jodhpur-342003, Rajasthan (instead of Vivek Vihar Yojana, Rajasthan-342005 (E-mail- bkbhadra63@gmail.com)
6. Dr. Amal Kar, Former Principal Scientist & Head of Natural Resources and Environment, Central Arid Zone Research Institute, Jodhpur A-1/6 baitalik Housing Society, KMDA Housing Complex, Baghajatin (Near Hiland Park), Kolkata- 700094 (E-mail- akarcz50@gmail.com)

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7. Sh. V.N. Prabhakar, Superintending Archaeologist, Archaeological Survey of India, Visiting Faculty, Indian Institute of Technology, Gandhinagar, Palaj, Simkheda, Gandhinagar- 382355 (E-mail- vnprabhu@iitgn.ac.in)
- ✓ 8. Shri Rana Chatterjee, Scientist 'D', CGWB, Jamnagar House, New Delhi (E-mail- rana3b@gmail.com)
9. Chairman, CGWB,
10. Chairman, CWC,
11. Member (SAM), CGWB,

Copy to:

1. PS to Hon'ble Minister WR, RD&GR
2. Sr. PPS to Secretary, MoWR, RD&GR
3. PPS to Special Secretary, MoWR, RD&GR
4. PS to JS(A&GW), MoWR, RD&GR
5. PS to JS(PP)
6. PS to JS(RKG)
7. PS to JS&FA, MoWR, RD&GR

BIO DATA OF THE MEMBERS OF THE EXPERT COMMITTEE

1. Professor K.S. Valdiya – Chairman of the Expert Committee

Prof. K.S. Valdiya is the recipient of many national awards, including S.S. Bhatnagar Prize (1976) of the Council of Scientific & Industrial Research, National Mineral Award of Excellence (1997) of the Ministry of Mines, Pitambar Pant Environment Fellow (1982–1984) of the Ministry of Environment & Forests, Hindi Sevi Samman (Ātmarām Puraskar) (2007) of the Ministry of Human Resource Development, Padmashree (2007) of the Government of India, G.M. Modi Award for Science & Environment (2012), Padma Bhushan (2015) of the Government of India, National Lecturer (1977–1978) of the University Grants Commission, D.N. Wadia Medal (1995) of Indian National Science Academy and L. Rama Rao Gold Medal (1980) of the Geological Society of India, Prince Mukkaram Jah Gold Medal (2000) and L.N. Kailasam Gold Medal (2009) of the Indian Geophysical Union, Professor K.S. Valdiya is a Fellow of all the three national science Academies of India, the Third World Academy of Sciences, the Geological Society of America and the Geological Society of Nepal. Presently Honorary Professor of Geodynamics at Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru. He has held high positions as Additional Director in Wadia Institute of Himalayan Geology, as Professor of Geology, Dean Science and Vice-Chancellor in Kumaun University, as Professor of Geodynamics (1995–1997) and Bhatnagar Research Professor (1997–2002) at the Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru, Golden Jubilee Research Professor of Indian National Science Academy at Jawaharlal Nehru Centre for Advanced Scientific Research. Distinguished Guest Professor at Indian Institute of Technology, Mumbai and Visiting Honorary Professor at the Indian Institute of Technology, Roorkee. He has written several original books and monographs, including Geology of Kumaun Lesser Himalaya (1980), Aspects of Tectonics: Focus on Southcentral Asia (1984), Environmental Geology: Indian Context (1987, Second Ed. 2013), Dynamic Himalaya (1998), Saraswati, the River That Disappeared (2002), Geology, Environment and Society (2005), The Making of India: Geodynamic Evolution (2010, Second Ed. 2016), Ek Thi Nadi Saraswati (2010), Geography, Peoples and Geodynamics of India in Purāns and Epics (2012), and Prehistoric River Saraswati: Geological Appraisal and Social Aspects (2016). He has written prolifically in Hindi, popularizing earth science and general science. His fields of specialization are tectonics with special reference to active faults, and environmental geology. Born on March 20, 1937 at Kalaw in Myanmar, he had his early education in a small town of Pithoragarh in Kumaun Himalaya and higher education at Lucknow University. Obtaining Ph.D. degree in 1963 from Lucknow University, he studied at Johns Hopkins University, USA as a Fulbright Fellow during 1965–1966.

2. Dr. R.S. Bisht

Dr. Ravindra Singh Bisht (R. S. Bisht) is an eminent archaeologist, known for his scholarship on Indus valley civilization and efforts to conserve Indian national monuments. He was honoured by the Government of India, in 2013, by bestowing on him the Padma Shri, the fourth highest civilian award, for his contributions to the field of archaeology.

Dr. Bisht started his career, joining the Department of Archaeology and Museum, Punjab and retired after 35 years of service, as the Joint Director General, Archaeological Survey of India.

Dr. Bisht, considered to be an expert on Indus valley civilization, has led many excavations related to the study of the civilization. Excavation projects at Dholavira in Kutch district of Gujarat, Banawali in Hissar district of Haryana, Semthan in Pulwama district of Jammu and Kashmir, Chechal in Vaishali district, and Sarai Mound in Nalanda district of Bihar, and Sanghol in Ludhiana district of Punjab are some of them.

Dr. Bisht has done pioneering work in the conservation of several Indian national monuments. During his stint as the Deputy Director stationed in Haryana, he was instrumental in the conservation of 11 monuments in Narnaul, the place where one of the first battles of Indian Rebellion of 1857 was fought by Pran Sukh Yadav and Rao Tula Ram against the British.[He has assisted in the preliminary survey and research of Ta Prohm, the Cambodian temple of 12th century. He was also involved in the conservation activities of several monuments in other north Indian states.

Another area of work of Dr. R. S. Bisht was in setting up and maintenance of museums across the country. He was involved in the establishment of Swatantrata Sangram Sangrahalaya museum at Red Fort, Delhi, Vishveshvaranand Vedic Research Institute museum in Hoshiarpur and the museum at the Department of Archaeology and Museum in Chandigarh. He has contributed towards the renovation, rearrangement and redesigning of museums at the Darbar Hall in Sangrur, Punjab, Darbar Hall, Old Fort, Patiala, Ratnagiri and Ropar. He has also played part in conducting several exhibitions such as the ones at Sultanpur Lodhi, Kurukshetra, Kamagata Maru naga and Rani ki vav, special displays of excavated materials from Banawali and Dholavira and an exclusive exhibition of Neolithic, Copper-Bronze age and Megalithic Cultures of India since Independence held at the National Museum, New Delhi, on the sidelines of the World Archaeological Congress of 1994.

3. Professor S.K. Tandon

Professor S K Tandon currently holds the Sir J C Bose Chair Professorship in the Department of Earth and Environmental Sciences, Bhopal. Earlier, during 2013-2015, he held the D N Wadia Chair Professorship in the Department of Earth Sciences, IIT Kanpur. He continues to be associated with IIT Kanpur as a Distinguished Honorary Professor and is also a Visiting Professor at the UCESS, University of Hyderabad. He has also been associated with the Department of Earth Sciences, IIT, Bombay as a Distinguished Visiting Professor.

He served the University of Delhi for more than three decades from 1976-2010 in various capacities as a Reader, Professor, Head of the Department of Geology, Dean (Faculty of Science), Dean(Research), and as Pro- Vice Chancellor.

Professor Tandon's primary research interests lie in Physical Stratigraphy and Sedimentology in addition to Geomorphology. He is currently interested in the development of River Science as a discipline in the context of the Anthropocene.

Professor Tandon has authored/coauthored about 150 research papers, edited books, book reviews, and general articles over the past 45 years. For his research work as well as for his teaching and mentoring , he has been recognized through the award of the INSA Young Scientists Medal 1974. Krishnan Gold Medal 1985, SS Bhatnagar Prize 1988, L N Kailasam Lecture Gold Medal 2010, Fellowship of Indian Academy of Sciences 1987, Indian National Science Academy 1998, NASI 1998, TWAS 2001. He has also delivered several distinguished memorial lectures including the Karunakaran Endowment Lecture at NCESS, Thiruvanthapuram, K D Malviya Lecture at KDMIPE, ONGC; West Memorial Lecture at WIHG; the V111th J R Kumaramangalam Lecture at the Foundation Day of Coal India Limited; P C Mathur Memorial Lecture at the Department of Geology, BHU.

Professor Tandon has also held several overseas visiting fellowships/positions including those at Dalhousie University, Halifax and the Guelph University in Canada, the University of Cambridge and University of East Anglia in U.K., the Shizuoka University and Kyushu University in Japan; and has carried out collaborative work with various earth science institutes in Hungary, Germany, and the USA.

More recently, Professor Tandon held the position of Councillor from 2010-2014 in the Executive of the International Union of Geological Sciences. He has also served as the Secretary and Vice-President of the Geological Society of India as well as the Vice-President and the President of the Indian Association of Sedimentologists.

4. Professor Rajiv Sinha

Rajiv Sinha is a Professor of Earth Sciences at Indian Institute of Technology Kanpur. With a Master's degree in applied geology from University of Roorkee (now IIT Roorkee) in 1987 and a PhD in sedimentology from University of Cambridge in 1992, Professor Sinha has worked on various aspects of river hydrology and groundwater systems during his career. Apart from his early work on proposing a new source area classification of Gangetic river systems, one of his most significant contributions has been the characterization of geomorphic diversity across the Gangetic plains as a function of the balance between stream power and sediment flux, thus demonstrating the variability in landscape evolution due to the coupling of climate and tectonic factors. Professor Sinha led the fluvial geomorphology group in a very large project on Ganga River Basin Management Plan sponsored by MoEF. He has also worked several other projects in the Ganga basin related to hydrological and sediment transport modeling, environmental flows and flood risk assessment. One of his current research is focused in the Ghaggar plains in NW India where the existence of a large River (Saraswati?) has been hypothesized and the archaeological findings in the area have indicated a large concentration of Harappan sites along the trace of the buried channel. A recent paper by Sinha focused on establishing the subsurface existence of this buried channel using a combination of electrical resistivity surveys and drilling of sediment cores. This work further led to developing a very large research programme on groundwater structure and dynamics in NW India and characterizing the heterogeneity of the alluvial aquifer systems. This significant research has yielded new insights on the alluvial aquifer systems in terms of spatial pattern of groundwater depletion, geomorphic controls on aquifer characteristics and distribution, and process understanding of aquifer deposition.

5. Dr. Bidyut Kumar Bhadra

Dr. B.K. Bhadra is Scientist/Eng. 'SF' at Regional Remote Sensing Centre (West), NRSC / ISRO, CAZRI Campus, Jodhpur. His academic qualification is M. Sc. (Applied Geology) in 1987 from IIT, Roorkee, Ph.D. (Himalayan Tectonics) in 1996 from IIT, Roorkee. He has More than 14 years' of professional experience (2002 onwards) at ISRO in the field of Satellite Remote Sensing & GIS in Palaeodrainage and Groundwater Studies. He also has the teaching and post-doctoral Research Experience at Pondicherry Central University for 7 Years from 1995 to 2002. He was awarded Young Scientist Project by Dept. of Science & Technology (DST), New Delhi in 1998. His publications include - Contribution in Book - 5, 32 nos. of Published Research Papers in Journals and 24 numbers of papers in Seminar/Conference.

6. Dr. Amal Kar

Dr. Amal Kar, who joined Central Arid Zone Research Institute, Jodhpur, in 1974, and superannuated from there in 2012, is involved in research on desert geomorphology, desertification, natural resources assessment and monitoring, and applications of geomatics in Earth resources studies for more than 40 years. Some of his major findings include the palaeochannels of the Saraswati River system, new understanding of desert geomorphology and sand dune formation, desert floods, neotectonics, palaeoclimatic reconstruction from desert sediments, and the impacts of human pressures and climate change on land degradation in arid India. Dr. Kar contributed to the UN system as a Consultant on Desertification (for Benchmarks & Indicators), Resource Person (for Early Warning Systems), and Trainer (for international researchers). He received a Science & Technology Fellowship to Japan (1999) and the ICAR Award (1983). He was a Visiting Professor at Tokyo University (2001), and also served Calcutta University and Tripura University as a short-term Visiting Fellow. Dr. Kar was an Editor of the international journal, Sustainability Science, Springer Verlag (2006-2011), and of a national journal, Annals of Arid Zone (1994-2012). He is also a past President of the Indian Institute of Geomorphologists (2010). Dr. Kar has more than 160 publications in peer-reviewed research journals and books, including a few edited books. Dr. Amal Kar, who now lives in Kolkata, is associated with some learned societies, and works as an independent researcher.

7. Dr. V.N. Prabhakar

Dr. V.N. Prabhakar is a visiting Faculty at the Archaeological Sciences Centre, Indian Institute of Technology, Gandhinagar since April 2014. Coordinating and setting up various labs for the Centre to facilitate the archaeologists to analyse their samples for understanding various perspectives of past cultures apart from carrying out researches on bead drilling technology of the Harappans.

Headed the Excavation Branch, New Delhi of the Archaeological Survey of India (ASI), Government of India from April, 2011 to March 2014 and conducted excavations at Rupnagar (Punjab) and Karanpura (Rajasthan), both of Harappa culture. Headed the field office of ASI in Aurangabad, Maharashtra from 2009 – 2011 and executed various responsibilities related to the exploration & excavation, overall administration, conservation and preservation of 166 nationally important heritage structures including the World Heritage Properties of Ajanta and Ellora Caves.

Obtained Degree in Doctor of Philosophy (2013) from the Kurukshetra University, India on the *"Burial Practices of the Harappans with Special Reference to Sanauli Excavation"*.

Specialises in Harappan and Field Archaeology with emphasis on application of sciences in Archaeology. Published around 25 articles in peer reviewed journals.