Journal of Indian Geomorphology
Volume 8, 2020 ● ISSN 2320-0731
Indian Institute of Geomorphologists (IGI)

The Eighth Prof. S.R. Basu Memorial lecture, delivered at the 31st National Conference of the Indian Institute of Geomorphologists (IGI) held at the University of North Bengal, Siliguri during 12–14 November 2019

The Saraswati River System: A Revisit with New Data and Interpretation

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Introduction

Saraswati River is one of the most enigmatic geographical entities in the Indian Subcontinent. Rig Veda described the river eloquently in many of its hymns, the essence of which was that it was a mighty Himalayan stream with six major tributaries (hence the name *Sapta-Saraswati*), and that it used to flow independently into the Arabian Sea. So vast was the river, especially near the confluence with its tributaries that it used to provide an ocean-like appearance. The bountiful natural resources contributed by the river system supported many human habitations and land-based livelihood functions, as well as centres of learning. By the time the later hymns of Rig Veda were composed, the Saraswati lost much of its glory, and the word *Sapta-Saraswati* began to be substituted with *Sapta-Sindhu* (i.e., the Indus with its six major tributaries). Description of the river in the subsequent Yajurveda changed to *Panchanadya* (a combine of five rivers) and *Panchadha* (a river that is split into five distributaries). The Mahabharata described the river in its chapter *Aaranyak Parva* as a large, swift-flowing former stream that lost its course at a place called Vinasana along the desert's margin, and whose remnants could be seen as a string of lakes lined with forest trees. These and other descriptions in our ancient texts provoked numerous scholars over the past centuries to identify the Saraswati and its major tributaries, and to map them properly to understand the evolutionary aspects of the river system, as well as to find their role on the development of civilization in the region.

Charles Frederic Oldham, a medical surgeon in the British India Army, first identified the Saraswati River with a former course of the Sutlej river that used to flow through the presently wide, misfit valley of the Ghaggar-Hakra river (first as anonymous in 1874, and then in his own name in 1893). He traced the river downstream through the presently disjointed segments of the Raini, the Wahinda and the Nara to the Arabian Sea (Fig. 1). Oldham argued that the Ghaggar River, with its source in the non-glacial Siwaliks, could not have provided the large perennial discharge of the Saraswati's description in the Rig Veda and that the Sutlej used to maintain the valley through several south-flowing early courses, known as the Naiwal, some of which he mapped. Oldham also suggested that the Yamuna used to contribute to the Saraswati river through the Chautang Nala which he considered as the Drishadvati river of the Rig Veda and the Mahabharata. Oldham (1874, 1893) also mapped the abandoned courses of several other major streams in the region,

including the Beas, the Ravi and the Indus. He concluded that the Saraswati became decimated when the Sutlej shifted away from the Ghaggar-Hakra valley to join the Beas. Oldham's findings led to many exciting research on the Saraswati river system, including the discovery of early human settlements along the abandoned Ghaggar-Hakra valley. Summaries of useful research on the subject are available in Radhakrishna and Merh (1999), Valdiya (2002, 2017), Panhwar (2003, 2011), Danino (2010), Anon. (2016) and Acharyya *et al.* (2020).

In the quest to understand the contexts of Oldham's discoveries and to know how much one learned about the Saraswati river system in a century and half after him, some of the old maps and records on the region were looked into, and a study was carried out on the major findings so far. The results were quite revealing. Before discussing the findings a summary of the early narratives on the Saraswati river system will be provided, followed by an analysis of the early maps and records on the system, especially those by the Survey of India (SoI). The paper will then discuss the major post-Oldham mapping efforts on the Saraswati palaeochannels, and finally provide some of the new findings based on digital remote sensing and geoinformatics. For analysis and comparison of the heritage maps since the early 18th Century, whose scanned copies were accessed from open sources; on-screen georeferencing was

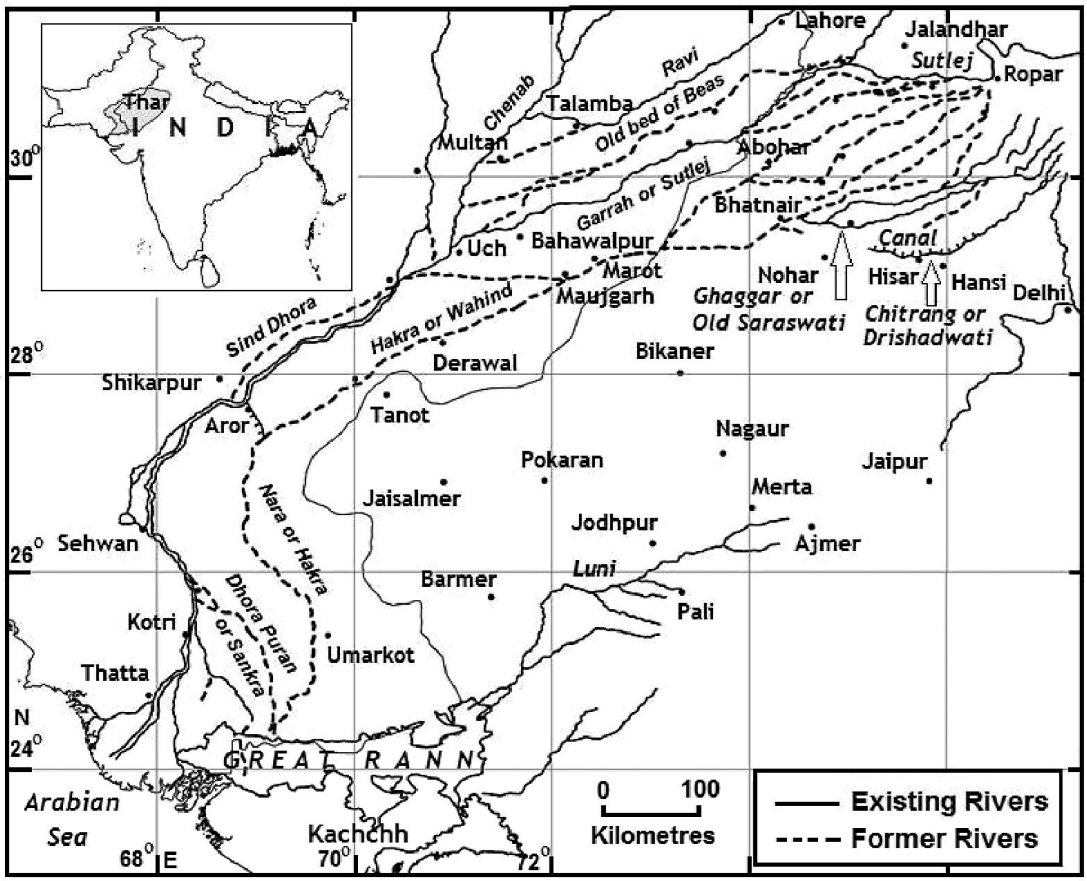

Figure 1. Existing and abandoned streams from C.F. Oldham's 1874 map of the Saraswati river system after georeferencing and digitization. International boundary and a key map are included for referencing purpose.

carried out using a uniform projection and reference ellipsoid. Subsequently all the major locations were geocoded, together with digitization of stream courses.

Saraswati river system in the Indian literature

There are many interesting descriptions of the Saraswati river and its major tributaries in the ancient Indian literature, including the Vedas, the Mahabharata, the Ramayana, the Puranas, etc. The rivers have also been described in many historical texts from the time of Alexander's invasion. A close reading of those texts helped the modern researchers to find out how dynamic the river system was, and what might have caused the Saraswati to become extinct. The important narratives and their likely interpretation regarding this river system are discussed below.

Descriptions in the ancient texts

Rig Veda, the oldest available text on India's environment describes the Saraswati as the river par excellence (*Naditame*), and as the most powerful among the rivers (*Nadinam asurya*). Rig Veda also describes the Saraswati as the first-ranking and the purest, which is fast flowing and ocean-like, having its course from the mountain to the ocean (*"Ekachetatsaraswati nadinam suchiryati giribhya aa samudrat"*; Ashtaka 5, Adhyaya 6, Anuvaka 6, Sukta 95, Varga 19, stanza 2; Max Muller, 1862, p242). A hymn in the Mahabharata mentions Sage Vasistha's praise of the Saraswati in the following words — *'Tvameva akashaga Devi meghesutsrijase payah, Sarvaschapas tvameveti tvatto vayamadhimahe'* (Mahabharata, Salya Parva; Satwalekar, 1973; p321), which can be translate as — 'Goddess, You reach the sky (through evaporation of your vast expanse of water) and provide the clouds with water; You are omnipresent in water everywhere, in this land (Kar, 2020).

The Saraswati was known to have the potential to breach its banks and flood the countryside, destroying the habitations and the assets of the inhabitant, as well as to shift its courses (avulsion). Thus in the Rig Veda there is a prayer which says — 'Guide us, Saraswati, to precious wealth; reduce us not to insignificance; overwhelm us not with (excess of) water; be pleased by our friendly (services) and access to our habitations, and let us not repair to places unacceptable to thee' (Wilson, 1857; p507). In another hymn of the Rig Veda, two component streams of the Saraswati — the Beas and the Satudri, inform the Sage Viswamitra that 'Fertilizing the land with this water we are flowing to the receptacle which has been appointed by the deity (Indra), the wielder of the thunderbolt, (who) dug our channels when he slew Ahi, the blocker of the rivers,....and obedient to his commands we flow as ample streams,.....be favourable to us in solemn prayers; treat us not (in) arrogant fashion of men' (Ashtaka 3, Adhyaya 1, Sukta 33; Wilson, 1857; pp51–52). Such hymns not only reveal the composers' knowledge of the geography of the region but also of the stream behaviour and its influence on human enterprises. Hence, there are repeated pleas through hymns for practicing conservation of Nature and for performing different rituals to remember its contributions.

With such knowledge, it is surprising that the Rig Veda does not mention the most dominant stream between the Yamuna and the Indus — the Sutlej, which is mentioned in the Mahabharata as the Satadru, a voluminous and fast flowing stream with hundreds of courses. Although few Vedic hymns like the above Sukta 33 of Ashtaka 3 mention a stream called the 'Satudri', a close reading of the relevant Rig Vedic verses suggests that the Satudri was a fast flowing companion stream of the Vipasa (Beas) in the Punjab Plains, which was not as wide as the latter, and that

both the rivers could be crossed on foot or on chariot during the lean period, despite both originating from the Himalayas. Based on the knowledge of the stream characteristics and the currently acquired knowledge of the landscape properties of the region, it was postulated that the crossing of the Vipasa and the Satudri by Sage Viswamitra (Rig Veda, Ashtaka 3, Adhyaya 1, Sukta 33, Varga 12–14), most likely took place from west to east, and somewhere between the present day Ferozepur and Harike (Kar, 2020).

The Mahabharata, while describing the lost river Saraswati, mentions in the Salya Parva that in the olden time the river came out piercing her grandfather's (i.e., Brahma's) lake, and that the whole world felt her gorgeous presence (*"Pitamahasya sarasah pravrittasi Saraswati, Vyaptam chhedam jagatsarvam tabaibhaboviruttamaih"*; Satwalekar, 1973, p321). This stanza refers to the origin of the Saraswati in the Manas Sarovar area (more specifically in the Rakshas Tal, which is known as the origin of the Sutlej river). In other words, the Saraswati of the Rig Veda was synonymous with the Satadru of the Mahabharata, and so there was no scope for mentioning the Satadru as a river in the Rig Veda. The Satudri was, in all probability, an old distributary channel of the Sutlej, a palaeochannel.

Apart from the Satudri, the Rig Veda mentions another palaeochannel very prominently, the Marudvriddha, that needs to be identified. As the name suggests, this old river used to get swollen with the arrival of cloud-bearing winds (Marut means here the monsoon wind, while Vriddha means old), and most probably it was an abandoned course of the Ravi or the Beas. Ludwig (1876) had suggested it to be a stream segment below the confluence of the Ravi with the Chenab, while Thomas (1883) suggested it to be a segment below the confluence of the Chenab with the Behat. Raverty, on the other hand, (as Nearchus, 1875) had suggested that the Yamuna was the Marudvriddha when it was flowing westward through the Chautang to the Ghaggar-Hakra valley.

In another text, the sages invoke the Saraswati as being one of the seven sisters and the mother of the Sindhu (the Indus). The sages request the Saraswati system of rivers that just like the earlier times when all the seven rivers used to flow together in volumes to fertilize the land and to produce abundant food and fodder to nourish the inhabitants, the Saraswati system should again come in spate (as before), along with the Indus — *"Aa yatsaakang yashasoh vaavasaanah Saraswati saptathi Sindhurmata; Yah suswayanta suyudughah suyudharah avi svena payasaa pipyanah"* (Ashtaka 5, Adhyaya 4, Sukta 36, Varga 2, stanza 6, Max Muller, 1862; p68). This stanza could be interpreted as an indication that the discharge along the Saraswati system of rivers was gradually becoming aberrant due to climate change (i.e., reduced strength and frequency of the southwest monsoon vis-a-vis increased Western Disturbances), which was leading to large scale spatio-temporal heterogeneity in rainfall distribution in the basin and in the periods of overbank flooding, with resultant uncertainties in soil moisture availability and in the production of some important crops in the fertile plains. At the same time the Indus was maintaining a steady discharge as before, possibly because its catchment area was never much influenced by the southwest monsoon, but by the Westerlies which was not declining. This way, the rationale behind the request of the sages for the *Sapta-Saraswati* to come to spate together with the Indus can be understood.

By the time the eighth Ashtaka of the Rig Veda was written, the Saraswati perhaps had lost much of its strength and glory, and so the order of praise to the rivers was changed to first mentioning the Sindhu in eloquent

terms, and then praise the Saraswati and its tributaries. Incidentally, this was the first time that the Rig Veda was describing all the streams from the Ganga in the east to the Indus in the west sequentially: 'Waters, the worshipper addresses to you excellent praise in the dwelling of the institutor of the rite; they flowed by seven through the three (worlds); but the Sindhu surpasses (all) the (other) streams in strength..... Accept this my praise, Ganga, Yamuna, Sarasvati, Sutudri, Parushni, Marudvriddha with Asikni, and Vitasta; listen, Arjikiya with Sushoma' (Ashtaka 8, Adhyaya 3, Sukta 75, Varga 6; Wilson, 1888; 204–205 pp). While the Parushni was the name of the Ravi, the Asikni was the Chenab or the Chandrabhaga, and the Vitasta was the Jhelum. A special mention was made of the Sushoma (Soan, which joins the Indus upstream of Kalabagh in Pakistan, right where the river disembarks from the Himalayas) and the Arjikiya (Beas, or the Vipasa, which meets the Sutlej near Harike in Punjab), both having substantial Himalayan catchments, but almost no presence in the plains during the period. Incidentally, the Ramayana mentioned three Saraswati rivers as one crosses the Yamuna and moves towards the Sutlej: the Prachi Saraswati (or the Sursooti of Rennell's 1788 map), the Saradanda Saraswati (or the Markanda which flowed through Sadhaura with its tributary the Sadadeni *nadi*) and the Ikshumati Saraswati or the Ghaggar (Bharadwaj, 1986). There are several other descriptions of the Saraswati river basin in the Ramayana.

The Mahabharata provides the first detailed description of the Saraswati as a lost river, or a palaeochannel, including its place of drying out at Vinasana (supposed to be downstream of Suratgarh), and its partial reappearance at places like Sirodbheda, Nagodbheda and Chamasodbheda, which were within the hostile desert country, and hence needed to be avoided for pilgrimage purpose. Sage Lomasa informs Yudhisthira in the Aranyak Parva that at Chamasodbheda all the ocean-bound rivers used to converge into the Saraswati (*"Eshavya Chamasodbhedah yatra drishya Saraswati, Yatranamavyavartanta divyah punyah samudragah"*; Satwalekar, 1960; p668). This puts the place somewhere between Marot, Derawar Fort and Uch (Uchcha in Sanskrit) in Pakistan. In the Drona Parva the Satadru is described along with the Vipasa, Iravati, Chandrabhaga and Vitasta in a cursed country named Aratta (possibly between Khairpur and Uch), where the land used to look like a sea full of crocodiles after the monsoon rains! Surely the Sutlej had shifted by then far away from the Ghaggar valley.

Upstream of Vinasana the Saraswati bed had become a string of lakes, justifying the name 'Saraswati' (i.e., rich in lakes; Ali, 1941). The possible cause was the weakening of the southwest monsoon that was providing lesser rainfall in the catchment areas of the Ghaggar, Markanda, Chautang, etc. (Dixit *et al.*, 2018; Neogi *et al.*, 2019; Singh and Sinha, 2019). People had already started migrating eastward from the Ghaggar valley, and were unable to perform Nature worship along the banks of the Saraswati river as was mentioned in the Rig Veda. We postulate that since the Rig Veda had prescribed the rituals to be performed along the banks of the flowing Saraswati only, and since human migration from the dry Ghaggar-Hakra valley had started eastward, a suitable perennial stream in the area of in-migration was identified for the ritual purpose and was named as the Saraswati *nadi*. According to the Mahabharata, the origin of that Saraswati *nadi* was in a spring in the Siwaliks, called the Plaksha Prasravana. The travel time from Vinasana to Plaksha Prasravana on horseback used to be about 40 days (Bharadwaj, 1986). While the Rig Vedic Saraswati has been identified with the wide, misfit valley of the

Ghaggar-Hakra through which the avulsion-prone Sutlej used to flow earlier via a series of Naiwals (Oldham, 1874, as Anon.), and the source of the river was traced to the Rakshas Tal in the Trans-Himalaya, the source of the Saraswati *nadi*, i.e., the Plaksha Prasravana, is traditionally identified with a spring at Adi Badri near Rampur (Dey, 1899; Krishnan, 1956), but Bharadwaj (1986) suggested it to be in the Lawasa forest in Nahan district. While tracing the Saraswati *nadi* in the plains, Bhadra *et al.* (2009) considered it to have occupied the upper course of the Chautang, but the old Survey of India (SoI) maps show distinctly the shifted courses of the river through Sadhaura, Jagdhauli, Mustafabad, Sthaneswar and Pehowa (Prithudaka of the Mahabharata) to Kharak opposite Shatrana where it meets the Ghaggar valley. The river is also shown prominently in Rennell's 1788 map. From the signatures on SoI maps and satellite images it appears that the Somb, the Chautang and the Markanda have captured considerable parts of the Saraswati *nadi*'s catchment area in the Siwaliks and in the adjoining foothills. It will be interesting to find if the Sadadeni *nadi*, now joining the Markanda downstream of Sadhaura, was formerly joining the Saraswati *nadi* near Saranwan, and if so, if the Saraswati *nadi*, rather than the Markanda, was the Saradanda Saraswati of the Ramayana.

Two companion streams of the Saraswati during the Rig Vedic period, the Drishadvati and the Apaya, also received good attention of researchers, especially because of their association with the disputed land and with the war at Kurukshetra in the narratives of the Mahabharata, and also because of their subsequent descriptions in the Puranas (Law, 1954). Rig Veda informs —*"Drishadvatyaang manushe Aapayaang Saraswatyang revadagne didihi"* (Ashtaka 3, Adhyaya 1, Sukta 23, Varga 23, stanza 4; Max Muller, 1854; p747). Wilson translated the stanza as "Do thou, Agni, shine on the frequented (banks) of the Drishadvati, Apaya, and Saraswati rivers" (Wilson, 1857; p25). Drishadvati is also mentioned in the Rig Veda as the Asmanavati (both the words meaning a stream with beds of pebbles and gravels; Bharadwaj, 1991). Cunningham (1871) identified the river's upstream segment with the modern Rakshi and the lower part with the Hansi-Hisar branch of the Western Yamuna Canal, while Dey (1899) identified it with the Ghaggar, but it is now identified as the Chautang (Rapson, 1914; Kar and Ghose, 1984). Apaya (also called the Apaga in the Rig Veda, and the Oghavati in the Mahabharata) was identified as the lower part of the Chautang near Ladwa (Cunningham, 1871; Thomas, 1883; Bharadwaj, 1986), and as a tributary of the Saraswati upstream of Sthaneswar and Kurukshetra (Law, 1944), both of which may have some justification, as the small west-flowing Siwalik-born streams between the Ghaggar and the Yamuna have many shifted and inter-mingling courses in the plains, forming a deranged drainage pattern. Several small lakes have formed along their courses. Thomas (1883) noted at least nine different stream and lake names in the Kurukshetra area.

As the Saraswati river was not physically present during the Mahabharata period, but the rituals and prayers ordained that both the Saraswati and the 'Sapta Saraswati' be invoked, the sages of the Mahabharata period, after identifying the Saraswati *nadi* as symbolic representation of the Vedic Saraswati, designated the following six streams as part of the Sapta Saraswati — Suprabha (at Pushkar, near Ajmer), Kanchanakshi (at Naimisharanya), Visala (at Gaya, Bihar), Vimaladoka (in the Haimavat mountain), Manas hrada (at Kosala), Suvenu and Oghavati (both near Kurukshetra; Ludvik, 2001). By doing so, the Rig Vedic concept of the *Sapta-Saraswati* as a large glacier-

fed Himalayan stream that nurtured a socio-culturally advanced and yet nature-conscious society, was substituted with the concept of the mingling of culturally enlightened societies in different river valleys that would spread the cultural messages contained in the Vedas. As we know now, many streams all over India have subsequently been named as the Saraswati. Yet, the rivers in between the Yamuna and the Indus, and the land through which these rivers flowed, traditionally constituted the domain of the Saraswati river.

Descriptions during the historical period

Many historical texts from Alexander's time onwards have described the major rivers, places and happenings within the Saraswati domain, that is the land between the Yamuna and the Indus. Alexander's biographer, Flavius Arrianus (or Arrian; 2nd Century AD), while reviewing the earlier works on Alexander's routes in the Punjab, informs that the width of the Chenab (then called the Acesines) where it used to meet the Indus to the southwest of Uch (then re-named as Alexandria) after being fed in the plains by the Jhelum (Hydaspes), Ravi (Hydraotes) and the Beas (Hyphasis), was about 3.5 miles (Chinnock, 1884). Accounts of a voyage by Alexander's army commander, Nearchus (~323 BC; Vincent, 1808), and the maps by Ptolemy (~150 AD; McCrindle, 1885) reveal that the Beas was the easternmost tributary of the Indus during Alexander's time and so the Sutlej was not a part of the Indus river system then.

In 325 BC Alexander went on a riverine expedition to the southeast of the Indus delta, beginning his journey from a place called Patala at the off-take point of a distributary of the Indus that was identified as the Sankra Nala (Vincent, 1808). Patala was a famous Buddhist centre, and a famous settlement from the time of the Ramayana (Haig, 1887). Vincent (1808) identified it as the historical town of Brahmanabad, which was subsequently located as the ruins near the present-day Mansura (Haig, 1884; Panhwar, 1983, 2011). Although the Indus has now shifted westward by ~30 km from its major prehistoric location (Biagi, 2017), the early narratives, the aerial-photo-based mapping of the Mansura area by Panhwar (2011) and our visual interpretation of the SRTM DEM data at 250 m resolution tend to suggest that the Indus then used to flow through the vicinity of Kot Diji, Sawri and Chanhu Daro to Patala where the Hakra-Nara, carrying the water of the Sutlej, possibly used to meet it after leaving the dune country; while the Ravi and the Beas used to flow into the Chenab to meet the Indus. The Sutlej possibly used to flow through the Hakra-Nara valley somewhere between Marot and Derawar Fort. The combined flow downstream of Patala was roughly through the Dhoro Puran. Sailing downstream from Patala, Alexander passed through a port which Vincent (1808) identified on the basis of his interpretation of the Greek narratives and coastal maps of Rennell and D'Anville as Bandar Lahri. Downstream, near the river's mouth, Alexander noticed a huge lake, which was possibly the embayment of the Kori Creek, and not a part of the Great Rann, for, according to Arrian the lake was full of many species of sea-fish (Vincent, 1808; Pithawala, 1936), and the fish could hardly survive in the highly saline shallow water of the Great Rann.

The texts of the early Arab and Persian scholars contain several interesting descriptions of the rivers and places in the Punjab Plains from 712 AD onward (see, Elliot, 1867, for narratives in the texts of al-Masudi in ~943 AD, Ibn Haukal in ~976 AD, al-Beruni in ~1028 AD, al-Idrisi in 1150, Umar-i-Usman in ~1262 AD, etc.). Based on Chachnama, an epic text in Persian by Ali Kufi (1226) on Sind's history during 7th–13th Century (trans. Fredunbeg, 1900;

Ahmed, 2012), and Beglarnama (~1625 AD; trans. Elliot, 1867), Oldham (1886) informs that the Nara had considerable perennial flow till the 11th Century AD, while Tarikh-i-Tahiri (1621; trans. Elliot, 1867) informs that the 'river of the Punjab' (i.e., the Sutlej) used to flow past Alor (east of Rohri) during the Sumra kingdom (1300–1439 AD) as Hakra, Wahind and Dahan, and "after fertilizing the land, the river pours its water in the ocean" (Elliot, 1867; p256). Ibn Batuta, while visiting the region in 1333, reached Bandar Lahri from Sehwan (on the Indus), and then travelled upstream to Bukkur, Uch and Multan for onward journey to Delhi. Unfortunately, he did not describe any river or the terrain in between (Husain, 1976).

Based on the narratives of the medieval scholars, an early map in Masalik-wa-Mamalik, a Persian document, and some large-format maps in the Indian Atlas of SoI (c. 1866 edition), Raverty (1892) provided a detailed account of the locations along the streams in the past and provided small-scale maps on the likely channel changes between the first conquest of Sind by the Arabs in 712 AD and the 18th Century. His translation of Umar-i-Usman's Tabakat-i-Nasiri (Raverty, 1881) is a major source of information on the hydrography of the region. According to it, during al-Beruni's time (~1028 AD) the Ravi used to meet the combined flow of the Chenab and the Jhelum to the east of Multan. Downstream, the combined stream used to be called the Trim-Ab (or the three waters) till Jhangra where the Beas used to meet, and the combined flow of the four streams was known as the Sind-Rud, which used to meet the Indus near Mithankot. According to him, Bijnot (or Wanjh-rut) to the west of Bikaner was a flourishing settlement on the Hakra at least till 1245 AD, when the Sutlej used to flow through Bathinda (a Naiwal) to enter the Hakra valley near Fort Abbas and flow through Bijnot, Islamgarh and Kishangarh (north of Tanot in Jaisalmer district). The confluence of the Chenab with the Beas (then independent of the Sutlej) was to the downstream of Uch, which together used to meet the Sutlej-Hakra near Khangarh. Subsequently the Sutlej shifted westward from the Bathinda course to flow through Abohar, and began to feed the Hakra from Marot downstream through Bijnot and Kishangarh. Another westward shift of the Sutlej from the Abohar course, however, took it away from Marot, and the Hakra's course through Bijnot and Kishangarh dried up. In the Punjab, a major flood during Taimur's invasion of Multan (1320-1324 AD) led to the shifting of the Chenab and the Jhelum by about 23 km, when the Chenab deserted the Ravi, and began to flow to the west of Multan rather than to the east of it. The Ravi was forced to meet the Beas, and the Chenab-Jhelum combine began to meet the Beas-Ravi about 65 km to the south of Multan, and the four rivers together joined the Indus in the name of Sind Rud (or the Rud-i-Sind), forsaking the Hakra. The Sutlej then explored a new course to the west of Abohar and began to feed a pre-existing course of the Ghaggar-Hakra near Khairgarh (that existed between Marot and Khangarh) through Mojgarh and Dingarh in the west. This course subsequently revealed the richest concentration of Harappan settlement along the Ghaggar-Hakra valley (Mughal, 1982). Raverty (1892) noted several former channels of the Ghaggar-Hakra between Dilawar (Derawar Fort) and Birsilpur, which were locally named as the Wahinda or the Raini, and felt as if "the Hakra at different periods has flowed over every part of it" (p426). He collected from the vicinity of Bijnot fragments of pottery, bricks and other archaeological specimen (possibly of Harappan age). After the Sutlej joined the system near Uch, the combined flow till Mithankot began to be known as the Panj Nad. The Indus upstream of this confluence

was known as the Sindhu or the Sind, while downstream the Indus used to be called the Mihran. As discussed earlier, the Sutlej used to flow, till the time of Taimur's invasion, partly through an eastern branch through Abohar into the Ghaggar-Hakra valley, but its main flow was slightly to the west, in between the Abohar Naiwal and its present flow through Ferozepur, Pakpattan and Bahawalpur, where the river used to be called as the Dhund-i-Dariya. Sometime during the later part of Akbar's reign (c. 1593 AD) the Sutlej occupied the Beas bed completely from Harike downstream, making the Beas its tributary. Although some of Raverty's suggestions, especially on the Indus that it used to flow eastward through the Chenab and the PanjNad into the Hakra-Nara, were far-fetched, and many of his criticism (as Nearchus, 1875) of C.F. Oldham's findings (as Anon., 1874) were largely unfounded, his interpretations of the medieval Persian texts were extremely useful in understanding the historical channel changes and their impacts on society. Raverty (1892) finally accepted all the major findings of Oldham on the Saraswati, except some historical narratives by Oldham, which he felt were incorrect.

Modern scientific mapping

The ancient descriptions of the river systems in Punjab and Sind, when read sequentially, provide the mental map of a large Himalayan river flowing parallel to the Indus to the Arabian Sea, and leaving many old and abandoned streams in the plains as the system gradually shifted westward to join the Indus. Our scrutiny of available old maps reveals that Herman Moll's Map of Asia (1715) was the first to draw a river from the northeast of Sirhind to the Indus delta, where it was joined by the easternmost distributary of the Indus (the Dhoro Puran; also called the Sankra Nullah) before meeting the Arabian Sea. At Sukkur a branch of the stream was shown to flow a short distance westward to meet the Indus, which matches with the description in the Tarikh-i-Tahiri (1621). Most European maps of India during the period used to depend heavily on Ptolemy, Idrisi and sundry travel documents, but none had depicted a stream parallel to the Indus, not even Moll's earlier map of Asia (c. 1705). Subsequent editions of the 1715 map and its copies for about a century named the river as the Chaul, Sitmegus, Dena, Diemad, etc., all of which refer to the Sutlej.

The role of Survey of India (SoI)

Modern scientific mapping of the Saraswati river as flowing independent of the Indus into the Arabian Sea began in the 18th Century. The first map of a Himalayan river, the 'Sursooty', joined by the 'Gaggar'/'Kenkar' river in the Sub-Himalayan Plains, and then getting obliterated but leaving traces as a 'supposed course of the Gaggar River' through the western part of Thar Desert and the Great Rann to the Arabian Sea near Koteswar, was published by James Rennell (1788), the first Surveyor General of the East India Company. The map also depicted the courses of other major Punjab rivers and their confluences, which differ from the present day confluences. Although his 'Map of Hindoostan, or the Mogul Empire' suffered from large spatial inaccuracies in the desert tract due to the lack of adequate reference points and route descriptions, his was the first palaeochannel map of the region, and it was based on many early narratives, including the voyages of Nearchus, the Ferishta, the Ain-i-Akbari, and the accounts of early European travellers. One of the streams in the 1788 map which was difficult to identify for a long time was the Dimmody river. This river could be traced by the author as a short ephemeral stream emanating from the Aravalli hills in Sikar district and flowing past Udaipurwati and Parsrampura to Nawalgarh. The river

typically flows once in a decade, but there are remote sensing signatures of its former flow path further west. Curiously, some 19th Century maps show the Dimmody's course continuing to the Nara near Sukkur (e.g., E. Bowen's 1747 'Map of the Empire of the Great Mogul'; John Cary's 1819 map of 'Sindetic Hindoostan'). A map on "Hind, Hindoostan or India" by L.S. de La Rouchette (1800), which was published by William Faden, names the course of the Nara to the south of Umarkot as 'Dimtadee'!

While Rennell's map is now mentioned in some literature reviews, one surprising omission is that of a detailed map of the Ghaggar-Hakra valley that was published in 1804. Soon after the 1788 map of Rennell, SoI published "A Map of the Countries to the West of Delhi as far as Cabul and Moultan", by Mirza Mogul Beg (prepared under Capt. E. Wilford of SoI; surveyed 1786–1796; published in 1804 and 1820). The map was prepared on the basis of field observations and measurements, supplemented by many secondary sources. Although this map also suffers from locational inaccuracy, it was perhaps the first clearly demarcated map of the Ghaggar-Hakra valley from near Tohana (written as 'Tehwauna') to Derawar through Fatehabad, Sirsa, Bhatner (modern Hanumangarh), Anupgarh and Marot. The valley is mentioned as the 'Old bed of the Chitrang or Chittangh which rises near Tanehsur and which remains dry except during the rains'. The valley downstream of Derawar is shown by the symbol of a stream till Rohri, where it is mentioned as the 'Dummoodee or Dumtodee' that joins the Indus. Upstream of Tohana the stream is named as the 'Caggar or Ghaghar or Panchnad', and is joined by the 'Sursootee R' downstream of Siwan. The latter is shown as originating from the Siwaliks to the east of Sadhaura, and flowing past Machhrauli, Bhulgarh, Mustafabad, Thanesar (ancient Sthaneswar) and Pehowa (ancient Prithudaka) to join the Ghaggar. The map also depicts a tier of land surfaces across the Punjab Plains, the most notable of which is a degraded scarp along the Sutlej's course from near Harike to Uch, as well as a

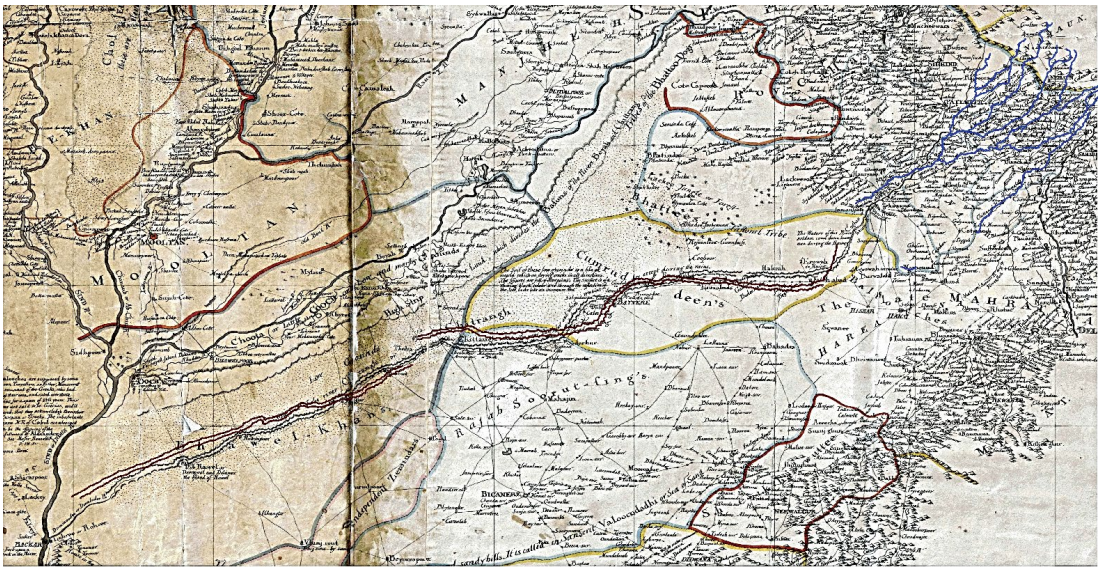

Figure 2. Ghaggar-Hakra valley and its surrounding areas from Mirza Mogul Beg's 1804 'Map of the countries to the west of Delhi as far as Cabul and Moultan' (sourced from https://zenodo.org). After geo-referencing of the coordinates, some of the best-fit segments of the Ghaggar valley (brown) and few present streams (blue) as mapped from the modern maps and satellite images have been superimposed on it.

number of abandoned courses of large rivers like the Beas and the Ravi. It also provides many short descriptions of the local physical and socio-cultural features on the map, which must have been immensely helpful for the map readers of the time. The map was georeferenced based on its coordinates, and then the vector layers of streams, valleys and places, digitised from modern maps and satellite images were superimposed on it. Although some locational inaccuracies were noticed in this less-frequented area, a large part of the valley and stream configurations matched well with the vector map details (Fig. 2).

From the 1820s onwards SoI carried out systematic detailed mapping of the region that was based on the Great Trigonometric Survey (GTS) method. The early maps depict many old and abandoned channels, including the clearly defined boundaries of the Ghaggar-Hakra valley, the Naiwals and the abandoned valleys of some large rivers like the Beas and the Ravi. The mapping concept and some terrain features appeared to have been partly derived from the SoI's 1804 map, but with higher accuracy. The maps are also rich in terrain details that are difficult to find on the maps of the post-canalisation era (i.e. after 1870s). A compiled 'Map of the Punjab and Adjoining Countries' (1853) shows several major alluvial scarps separating the younger alluvial plains (*khadar*) from the older alluvial plains (*bangar*), as well as major terraces and incision features (Fig. 3). The features were duplicated in many subsequent atlases of the period (e.g., Keith Johnston's map of India, northern sheet, 1873; Fig. 4), and must have helped Oldham, Raverty and other researchers of the period in drawing the palaeochannels.

The credit for the first mention of the Ghaggar valley as the Saraswati river is given to the French geographer, Vivien Saint Martin (see Danino, 2010; Valdiya, 2017), for his text book on the Vedic rivers (St. Martin, 1855), but the credit perhaps should go to the Norwegian Indologist, Christian Lassen (1847), who not only identified the Saraswati with the Ghaggar valley, but also informed that the Saraswati *nadi* that is given religious importance, is 'insignificant'. Lassen profusely acknowledged William Jones, H.H. Wilson and other Indologists at the Asiatic Society of Bengal, as well as Carl Ritter, the Geographer, as his sources, while

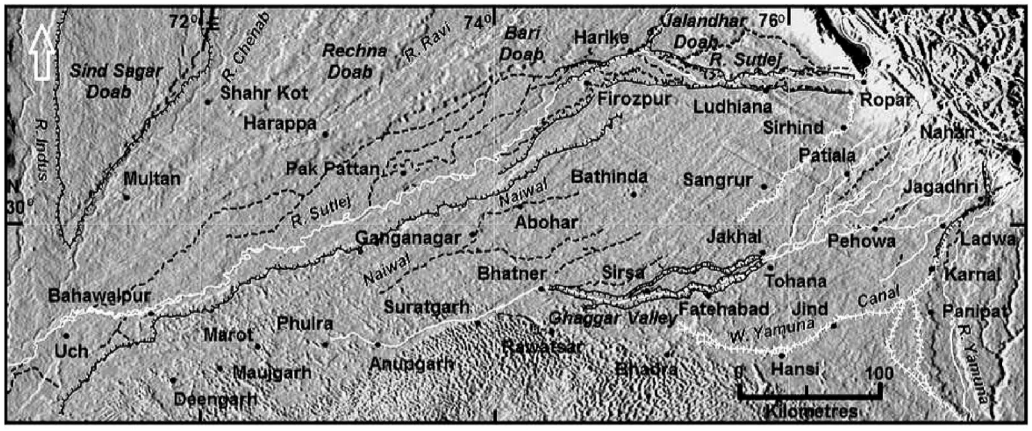

Figure 3. Some of the digitised topographical details from SoI's 16 inch to a mile 'Map of the Punjab and adjoining countries' (1853), which was geo-referenced. Features shown are: existing streams (white lines), abandoned channels (dark dashed lines), Ghaggar valley (double combed lines, dark), alluvial scarps (single combed lines, dark) and canals (crossed lines, white). Background image is of the SRTM 1 km DEM to show the level of correspondence between the two.

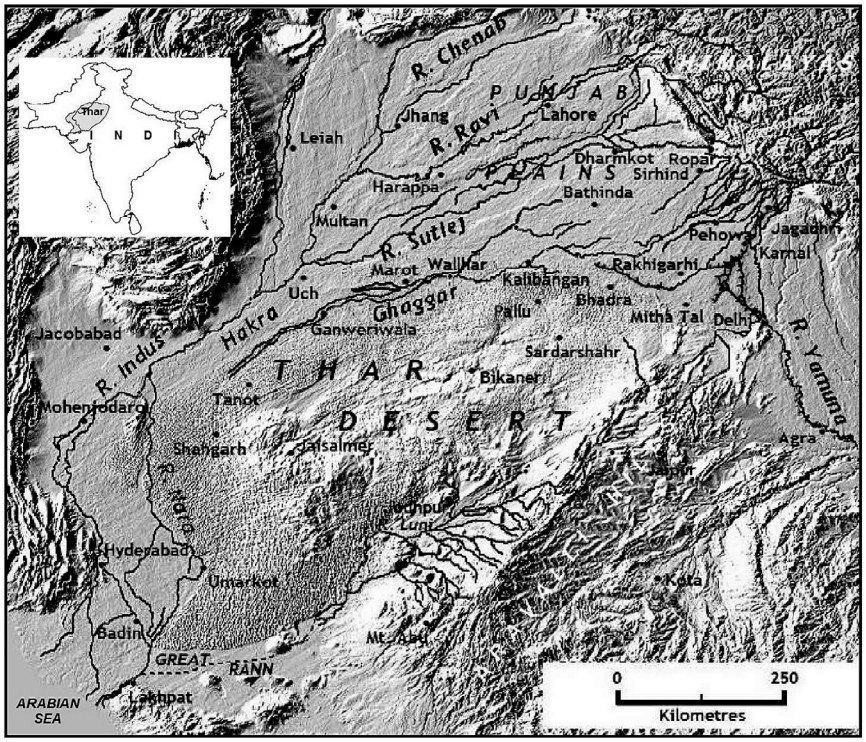

Figure 4. Present and former streams in A.K. Johnston's 1873 map of north India, after it was geo-referenced. Background image shows the SRTM-1 km DEM.

St. Martin acknowledged Lassen as his major source. It may be worthwhile to mention here that in 1821 Aaron Arrowsmith published "An improved map of India" in 9 large sheets (16 inch to a mile scale) based on the SoI's many route survey and revenue survey maps. The sheet-1 of this series shows the Ghaggar river (written as 'Gagur') downstream of its confluence with the 'Sursooty' river at Moonuk (or Munak) as "Surrusuretty River", flowing past Futtiabad (Fatehabad) and Seerah (Sirsa). This is the same Ghaggar river that the SoI maps of 1804 and 1820 show in a wide valley till the vicinity of Rohri (ref. Fig. 1). In other words, Arrowsmith and other map-makers of the time knew the Ghaggar as the Saraswati river long before St. Martin's suggestion, but what was missing was the identification of the Sutlej as the river's source! While acknowledging C.F. Oldham for identifying the Sutlej's courses through the Naiwals and the Ghaggar-Hakra-Nara to the Arabian Sea as belonging to the Rig Vedic Saraswati, it must also be reminded that it was rather H.B.E. Frere who obliquely suggested in his paper on the Great Rann and the Indus Delta that the old and the abandoned stream beds from the vicinity of Sirhind to Rohree, and the continuation along the Nara, could be those of the Saraswati (Frere, 1870). Modern reviews seldom credit the above sources.

Other maps

Field recognition of palaeochannels from the observation of abandoned valleys became increasingly difficult after the valleys began to be converted into canals. The progressive conversion of many palaeochannels into canals has been described in the literature since the 18th Century. For example, Rennell's 1788 Memoir describes how Feroze Shah Tughlaq took keen interest in

agricultural development and so, in 1355, after reaching Debalpur, he "made a canal 100 miles in length, from Suttuliz to the Jidger". He then cut a channel from the Yamuna (near Jagadhri), 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, mainly due to squabbles and wars. Oldham (1874) found the canal to be partly along the Chautang (Drishadvati). Numerous studies since then have not only evaluated and re-confirmed C.F. Oldham's thesis but have also discussed how the river system evolved and how it influenced the growth and demise of the Harappan culture (Pithawala, 1938; Wadia, 1938; Ali, 1941; Stein, 1942; Wilhelmy, 1968, 1969; Mughal, 1990; Sarkar *et al.*, 2016; Petrie *et al.*, 2017; Singh *et al.*, 2017; Clift and Giosan, 2018). The most notable maps of the period were those by Wilhelmy, providing new information based on narratives for the reconstruction of the channel changes in the Indus Delta since 325 BC (Wilhelmy, 1968), and in the Punjab Plains since ~2000 BC (Wilhelmy, 1969). Ignoring his attribution of 2000 BC and Vedic Period for the courses in Punjab Plains, we find the maps based on aerial photo interpretation interesting. Superimposing Raverty's (1892) stream network during Arab invasion (~712 AD) on Wilhelmy's stream networks for 2000 BC and 600 BC (Fig. 5) we find the suggested time lines worth investigating through geo-chronometry.

Remote sensing-based mapping

The first satellite image-based mapping of the Saraswati-Drishadvati palaeochannel system was carried out by Ghose *et al.* (1979), who interpreted the coarse-resolution (79 m), near-infra-red band images from the Multispectral Scanner on board the ERTS-1 (re-named as Landsat-1) satellite (Fig. 6). The basic feature identification was followed by extensive field verification of the signatures in the Indian part, especially in respect of

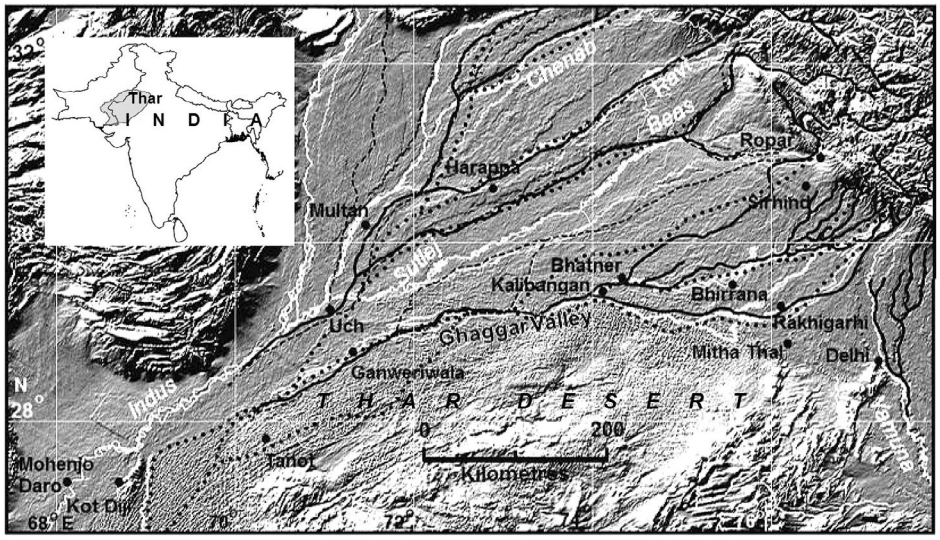

Figure 5. St ream networks extracted from Wilhelmy (1969) for 2000 BC (dark, solid lines) and 600 BC (dark, dashed lines), and from Raverty (1892) for ~712 AD Arab invasion of Sind (dark dotted lines), after the above small-scale maps were geo-referenced. Modern streams are in white; background image is SRTM-250 m DEM.

vegetation banding, sediment characteristics, evaporites, groundwater condition, etc. In the heavily canalised Punjab Plains, the present author could identify not only the Naiwals and the other major abandoned channels mapped earlier by Oldham (1874), but also few others that were unreported so far.

In the Thar Desert a few south-flowing courses from the Ghaggar-Chautang valley system were identified, especially through the western part of Jaisalmer and adjoining part of Pakistan, with evidence for alluvium and potable water under the thick aeolian sand cover. Kar and Ghose (1984) identified the south-flowing older courses of the Saraswati-Drishadvati river system through the Punjab Plains and the central and eastern parts of Thar Desert, which they named as the proto-Saraswati and the proto-Drishadvati. The emerging pattern suggested a gradual westward shift of the system from the initial south-flowing courses in eastern Thar during the Late Quaternary period (Fig. 6). The most likely causes were identified as the oscillating behaviour of the Sutlej river, tectonic activities in the sub-Himalayan plains, and variations in climate that led to burial of some old stream beds by advancing sand, and opening up of new ones in the desert plains. The mapping was followed by geophysical exploration along a potential stretch of the buried stream to the west of Jaisalmer for

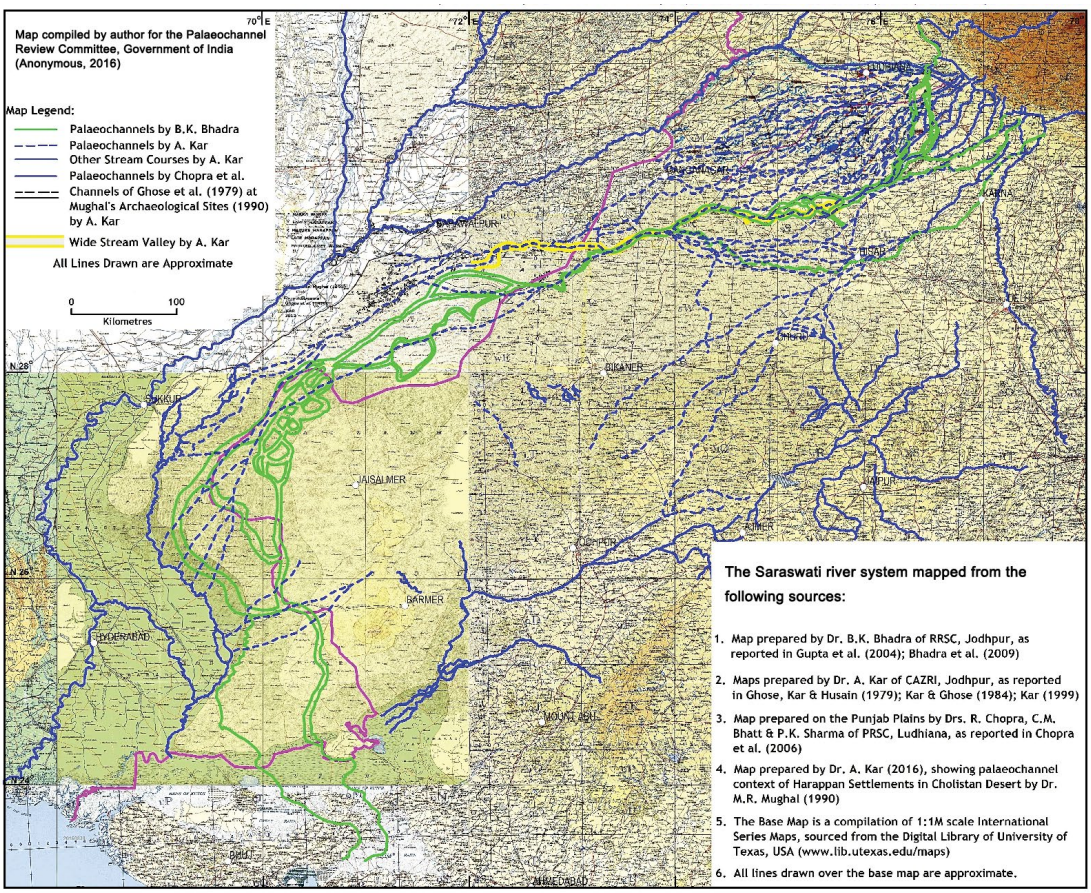

Figure 6. The Saraswati river system mapped from satellite image interpretation by researchers from CAZRI, Jodhpur, ISRO-RRSC, Jodhpur, and PRSC, Ludhiana. Some Harappan settlements mapped by Mughal (1990) in the Cholistan Desert are also shown. Background image is a mosaic of 1:1M International Series maps (1943–1961).

groundwater (Kar and Shukla, 2000; Fig. 7). Dating of the groundwater along the same palaeochannel in Cholistan Desert (Geyh and Ploethner, 1995) suggested no recharge for the last 5000 years. It was also found that some of the mapped palaeochannels hosted numerous Harappan settlements (Mughal, 1982 and 1990; Fig. 8).

Using the Landsat-1 images Yashpal *et al.* (1980) mapped the Ghaggar valley and the easternmost course of the Sutlej. They suggested that the mapped courses were not available on SoI maps, and that the flow paths represented the courses of the Saraswati river during Harappan civilization. As discussed earlier, Ghaggar valley was mapped in great detail over a century ago by SoI, and the easternmost flow path of the Sutlej was known since Oldham (1874). Other subsequent satellite-based palaeochannel mapping identified several important new courses through Punjab, Haryana and Rajasthan, or validated some earlier findings (Bakliwal and Grover, 1988; Rajawat *et al.*, 2003; Gupta *et al.*, 2004, 2011; Chopra *et al.*, 2006; Bhadra *et al.*, 2009). Georeferencing of the maps which survived the scrutiny of time and their compilation provides a summary of the major findings (Fig. 6; Anon., 2016; Orengo and Petrie, 2017). Geo-chronological

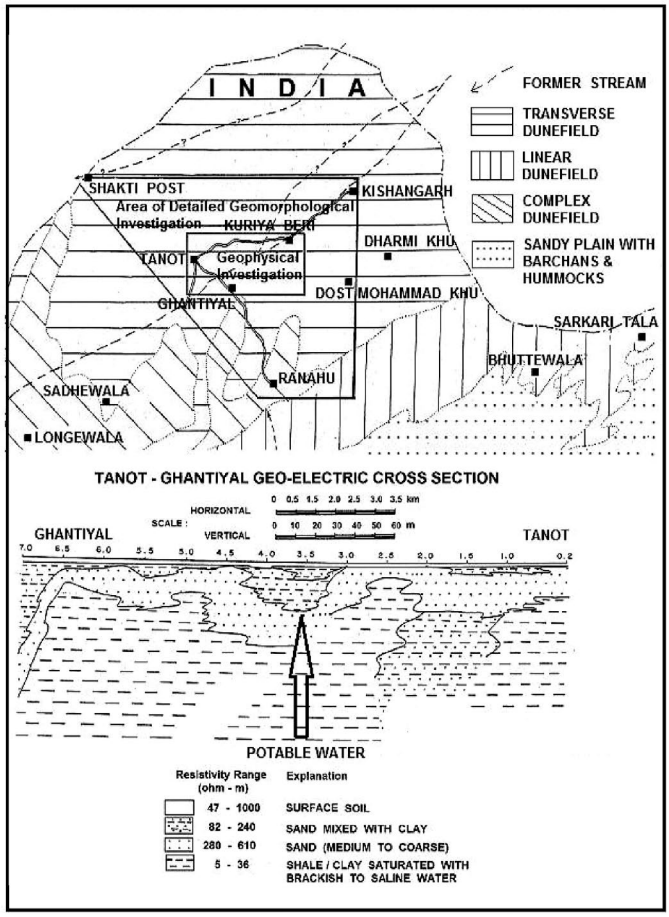

Figure 7. Location of potable aquifer through geophysical depth sounding along a Saraswati palaeochannel through the western part of Jaisalmer district (adapted from Kar and Shukla, 2000).

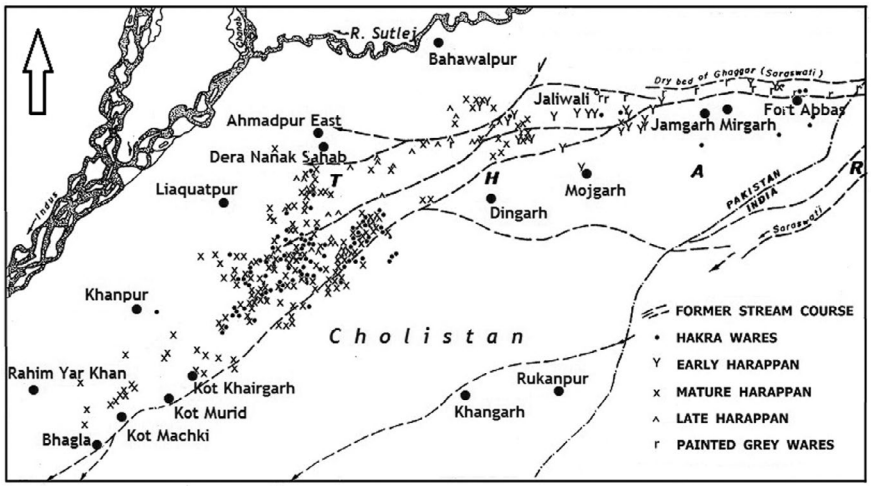

Figure 8. Ancient settlements in Cholistan desert (Mughal, 1990) superimposed on the Ghaggar-Hakra palaeochannels that were mapped from Landsat-1 near-infrared band images (Ghose *et al.*, 1979).

studies on fluvial sediments have confirmed that the Harappans had settled in the Ghaggar-Hakra valley long after it was deserted by the Tons-Yamuna and the Sutlej (Clift and Giosan, 2018; Singh and Sinha, 2019; Kar, 2020). During the Harappan civilization the Ghaggar-Hakra valley had become under-fit and was occupied by a set of low energy streams from the Siwaliks.

Present digital mapping

Recently the present author carried out digital analysis of some optical and microwave satellite sensor data to identify and map the palaeochannels in the Yamuna-Sutlej Interfluves (YSI), the Thar Desert and the deltaic plains of the Nara (Kar, 2020). The DEM data at different resolutions from SRTM (1 km, 250 m and 30 m), ALOS-World3D (or AW3d30 m) and CartoDEM (30 m) were subjected to some filtering and edge enhancement techniques to find the palaeo-valleys in the plains and within the dune infested areas, and to map the major geomorphic surfaces, alluvial scarps and other displacement zones. ASTER data of Thar Desert was subjected to band ratio analysis to locate the distribution of evaporites as sulphates and carbonates, and to thermal index analysis for moist area discrimination. Additionally, standard FCCs of Sentinel-2 and Landsat ETM+ bands were visually interpreted for mapping and the results were matched with the ground information database from across the desert. A short overview of the major findings is provided here.

Mapping in the Yamuna-Sutlej interfluves of the Punjab plains

In the YSI many palaeochannels occur on a broadly convex older land surface, called the *bangar* (older alluvial plain). Digital processing of the SRTM 1 km DEM data revealed that most palaeochannels occur within some pre-existing large palaeo-valleys with breached levees, the most notable of which was a wide silted-up valley of the Tons-Yamuna from the margin of the Somb river westward through Jagadhri, Darazpur, Hartan, Kurukshetra, Sthaneswar, Sarsa and Siwan to Sagri, where it used to meet the Ghaggar from the north. Another major palaeo-valley of the Tons-Yamuna was

traced from Jagadhri southwestward through the vicinity of Ladwa, Asandh and Safidon to Jind, and then partly through the Hansi branch of the West Yamuna Canal to Hisar and then along the entrenched meandering valley of the Chautang through Bhadra, Nohar to Suratgarh, where it used to meet the wide Ghaggar-Hakra valley (Fig. 9 and 10). Following Oldham (1874) the two palaeo-valleys are designated as belonging to the Drishadvati river. Different segments of the two valleys are occupied by small, Siwalik-born streams like the Rakshi, the Chautang, the Saraswati *nadi* and the Markanda. In between a number of distributary valleys exist due to avulsion.

Kar and Ghose (1984) had suggested that the Drishadvati's deflection from the present Yamuna was from Jagadhri to Jind and Hisar to meet the Saraswati near Suratgarh, while some other studies suggested that the deflection was from Karnal for the course through Hansi and Hissar. Pati *et al.* (2018) felt that the south-flowing course along the West Yamuna Canal originated from near Karnal and was active prior to 3000 BC, while the westward course through Jagadhri and Sthaneswar to the Ghaggar was active during 2300 BC. In between they dated another west-flowing channel from Karnal to 2600 BC, which joined the Ghaggar near Fatehabad. Simulation of the drainage network on the YSI from SRTM 1 km DEM to find the likely flow path of flood water in the event of a catastrophic hydrological event in future showed, that despite the maze of canals and the surface modifications, the flow paths followed approximately the valleys drawn by the present author from near Jagadhri towards the west and the south, rather than from Karnal (Fig. 11). The western limit of the Tons-Yamuna palaeo-valley system is marked by a drop in the land surface by about 5 m, to the west of which is the domain of the palaeo-Sutlej river.

Numerous old channels of the Sutlej could be identified between Shatrana and Sagri in the east and India's border with Pakistan in the west, which used to meet the presently misfit, wide valley of the Ghaggar-Hakra, first from near Ropar, and then from near Dharmkot. The Naiwals, which are shown so prominently in Oldham's 1874 map, were part of that system. The easternmost recognisable old course of the Sutlej could be traced from the vicinity of Lutheri, Sirhind and Patiala southward, roughly along the middle and the lower segments of the Patialewali Nala, and then through the lower course of the Ghaggar to Shatrana and Sagri. Gradual westward shifting of the Sutlej led to new valley formation, first through the vicinity of Sirhind and Nabha, which used to meet the Ghaggar-Hakra valley near Jakhal and Akalgarh, and then through Chamkor-Dabwali, Ludhiana-Muktsar, Dharmkot-Mudki-Faridkot, and

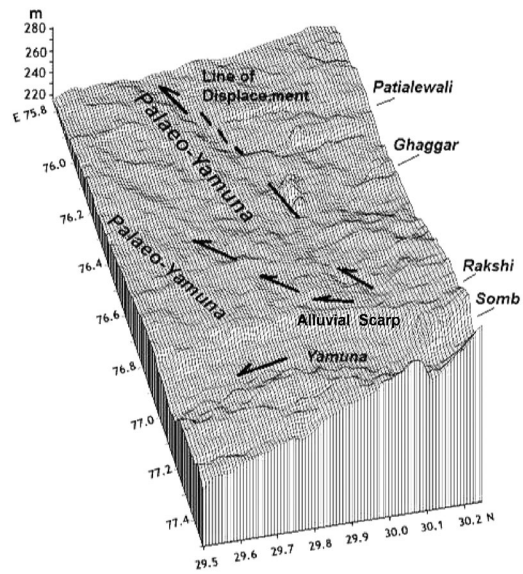

Figure 9. Weir-fence diagram showing the silted-up remnants of two major palaeo-Yamuna valleys from the northern margin of a high alluvial scarp along the present Yamuna River. The features were extracted through digital processing of the SRTM 1 km DEM data. Also highlighted are some Siwalik-born streams joining the palaeo-Yamuna course across an active lineament.

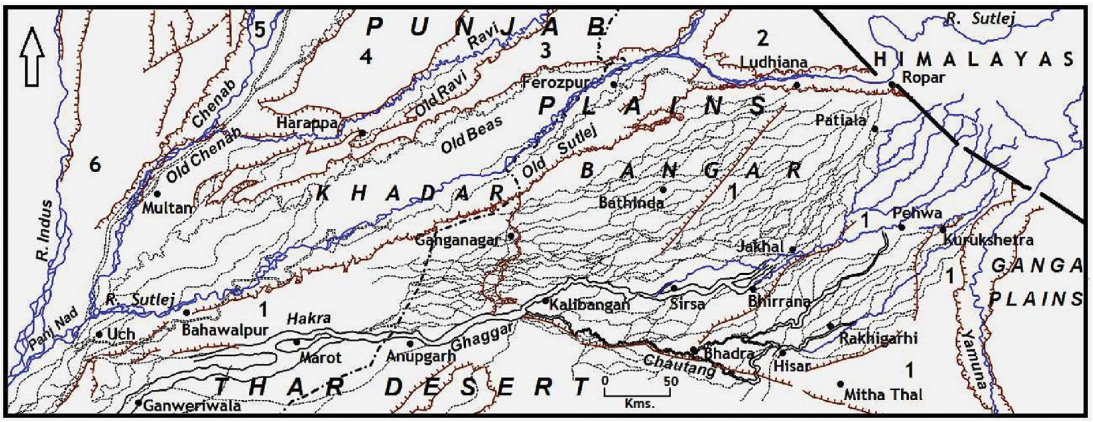

Figure 10. A dense network of palaeochannels of the Sutlej and the Tons-Yamuna on the YSI, as interpreted from Landsat MSS, TM and ETM+ FCCs and from SRTM1km DEM. The major interfluves are numbered: (1) Yamuna-Sutlej Interfluves (YSI); (2) Bist or Jalandhar Doab; (3) Bari Doab; (4) Rechna Doab; (5) Jech Doab; and (6) Sind Sagar Doab.

Zira-Rattewala. In the process of this shifting the Sutlej fed the Ghaggar-Hakra valley progressively westward from near Shatrana, the major westernmost feeding point being near Dingarh and Derawar Fort, a distance of about 400 km. Singh *et al.* (2017) dated the older Sutlej channel deposits at 25 m depth along the Sirhind course as ~31 ka, and the youngest at 4 m depth as ~16 ka, while Chatterjee *et al.* (2019) dated the Sutlej channel sand at ~15 m depth along the Sirhind course near Jakhal as 9 ka. By contrast, Pati et al (2018) dated the youngest Sutlej deposits along the Patialewali and the Sirhind courses as of <2100 BC (4 ka).

The long period of activity of the Tons-Yamuna and the Sutlej over the YSI (~ 85 ka; Singh and Sinha, 2019) led to the development of coalescing alluvial fans in the YSI, with multiple lobes as the apex of the cones shifted over time. The process of channel stacking and alluviation over time (Van Dijk *et al.*, 2016) also resulted in the formation of thick alluvial plain of the *bangar*. After interpreting the DEM data for alluvial scarps on the YSI, two surfaces were identified each for the Tons-Yamuna and the Sutlej (i.e., an old surface and a new surface). The mean height of the Tons-Yamuna Old Surface in the southeast is the highest (227 m), suggesting that this could be the oldest surviving land surface over the YSI. Large parts of the *bangar* surface typically has a dark brown, fine loamy calcic soil with abundant mica, which in the pre-canal period used to provide a shining-black, hard surface with mud cracks (see SoI map of 1804), facilitating faster travel on horseback (the Chitrang Zameen of Raverty, 1892). The large valley remnants on the DEM mostly belong to the avulsion-prone Sutlej and the Yamuna of the post-LGM period. Excellent relationship exists here between the geomorphic properties of the landscape and soil development (Sehgal, 1974; Srivastava *et al.*, 2015). Near the foothills, the *bangar* soils are mostly reddish brown with a strong argillic horizon due to the impact of outwash sediments from the Siwaliks during the post-LGM melting of ice sheets. Most soils across the YSI report this capping of different thickness. High water influxes after the LGM, especially during the early Holocene monsoon strengthening (~10 to 8 ka), not only led to the shifting of several channels along the pre-existing valleys, but might also have aided in the incision of some valleys that left many palaeochannels' confluences

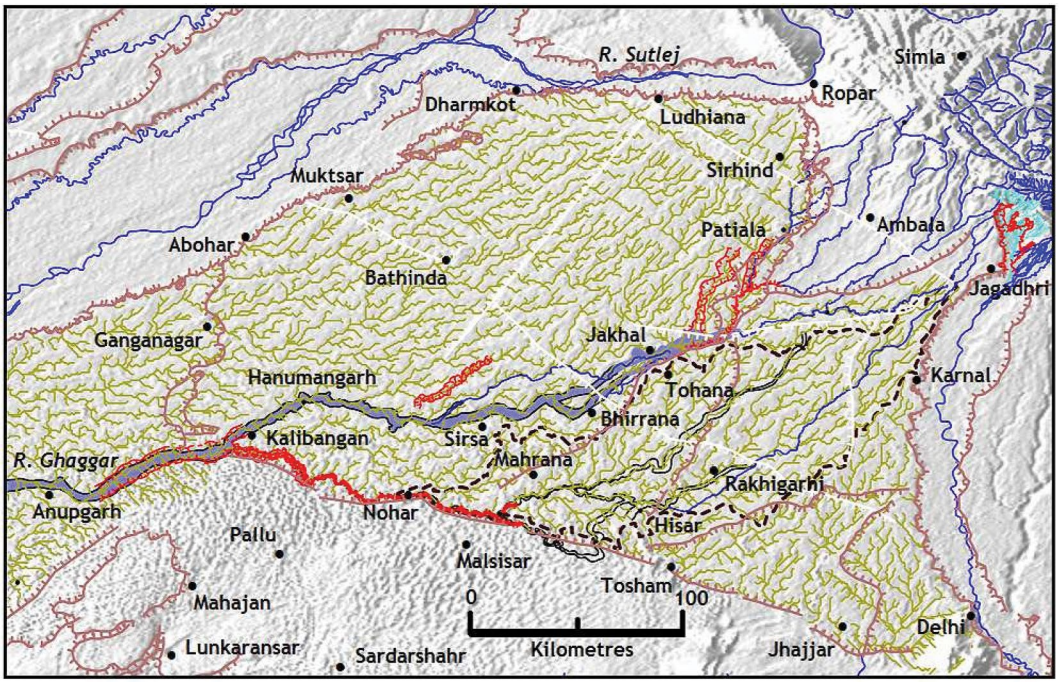

Figure 11. Simulated drainage pattern (dark green) over the YSI, as extracted from the SRTM 1 km DEM data. Also shown are the major alluvial scarps (light brown combed lines), major tectonic lineaments (white combed lines), incised valleys (red) and the catchment area of the S-flowing palaeo-Yamuna (dark brown dashed line).

with the new incised valleys as 'hanging'. The primary causes for the terracing, were the warping and related neotectonic activities (Fig. 12). In the central part the old valley fills and the river terraces have developed well-drained soils without much secondary carbonates (Srivastava *et al.*, 2014). During the Early Harappan period (~ 4.8 to 4.5 ka) much of the Ghaggar valley carried a seasonal stream within the wide valley. The climate was then transiting from a wetter to a drier regime, and hence, the impact of the southwest monsoon was getting reduced and the winter/spring monsoon was becoming frequent, but both were active, providing frequent rains from both the seasons (Kathayat *et al.*, 2017; Giesche, *et al.*, 2019). Such terrain and climatic features might have provided the people a rare opportunity for assured cropping practices and allowed hundreds of ancient settlements to flourish in the Ghaggar-Hakra valley.

The old levees along the large valleys in the eastern part of the *bangar* often have a buried soil (8–6 ka) with an organic-rich A horizon that was utilised by the Early Harappans for multi-cropping in the summer and the winter monsoon (Neogi *et al.*, 2019). The inhabitants might have found in the catenary soil development from the levee top to the valley bottom excellent opportunities for an integrated agro-pastoral land use, such that the higher slopes with organic-rich soil were dominantly used for cereals like rice and wheat, the middle slopes for coarse grain crops like millets and barley, as well as cotton, and the clay-rich marshy lower slopes and valley bottoms more for open pasture, fuelwood collection and water conservation, as could be understood from the in-depth studies of ethno-botany and food habits from archaeological remains at many sites (Madella and Fuller, 2006; Bates *et al.*, 2018). The western part of the *bangar* was

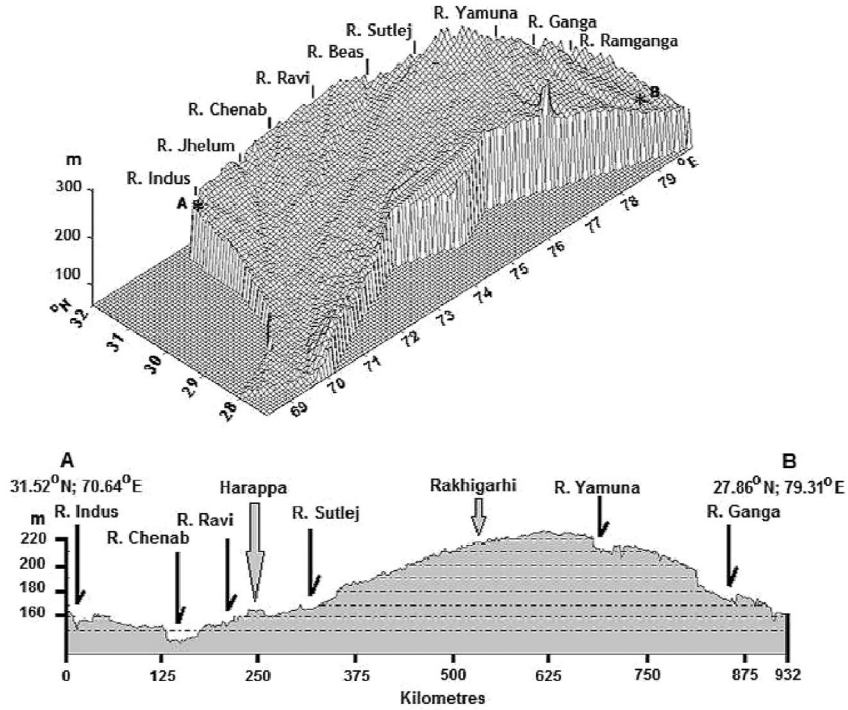

Figure 12. A wire-fence diagram of the YSI to show (a) the effects of warping on terrain height. (b) Surface profile along a transect from the Indus bank in the west to the Ramganga bank in the east shows how the stream cross-sections are also getting affected by the warping.

more dry and sandy, and so favoured regular transhumance and a dominantly pastoral land use (Fairservis, 1986). Yet, cattle and buffalo, preferring C4 forages, were important components of the households across the plains, as also the free-moving goats and sheep, which used to browse and nibble at both C3 and C4 plants. This means that large-scale domestication and management of these animals was on the basis of the availability of different kinds of forage and pasture species (Lightfoot *et al.*, 2020). The YSI's *bangar* landscape thus provided the Harappans with enough resources to practice multi-cropping and different types of land use, which evolved into the sustainable traditional practices that one can find now in many parts of the region (Kar, 2014).

Flanking the *bangar* is the younger khadar surface that has been constructed by the shifted Sutlej-Beas in the west and the Tons-Yamuna in the east. The fall from the *bangar* surface takes place along a 2–5 m high alluvial scarp. It suggests an abrupt event during late Quaternary period, the precise time and reasons for which are yet to be investigated properly. The shifting away of the Sutlej from the YSI with a strong E-W incision has saved most palaeochannels on it from being erased by the recent Himalayan streams. Palaeochannels on the Doabs in the west are not so fortunate, and are getting gradually obliterated by numerous south-flowing torrential streams. How much this process is accelerated by climate change and how much by neotectonic events is not yet known, but there is evidence for gradual upwarping of the sub-Himalayan plains

during the post-LGM period that is tilting the land westward from the Yamuna axis, leading to large-scale westward shifting of the Punjab rivers (Kazmi, 1995; Belcher and Belcher, 2000; Valdiya, 2003; Schuldenrein *et al.*, 2007; Srivastava *et al.*, 2014; Kar, 2020). Along the mapped Tons-Yamuna valley through Jagadhri and Sthaneswar to Sagri, a deranged drainage pattern is noticed, along with the formation of ephemeral lakes astride many streams, especially the Saraswati *nadi* and the Chautang in the Ladwa-Kurukshetra-Pehowa area. The features most probably developed on a relatively subsiding block carrying the seasonal streams in front of an ESE-WNW block that is getting uplifted, warped and tilted northward, and is recording numerous mild seismicity (Gula-Ladwa High of Srivastava *et al.*, 2014; Markanda Fault of Pati *et al.*, 2018). Mapping also revealed that the Saraswati *nadi* had a distinctly separate flow path than that of the Chautang.

Mapping in the Thar desert and the delta

Several digital processing of the DEM data of Thar Desert were carried out and it was found that high-pass filtering of the SRTM DEM data in a 7×7 pixel window was helpful in identification of the palaeo-valleys through dune-covered areas of the northern Thar (Fig. 13). Use of an adaptive filter and a minimum filter in 7×7 pixel windows helped to highlight the inter-dune topographic variations and to delineate the *bangar* surface beneath the dunes, including the suspected valley forms in them. In all the cases the delineated boundaries were verified from satellite image FCCs and field data. Band ratio analysis of the ASTER data helped to identify some gypsum-rich areas along the palaeochannels, especially in the eastern and the central parts.

Broadly, two extensive alluvial land surfaces could be mapped in the northern Thar beyond the hill-pediment sequences of the Tertiary formation between Bikaner and Phalodi. These surfaces are mostly covered by tall sand dunes, but can be traced along the inter-dune plains as high benches, where the soils are progressively more calcic than in the Punjab Plains due to insufficient leaching, and are capped at places by massive gypsum. The eastern land surface is at a higher elevation and almost co-terminates with the Tons-Yamuna old surface of YSI, while the western land surface is co-terminous with the Sutlej Old Surface of the YSI. In the north, both the surfaces are detached from the YSI by the incised Chautang (Drishadvati) valley along the foundered southern margin of the up warped YSI. In the west the *bangar* surface ends along the degraded alluvial scarp to the west of the Ghaggar-Hakra valley that was mapped by SoI long ago. Several alternate layers of gypsum and calcretes are found in many deep profiles along these surfaces (e.g., at Malsisar, Pallu, Jamsar, Rojri, etc.), which were the sites of significant drainage impedance. At Jamsar the age of a near-surface massive gypsum layer was constrained between two aeolian sand layers of 8 and 5.5 ka (Kar *et al.*, 2004; Singhvi and Kar, 2004), indicating its formation under a lacustrine condition during the high monsoon regime of mid-Holocene period. The period recorded laminated silt-clay deposition in the saline lakes of Tal Chhapar and Parihara in the east (Achyuthan *et al.*, 2007). Perched on the Tertiary formation of Bikaner-Phalodi is an upper Pleistocene fluvial deposit whose mean age at a depth of 6 m is ~180 ka (Blinkhorn *et al.*, 2020). The *bangar* surfaces occur at the downslope end of it, and might have developed since at least 150 ka. This needs systematic chronological investigation.

Palaeochannel mapping re-confirmed the previous delineation (Kar and Ghose, 1984) of the proto-Drishadvati courses to the south of the Chautang, roughly through Siwani, Sidhmukh and Rajawas to Sardarshahr. The

proto-Saraswati courses could be traced from Tibi southward through Rawatsar, Bharamsar, Pallu, Sardarshah and Bhadasar to Dungargarh (Fig. 14).

Along these courses we noticed a thick layer of mica-rich grey silt and sand of the Himalayan provenance at the base of 8–10 m deep freshly-dug wells, and also slightly brackish to potable water in some of those. Recent groundwater exploitation along the valley through Sardarshahr and Dungargarh has led to irrigated cropping along a narrow strip, enhancing its satellite signatures. Downstream of Dungargarh one former west-flowing course was traced through Kuchor, Nokha, Champasar, Bap and Madasar, while a south-flowing course was traced from Bhadasar to Bidasar, Tarnau, Ren and Pundlu to the Jojri valley. DEM data additionally revealed two major former south-flowing courses from the vicinity of Pundlu to the Luni River through a limestone terrain. One of these, a filled-up ancient valley through Indawar and Mugdara to Latoti has a set of two small degraded strath terraces marking the limits of the valley that was subsequently cut again by the recent channels. The other course through Borunda and Ransigaon has a wide erosional valley cross section with short terraces, and appears to have become a victim of stream piracy by the Jojri. To the south of this confluence the Luni used to flow through a more easterly course to join the Jawai river near Jalor. One of the distinctive features of the southern Thar is the absence of *bangar*-like extensive older alluvial plain at a higher plane and with considerable thickness, although a set of two narrow terraces is noticed along some streams. The region appears to have experienced some major tectonic events in the post-LGM period, roughly to the south of a line joining Sukkur, Ramgarh, Phalodi, Asop and Kishangarh, as understood from features of knick points and short escarpments in the rocky/ gravelly terrain of Jaisalmer-Barmer, as well as features of stream incision

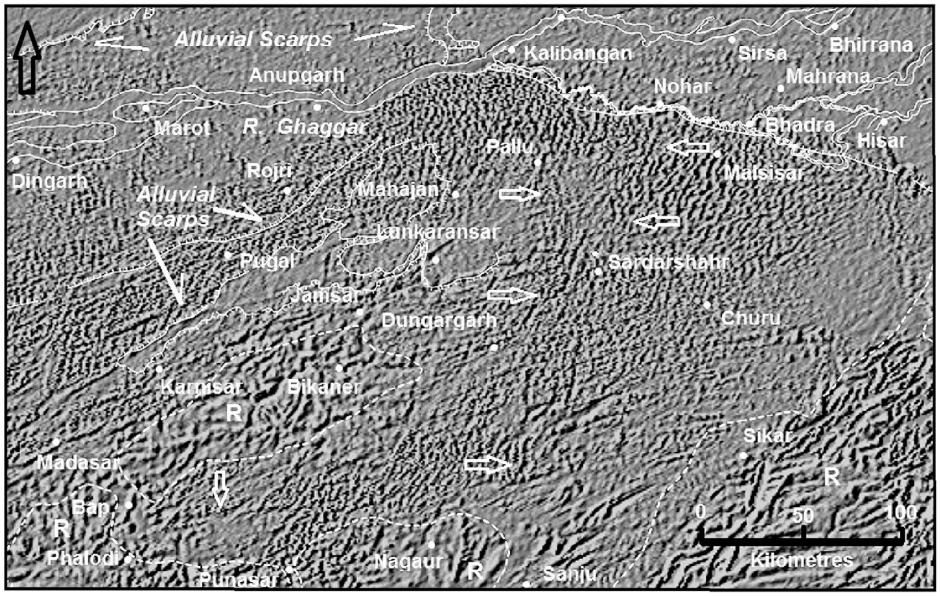

Figure 13. Stream valleys (white wide arrows) through the dune-infested northern Thar, as revealed from high-pass filtering of the SRTM-1km DEM data, using a 7x7 moving window. Also shown are the major alluvial scarps (white combed lines), boundaries of rocky/gravelly uplands (white dashed lines, and marked 'R'), and the valleys of the Ghaggar-Hakra and the Chautang valleys (white lines).

alternating with braiding and lake formation along stream beds in the Luni-Jawai plains (Kar, 1995).

be understood from the perspective of the observer making the comment. The observer was most probably viewing the water spread

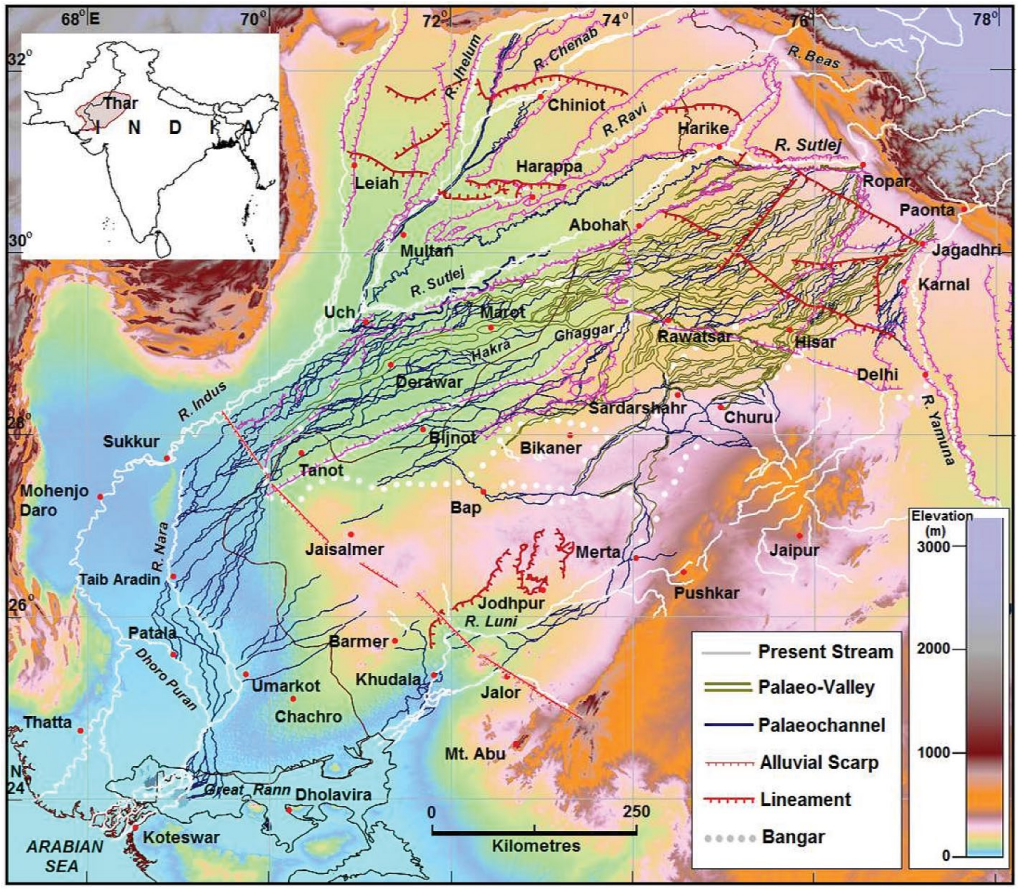

Figure 14. Present and former streams within the Saraswati River basin, as interpreted from digital processing of the satellite sensor data, including the DEM and the thermal sensor data. Also shown are the major Bangar land surfaces over the YSI, the alluvial scarps and some major tectonic lineaments.

Along the western fringe of the desert visual interpretation of the SRTM 250 m and AW3d 30 m data helped to map the dry beds of the Wahinda and the Raini, and their upstream connectivity with the Sutlej near Bahawalpur and Jhangra (Fig. 14). Many of these palaeochannels became active during the extreme flood of 1871, especially as the Sutlej could not accommodate the large flow through it (Barns, 1872). One of the Rig Vedic hymns describes the expanse of the water of Saraswati's as ocean-like, which could

at the confluence of two or more large rivers, and possibly during the monsoon rainfall when the rivers were in spate. Now it is known that during the Civilization period the Ghaggar-Hakra valley contained over most of its part a shrunken seasonal stream, and the Sutlej might have flowed into it downstream of Marot. The ocean-like description was probably meant for a segment of the Ghaggar-Hakra valley downstream of Marot, and roughly in the vicinity of Ganweriwala-Uch, where the Sutlej might have its erstwhile

confluence with the Ravi, Beas and Chenab, receiving the additional snow-fed discharge from the Jhelum. Possibly the Ghaggar and the Chautang were also contributing to the water spread during the time of observation.

In the deltaic terrain interpretation of the SRTM data with 250 m and 1 km resolution helped to map several former distributaries of the Nara from Taib Aradin, the place from where the river leaves the dune covered area to enter the Indus delta (Fig. 14). This was possibly the apex of the Saraswati delta during Alexander's time. The ancient town of Brahmanabad (Patala), from where Alexander sailed to the river mouth, was approximately 50 km to the south of the apex and at the confluence with the Dhoro Puran. Panhwar (2011) has mapped the area in detail from aerial photographs. Downstream of Umarkot the Nara's flow into the Great Rann was through at least three major distributaries between Vingur and Mithi, with the hint of a progressive westward shifting as the area experienced major earthquakes along the Allah Bund. Vigakot and Sindri used to be major settlements and functioned as important riverine trading posts within the Rann, having a higher land surface like that of the Banni till 1819 when a major earthquake ruined and sank them.

The overall stream pattern and behaviour to the west of the Yamuna suggest a gradual westward shift of all the major Himalayan rivers, which is related to neotectonic activities, including constant warping of the deep alluvium in front of the Himalayas (Fig. 12). At the same time, changing climate from wet to dry and back is also influencing the relative strength of the fluvial and the aeolian processes, the latter forming and mobilising the sand dunes, which choke the river pathways in the desert. The more ancient courses of the Yamuna from near Jagadhri, and those of the Sutlej from Ropar, were possibly through the desert, which we call the proto-Drishadvati and the proto-Saraswati, respectively. Gradual westward shifting of the two rivers took them to the Ghaggar-Hakra and the Chautang valleys. Further westward shift of the Sutlej to form a new floodplain left the Thar Desert and the YSI at a higher plane. Pending a detailed geo-chronological exploration of the palaeochannels and palaeo-surfaces, the broad stages of channel shifting are suggested in Fig. 15. Although the Saraswati river has ceased to exist as an independent entity and its source streams have joined either the Ganga or the Indus, the river has left the *bangar* with many resources for the Harappans and the subsequent generations to gainfully exploit.

Conclusions

The geographical details on the land and the rivers between the Yamuna and the Indus, as provided in the ancient texts from the Rig Veda onwards, and in the historical narratives since Alexander's time, were immensely helpful in the initial research on the spatial context of the Saraswati river system. Yet, the full potentials of those narratives, especially in the Rig Veda and the Mahabharata are yet to be meaningfully exploited for the location and timing of many events that are described in allegorical fashion. As recent geo-chronological and geophysical studies have started to provide vastly improved knowledge on the functioning of the system during different time slices, careful re-analysis of the ancient texts may help to convert many narratives into workable spatio-temporal database on the landscape properties, human settlements, land uses, etc., for time-series mapping. The small attempts to analyse the narratives on the chariot crossing of the Vipasa and the Satudri, and on the ocean-like expanse of the Saraswati suggest that such efforts may be worth taking.

Maps by SoI have played a major role in the mapping and understanding of the spatial

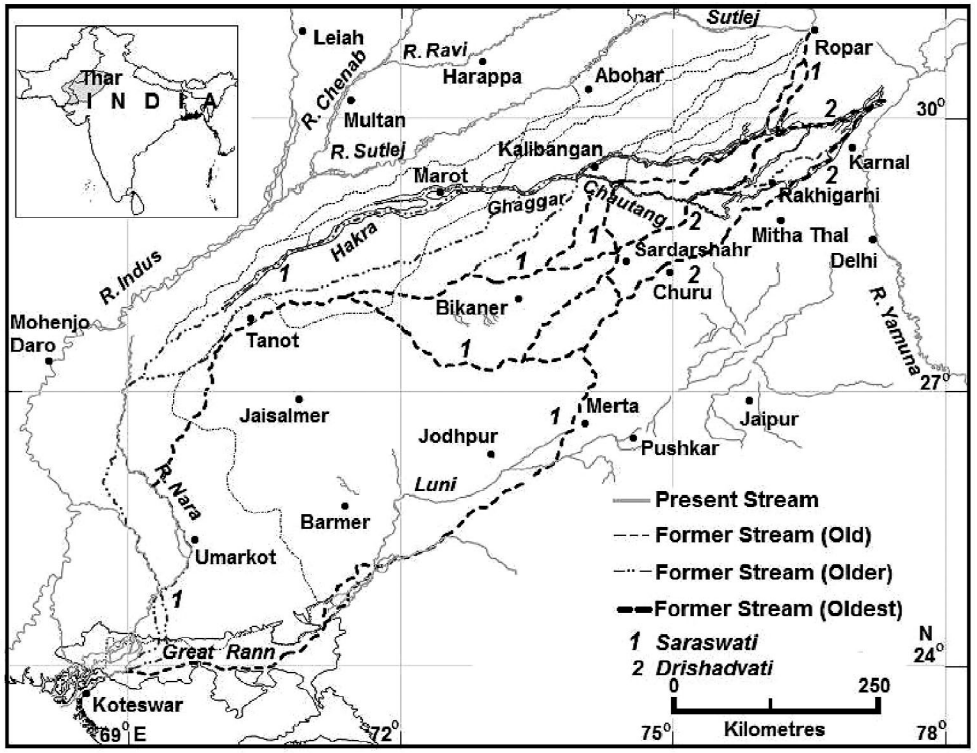

Figure 15. Suggested relative age of the dominant near-surface former streams, as extracted from remote sensing data, with the hints of a gradual westward shift of the channel networks.

context of the river system since Rennell's time, but this important source has never been properly acknowledged. Two important SoI maps of the Punjab plains for 1804 and 1853 were found, which might have helped in preparation of other subsequent maps of the period, and also in understanding the landscape of the Saraswati river basin, but are not cited. Many such SoI maps still remain poorly consulted by the modern researchers, leading to grossly imprecise conclusions. The heritage maps of SoI, if made available in usable format, will immensely help to understand and map the landscape changes over the last two centuries.

Visual analysis of satellite images have helped to map many palaeochannels since the first such efforts was reported in 1979. The present study with the DEM and ASTER data shows that digital processing of such non-conventional satellite data can be of immense help in palaeochannel mapping and in understanding their topographical context. Contrary to the views of many current researchers it was found that a low spatial resolution satellite sensor data is often a boon for palaeochannel mapping. Such data suppress the signatures from many unnecessary minor features and highlight only the large features with continuity, like an old valley, an abandoned stream or an alluvial scarp.

A major achievement during the present study was the identification of the *bangar* land surface below the tall dunes of Thar Desert, which helped to intuitively link the Himalayan palaeochannels with the alluvium and the evaporite sequences in the desert. It was also found that the Harappan settlements were all concentrated in the *bangar* area, and

tended to avoid the khadar area of large rivers, whether at Harappa or elsewhere, especially due to the unpredictable nature of those rivers. Besides providing landscape stability, the *bangar* area also provided the inhabitants with many diverse land, soil and edaphic resources, especially as the Tons-Yamuna and the Sutlej stayed there for a large part of Quaternary period and enriched the area with such bountiful agricultural resources, that it continues to provide rich dividends to the farming communities.

Acknowledgement: I thank Professor Sunil De and the other Trustees of the Professor S.R. Basu Memorial Lecture for asking me to deliver the 8th Lecture in memory of my teacher.

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Date received : 27 December 2020
Date accepted : 31 December 2020