Chapter – 1

Introduction

1.1 The youngest period of the Earth

Quaternary is the youngest period in Earth's history, spanning from 2.6 Ma to the present (Walker et al., 2013). During this interval the global climate had changed frequently and dramatically, with alternating cold ice ages and warm interglacial periods (Richards and Andersen, 2013). The extreme climatic conditions carved the surface of the earth to create fascinating landscapes. Towards the end of the Quaternary (~ 0.2 Ma), anatomically modern humans appeared on this planet and finally the earth witnessed the dawn of human civilizations. Therefore, Quaternary is not only a period of mesmerizing geological changes but also a period of human-nature interactions. People of twenty-first century are witnessing the latest phase of the Quaternary, known as Holocene when Earth is experiencing an unusually warm climate. The geological consequences of the rapid climatic change have its own potential dangers to the human habitability on this planet. Therefore, scientists from multiple fields of research are involved in studying dynamic changes of this youngest phase of the earth. One of the best ways to understand the future course of the changing earth is to study the ancient environmental archives which preserve the effects of past changes. The most faithful record keepers of the surficial process are the sediments. They preserve records of various geo-tectonic and climate induced surface processes as well as biological activities. In addition, they also preserve traces of mankind's evolution. The effects of climate induced surficial processes (e.g, glacio-fluvial, aeolian activities etc.) which mould earth's crust are more prominent and well preserved during the Quaternary than any other geological periods (Richard and Anderson, 2013) because, tectonics plays a minor role in continental re-distributions during short timescales. Although, the Quaternary period is geologically well studied, a lot of questions pertaining to how the coupling of climate and tectonics shapes the landscapes that ultimately influences the course of human civilizations have remained unanswered. Therefore I undertook this study of geochemical and isotopic investigation of late Quaternary sedimentary archives of western India to answer some of these questions particularly those related to the interplay of climate, geomorphology and human civilization.

1.2 Sediment provenance and Landscape evolution

One of the important steps to understand the landform evolutionary processes is to decipher the sources and transport pathways of the sediments that form the integral part of the landscapes. The study of sediment provenance basically deals with the identification of possible sources and reconstruction of the past climatic and physiographic conditions under which the sediments got generated and transported to the sink. In general, deciphering the provenance of sediments in a given basin which might have been derived from multiple sources is a complex affair. The study becomes further complicated due to various sedimentary processes and post-depositional alteration those after the original source signatures. The initial studies on sediment provenance began in the 19^{th} century, however, most of these were qualitative and primarily depended on mainly heavy mineral assemblages and petrography (Judd, 1886; Mackie, 1899a, 1899b; Thurach, 1884). The next century witnessed the advancement in provenance investigations when attempts were made to quantify the source contributions and identify source tectonic settings from mineralogical assemblages (Pettijohn et al., 1972). Geochemistry as a tool for studying sedimentary archives became important in the late 20^{th} century. Several workers used sedimentary geochemistry to calculate the composition of continental crust as well as quantifying provenance (Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch, 1986; Taylor and McLennan, 1985). It is now a common practice to use chemical composition of sediments for identifying provenance, interpreting tectonic settings at the source region and reconstructing the prevailing climatic conditions during sediment generation and deposition. Trace elements, especially the Rare Earth Elements (REEs) are known to behave as a chemically coherent group and are useful in deciphering the sediment provenance due to their non-fractionating behaviour during weathering or diagenesis (Taylor and McLennan, 1985). Similarly, Sr-Nd isotopic compositions of the sediments have been used to fingerprint the source signature of sediments. Although, Sr isotopes are reported to get altered during extensive chemical weathering, abundances of Nd isotopes do not undergo any change during weathering, transportation and diagenetic processes (Basu et al., 1990; DePaolo, 1988; Gleason et al., 1994; Miller and O'Nions, 1984; Nelson and DePaolo, 1988). The combined Sr-Nd isotopic systematics is one of the most robust and popular tool for determining sedimentary provenance. In the recent decade Pb-Pb geochronology of the detrital zircons has also become a popular tool for such studies. In the present work, attempts have been made to understand the sediment sources and their depositional pathways using trace element geochemistry and Sr-Nd isotopic ratios of bulk sediment as tools.

Figure 1.1: Google Earth image of the western Indian subcontinent, showing the major Quaternary geomorphic terrains.

1.3 Quaternary of Western India

The Quaternary sedimentary deposits can be found almost all over the globe. However, the interest of this work is to study a region where multiple Quaternary geomorphological provinces representing various environmental conditions have coexisted together and have played a major role in building up the history of humanity. Such a unique combination can be found in the Indian sub-continent. The western part of the Indian sub-continent is home to a unique repository for Quaternary sediments representing different climatic and geomorphic regimes (Fig. 1.1). Originating from the Higher Himalayas, five perennial rivers of Punjab flow towards south-west, and meet the river Indus at Mithankot in Pakistan creating one of the most fertile and well-watered interfluves of the world. Surrounded in the north and west by the floodplains of the mighty glacial-fed rivers, lies the vast expanse of arid Thar Desert, covered with aeolian sands and is devoid of any major rivers. Just south of the great sand sea lies the salt encrusted low lands of the Great Rann of Kachchh, unique of its kind, which was probably a shallow marine gulf during the early Holocene. The eastern boundary of the desert is demarcated by the Proterozoic Delhi-Aravalli fold belt. The semi-arid zone ephemeral rivers (e.g., Luni) originating from this mountain ranges create their alluvial deposits along the eastern fringes of the desert. In this enigmatic backdrop of extreme climatic conditions and contrasting landscapes, the seed of the first Indian civilization was sowed. On this very land, appeared the Bronze Age Harappan Civilization. The Harappan Civilization thrived along the floodplains of the Indus and associated rivers, now arid region of the Thar Desert and the Great Rann of Kachchh (Fig 1.2). The growth and decline of this pre-historic civilization was directly linked with the late Quaternary environmental changes and landscape evolutions in the western Indian sub-continent. However, there are debates over the exact factor(s) for the decline. Some believe that this civilization flourished along a mighty paleo-river called the Saraswati, originating in the Higher Himalayas, flowing through the now arid land of the Thar Desert and draining through the Great Rann of Kachchh into the Arabian Sea as an independent river parallel to the Indus, during ~5000-3500 years ago (Ghose et al., 1979; Valdiya, 2013). Many, however, postulate that the river had stopped flowing much before 5000 years ago and that the human settlements of the Harappan age occupied paleo-channels of this river (Clift et al., 2012; Giosan et al., 2012; Tripathi et al., 2004). Many workers consider the climatic changes and associated adversities caused the demise of the Harappans (Giosan et al., 2012; Sarkar et al., 2016). The existence of the lost river and its association with the Harappans is still a matter of debate.

The present work makes an attempt to unravel some of the mysteries by trying to understand the overall landscape evolution in the western Indian sub-continent during late Quaternary using the sedimentary proxies from different environmental conditions as a window to the past of this land and its people.

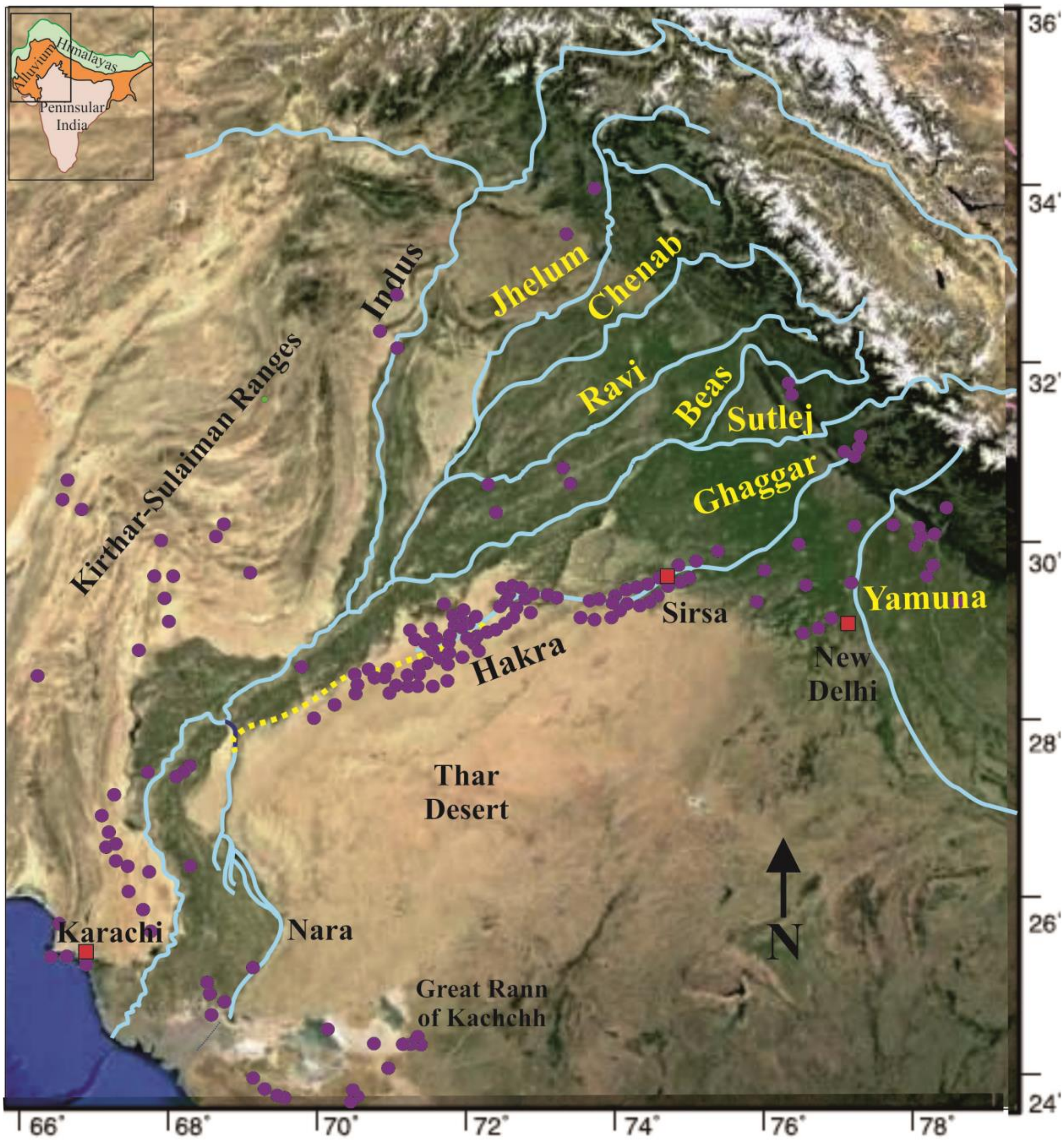

Figure 1.2: Settlement distribution of Harappan Civilization in the Western Indian sub-continent.

1.4 Quaternary sedimentary deposits of Western India

As discussed in previous sections, the western part of the Indian subcontinent hosts a unique combination of extreme geomorphological terrains which got developed primarily during the course of the Quaternary period. Brief introductions to each of the western Indian Quaternary landscapes are provided below. The geology, previous work and evolution of these terrains will be discussed in detail in the subsequent chapters.

- ***The Ghaggar Floodplain***: Just below the foothills of the Himalayas lie the vast Indus-Ganga-Brahmaputra floodplains. Numerous glacier-fed and rain-fed rivers flow within these plains. If we look only at the western part of the plain, we can see a clear drainage division (Fig 1.3A). The five rivers of Punjab (Sutlej, Beas, Ravi, Chenab and Jhelum) flow towards the west and meet the river Indus, which flows into the Arabian sea. On the other hand, Yamuna and its tributaries meet the Ganga and flow towards east into the Bay of Bengal. In between the Sutlej and Yamuna interfluve lays the floodplain of a small ephemeral river called the Ghaggar. Apparently insignificant, this river channel has a fascinating yet debated past. This river has often been associated with the previously discussed paleo-mega river (Saraswati) which has been hypothesised to water the Harappan heartland. The decline of the river system was probably due to river piracy and increased aridity or some other reason that is yet to be discovered. The present day small river channel of Ghaggar is therefore archaeologically significant. More than a century of scholarly works have been done on this area. However, due to lack of robust chronological and geochemical data, the antiquity and past nature of the river are still being debated. In the present study an attempt has been made to resolve these issues.
- ***The Great Rann of Kachchh***: The Quaternary terrain of the Great Rann of Kachchh is situated at the western most end of India (Fig. 1.3B). It is a monotonously flat, salt encrusted and desolate landscape. The sediment deposition in the GRK began in an extensional setup during the Mesozoic and continued through the Quaternary (Biswas, 1987). However, during the course of this deposition subsequent to India-Eurasia collision, the basin changed from an extensional regime to a compressional. The GRK basin was part of a shallow marine gulf even during the pre-historic times and played a major role in the maritime activities when the Harappans settled in this area (Merh, 2005). The GRK is also

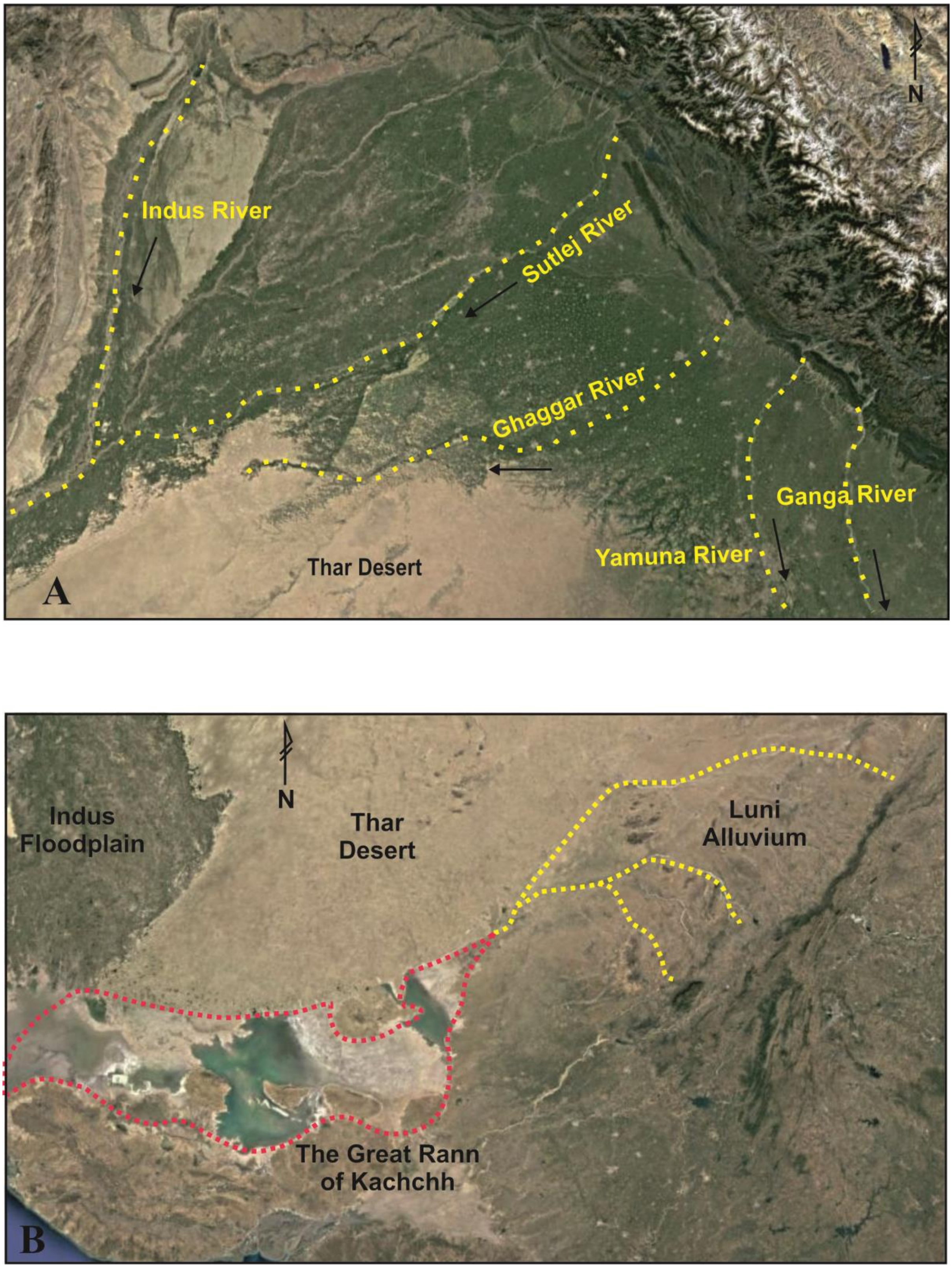

Figure 1.3: (A) River network in the Indus-Ganga floodplains. The Ghaggar river can be seen as a small discontinuous channel flowing in the drainage divide between the Sutlej and Yamuna interfluves.
(B) Google Earth image of the Luni river alluvium and the Great Rann of Kachchh.

hypothesised to host the purported delta of the mega glacial fed river (Saraswati) which used to flow through the now arid western parts of the Thar Desert (Malik et al., 1999). In spite of its geological and archaeological importance, very little is known about the source and depositional pathways of the sediments in the GRK basin. Therefore, in the current study emphasis is given on understanding the provenance of sediments in the GRK.

- ***The Luni River Alluvium:*** The only major drainage of the Great Indian Desert is the Luni river (Fig. 1.3B). The Luni is an ephemeral river which originates at the foothills of the Aravalli ranges and flows westward into the Great Rann of Kachchh. The Luni is an arid zone river system thus, responds rapidly to minor changes in climatic conditions. Many earlier workers have studied the climate controlled alluvium development of this river. However, very little is known about the geochemical composition and provenance of the Luni sediments. The sediments of the Luni floodplain are derived primarily through physical weathering. Besides the source rock geochemistry, different sedimentological processes and weathering intensity also control the chemical composition of sediments deposited in the basin. Therefore, in the current study attempts have been made to geochemically characterize the Luni alluvium and understand the control of climate, weathering and source lithologies, on the chemical compositions of the sediments.
- ***The Thar Desert***: The most enigmatic landscape of the western India is probably the Thar Desert which is the easternmost extension of the great Sahara-Arabian sand sea. Bounded in the north and west by the floodplains of major river systems, in the west by the Aravallis and in the south by the Great Rann of Kachchh, the Thar Desert stands as unique landscape (Fig. 1.1). Due to the arid climate, wind activity has been dominating this region and sand dunes have been forming over the past 200 kyrs (Dhir and Singhvi, 2012). During the last glacial maxima (LGM), expansion of the desert was the largest during entire existence. Towards south it had extended up to the Orsang valley, Gujarat (Juyal et al., 2006). Following the LGM the desert shrunk westward. At present, the most active part of the desert lies in its north and north-western sectors. A lot of efforts have been made on the understanding of the antiquity of the Thar Desert, dune dynamics and climatic control over the desert activities. However, knowledge on the sources of Thar sand is very poor. For understanding the development of the Thar, one major step would be to identify and quantify the provenance of the sand. Therefore, during the course of the present investigation, a reconnaissance geochemical study was carried out on the sub-surface sands from strategically selected locations that spread all across the desert.

1.5 Objectives and Approach

The present study aims to understand the origin and evolution of the thick sequence of Late Quaternary sediments in the western India. The specific objectives of my work to achieve the above were to:

- study the sediment provenance of the Ghaggar and the Luni river alluviums, the Great Rann of Kachchh and the Thar Desert
- recognise paleo-drainage patterns to decipher the fluvial conditions during the Harappan period
- understand the Paleo-environmental conditions and the response of fluvial systems to the changes in climatic conditions
- construct the late Quaternary landscape evolution of the western Indian sub-continent.

Approach: To achieve the objectives of this study several field and laboratory methods were employed. Field works were integral part of this study for establishing field relationship of different sedimentary facies based on stratigraphic principles and for collecting appropriate samples. Ages of the collected samples were constrained using several geochronological techniques (eg. C-14 and Optically Stimulated Luminescence dating). Further chemical analyses were performed after establishing the stratigraphy. For identifying and quantifying different sediment sources we have analysed the trace element geochemistry and Sr-Nd isotope geochemistry of the collected sediment samples. Also in the Ar-Ar age of detrital mica grains were analysed for the source identification purpose.

1.6 Thesis outline

The present thesis is divided into seven chapters.

- The ***First Chapter (Introduction)***, as already described above, provides an introduction to the Quaternary continental sediments deposited in the western Indian sub-continent and introduces the scope of the work and its importance in understanding of the landscape evolution of the region. It also lists the major objectives of this work.

- The ***Second Chapter (Methodologies),*** deals with sampling procedures and details of various analytical techniques used in this study.
- The ***Third Chapter (Evolution of the Ghaggar River System in NW India and its archaeological connection),*** presents the results of my geochemical and chronological studies on the sediments, shells and archaeological artefacts from the Ghaggar alluvium of NW India. Here, I discuss the evolution of the Ghaggar river system during the Late Quaternary and its connection to the development of the Bronze Age Harappan Civiliztion.
- In the ***Fourth Chapter (Provenance of Mid-Holocene Sediments in the Great Rann of Kachchh),*** an attempt has been made to delineate the provenances of the sediments deposited in the GRK basin since mid-Holocene using geochemical and isotopic tracers and to reconstruct the palaeo-drainage condition around this area.
- The ***Fifth Chapter (Geochemistry of Quaternary Alluvium in the Luni River Basin),*** focuses on the geochemical properties of the sediments deposited in the Luni river alluvium and the control of weathering on sediment composition. It also deals with the isotopic provenance identification of the Luni river sediments.
- In the ***Sixth Chapter (Geochemical Provenance of the Thar Desert Sand),*** an attempt has been made to identify and quantify the sources which contributed sands into the Thar Desert, using geochemical and isotopic tracers on aeolian sediments collected from all across the desert.
- The ***Seventh Chapter (Summary and Conclusions)***, summarizes important findings of the study and describes future research directions to further resolve the outstanding issues in the Quaternary evolution of the Western India.