CHAPTER 1
INTRODUCTION

RATIONALE

The Kachchh basin, located on the western continental margin of India, is a pericratonic rift at the trailing end of the India plate (Biswas, 1982, 1987). The Kachchh Rift Basin (KRB) is believed to be formed in the Late Triassic when the Indian plate broke from the Gondwanaland. Considering the evolution of the basin, the Kachchh Rift Basin (KRB) has undergone two major phases of stress changes in its evolutionary history. The first phase was marked by extensional regime that began in the Middle Jurassic and persisted until the Late Cretaceous. The first phase is followed by an inversion in the stress regime during the Cenozoic, resulting profound changes to the basin's topography and tectonic framework of the basin. The present structural, tectonic and geomorphic framework of the basin is the product of the second phase, where compressive stress regime prevailed which were periodically released along E-W trending master faults (Biswas, 2016a; Maurya et al., 2017).

The Kachchh basin is currently undergoing largescale coseismal deformation evidenced by the large magnitude earthquakes witnessed in the region in the last 200 years (Maurya et al., 2017). The principal E-W trending fault systems of the basin are classified as active with the potential to generate large magnitude earthquakes in the future (Rajendran and Rajendran, 2001; Maurya et al., 2017; Padmalal et al., 2019; Tiwari et al., 2021; Shaikh et al., 2022). The major earthquakes in the region include, 1819 Allah Bund earthquake (Ms 8), 1956 Anjar earthquake (Ms 6.1) and 2001 Bhuj earthquake (Ms 7.9) (Oldham, 1926; Tandon, 1959; Bilham, 1999; Mandal and Chadha, 2008). The available seismic record of the basin is limited to last few hundred years. However, it has indicated that the structurally controlled landscape of Kachchh is formed as a consequence of multiple phases of tectonic activity along the various faults during the Cenozoic (Biswas, 1974, 2016a). No attempt has been made so far to understand the long-term geomorphic evolution of landscape and fault scarps in the basin.

Topographic evolution in a tectonically active terrain is primarily controlled by active block movements along the principal fault systems. A systematic study on landscape and related geomorphic features is essential for estimation of long-term tectonic movements along fault-controlled regions (Garcia et al. 2003; Bull, 2011). The nature of tectonic movement in a fault-controlled terrain may be directly influenced by the rate of stress accumulation and release. The spatial and temporal rate of stress accumulation and release along a fault can directly control the pattern and style of landscape development in such terrains. Consequently, documentation or record of different geomorphic indicators are essential for understanding the current seismic activity and in a long-term perceptive. Therefore, generating geological and geomorphic data on fault-controlled landforms are extremely essential in view of the understanding the seismic hazard and evolutionary trend and development of the basin.

The stress changes associated with the Indo-Eurasian plate collision tectonics are linked to the deformation in the Kachchh basin. The push exerted by the Indo-Eurasian plate from the north and the spreading of the Mid-oceanic ridge (MOR) at the south in the Indian ocean have significant effect on the evolution and on-going deformations that witnessed in the Kachchh basin (Thakur and Wesnousky, 2002). The landscape changes associated with such deformation are not delineated so far in a long-term perspective for the basin. Though, much information is available on the formation and origin of the basin, there are several issues which are uninvestigated, which can help to reconstruct and differentiate the tectonic evolution during the Quaternary and pre-Quaternary time span. Important questions that are unanswered include the kinematics and rejuvenation of various fault systems and consequent development and retreat of associated scarp. The present study provides detailed information on the fault zone evolution, extent, nature, maturity and geomorphic evolution of Kachchh Mainland Fault (KMF).

The data available is mostly about the pre-Quaternary stratigraphy, tectonic evolution and regional scale geomorphology of the basin. However, data concerning the slip rate, recurrence interval, fault generated landforms and long-term landscape evolution are not outlined in the basin. Furthermore, there are limited studies available that document history of these faults and evolution of tectonic landforms in the basin during the pre-Quaternary period. For this purpose, the fault generated landform (fault scarp) along the Kachchh Mainland Fault (KMF) is studied and mapped in the present work. These geomorphic landforms aided by chronology can give a clear picture of long-term tectonic evolution of the fault system that shaped the geomorphic configuration of the basin. Moreover, the pre-Quaternary and Quaternary tectonic events of the faults in the basin give a more realistic picture of the history and evolution of the basin. Such database can enrich the present understanding and construction of a more realistic hazard map for the faults in the Kachchh basin. Moreover, the present work will provide a clear understanding on the evolution and development of fault-controlled landforms in a tectonically active terrain.

THE KACHCHH RIFT BASIN (KRB)

The present landscape of Kachchh basin is characterised by uplifts or highlands separated by extensive plains from one another. The major uplifts of the basin include the Island Belt Uplift (IBU), South Wagad Uplift (SWU), Kachchh Mainland Uplift (KMU) and the Deshalpur Uplift (DU). These uplifts are characterised by steep vertical to subvertical scarps forming geomorphic expression of the uplift bounding faults. The nature and morphology of the vertical to sub-vertical scarps are characteristic of each uplift and uplift bounding fault of the basin. The major uplift bounding faults of the basin are Kachchh Mainland Fault (KMF), Island Belt Fault (IBF), South Wagad Fault (SWF) and Gedi Fault (GF). These uplifts are composed of flexure zones with many asymmetric domes and anticlines of various sizes and shapes. The fold axis of the domes and anticlines are generally oriented in concordance with the fault systems of the basin. The orientation of fold axis of the domes and anticlines suggest a major connection to the formation of the deformed structures with the faulting activity (Biwas, 1993). The uplifts of the basin are majorly composed of Mesozoic rocks while the Tertiary and Quaternary rock units occupy the periphery and depressions or plains formed in-between the fault bounded uplifts or the margins of the uplifts.

The KRB is characterised by high seismic activity and have been a site for some of the deadliest intraplate earthquakes in the recent history. The 26 January 2001, Bhuj earthquake is the biggest and notable earthquake reported from the basin in last two decades. The epicenter of this earthquake is 15 km northeast of Bhachau and 60 km east of Bhuj. (Biswas and Khatri, 2002). Following the major event, the basin experienced aftershocks and more frequent earthquakes of lesser magnitude. Numerous earthquakes between magnitude 5 and 8 occurred in the basin in the past, in addition to the devastating Bhuj earthquake of 2001 (Biswas and Khatri, 2002). These events have caused a huge damage and causality in Kachchh and the adjoining districts on the state of the Gujarat. The seismological research with little information regarding past earthquake events makes the interpretations on earthquake potential of fault systems very difficult in the region. The basin is characterised by multiple intrabasinal faults and all these faults are believed to have potential to produce large magnitude earthquakes in the near future. Therefore, the basin is included in the most vulnerable zone in the seismic zonation map of India with multiple seismogenic sources (Rajendran et al., 2008).

SCOPE AND OBJECTIVES

Though the neotectonic signatures of the principal active faults are fairly well established, a geological study linking the long-term tectonic evolution and scarp development has not been carried out. The fault scarps and escarpments have been attracting the attention of geomorphologists since the last century. During the last three decades the much attention has been given to the fault bounding flexure zone and drainage characteristics of the Kachchh basin. Despite the fact that much work has been done on the geomorphological aspect, little has been done for the systematic study of fault scarp and long-term evolution along the major fault systems. The present study was focused on establishing the morphology, extent, geometric characteristics and evolution of scarp along the seismically active Kachchh Mainland Fault in the Kachchh Rift Basin using extensive field, remote sensing and cosmogenic isotope-based studies. The data generated on geomorphic characteristics, timing of faulting events, drainage development and Quaternary stratigraphic development along KMF are interpreted in conjunction with the available tectonic and structural data. The study also attempts to explain based on Late Quaternary tectonic events, the reasons for high and anomalous distribution of seismicity in the basin and vulnerability of the KMF to high magnitude earthquakes in a qualitative sense. The present study is the first attempt at building up a comprehensive understanding of the landscape evolution in the KMF and the KRB from a long-term perspective.

The study provides primary data base on geomorphologic characteristics, timing of landscape evolution, Quaternary stratigraphy and tectonic evolution along KMF. Eastward lateral propagation of the KMF during the Late Quaternary time period can be established on the basis of unequivocal evidence from scarp parameters, drainage characteristics and geochronological studies. Active surface deformation and drainage anomalies going on in the present time is a response to multiple cycles of Late Quaternary reactivation of KMF. The data could be used for qualitative characterisation of extent of fault and its nature, maturity and long-term tectonic evolution. The study also throws light on the landform development and degradation in tectonically active terrains of the much-fragmented western continental margin of the Indian plate. Additionally, the present research will also provide information about fault zone evolution over time scales which are beyond instrumental measurements or historical records. The data generated and presented in the succeeding chapters is intended to provide a foundation for constructing landscape evolutionary models of the Kachchh basin. The following are the objectives of the study.

1. To characterise and delineate the tectonic phases of scarp evolution along the KMF during Late Cenozoic.

2. Reconstruct the geomorphic evolution vis-a-vis tectonic phases during late Cenozoic time.

3. Develop a long-term evolutionary model for fault scarps of the Kachchh Mainland Fault.

STUDY AREA

Location

The area of study is located in the Kachchh district of the Gujarat state. The Kachchh is the biggest district in the state with an area of approximately 45,674 km^2. The basin encompasses an area of around 43097 km^2 that extends over the Kachchh district and Santalpur Taluka of Banas Kantha district of Gujarat. In which, the study roughly covers an area of about 2630 km^2 of the Kachchh district. The present work is focussed along a narrow zone comprising the KMF and the Northern Hill Range. The zone is situated in the central part of the Kachchh district. KMF being the longest fault in the basin, covers a large area extending between villages of Lakhpat in the west and Devisar in the east of the Kachchh district (Fig. 1.1). Further west of the Lakhpat village is the Arabian sea. The study area lies between latitudes 23^{0}49’25’’N and 23^{0}20’29’’N and meridians of longitudes between 68^{0}45’10E and 70^{0}7’37’’E. The study area is situated in the central part of the Kachchh basin and is bounded by the vast plains of Rann of Kachchh to the north and the rocky plains of Mainland Kachchh (Bhuj-Nakhatrana low) to the south. Further south of the rocky plain is the Katrol Hill Range.

Communication

The Kachchh district in the state of Gujarat has a reasonably good network of metallic and non- metalled roads for accessing different field locations. The National highway passing through the Kachchh district connects the district with the other districts and with the other parts of the country. The BSF and Army on the purpose of transporting essentials and army men has established many motorable roads in the inaccessible terrain of Great Rann and Banni plain. This establishment resulted in a well-connected dense network of roads linking even the small town and villages of the district. Moreover, railway link is also available in the district connecting the major stations of the Kachchh district to

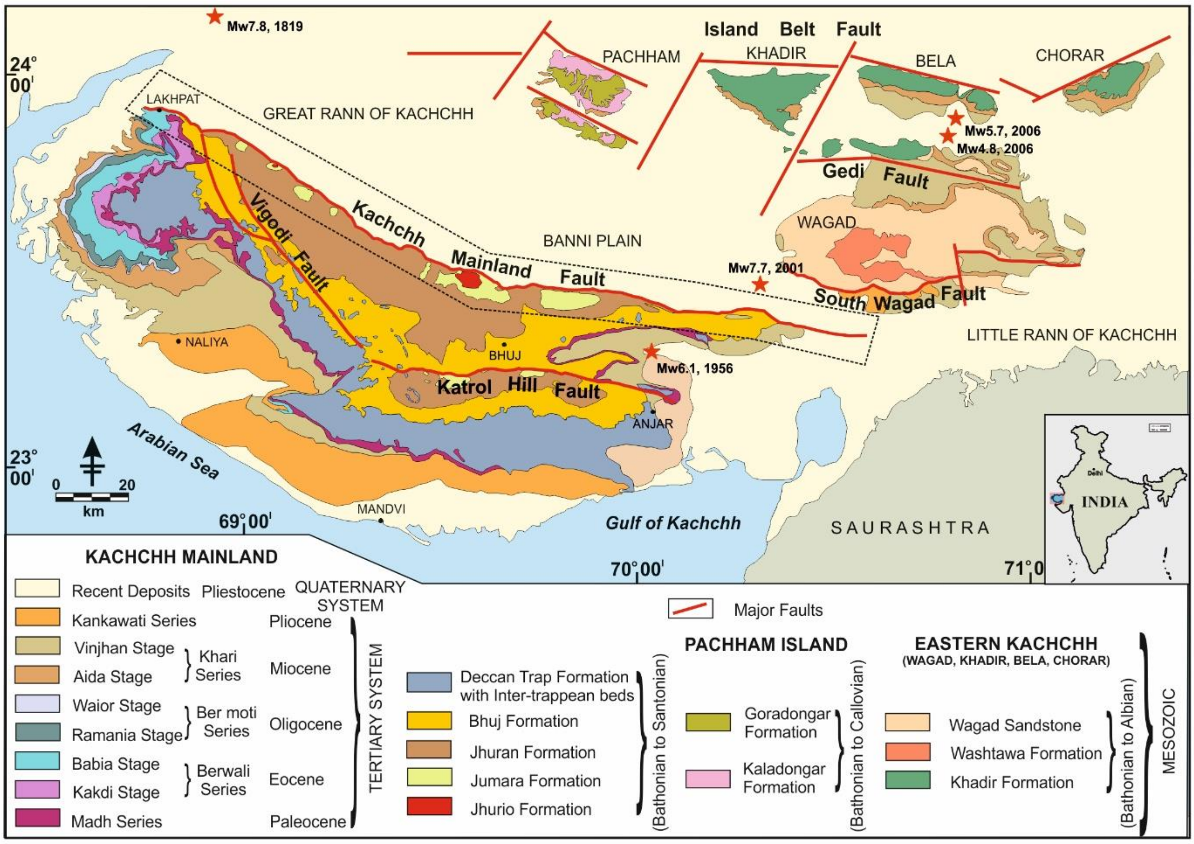

Figure 1.1 Geological map of the Kachchh Rift Basin (after Biswas & Khattri, 2002). Original map was digitized and redrawn by Patidar (2010). Boxed area with dotted line shows the location of the study area. The major fault systems and epicenters of historical earthquakes are also highlighted in the map.

the other part of the state and country. The KMF and its vicinity can therefore be accessible through these road facilities. The district is also connected to the other parts of the country through Bhuj Airport. The airport facility makes it convenient for people from all around the nation and world to visit the area with ease because of reduced amount of time they have to spend travelling. Kachchh district being one of the fastest growing economic and industrial hub have two ports, the Kandla and Mundra port. The port facility provides transport access to the district.

Physiography

Physiographically, Northern Hill Range, Katrol Hill Range, Wagad, and Island belt are comprised of hilly terrains, whereas, Samakhiali-Lakadia plain, Banni plain and the Great Rann are comprised gently undulating terrains. The Northern Hill Range marks the northern margin of the Mainland Kachchh which abuts against the Banni plain and Great Rann of Kachchh in the north. The Northern Hill ranges also form the longest ranges in the Kachchh basin. The steep scarp faces, forming the margin of the ranges are the most conspicuous landscape feature of the area. This escarpment marks the geomorphic expression of the Kachchh Mainland Fault, which is the most significant geomorphological feature of the study area. The Northern Hill Range (NHR) shows typical mountainous terrain with structurally controlled topography and deep valleys. The Jhura hill has the highest elevation in the NHR, and is located in the eastern part of the study area. The hill range gradually loses its elevation towards the east and disappears below the Samakhiali-Lakadia plain. Towards the west, the hill ranges lose the elevation at the western end of Lakhpat and merges with Kori creek. The low-level flat saline terrain of the Banni-Great Rann sub-basin represents the recently uplifted floor of a palaeo-gulf.

Drainages

The drainage pattern of Kachchh exemplifies the combination of structural morphology and tectonic controls during Quaternary period. The regional drainage pattern of the Kachchh basin is generally parallel, however the rivers form radial drainage to centripetal pattern in the near the dome hills (Biswas, 1993). The study area has a large number of rivers, reservoirs and lakes. The rivers are showing the similar drainage trend like the regional drainage pattern. The crest line of the Northern Hill forms the major drainage divide which have resulted in the north and south flowing drainages. The Northern Hill ranges are broken into several domal hills separated from one another by wide saddles. Larger rivers like Pur, Khari, Nirona flows through the saddle regions of the Northern Hill ranges. The streams originating from the northern slopes of the Central highland (Katrol Hill Range), join the streams originated from the Northern hill range and pour their water into the Kaila, Pur, and Kaswali streams which, in turn, debouch into the Ranns. The river generally debouches into the vast monotonous plains of Rann of Kachchh or the Banni. The drainages are ephemeral in character. The drainages systems expect the few major drainages, remain dry throughout the year. However, the drainage density of Kachchh is very high for a hyper arid region. The south flowing rivers in the study area either merge with north flowing rivers or end in the rocky plains of the Bhuj.

Climate

The Kachchh region is known for its arid to hyper-arid climatic conditions. The annual rainfall is the range of 250-400 mm/year and spread over the entire monsoon months of June to September. The month May marks the hottest month of the year, where the temperature in the daytime often reaches up to 48^{o}C. The temperature drops to less than 10^{o}C during the month of January. Coldest months of the year are December and January. The wide fluctuations in temperature is an account of the Tropic of Cancer that passes through the Kachchh region. During summer, strong sand storms are common in the area, albeit they occur for a short duration of time. The cold wave may persist as a consequence of NW disturbances, which may cause temperature to drop to the minimum level. Throughout the year, humidity remains high, with coastal areas witnessing extreme humidity levels.

Flora

Vegetation in Kachchh region is very sparse due to low precipitation. The semi-arid climate existing in the Kachchh is ideal for the growth of thorny and non-thorny trees and shrubs. Non thorny species include Jal-salvador, Ganzi grenia etc., while thorny species include Baval, Kher, Acacia, etc. Whereas, the Acasia Arabia (Gandobaval) dominates the major portion of the terrain. The swamps with mangrove forests and grasses covering dunes and sand flats may be seen along the coastline. Following are the most common types of flora that are be found in the region under study- Melia azadirachta (Limbdo), Avicennia officinalis (Tavar, Tarvariyan), Leptadenia spartium (Khip), Sueda maritima (Lano, Luno), Casuarina Equisetifolia (Saru), Halopyrum mucronatum (Dariyai Kansdo, Dariyai Kans), Acacia arabica (baval), Cassia auriculata (Aval), Zizyphus jujuba (Bordi), Sporobolus indicus (Velari charchar), Euphorbia tirucalli (Thor, Kharsani Thor, Dandalio Thor) Leucoena glauca (Laso baval, Vilayati baval) Butea frondosa (Kesuda no jhad), Acacia jaquemonti (Tal bavari), Acacia leucophlaea (Harmo baval), Tamarindus indicus (Amli), Sapindus emarginatus (Aritha), Cactus indicus (Hathlo thor), Ficus bengalensis (Vad), Eugenia jambolana (Jambu) etc. In addition to a wide variety of fruits and vegetables are cultivated in the area. The most common agricultural crops are Wheat, Cotton, Bajara, Jowar, Mag and Math.

Fauna

The Kachchh region has long seashore and extensive desertic conditions. This perhaps, provides Kachchh an incredible diversity of wild life and attract a large number of avifauna. The Kachchh is a home to significant variety of avifauna. The most common types of livestock in the region include horses, camels, oxen, cow, buffaloes, sheep, goats and asses. The area is home to a wide variety of wildlife species, including Panthera pardus (Panther), Chinkara (Gazella Gazella) (local name Chinkara), wild asses (Equus Onager Indicus) Neelgai or Blue Bull (Bojh), Wild Boar or Jungli Budhar (Sus Scrofa), Indian Wolf (Canis Lepus), Jackal or Shiyad (Canis Auresug), striped Hyena or Jharak (Hyena Hyonna), Desert Hare or Sasla (Lepus Nigricollis Outchensis), Indian Fox (Vulpe Bengalenisis), Mongoose (Herpestus Smithi), jungli cats, desert cats, Pangolin, Indian Porcupine and long eared hedgehogs. Typically, these animals choose habitats close to the hills of the district and little rann of Kachchh. The Lepus Nigricollis, also known as Indian hare is a frequent sight in the open fields. The Caracal is the most unique and uncommon animal found in Kachchh. Kachchh is also home to a wide variety of reptiles, the most common of which are the snakes. Following are examples of reptiles that are often encountered: Crocodile or Mugger, Monitor Lizard or Patla Gho, Kachchh Rock Gecho (Garodi), Desert Monitor Lizard, spiny-tailed lizard or Sanda (Uromastyx Hardwicki), flat-tailed lizard or Khann, Starred Tortoise and fresh water turtle (Lissemus Puctata). The region is also home to several varieties of poisonous and non-poisonous snakes including Black Krait, Black Cobra (Najatripudians), Russels Viper (Vipera Russeli), Saw Scaled Viper (Echlis Carinatus), Sea Snake (Hydrophis Spiralis) etc. are poisonous snakes, while Python (Python Molurus), Sand Boa (Eryx Conicus), Rat Snake (Piyas Mucosus), Royal Snake (Zamenis Diadema) etc. are in the category of non-poisonous snakes. A large variety of resident and migratory birds are commonly found in Kachchh. The organic rich zone of the coastal flats sorrounding the Gulf of Kachchh and the huge saline expanse of the Little Rann of Kachchh is a wintering spot for migratory birds.

People and Occupation

Kachchh district is home to a wide variety of communities and groups of people. Due to the fact that around 80% of the population lives in rural areas, the economy is mainly dependent on agriculture and cattle rearing. The agricultural sector is a primary contributor to the local economy of the area. The area is also known for the quality of its handcraft. Today, Kachchh is becoming an increasingly important industrial hub not only in the state of Gujarat but also in the entire nation. The rapid phase of industrialization between Gandhidham-Mundra and Bhuj-Bhachau during the recent have been attributed to the establishment of many big ports in the coastal parts of Kachchh. The recent growth in the industrial sector has opened up a new door of possibility for the local population to strengthen their economic base and improve the standard of living.

APPROACH AND METHODOLOGY

In order to reconstruct the detailed geomorphic evolutionary history, including the nature and timing of tectonic activity along active faults it is necessary use a holistic approach that incorporates geomorphic, geological and chronological data. The KMF is characterised by marginal flexure zone (Northern Hill Range) to the south with a northward facing vertical to subvertical scarp. The north facing scarps are the most spectacular tectonic landform of the basin. It is therefore obvious that working out composite tectonic history of the fault scarps, complex interaction between fault activity and erosional processes is the key for developing a landscape evolutionary model of the basin. Evidenced by the vertical to subvertical scarp twin parallel scarp faces, multiple phases of colluvio-fluvial deposition, dissected Quaternary deposits, incised valley and gorges, it is obvious that the region has undergone many stages of uplift during the Quaternary as well as pre-Quaternary period. The scarps are highly degraded with variable amounts of retreat along the segments of KMF. The present study was carried along the KMF, which show significant vertical to subvertical fault scarps at the northern limit of the Mainland Kachchh. A comprehensive approach involving detailed field mapping of the landforms, DEM modelling and stratigraphic and shallow subsurface studies of the Kachchh Mainland Fault (KMF) using GPR has been applied to reconstruct the geomorphic evolution of the study area. The brief methodology employed for carrying out the present study is described below and in the flow chart (Fig. 1.2).

- Available published data on the tectonic evolution, stratigraphic, structural and seismotectonic aspects of the Kachchh Rift Basin were critically studied and evaluated to understand the regional geological setting and possible influences on the landscape development along the active fault zone. The literature review on the footwall topographic evolution on major rift systems of the world helped in framing an approach for landscape evolutionary studies on Kachchh rift basin.
- Available geological and subsurface data on KMF was critically evaluated to delineate the subsurface structural features and to infer the nature of basement

configuration. This study was supplemented by detailed field investigation along KMF to generate additional data on the fault zone.

- Mapping various tectonic and geomorphic landforms along the KMF using satellite imagery and available high resolution Digital Elevation Model (DEM) and preparation of base maps for the fault zone. High resolution 1 arc Shuttle radar Topography Mission (SRTM) data and Sentinel data was used for mapping and preparing base map.
- The profiles were constructed perpendicular to the scarp using available high resolution digital elevation data to extrapolate/model and compare the composite scarp morphology of the various fault zones/segments. The data generated from the field investigation was incorporated to generate a more accurate result.
- Multi-proxy data were generated on fault scarp lateral extent, continuity, colluvial fans, geometry of other sedimentary deposit in the vicinity, fault lines and fault traces. GIS technology and field data were used to derive quantitative attribute of the landscape.
- Morphometric analysis was carried out on selected rivers originating from Northern Hill Range Flexure zone and those rivers deriving from scarp face to decipher the major controlling factors on the landscape and its influence in geomorphic modification as well as degradation of the fault scarps. Long profiles of the rivers are constructed using elevation-distance data obtained from the Survey of India toposheet and data gathered from the field.
- The exposed Quaternary sediments were studied in detail with a view to understand the genetic aspects of the landforms and stratigraphic evolution. Both, the fluvial and colluvial sediments were investigated during the course of the study to understand slope process that led to evolution of present landform.
- Chronological data of undegraded scarp surfaces and other tectonic landforms in the vicinity of the faultzone (KMF) were generated using ^{10}Be cosmogenic surface exposure technique to determine the age and phases of tectonic reactivation of KMF.
- Extensive field mapping supplemented by shallow sub-surface geophysical studies using Ground Penetrating Radar (GPR) was done to map the KMF precisely and calculate the amount of scarp retreat on different segments of the KMF.
- The morphostratigraphic evolution of the fault zones was reconstructed based on detailed field criteria, field relationships of the various landforms and stratigraphic

data. Major tectonic events responsible for the overall geomorphic evolution of the area were also identified.

- The data generated from the field and multidisciplinary studies in the laboratory were synthesized and critically evaluated to develop a long-term evolutionary model for scarp development along KMF.

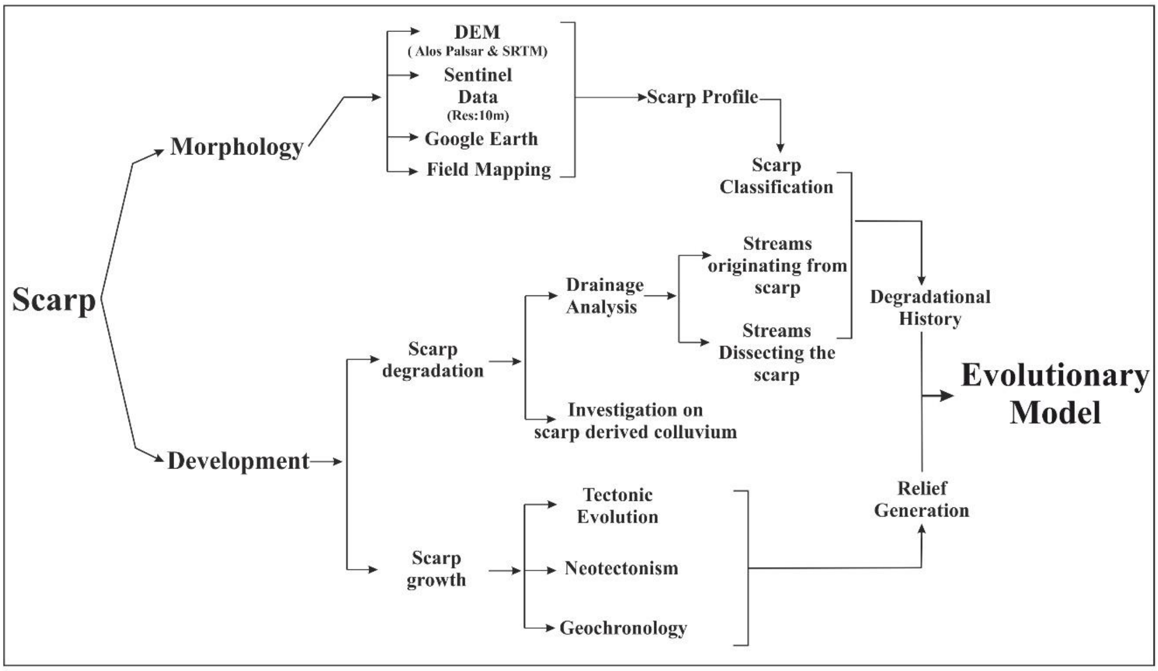

Figure 1.2 Flow chart showing a brief outline of methodology adopted for the present study.

ARRANGEMENT OF CONTENTS

The present work is organised into nine chapters. The presentation of the research work begins with a brief introduction of the KRB from the perspective of major tectonic elements, the research question that motivates the present study, the importance of fault scarp studies along KMF, the main objectives of the present study, details of the study area including communication, flora, fauna, climate, people and occupation, as well as a brief discussion of the methodologies that were followed to address the objectives. The detailed description of the methodologies is given in the respective chapters.

The second chapter introduces the study area and describes the major lithological units of the KRB and their mode of occurrence. The chapter also describes in detail the important geological events occurred in the basin that contributed to the present structural setup of the KRB.

The third chapter analyses the morphological characteristics of the fault scarps along the KMF. The elevation, relief and amount of retreat have been evaluated for fault scarp along the KMF. Swath profile was constructed to examine the height, slope and curvature and to understand the nature of variation of these parameters along different segments of KMF. The chapter also discuss the characteristics of the twin parallel scarp along the KMF and their importance in long-term evolutionary studies. In this chapter an attempt was made to estimate the tectonic variation along segments of KMF.

The main objective of the fourth chapter is to discuss the scarp degradation and erosional process of the fault scarp along the KMF on the basin of morphological data presented on the previous chapters, field investigation and results of numerous studies undertaken by the other workers. An attempt was made to discuss the major neotectonic signatures and deformations along the KMF that resulted in the present transient topography. The chapter also discusses the probable mode of evolution of the fault scarps and mode of the retreat during the Late Quaternary period.

The fifth chapter deals with the analysis of long profile of selected rivers from the Jara-Jumara sector of western KMF. The characteristics of the semi-logarithmic and normalised long profiles of the sector are discussed in the detail in this chapter. In addition, the role of tectonics, lithology and structure has been evaluated in the present chapter. The chapter also attempts to discuss in detail the Hack's stream gradient index and to identify the major zone of variation in profile and to see their role in scarp degradation.

The analysis of long profile of selected rivers from the Kas Hill sector is summarised in the sixth chapter. The characteristics of the semi-logarithmic and normalised long profiles of the sector were discussed in the detail in this chapter. In addition, the role of tectonics, lithology and structure has been evaluated. The chapter also attempts to discuss in detail the Hack's stream gradient index and to identify the major zone of variation in profile and to see their role in scarp degradation. The variation in the morphometric characters of drainage networks along the segments of eastern KMF was linked to scarp degradation and development in these segments.

The chapter seven addresses the cosmogenic exposure dating of the scarp and important strategic landforms along the KMF. The chapter also discusses in detail the geological settings of the sampling sites, sample selection strategy adopted for the cosmogenic exposure dating, chemical processing of the samples for cosmogenic exposure dating and the results. The timing of major tectonic events that led to scarp formation and degradation in the Late Quaternary period is also addressed in this chapter. Taking all these into consideration an attempt was made to propose a model for drainage evolution and gorge formation along the KMF.

The chapter eight gives an overview of the main findings of the study with reference to the research question posed in the study. The chapter discusses in detail the major geomorphic and geological factor that led to the scarp development and modification along the KMF. The chapter end with an evolutionary model for fault scarp development along the KMF in the KRB. The future research directions in the area are also included in the chapter.

The conclusion chapter is a concise discussion of the important findings that were gathered from each of the previous chapters. The complete list of all the references used in the present work is provided at the end.