Chapter -1

INTRODUCTION

THE RATIONALE

Neotectonics is a subdiscipline of tectonics. In geologic literature, however, the term is defined in different ways. The term is attributed to Vladimir Obruchev (1948), who defined it as 'recent tectonic movements that occurred in the upper part of Tertiary (Neogene) and in the Quaternary, which played an essential role in the origin of the contemporary topography'. The term is also meant to refer to the motions/deformations in question themselves. The corresponding time frame is referred to as the neotectonic period. The preceding time is referred to as palaeotectonic period. According to Becker (1995), the neotectonic period starts from the middle Miocene. Some authors consider neotectonics to be basically synonymous with 'active tectonics', while others At the University of Nevada, Reno, Center for Neotectonic Studies, neotectonics is defined as 'the study of geologically recent motions of the Earth's crust, particularly those produced by earthquakes, with the goals of understanding the physics of earthquake recurrence, the growth of mountains, and the seismic hazard embodied in these processes'.

Pavlides (1989) suggested the following definition: "Neotectonics is the study of young tectonic events which have occurred or are still occurring in a given region after its orogeny or after its last significant tectonic set-up".The tectonic events are recent enough to permit a detailed analysis by differentiated and specific methods, while their results are directly compatible with seismological observations. This approach has been accepted by many researchers.

Active faults are the most common sources of earthquakes and tectonic movements and that it is likely to have another earthquake sometime in the future. An active fault is a fault which has had displacement or seismic activity during the geologically recent period. In the United States, an active fault is generally defined as a fault which displaced earth materials during the Holocene Epoch (during the last 11,000 or so years before present). To legally qualify as an active fault, the fault must be sufficiently active and well-defined. Some workers classify active faults as those faults that have moved one or more times in the last 120,000 years and are likely to move again. The evidence that a fault is active is that it repeatedly breaks the earth's surface.

As discussed above, there is also disagreement as to how far back in time 'geologically recent' is, with the common meaning being that neotectonics is the youngest, not yet finished stage in Earth tectonics. A general agreement has been emerging that the 'actual time frame may be individual for each geological environment and it must be set back in time sufficiently far to fully understand the current tectonic activity'. Keeping in veiw of the fact, that the area of present study is located in Kachchh region, an area well known for recurrent seismic activity, it is imperative that the tectonic history of various faults is known for atleast the Quaternary period. In the present study, therefore, the tectonic activity that has occurred during the Quaternary period is classified as neotectonics. This meaning is implied at all places in the thesis wherever the term neotectonics is used.

Due to recurrent seismic activity, the hyper-arid region of Kachchh is better known for the active coseismic deformation and the long history of devastating earthquakes. The documentary evidence show that the region has been greatly affected by several large magnitude earthquakes in the recent past. The 1819 Allah bund earthquake significantly changed the Quaternary landscape of the northern Kachchh, particularly the Great Rann of Kachchh. The earthquake of 1956 completely demolished the old town of Anjar. The earthquake of 26th January 2001, caused devastation all around the Kachchh region. The long history of devastating earthquakes indicates continuous rejuvenation of the area. However, assessment of future seismic activity on the basis of recorded seismic history during the last 100-200 years is bound to leave several lacunae. Hence, it is extremely important to enlarge the database beyond instrumental records. It is also crucial to understand the behaviour of the active faults in recent past to properly appreciate the future seismic risk. A detailed study on the documentation of the successive tectonic events along various fault systems, related landform development during Quaternary is essential. Ideally, first task should be identification of seismogenic faults/ active faults and then look for palaeoseismic features through trenching along such faults to know their past history. The ultimate aim is to evaluate seismic risk and seismic hazard mitigation as accurately as possible.

Hazard estimation in seismically active areas have to rely heavily on geological data generated along faults. The major criteria to categorise a fault as active fault depends on several factors. Faults located in close vicinity of populated areas have received maximum attention due to their potential of inflicating heavy loss of life and property in case of a seismic event. Looking at the large number of active faults located around the globe, the number of well investigated fault systems are very few viz. San Andreas Fault, the Wasatch Fault, the Chishang Fault, Wellington Fault and few others. All these faults display a wide variety of tectonic setting and geometries. However, against this, there are more areas categorized as possessing high seismic risk where very little or negligible information is available about the faults. In many cases, a lot of basic data needs to be generated like precise location of fault, documentation of evidences of neotectonic activity and provide evidence of fault slip in historic and pre-historic times.

The present study deals with such an area, the Kachchh palaeorift basin located on the western continental margin of India. The Kachchh palaeorift is criss-crossed by several latitudinal (E-W trending) faults which form the prominent tectonic and geomorphic fabric of the basin. The region has been affected by several earthquakes in the last 300-400 years which include two large magnitude earthquakes - the 1819 Allahbund earthquake and the 2001 Bhuj earthquake, which occurred within a span of less then 200 years. However the relation of the recurrent seismic activity and the various faults is yet to be established. Two factors have been responsible for this. One is the lack of precise instrumental data on the seismic events which occurred in the pre-instrumental era (1940's). The second is the lack of information on the on the seismic events that have occurred before ~400 years. In other words, the seismic and neotectonic history of Kachchh is incomplete or fragmentary at best. The present knowledge of the geological and tectonic evolution of the Kachchh basin is largely based on the series of papers by Biswas, which is mainly deal with pre-Quaternary time.

The study describes detailed surface and subsurface data generated in the Katrol Hill Range and the E-W trending Katrol Hill Fault (KHF), which is the range bounding fault located to the north of it. The KHF is a major, E-W trending range bounding fault located in the central part of Mainland Kachchh. The fault all along its length bounds the youthful and rugged topography of the Katrol Hill Range to its south and an undulating rocky plain to the north. Geomorphologically, the fault is expressed as a linear series of north facing range front scarps. Considerable ambiguity exists at present regarding the precise location of the fault and its structural attitude. On the available maps the KHF is normally marked as a fault line running along the base of the scarps. However, this is a very simplistic way of representing the fault and is of little value for carrying out detailed seismotectonic and palaeoseismic studies.

The KHF marks the lithotectonic contact between the younger Bhuj Formation with a lower relief to the north and the older Mesozoic Formation to the south. The fault is mostly concealed under a thin cover of surficial Quaternary deposits, however, few outcrops do occur far and between. This partly explains the ambiguity in respect of its precise location. In some of the stream sections the fault plane is found to be exposed, however, these exposures are few and far between, which does not allow for continuous lateral mapping and infer about the changing nature of the fault at depth. Owing to the area specific problem of precisely locating the fault, Ground Penetrating Radar (GPR) was used extensively. It was found necessary to utilize the GPR technique to establish the continuity of the fault with precision and also to locate and determine offsetting along transverse faults. It was also found necessary to determine the behaviour of the fault plane along its length and find out the nature of movement and prevailing tectonic environment.

The study along KHF is also significant in view of the fact that several large towns like Bhuj, Anjar, Nakhatrana and Bhachau are located in close vicinity (<10 kms) of this fault. Moreover, the rapid industrialization taking place between the Bhuj and Bhachau closely parallels the KHF. The salient features of the present study include precise mapping of the KHF and associated transverse faults, its nature and attitude in the shallow subsurface, reconstructing the stratigraphy of the Quaternary deposits, neotectonic evolution and provide evidence in respect of its active nature. Data generated along several lines are converged to reconstruct the Quaternary tectonogeomorphic evolution of the KHF and the Katrol Hill Range and classify and demonstrate the KHF as an active fault capable of generating large magnitude earthquakes in the region. The study is intended to serve as a background for future seismotectonic studies and improved seismic hazard estimation of the region. The study also serves a model for initiating similar studies and generating similar data along other active faults of Kachchh.

PURPOSE AND SCOPE

The Kachchh basin is an excellent example of landscape that has evolved in response to tectonic activity along faults. Currently the Kachchh basin is a palaeo-rift graben whose geological evolution during the post-rift (inversion) stage has been marked by periodic reactivation of the various intrabasinal faults (Biswas and Khattri, 2002) which are responsible for recurrent seismic activity in the region. The landscape configuration of Kachchh is controlled by the various faults and associated structural features. The long history of devastating earthquakes is indicative of the active nature of the faults. The region falls in seismic zone V, categorized as an area possessing the highest seismic risk in the country. This necessitates formulation of improved seismic hazard evaluation and mitigation strategies on priority basis. Since the recorded seismic history of the region is very short, particularly of the instrumental earthquake data, it is necessary to extend this record back in time through geological methods. This however requires large amount of geological imputs, particularly on the reactivation histories of the various faults in the recent geologic past and its role in the evolution of present landscape. Such studies on the faults of Kachchh basin are, however, very few. Although, the pre-Quaternary tectonic and sedimentary evolution of the basin is now well known, the same cannot be said about the Quaternary evolutionary history. The present study is aimed at addressing these issues by way of investigating the Katrol Hill Fault (KHF) which shows considerable impact on the landscape of Katrol Hill Range, located in the southern Mainland Kachchh. A significant feature of the faults trending irrespective of the direction in which they trend, is the prominent geomorphic expression as a long line of scarps. The north facing steep Katrol Hill Fault scarp and presence of domal structures show an ideal example of fault generated mountain fronts (Thakkar et al., 1999). The area exhibits varied topographical features, typical of areas, which have suffered active tectonics. To the north of the KHF lies the central rocky plain of Bhuj identified as an Early Quaternary rocky surface (Biswas, 1974).

The Katrol Hill Range forms a significant part of the landscape of the southern Mainland Kachchh (Figure 1.1). It is bounded by the Katrol Hill Fault (KHF) to the north. The hill range corresponds to the flexure zone to the south of the Katrol Hill Fault (KHF) with the rocky plain of Bhuj to the north. The various domes associated with this hill range are, Ler dome, Gangeshwar dome, Shiv-Paras dome, Khatrod dome and Chadwa dome (Thakkar et al., 1999). All major drainages of the Mainland Kachchh arise from the Katrol Hill Range and flow outwards meeting the Arabian Sea, the Gulf of Kachchh and the plain of Banni and the Rann in west, south and north respectively (Figure 1.2). The range effectively divides the drainage of Mainland Kachchh into north flowing drainages and the south flowing drainages. Two major fault trends occur in the area. One is the major E-W trend that governs the landscape shaping, the second is the NNE-SSW and NNW-SSE transverse trend that displaces the E-W trending structures. This suggests that the relationship of the landscape with structural complexity of the area is complex.

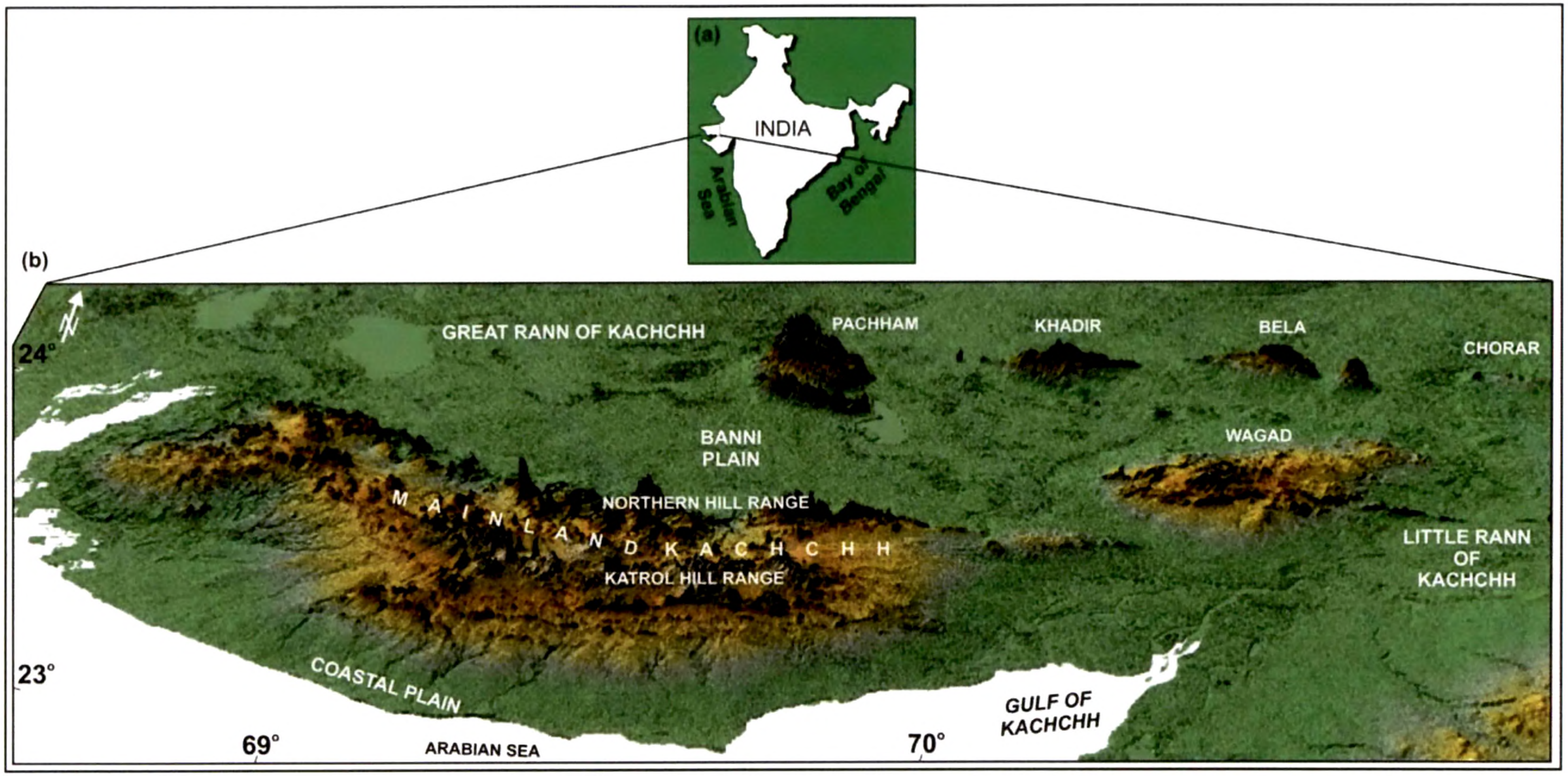

Figure 1.1 (a) Location map. (b) Digital elevation model (DEM) of Kachchh prepared from SRTM data (http://srtm.csi.cgiar.org). The Katrol Hill Range is the area of present study.

Lot of details on the Mesozoic stratigraphy and tectonics of the Katrol Hill Range are available, mainly worked out by Biswas. However, Quaternary evolutionary history of the area is not known. The impact of geological structures on landscape, Quaternary stratigraphy and neotectonic movements is also not known. Moreover, the precise fault trace of KHF and its reactivation history is ambiguous. The present study, therefore involved detailed geomorphological, Quaternary stratigraphic, and fault mapping using Ground Penetrating Radar (GPR), a modern geophysical tecthinique for investigating the shallow subsurface. The study was also aimed to understand the active nature of the KHF and its capability to produce large magnitude earthquakes in future. The study was carried out to achieve the following objectives.

1. To delineate the relationship between the structural elements and the landscape configuration,
2. Reconstruction of Quaternary stratigraphy including those occurring within the Katrol Hill Range and those overlapping the Katrol Hill Fault (KHF),
3. Precise mapping of the KHF and determine its subsurface geometry and nature,
4. Reconstruct the Quaternary reactivation history and to provide evidence for active faulting along the KHF,

STUDY AREA

Location: The study area falls in the Kachchh district of Gujarat State. The area of investigation is enclosed between 23°00′ and 23°15′ N latitudes and 69°25′ and 69°50′ E longitudes (Figure 1.1). The study area forms part of Bhuj, Anjar and Nakhatrana talukas. Geographically, the entire Katrol Hill Range and a part of the rocky plain to the north is included in the area of present study (Figure 1.1). The area covered in the study is approximately 1200 sq. kms.

Physiography: The study area shows two distinct physiographic units. One is the rugged hilly terrain of the Katrol Hill Range which forms >75% of the study area, while the second is the gently undulating rocky plain very well observed around the town of Bhuj. The straight north facing escarpment forming the northern margin of the range is the most conspicuous landscape feature of the area. This escarpment marks the geomorphic expression of the Katrol Hill Fault, the most significant geological feature of the study area. The Katrol Hill Range shows typical mountainous terrain with several peaks, mainly concentrated in the northern part and deep valleys (Figure 1.1). The highest peak is the Khatrod peak which is 349 amsl which is located along the northern edge of the range. The range gradually loses elevation towards the south. Most of the hills trend in E-W direction, as a consequence valleys also trend in the same direction. The Rivers in the northern part follow these valleys before turning northwards and finding a way out into the rocky plain located to the north of the range. The south flowing rivers follow the general gradient of the Katrol Hill Range which is towards south.

Communication: Kachchh has a reasonably good network of metalled roads. The Ahmedabad-Kandla National Highway is the only national highway in the entire Kachchh district which connects it with other parts of the country. Amongst the state highways, the important ones are the Bhuj-Anjar-Gandhidham road, Bhuj-Mandvi Road and Bhuj-Desalpar-Roha-Naliya-Jakhau road. Apart from these major roads other roads connecting various villages and small towns also exist. The rail link is also available upto the study area through Anjar-Bhuj route. To the south of the study area, several major ports like Kandla and Mundra alongwith smaller ones like Mandvi are located. The only functioning airport available for civilian air travels is the Bhuj airport.

Drainage: The drainage density of Kachchh is very high for a hyper arid region. Most of the drainages of study area originate from the Katrol Hill Range or Central Kachchh Highland which is the main watershed of Mainland Kachchh. The rivers are ephemeral and monsoon fed. Duration of flow of water in the rivers lasts from a few hours to few days during the monsoon. The rivers exhibit steep cliffy banks and have steep gradients. Some of the rivers do not bear the same name throughout their courses, also, more than one rivers are found to bear the same name. The Khari, Rukmawati, Pur and Pat are the major north flowing rivers originate from the Katrol Hill Range and drain through the low laying rocky plain of Bhuj and cross the Northern Hill Range before disappearing in the Banni plain. The major rivers draining towards south from Katrol Hill Range are the Naira, Kankawati, Kharod, Khari, Rukmavati, Nagwanti, Phot, Bhukhi, Sankra and Sang Rivers, which meet the Arabian sea and Gulf of Kachchh (Figure 1.2).

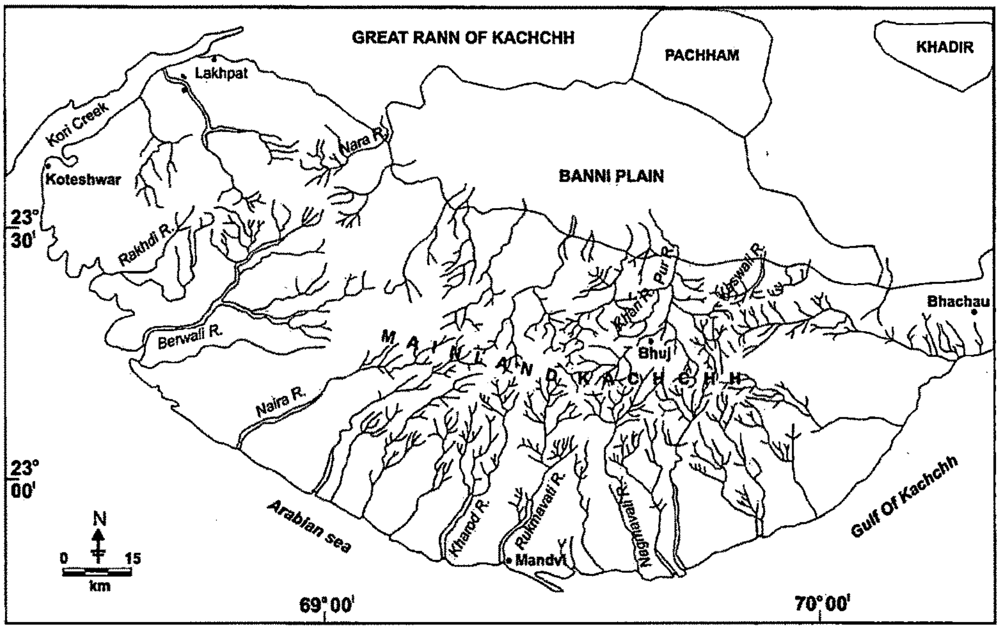

Figure 1.2 Drainage map of Mainland Kachchh. Note the drainages originating from Katrol Hill Range and flowing towards north and south.

Climate: The Kachchh region in general falls within the hyper arid belt of western India. Average rainfall in the district is between 300 to 400 mm/year. On an average there are very less, approximately 15 rainy days during the entire year. The day temperatures particularly in summers are generally low in the coastal region than the interior. In summers the day temperatures go above 46° C. January is the coldest month of the year when the mean daily maximum is 26^0 C and the mean daily minimum is 11^0C. However, during the cold wave conditions due the NW disturbances, temperature goes down below the minimum level. Humidity remains high throughout the year along the coast generally exceeding 60% on the average.

Flora: Kachchh has practically no forests and very few trees. The Kachchh flora is mostly characterised by thorny and non-thorny shrubs and trees. The wild tree growth is almost entirely confined to throny species like Baval, Kher etc. Several varieties of Acacia occur. The coastline exhibits swamps vegetated with mangrove forests and grasses covering dunes and sand flats. The main varieties of flora found in the study area are - Avicennia officinalis (Tavar, Tarvariyan), Leptadenia spartium (Khip), Casuarina Equisetifolia (Saru), Halopyrum mucronatum (Dariyai Kansdo, Dariyai Kans), Melia azadirachta (Limbdo), Acacia arabica (baval), Cassia auriculata (Aval), Sporobolus indicus (Velari charchar), Sueda maritima (Lano, Luno), Euphorbia tirucalli (Thor, Kharsani Thor, Dandalio Thor) Leucoena glauca (Laso baval, Vilayati baval) Butea frondosa (Kesuda no jhad), Zizyphus jujuba (Bordi), 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. The coastal plain is extensively used for agriculture where various crops (jowar, bajri wheat, mag and math) including those of fruit and vegetables are grown.

Fauna: The chief domestic animals found in the area are horses, camels, oxen, cow, buffaloes, sheep, goats and asses. Absence of forests means a general lack of wild animals. The wild animals are the Panthera pardus (Panther), Canis lupus (Indian wolf), Canis aureus (Jackal), Vulpes bengalensis (Fox), Sus scrofa (wild boar), Antelope cervicapra (Black buck), Equus hemionus pallas (Wild ass), and Lepus nigricollis (Indian hare) and various kinds of poisonous and non-poisonous snakes. The resident and migratory birds are commonly found in Kachchh. The migratory birds are found plentiful during winter season in the organic rich zone of the coastal flats bordering the Gulf of Kachchh and the vast saline expanse of the Little Rann of Kachchh.

People and occupation: The composition of the people of Kachchh differs much from those of other parts of Gujarat in a number ways. This is because of its distinct geographic identity and historical factors. Approximately 75-80% of the population lives in rural areas and the rest in urban areas. As a majority of the population resides in rural areas, the economy of the region is agro-based. The coastal areas of Kachchh have many big ports and the new industrial corridors developing between Gandhidham-Mundra and Bhuj-Bhachau are providing modern avenues of employments to the rural people.

APPROACH AND METHODOLOGY

The Kachchh region is ideal for carrying out neotectonic studies. In spite of a general agreement that the Kachchh is geodynamically very sensitive, the information on exact nature of the Quaternary tectonic activity that has been operative in this part of Western India remains to be understood. Geomorphic evolution of seismically active areas is strongly controlled by tectonic activity. Reconstructing the geomorphic evolution of such reactivated sedimentary basins usually involve study of a variety of tectonically formed geomorphic features. This approach usually results in the delineation of the nature of neotectonic activity, however, it is difficult to constrain the timing of neotectonic activity unless geomorphic data is combined with the stratigraphic data. It is therefore essential to employ a comprehensive approach involving geomorphic and stratigraphic data to enable reconstruction of a detailed geomorphic evolutionary history including the nature and timing of tectonic activity (Chamyal et al., 2002). The present study is carried out along southern Mainland Kachchh, which is an area having significant imprints of neotectonic activities in recent past. A comprehensive approach involving detailed field mapping of the landforms, DEM modeling and stratigraphic and shallow subsurface studies of the Katrol Hill Fault (KHF) using GPR has been applied to reconstruct the geomorphic evolution of the study area. The detailed methodology employed for carrying out the present study is described below.

- Available published data on the stratigraphic, structural and seismotectonic aspects of the Kachchh region were critically studied and evaluated to understand the regional geological setting and possible influences of these on the geomorphic set up of the study area.
- Regional scale geomorphic set up of the study area was delineated using Survey of India topographical maps (No. 41E/8,12,16 and 41F/5, 9,13) and satellite images.
- Field mapping of various geomorphic features and landforms was carried out. The landforms of the study area were initially categorized into Quaternary and pre-Quaternary geomorphic features and were mapped separately before synthesising them to reconstruct a comprehensive neotectonic evolution of the study area.

- The DEM (Digital elevation models) of the study area were prepared with different resolutions to appreciate the role of various tectno-geomorphic features in landscape evolution.
- The exposed Quaternary sediments were studied 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.
- Ground Penetrating Radar (GPR) was used for the precise mapping of the Katrol Hill Fault (KHF) and also for determining its nature in the shallow subsurface.
- The morphostratigraphic evolution of the area 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. Reactivation events have been identified thereby establishing the active nature of the KHF.