Chapter - 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

Saurashtra region of Gujarat state in western India is described as an uplifted horst bounded by faults on all sides (Biswas, 1982; Merh, 1995). Dominantly comprising Deccan Traps with Mesozoic and Cenozoic sedimentary rocks at it northeastern margin, it is bounded by the Kachchh rift to the north, the Cambay rift to the east and the offshore faults related to the Narmada rift in the south (Biswas, 1987). Surrounded by neotectonically active rifts and their related fault systems (Figure 1.1), the Saurashtra horst presents itself as a region of geological and structural homogeneity as there are no active faults reported from the region. Recent field studies in SW Saurashtra, however, suggest complex structural pattern with deformation of trappean lava flows and strike-slip faulting (Vanik et al., 2018). Recurrent earthquake swarm activity since 1872 till present (Rastogi et al., 2013), over a large part of the region also indicates existence of tectonic elements in the Deccan traps, many of which are yet to be mapped. Recurrent earthquake swarm activity covers several parts of Saurashtra like the areas around Junagadh, Dwarka, Rajkot, Paliyad, Ghogha and Bhavnagar (Bhattacharya et al., 2004). Since 1800s, the earthquake swarms are particularly noticeable and recurrent in three areas viz., Junagadh district in the SW, Bhavnagar district in east and Jamnagar district in northern Saurashtra (Bhattacharya et al., 2004; Yadav et al., 2011; Rastogi et al., 2013; Singh and Mishra, 2015; Mahesh and Gupta, 2016; Singh et al., 2017).

It has been shown that detailed analysis of landscape and drainage networks provide important insights on geological factors controlling landscape evolution in tectonically and seismically active areas (Tsodoulos et al., 2008; Pérez-Peña et al., 2010; Dar et al., 2013). However, in depth morphotectonic studies and landscape analysis are not available from the Deccan Trap dominated region of Saurashtra. Moreover, all studies on Quaternary geological aspects of Saurashtra are confined to the Middle to Late Quaternary miliolite sediments. The landscape of Saurashtra is highly varied in terms of relief, landforms and drainage characteristics which is in contrast to the landscapes developed over Deccan Traps elsewhere (Chamyal et al., 2003).

The present study intends to provide a tectono-geomorphological perspective of the SW Saurashtra (Figure 1.1), which includes the swarm activity prone area around Talala based on geomorphological field studies and detailed analysis of landscape and drainage characteristics. The main objective of the present study is to provide morphotectonic data from SW Saurashtra to understand evolution of landscape in response to tectonic activity.

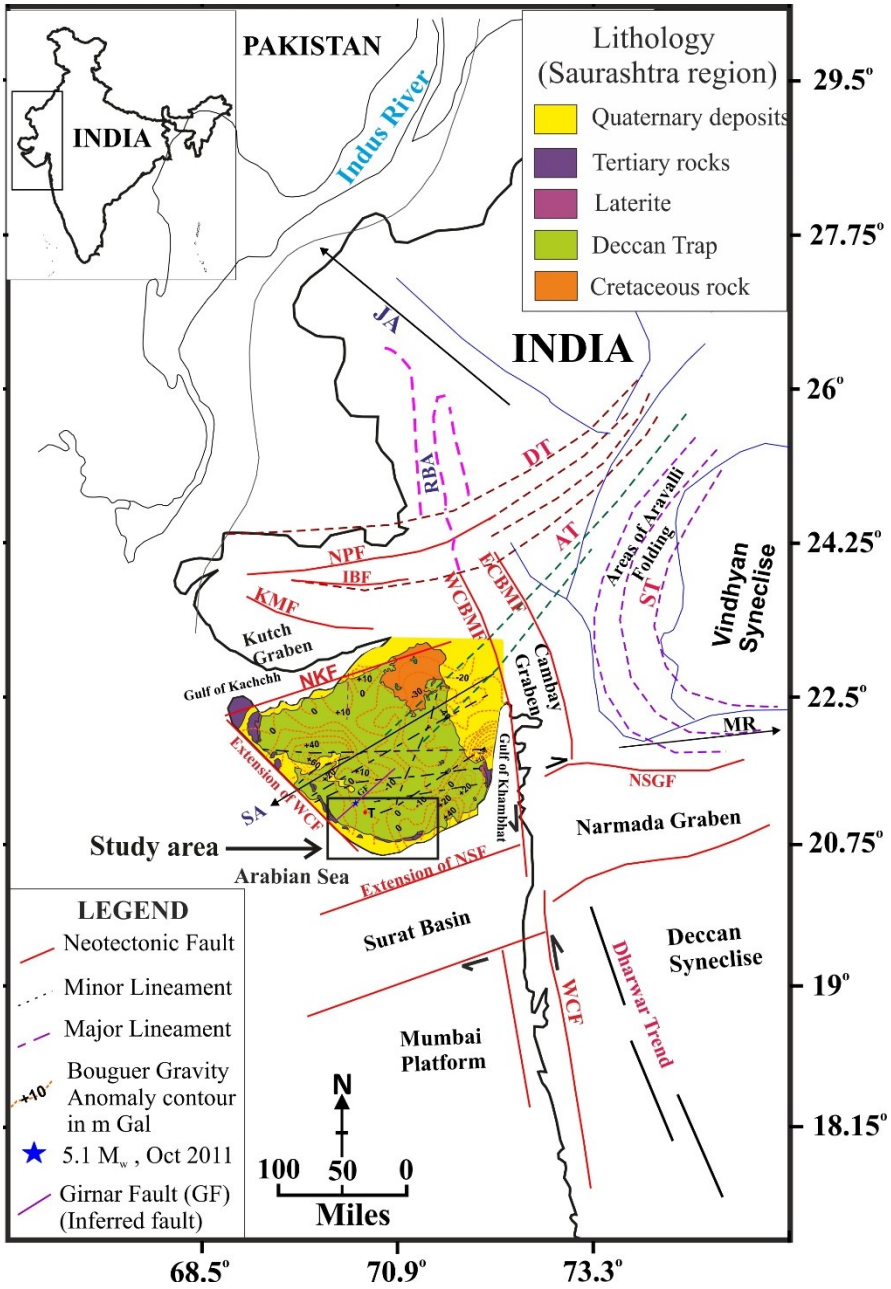

Figure 1.1 Tectonic map of Gujarat region that showing major and minor structural lineaments, peri-cratonic rift basins, gravity anomaly and major faults (after Vanik et al., 2018). Box shows the location of the area of present study. Pink, green and maroon dotted lines: ST- Satpura Trend, AT- Aravalli Trend, and DT- Delhi Trend, respectively.

Red line: major regional faults: IBF-Island Belt Fault, NPF- Nagar Parker Fault, KMF-Kutch Mainland Fault, WCF- West Coast Fault, WCBMF- Western Cambay Basin Margin Fault, ECBMF- Eastern Cambay Basin Margin Fault, NSF- Narmada Son fault, NSGF-Narmada Son Geofracture. JA- Jaisalmer Arch, SA- Saurashtra Arch, RBA-Radhanpur Barmer Arch, MR- Malwa Ridge are the tectonic regional arch and ridges surrounding Saurashtra peninsula. Blue star: Mw 5.1 earthquake on Oct 2011 near Talala (T). Pink line: inferred causative Girnar Fault (GF) based on deep seismic profiles and gravity studies. Map includes geological and seismotectonic data from Biswas (1987), Merh (1995), Dasgupta et al., (2000) and Rastogi et al., (2013). Several other lineaments with varying structural trends are mapped by Bhattacharya et al., (2004) in SW Saurashtra region. Geological map of Saurashtra region showing lithological data (after, Merh, 1995).

1.2 OBJECTIVES

The present study was focused on understanding the geological and tectonic controls on landscape evolution of SW Saurashtra, western India. The study was focused on the following objectives.

1. Identify and characterize role of structural elements and its linkage to landscape evolution in SW Saurashtra.
2. To reconstruct the morphotectonic evolution of SW Saurashtra.

1.3 STUDY AREA

Location

The study area covers ~ 4200 km^2 of the region falls under Gir Somnath district in south and parts of Junagadh and Amreli district in SW and SE corner of Saurashtra, also considered as a part of Kathiawar peninsula. The Gir National Park is a protected forest area and a wild life sanctuary is situated in the present study area covering ~ 1400 km^2. The study area lies between parallels of latitude 20°40′ & 21°22′ and the meridians of longitude 70°20′ & 71°34′ bounded by Bhavnagar district at east, Rajkot district at north, Junagadh district at west and Arabian Sea at south. The area covers ~140 km long coastline from Veraval port in the west up to Jafarabad port in the east.

Physiography

The study area is divided into four physiographic regions namely hills, Gir reserved forested region, major rivers and coastal plain on the basis of topography, climate, geology, soils and vegetation. The chief glory of Junagadh and Gir Somanth district lies in the hill ranges widely extended in the Gir forest zone and coastline. The highest hill, Mt. Girnar, is 530.66 m above MSL and almost all the hill ranges are

covered with dense forests. These hills have gradients varying from easy gentle slope to very difficult steep inclines. The geological structure of the district is mainly composed of Deccan Trap and trappean dykes along with small tracts of alluvium, blown sand, etc. are seen in the coastal belt. The alluvial soils found in plain areas are known as 'Ghed' and are fertile which supports good crops. There are black cotton soils in north-western parts and brackish type in coastal belt and area has good commercially workable deposits of chalk clay and limestone.

The Amreli district Amreli is sub-divided into four physiographic regions, namely Bhadar river plain, Shetrunji River plain and Amreli Coastal Plain. The extreme north of the district shows hilly terrain and drained by Dhantarvadi River. The northern talukas of Babra and adjoining areas which form the part of the central tableland of Saurashtra is formed to undulating land with ill-defined barren hill ranges. The terrain in this region is predominantly rugged and undulating with an elevation ranging from 14 to 648 meters above sea level and south-western part is covered with the Gir forests where Asiatic lions reside. The north- eastern part of the district with elevation varies between 103 and 202 meters above sea level and eastward slope. The region extends over the coastal parts of the district, occupying Jafarabad and parts of Rajula talukas with the elevation range between 5 and 147 meters above sea level with southward regional slope. The coastal part which forms the remaining part of the district is plain without any trees expect those rose along the roads and near wells. The coastal belt which forms the remaining part of the district is a gently sloping plain.

Drainage

The drainages of the Saurashtra peninsula shows overall radial pattern originating from the central part of the region in trappean highlands flow out in all the directions largely towards coast. The study area is prosperous in account of rivers, reservoirs and lakes. The rivers in Junagadh and Gir Somnath district are Bhadar, Saraswati, Uben, Ozat, Hiren/Hiran, Shingoda/Singwada, Sabali, Somat, Meghal, Machundri, Rawal, Rupen and Sangawadi flowing towards south in Arabian Sea. The major rivers flowing in Amreli district includes, Malan, Raidi, Dhantarvadi and Shetrunji River. These rivers are controlled by the lineaments and the topography. The Shetrunji River occupies the largest basin area originated from the Dhundi hills in the Gir forest area up to south of Bhavnagar. The other drainages are few ephemeral streams which debouch in the

Arabian Sea. The coastal area is a narrow band covering ~ 7 km with the marine cliffs ascends towards east.

Climate

The climate of the southwest region of Saurashtra is very rough semi-arid specially observed at the plains which are mostly hot and Gir Forest zones. The Junagadh district experience very mild climate mainly due to the coastal areas. However, the hottest month is May and the coolest month is January with occasional foggy weather. The annual rainfall received is during the SW monsoon season i.e., from June to September. Since last five years, the monsoon season with higher precipitation is mostly accompanied by windy breezes. The average rainfall in the district is about 657 mm in which 25.9 inch is annual precipitation. The temperature of the district varies, however the average annual temperature is ~26° C. The annual rainfall in Amreli district is also expected during the SW monsoon. There is a huge variation in the annual precipitation yearly. The average annual rainfall is about 585 mm and 23 inch per year. The region has also experienced strong cyclonic storms in Arabian Sea post monsoon along with extensive rainfall. Between May and October month, the area also experiences frequent thunderstorms.

Occupation

Agricultural labors and cultivators are the primary sectors that are occupied by more than half of the total population. The overall working crowd contains 35% cultivators, 22% agricultural labors along with livestock workers, forestry and fishing employees. The secondary and tertiary workforces are 26% and 13% respectively in the Saurashtra region. The non-primary agricultural economy is developing due to high percentage of manpower in this area. The household industries, transportation, trading, manufacturing are occupied by 39% of total workers.

Flora

Main flora species of Junagadh district are Teak (Saag) and Bamboo. The other species are Rayan, Haldu, Shisham, Gorad, Kadam, Sag, Sajad, Khair, Babul, Arduso, Khakro, Karnj, Jambu, Amla, Behda, Satsado, Dhawada, Semlo, Bili, Bordi, etc. Timber and firewood area major forest products. While the forests in Amreli district only requests charcoal and firewood. Due to variation in rainfall, altitude, soil etc., the area shows varied flora. The forest areas are classified in to the three different types, i)

Mangrove forest having species of trees such as Avicenniac Officinalis (Cher), Rhizophora Mucronata (karod), coripos (kunri), Acacia Senegal (Gorad), Acacia Arabica (DesiBaval), ii) open scrub forests with species such as Acacia Arabica (Baval), Acacia Senegal (Gorad), Capparis Decidua (Karda), Diospyros Melanoxylon (Timaru), and Buteafrondosa (Khakhra), iii) Grasses of different types such as Eremopogonfoveolatus (saniar), Andropogonischaemum (Zinzvo), Andropogonintermedius (Dharfada), Anthistiriaimberbis (Ratadu). The fruits commonly grown are mango, coconut, chikoo, papaya and banana.

Fauna

The Junagadh district has very efficient dual purpose breed of "Gir Cow" and "Jafrabadi Buffaloes". The Amreli district like all other districts of Saurashtra has seen a rapid decline in the number of wild animal. This site of affairs is due to indiscriminate killing by shooting and snaring of animal and the destruction of natural vegetation by overgrazing. A short account of the better known animal is: Lion (Pantheraleo) (Sinha), Panther (dipado), Hyena (jarakh), Wolf (Nar), Jackal (shial), Fox (Lonkadi), Wild Cat (Jangali Bilado), Wild pig (Bhund), Spotted Deer (Chittal).The chief domestic animals are cow, buffalo, horse, camel, sheep, goat and donkey. The important wild animals of cat family are Pantheraleopersica (Asiatic lion) in the Gir Forest, Panthera Paradus (Panther), etc.

Transport and Communication

Junagadh district is well connected to other districts such as, Rajkot, Bhavnagar-Amreli through National Highway 8D and 8E respectively. The district is also connected to Jamnagar and Porbandar through NH8E (Ext.), with a total length of 43 km. The district has Junagadh -Veraval and Veraval - Somnath railway lines and is connected to Ahmedabad and Rajkot cities through rail. Junagadh is bounded on south and west by Arabian Sea and has some important ports on its long coast lines, viz. Veraval and four minor ports, namely, Mangrol, Navabandar, Rajpara and Simar. Amreli district is well connected to Ahmedabad, Vadodara, Surat, Rajkot, Jamnagar, Mahesana, Ankleshwar, Gandhinagar, etc. by roads. Almost all the talukas of Amreli are well connected with the rail network and 120 km broad track with 18 railway stations are available. The district has a good coastline about 62 km of Arabian Sea. There are two intermediate ports

Jafarabad and Pipavav and only one minor port Kotda. Jafarabad port is situated on the south-east coast of Saurashtra peninsula, well known as a fishing port.

1.4 APPROACH AND METHODOLOGY

The present study has utilized multiple lines of data generation with a view to delineate the precise tectono-geomorphic setting of the SW Saurashtra region. The methods employed include field studies, tectono-geomorphic analysis, DEM analysis and drainage and landscape parameters sensitive to tectonic activity based on data extracted from Survey of India topographic maps on 1:50,000 scale. Field studies comprised investigations of tectonic influences on geomorphic set up, landscape configuration and fluvial geomorphic characteristics. The geomorphic data generated was used to interpret neotectonics and its possible linkage with observed seismicity.

Areas with topographic discontinuities affected by tectonic and geomorphic processes lead to development of multiple linear features along stream networks and landscape (Ananaba and Ajakaiye, 1987; Jordan et al., 2005; Solomon and Ghebreab, 2006; Masoud and Koike, 2011; Pinheiro et al., 2019). The trappean lava flows are known for prolific development of lineaments which were analyzed on regional scale (Kaila et al., 1981; Bhattacharya and Subrahmanyam, 1986; Ramasamy, 1995; Peshwa and Kale, 1997; Mishra et al., 2001). In the present study, lineaments in SW Saurashtra were extracted in the form of dykes, scarps, extensive linear ridges, straight channels, tonal variations and others. Rosettes were drawn for determining the major trends.

Survey of India topographical maps of scale 1:50,000 of all the drainage basins in SW Saurashtra were digitized to analyse drainage patterns and determine the drainage basin parameters and various geomorphic indices. ASTER Global Digital Elevation Model (DEM) derivative of Shutter Radar Topography Mission (SRTM) data with 90 m resolution were used for terrain analysis and extraction of land surface parameters for regional scale geomorphological analysis (Reuter et al., 2007; Grohmann et al., 2007, Han et al., 2012; Joshi et al., 2013; Pande and Moharir, 2017; Prakash et al., 2017; Jia et al., 2019; Mangan et al., 2019). Slope map and aspect map were generated to understand precisely the slope angle, direction of the slope and the topography of all studied drainage basins (Chang and Tsai, 1991; Ruszkiczay-Rüdiger et al., 2009; Oh et al., 2010; Joshi et al., 2013). Topographic profiles were created for all the drainages aligning parallel to that of main trunk stream from the source to the river mouth. Erosion-uplift equilibrium is

revealed by studying the longitudinal river profile which is one of the indicator of active tectonics (Schumm et al., 2000; Keller and Pinter, 2002; Molin and Fubelli, 2005; Menendez et al., 2008; Bull, 2009; Joshi et al., 2013).

The channel configuration of all the drainage basins were quantitatively analysed for stream order, drainage density and bifurcation ratio (Horton, 1945; Tucker and Bras, 1998). The geomorphological evolution of the drainage basins were determined by calculating linear parameters of the drainages along with some basic parameters on areal as well as relief aspects (Reddy et al., 2004; Altin and Altin, 2011). Geomorphic indices are useful for quantitative measurement of drainage basin topography to the regions undergoing tectonic deformation (Keller and Pinter, 2002; Dehbozorgi et al., 2010; ¨ Özkaymak, Ç, and S¨ozbilir, 2012). The basin length, perimeter, area, stream number, stream order, channel slope, drainage density has been extracted from DEMs. Stream frequency (Fs), drainage texture (T), form factor (Ff), elongation ratio (Re), circularity ratio (Rc), relief ratio (Rr), ruggedness number (Rn) and longitudinal stream profile were also calculated with the help of the extracted data. The morphotectonic indices that were integrated along with the geomorphic indices are Stream length-gradient index (SL index), Valley floor width to height ratio (Vf ratio), basin Asymmetric Factor (AF) and Hypsometric curve and hypsometric integral for estimating tectonic influences on landscape development of the basins.

The broad methodology of the present study is as follows:

- Relevant literature available on geological, geomorphic, structural and tectonic characteristics of the Saurashtra region were analytically studied to primarily understand the geological and structural set up and its influence on Quaternary landscape.
- Interpretation of the various satellite images for identifying various seismotectonic landforms, faults based on satellite data, drainage patterns and preparation of base maps with the help of Survey of India (SOI) toposheets. The study area, therefore, divided into two morphotectonic domains with the help of base maps and remote sensing analysis.
- Detailed geomorphic mapping of the study area was carried out demarcating structural elements and aeolianite ridge system with the help of SOI toposheets, satellite data and GIS software.

- The Digital elevation models (DEM) of 30 m resolution were used to produce slope data, aspect data and to generate lineament map of the study area to observe the tectono-geomorphic features associated with the landscape evolution.
- Extensive field investigations carried out to map several geomorphic features, erosional and depositional landforms, fluvial characteristics, faults, brittle shear zones and Quaternary miliolite deposits to reconstruct the landscape evolution of the study area.
- Paleostress analysis carried out from fault-slip data in trappean terrain and joint sets data of exposed Tertiary and Quaternary deposits to deduce SHmax (maximum horizontal stress) and to comprehend regional stress trend.
- Aeolianite ridges were identified and mapped with the help of DEM analysis and detailed field exploration to know its morphological characteristics.
- Morphotectonic analysis were carried out using geomorphic indices and morphometric parameters of ten drainage basins to evaluate tectono-geomorphic evolution with respect to structural deformation of the SW Saurashtra.
- The data generated through field studies, remote sensing analysis, lineament mapping and quantitative analysis were synthesized and critically evaluated to reconstruct the tectono-geomorphic setting and morphotectonic evolution of SW Saurashtra.