CHAPTER 4

TECTONIC CONTROLS ON FLUVIAL SYSTEM

The drainages of western KRB comprise north-flowing rivers incising through the rocky landscape and disappearing into the flat Rann surface after cutting through the NHRFZ and KMF scarp. The drainage density is very high which strongly contrasts with the hyper-arid desertic climate of the region (Fig. 1.1b). In fact, the streams of the area rarely witness the consistent flow of water even during the monsoon season due to hyper-arid climatic regime. The main drainage divide is not formed by the Jaramara scarp, instead, the rugged hilly topography of the Ukra intrusive that occupies a large part of the back slope of the scarp and the crest of the Gugriana Hill Range form the main drainage divides. From the intrusive, several short streams originate that flow southward into the rocky plain further south meeting the Nara river.

All drainages follow structurally controlled courses. All saddle zones between successive domal structures in the NHRFZ are occupied by streams. The Karanpur stream flows northward between the Lakhpat anticline and the Karanpur dome. The Ghuneri stream occupies the zone between the Karanpur dome and Ghuneri dome. The Katesar stream flows between the Ghuneri dome and the Mundhan anticline. The western fringe of the Jara dome adjacent to Mundhan anticline towards west is drained by the Gandi river. The saddle zone between the Jara and Jumara domes is occupied by the Jara river. The eastern fringe of the Jumara river is drained by an unnamed stream. The Nara river incised through the centre of the Nara (Manjal) dome. The Makdawali river meets the Banni plain through the wide saddle between the Nara (Manjal) dome in the west and the Keera dome in the east. The Nara river and Makdawali river are the largest rivers which occupy more than half of the present study area. Both river arise in the Gugriana Hill Range and flow northwards through the Central Rocky Plain and NHRFZ. The other streams in the inter-domal saddles are shorter in length and show relative les incision. Major part of the study area is drained by the Nara and Makdawali rivers. However, the fluvial geomorphic set up of the Jara and Jumara domes is different and comprises spectacular landforms like water falls and gorges. The drainage characteristics of Jara and Jumara domes are described first followed by the Nara and Makdawali rivers.

FLUVIAL SYSTEM OF THE JARA AND JUMARA DOMES

The Jara and Jumara domes are drained by north flowing rivers which show remarkable correspondence with the structural setup of the area (Fig. 3.5a). The drainages flow northward in anti-dip direction, dissecting through the rugged hilly topography of the NHRFZ suggesting a strong component of long-term tectonically induced erosional processes (Bishop, 2007). Deeply incised bedrock channels and knickpoint generation are conspicuous features of the various rivers. Each structural sub-domain of the area shows a strong influence on the drainage network superimposed over it (Fig. 3.5).

The Jumara and Jara domes show a prominent radial drainage pattern which is conformity with their structure (Fig. 3.5a). The Jaramara scarp does not form a prominent drainage divide, however, several streams originate at the base of the scarp which flow northward along their structurally controlled courses through the Jumara and Jara domes (Fig. 3.5a). Only two rivers, the Jara river and the Jumara stream originate on the back slope, just behind the crest of the scarp (Fig. 3.5a). These two rivers, particularly the Jara river has developed a spectacular gorge as it flows northward through the scarp and further incising through the low hilly topography of the Jara dome (Figs. 3.5). The river shows three prominent knickpoints within the gorge.

The Gandi river shows the most interesting course that circles around the southwestern and western margin of the Jara dome (Fig. 3.5a). It originates from the western part of the Ukra intrusive on the back slopes of the Jaramara scarp and flows in a northwest direction following the swerving strike of the Mesozoic strata and takes a sharp turn to flow northward through the western fringe of the Jara dome (Fig. 3.5a). The channel reach of the Gandi river from north of Lakhapar is deeply incised. The river shows three prominent knickpoints, out of which the middle one formed in the rocks of Ukra intrusive is ~25 m (Figs. 4.1a, b and c). This knickpoint formed at the western fringe of Jara dome is the biggest in the entire study area. The Jara river, as described earlier, forms a deep gorge across the Jaramara scarp and shows a deeply incised channel all throughout its course on the eastern fringe of the Jara dome (Fig. 4.2). A parallel stream to the west of Jara river that originates at the base of the

Jaramara scarp also shows a deeply incised channel at the eastern margin of the Jara dome (Fig. 3.5). Similarly, there are streams that follow structurally controlled channels but with significantly less incision, at the eastern as well as the western margin of the Jumara dome (Fig. 3.5). A neotectonic component of tectonic uplift is implicit from the seismically active nature of the area and youthful nature of the drainages.

Continuous uplift led to constant erosion and negligible Quaternary depositional activity. All sediments generated by extensive erosion were carried away and deposited in the basin to the north of KMF which is presently identified as the Great Rann sub-basin. The Great Rann is a large E-W trending sub-basin bounded by the KMF in the south (Maurya et al., 2013). The basin preserves a huge thickness of Quaternary fluvial and shallow marine sediments (Maurya et al., 2013). The maximum thickness of the Quaternary sediments of ~300 m is found closer to the KMF and comprises shallow marine Holocene sediments at the top with fluvial sands below (Biswas, 1987; Maurya et al., 2013). The Quaternary sediments are underlain by full sequence of marine Tertiary and Mesozoic Formations (Biswas, 1987, 1993). The maximum thickness of Quaternary sediments together with the subsurface fluvial sediments was primarily facilitated by tectonic activity along the KMF. This resulted in continuous uplift of the upthrown block leading to erosion in the uplifted block and deposition of eroded sediments in the downthrown block i.e., the Great Rann sub-basin. This explains the occurrence of deeply incised bedrock channels, Jara river gorge, large knickpoints and the absence of Quaternary sediments in the Jumara and Jara domes. The role of tectonic uplift as a major factor in the formation of erosional landscape of study area is corroborated by the paleoclimatic studies from the Thar Desert which show that large scale aridity existed in the region for most part of the Quaternary Period (Dhir and Singhvi, 2012) and continues at present (Machiwal et al., 2016).

The most spectacular gorge is the Jara river gorge which is formed in the central part of the Jaramara scarp (Fig. 4.2). The Jara river originates on the back slope, close to the contact of the Jhuran Formation with the Ukra intrusive body and forming a deep narrow gorge across the scarp within a short distance and flowing further north in a deeply incised bedrock valley. Three major knickpoints are observed within the Jara river gorge that testifies to the profound tectonic uplift induced long-term rejuvenation of the scarp. Neotectonic uplift is inferred as the river has formed a deep gorge within Quaternary aeolian miliolite deposits underlain by rocks of Jhuran Formation (Fig. 4.2).

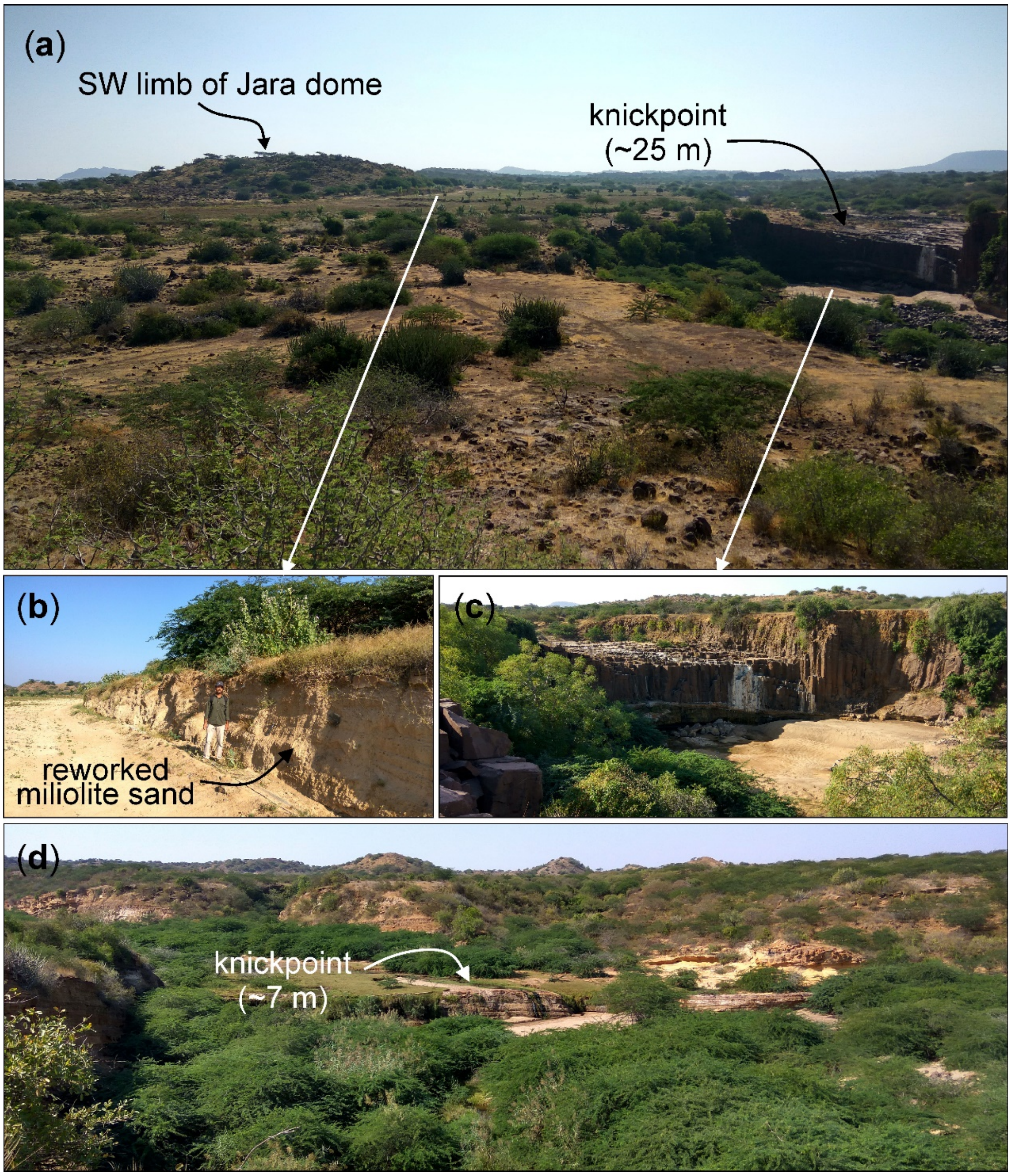

Fig. 4.1. (a) Panoramic view of the large knickpoint along the Gandi river to the north of Lakhapar. Note the cliffs on the left bank and the wide gently sloping terraced surface on the right bank. Also visible is the SW dipping Ukra intrusive forming the knickpoint suggesting its concordant nature. (b) Close view of the horizontally stratified fluvially reworked miliolite sand exposed in an artificially cut section. The white arrow indicates the location of the section in a. (c) close view of the knickpoint shown in a. (d) View of the ~7 m knickpoint formed in Mesozoic rocks ~3 km downstream of the location shown in a.

The other river that has dissected through the scarp is the Jumara river that arises just behind the crest of the scarp and flows northward. The river forms a wide gorge but shallower than the one described above and flows further north through the central part of the Jumara dome.

All rivers show structurally controlled courses (Fig. 3.5). Prominent control of domal structural setup on drainage configuration also points to sustained uplift that continued during Quaternary. The presence of the knickpoints, both small and large, along the rivers also suggest that the drainages are in a state of continuous rejuvenation (Fig. 3.5). Longitudinal profiles of even the large rivers like the Jara river and Gandi river show large knickpoints and steep profiles. The ~25 m knickpoint in Gandi river and the Jara river gorge over the Jaramara scarp provide evidence of Quaternary tectonic activity (Figs. 4.1 and 4.2).

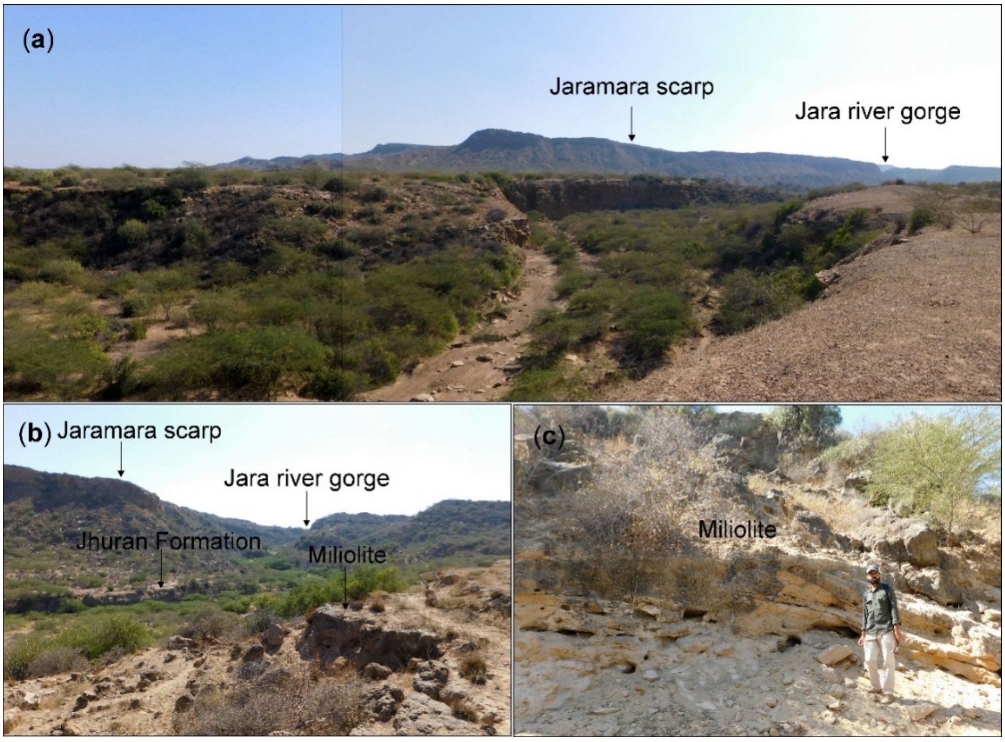

Fig. 4.2. (a) South facing panoramic view of the Jaramara scarp and the deeply incised channel of Jara river in the foreground. Note the youthful and undirected nature of the scarp with the lone Jara river gorge at the extreme right of the photo. The channel in the foreground is incised by ~30 m into the Jhuran Formation exposed in the cliff. The surface is incised by the river in the low undulating topography over the Jara dome. (b) View of the mouth of the Jara river gorge striding the scarp face of the Jaramara scarp. In the foreground is the exposure of aeolian miliolite with incised cliffs of Jhuran Formation at a lower level in the Jara river valley. (c) Close view of the miliolite exposure showing large-scale aeolian cross stratification.

The miliolite represents a broadly multi-phased sedimentation that deposited aeolian miliolitic sands in scattered depressions (Biswas, 1971). At places, the aeolian miliolite deposits are found to be fluvially reworked (Maurya et al., 2017) (Figs. 4.2b and c). U/Th dating (Baskaran et al., 1989) and OSL dating (Sharma et al., 2017) suggest several phases of aeolian deposition and fluvial reworking of miliolite sediments up to approximately 11 Ka BP. The outcrops of miliolite are relatively more in eastern Kachchh while they are rare in western Kachchh. The extensive field studies in the Jumara and Jara domes revealed very few isolated outcrops of miliolite deposits. The most significant one comprises aeolian miliolite at the head region of the Jara river gorge which indicates deposition in a depression on the backslope of the Jaramara scarp (Figs. 3.5b). The Jara river in its gorge reach over the Jaramara scarp shows a drop of ~60 m in a distance of ~1 km. Out of the total drop of ~60 m elevation difference in river bed profile, ~25 m is in the incised miliolite sediments (Fig. 3.8). The deep incision in miliolite deposits is attributed to post miliolite tectonic uplift in Late Pleistocene to Holocene times.

The other significant outcrop is a small patch of reworked miliolite located on the right bank of Gandi river and adjacent to the ~25 m knickpoint (Figs. 4.1a and b). This knickpoint is the largest in the study area and is formed in the Ukra intrusive rocks (Figs. 3.5 and 4.1), which is the most competent lithology in the study area. On the right bank of the river at this site, a wide flat terrace surface over the fluvially reworked miliolite sand is observed (Fig. 4.1a). The slope of the terrace surface is inconformity with the SW dip of the underlying rocks that forms the southwestern fringe of the Jara dome. In contrast, the left bank exposes vertically incised cliffs that expose Ukra intrusive rocks with the ~25 m knickpoint on the downstream side (Figs. 4.1a–c). Therefore, it is inferred that the ~25 m knickpoint along the Gandi river include a component of post miliolite uplift (Fig. 4.1). However, the magnitude of the uplift is not clear as no other comparable terraces are found along the Gandi river and other rivers of the study area. However, based on available chronology and the geomorphic characteristics of the two isolated outcrops in the study area, the incision of miliolite deposition in the study area is attributed to tectonic uplift during terminal Pleistocene to Holocene times.

NARA RIVER BASIN

The Nara river basin is the largest drainage basin in the study area (Fig. 4.3). The river drains part of the Gugriana Hill Range, the southern slopes of the NHRFZ, the Central Rocky Plain and the Nara dome. There are three major tributaries- Khari River, Bhukhi River and Photwari River in the upper reaches of the Nara basin. The Khari and Bhukhi rivers originate in the Gugriana Hill Range while the Photwari river originates on the southern slope of the Northern Hill Range. The Photwari river shows incised bedrock channels with several knickpoints. The Bhukhi river shows a large knick point in the vicinity of the GUF. The three tributaries meet up to form the Nara river channel which flows further eastward through the middle of the SE sloping Central Rocky Plain. The river takes a sharp turn towards NNE after Meghpar. Overall the drainage density is very high which is inconsistent with the hyper-arid climatic setting of the study area.

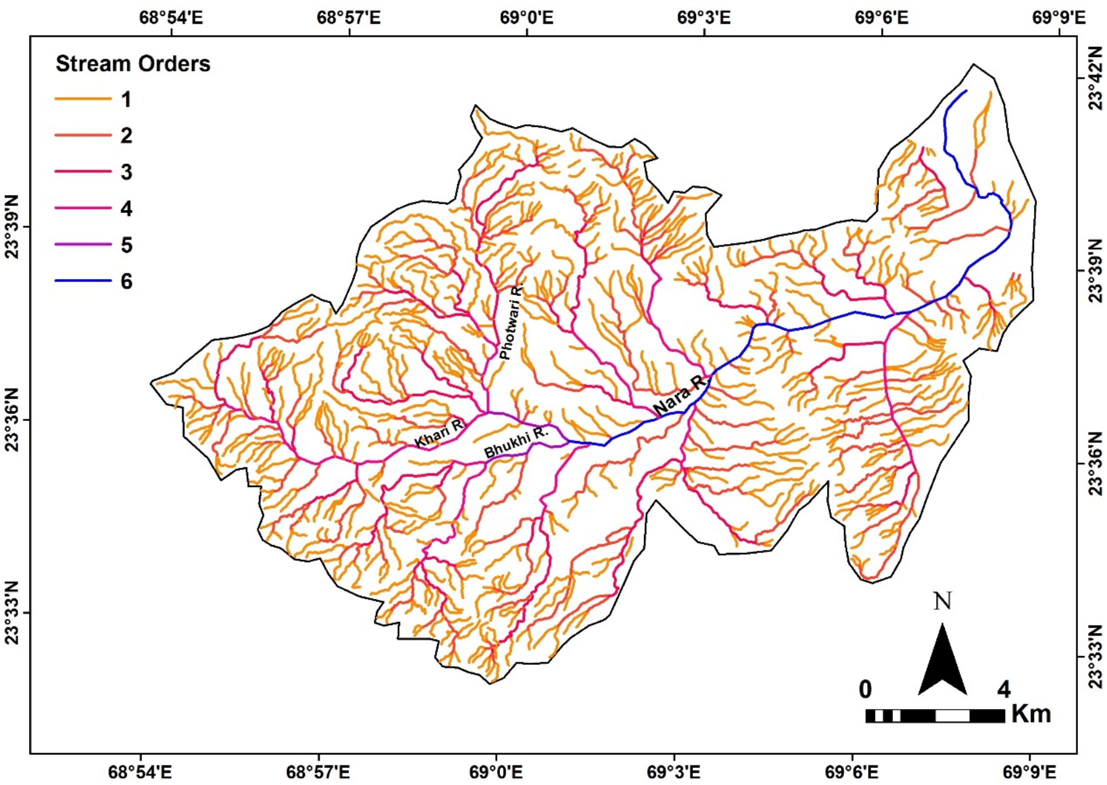

Fig. 4.3. Stream Ordering map of Nara River Basin

Geomophologically, the Nara river basin is divided into five geomorphic zones – a) Upland rugged zone (Gugriana hill range (Khari river and Bhukhi river) and Southernmost slope of Northern Hill range (Bhukhi River), b) Rocky plain with ENE trending channel, c) Rocky plain with NE channel trend, d) Northern hill range (Nara dome) and e) Fan shaped alluvial deposits. The topographic section along the length of the basin shows the above mentioned geomorphic zones. Three prominent fault scarps observed with the presence of exposed fault plane observed in the field. The significant variations observed in the profile is rugged mountainous topography of Gugriana hill range and NHRFZ and rocky plain in the middle reaches of the basin (Fig. 4.4a). The alternative rugged and planar landscape is distinct in this basin. The contact between Bhuj Formation and Jhuran Formation is observed in between GUF and VF. The Fan deposits towards the mouth of the river is covered by recent alluvium shows sudden change in the topography north of KMF scarp. The prominent incision of Nara River with strong influence of faults in the basin can be observed.

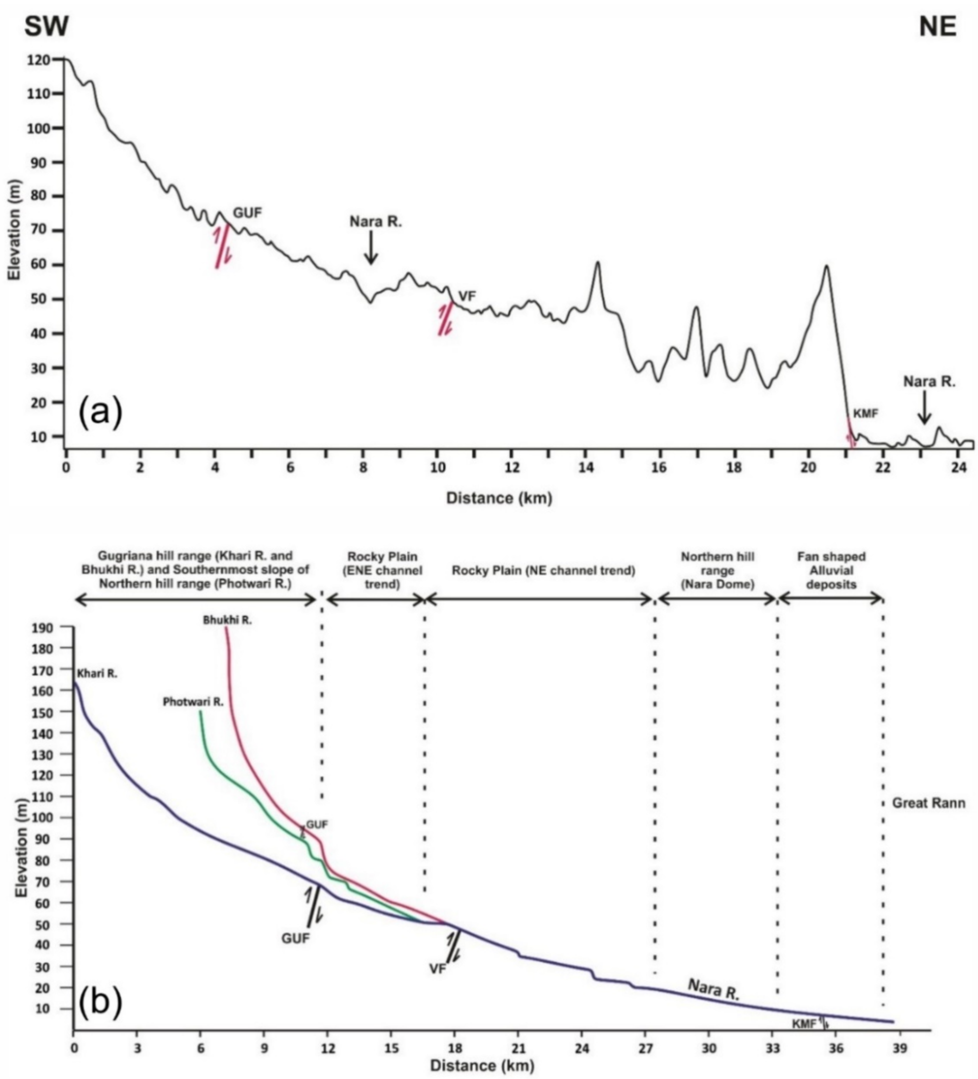

Fig. 4.4. (a) Topographic profile drawn along the Nara river basin. (b) Longitudinal profile of the Nara River.

The course of the Nara river in the Rocky Plain lies in Jhuran Formation with the presence of NW trending VF that crosses the Nara River near Meghpar (Fig. 4.4b). The streams observed are parallel to sub-parallel type of drainage pattern. The change is slope from steep to moderate is observed at this zone. Several knickpoints observed are may be due to the presence of KMF scarp further downstream (Fig. 4.4b).

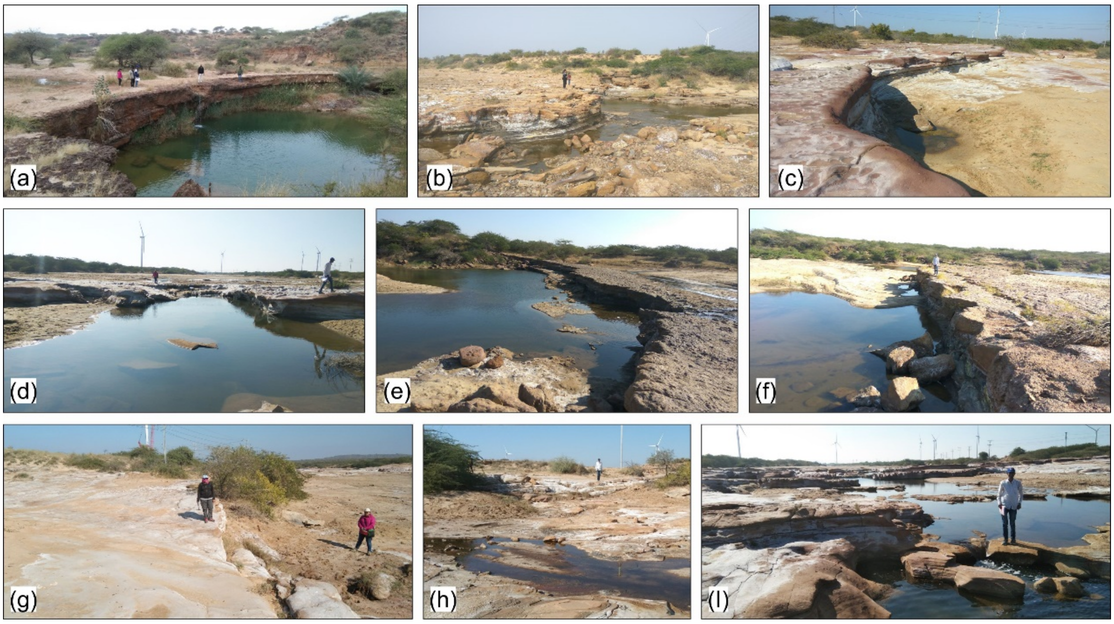

Fig. 4.5. (a) ~8 m high knickpoint formed in the Nara river in the vicinity of the NW-striking GUF. (c) to (f) and (i) 2–3 meters high knickpoints formed towards east of the VGKNFS. (g) and (h) View of a fluvial hanging valley that meets with the main stream of the Nara River.

The topography is undulating with the presence of multiple faults and step like knickpoints observed in the field (Figs. 4.4 and 4.5). The drainage frequency at this zone is very less compared to the upland zone. The parallel type of drainage patterns are observed with long streams and also angular drainages observed bending at almost right angle along its course. This is due to the presence of fault which also formed knickpoints in the Bhuj Sandstone. Several other local faults observed in this zone forming small rapids and knickpoints that show retreat towards upstream (Fig. 4.5). This makes the landscape uneven in the middle reaches of the drainage basin. The main trunk stream change its course from SE and flows towards NE. The sharp meanders, strong incisions and displacements observed in this zone. This zone is prone to many cross faults and major faults and significant fluvial erosional landforms like valleys, mature river course, rapids, waterfalls, potholes and sharp meanders.

MAKDAWALI RIVER BASIN

NW-SE trending Gugriana hill range is the source of the Makdawali River where several tributaries meet the trunk stream. The upland zone covers very less area of the drainage basin with elevation from 190 m up to 80m. This zone consists of undulating topography with wide channel bends and steep gradient (Fig. 4.6). The presence of sandstones of Bhuj Formation and several cross faults along with NW trending scarp observed in this zone. The drainages observed in this zone are mainly dendritic to parallel type of drainage patterns. This is due to the presence of uniform lithology and high relief with steep slopes. There are very few tributaries and mostly flow towards N to NNE direction towards the slope. The sharp gradient change from the hilly terrain towards rocky topography observed with an abrupt variation and fault.

The topographic profile (Fig. 4.7) shows the landscape development of the Makdawali river basin from the Gugriana hill range to the Great Rann. The traverse is taken at the centre of the drainage basin that includes all the geomorphic zones, fault line and the main trunk stream. The topography observed is uneven and gently tilts towards NE. The basin relief is very high throughout with the high elevation observed near the mouth of the river. The domes are observed along the KMF zone in the Kachchh region. In the rocky plain area, the ruggedness of topography is observed with a gentle northeastward gradient. The presence of VF and the incision of the tributaries is seen in this zone (Fig. 4.7). Overall, the basin shows the variation in landscape in upland zone, rocky plane region and the downstream of this zone. This may be due to the obstruction of domes causing the change in the flow and course of the river.

The presence of prominent fault planes, several knickpoints, gradient change and local displacements is observed in this zone during field investigation and remote sensing studies (Figs. 4.6 and 4.7). The knickpoints are observed at the fault zone with the presence of structural features and geomorphic evidences. The river till the saddle zone is showing smooth line up to the KMF zone (Figs. 4.6 and 4.7). The drainage basin of the Makdawali River mostly shows parallel type of drainage pattern. The river channel shows different channel trends from source to mouth. The distinct characteristics of the drainage basin is the asymmetric shape and difference in drainage frequency. The hilly region shows small channels with high density while the rocky plain in the central part of the basin shows very less channels but longer streams. In the larger scale, due to the presence of fault, high gradient change and strong geological and lithological variation, the Makdawali River basin shows parallel drainages.

Fig. 4.6. (a) View of the large knickpoint along the Makdawali river to the east of the VF. (b) View of the potholes formed on the footwall side of the NW-striking VF when it crosses the Makdawali river. (c) View of the ~2 m high knickpoint formed in the Mesozoic rocks, due to reverse slip along the ~W striking cross-fault. (d) to (f) 2–3 m high step-like knickpoints formed in the Makdawali river.

The significant structural and topographical controls on the river tributaries in the north-western section have caused the distinctive bend of the main stream to occur, a feature observed in several areas at a significantly smaller scale. Also, towards the southern and central provinces as well as in a minor area in the northern province of drainage basin, Nara tributaries are seen to flow in a nearly parallel manner, which may be indicative of a certain structural discontinuity such as the presence of a fault system. Furthermore, trellis type of drainage pattern is prominent in the south-western division with a similar pattern also recurring towards the central east, wherein precisely the major tributary exhibits the property whereas smaller subtributary systems are more or less in a parallel drainage. Towards the north-eastern section, the river follows the same geometry.

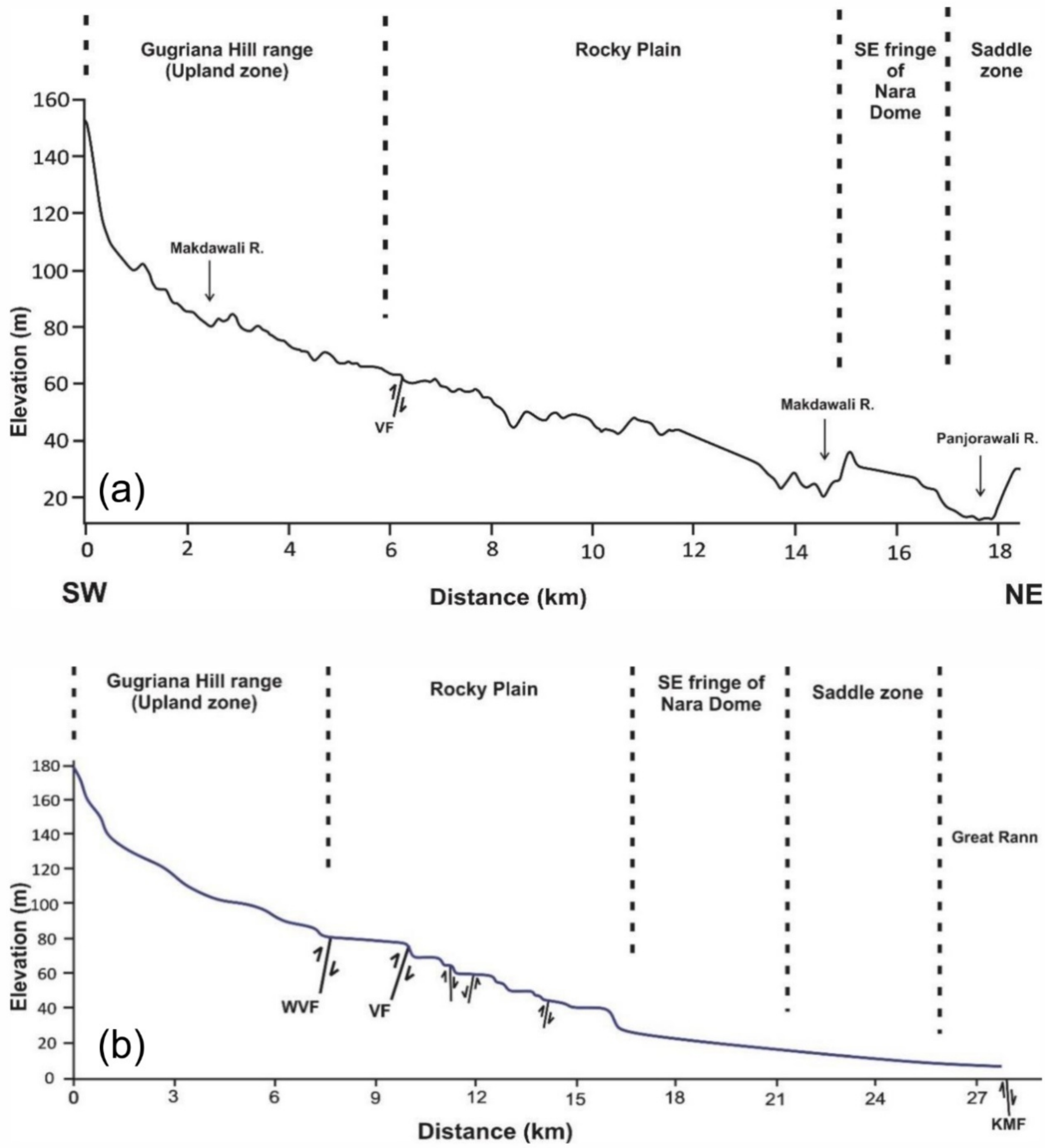

Fig. 4.7. (a) Topographic Profile along Makdawali River basin from upland region to the KMF zone showing major geomorphic divisions. (b) Longitudinal profile of Makdawali River showing major geomorphic divisions.

Longitudinal River Profiles

The longitudinal profiles of the four most deeply incised rivers in the western part of the NHRFZ are shown in Figs. 4.8a, b, c and d. The profiles clearly show the incising nature of the rivers and the effect of rejuvenation on the drainages in response to long-term tectonic uplift along the KMF.

The profiles are broadly concave up, steep and show multiple knickpoints (Figs. 4.8a, b, c and d). All profiles are from their origin to the KMF zone beyond which the rivers discharges in the flat topography of the Great Rann sub-basin. The longitudinal profile of the Gandi river (Fig. 4.8a) show three prominent knickpoints. The middle one is the largest knickpoint which shows a fall of ~25 m followed downstream by another knickpoint with ~7 m fall. Presence of multiple knickpoints is strong indicator of the river responding to sustained long-term tectonic uplift.

The profile of the Jara river is also broadly concave up with multiple knickpoints (Fig. 4.8b). The river arises from the backslopes of Jaramara scarp and flow northward in anti-dip direction. It forms a narrow deep gorge as it emerges from the Jaramara scarp. The gorge reach of the river is shown in Fig. 4.8b. The river shows a drop of ~60 m within the gorge reach which is ~1 km long. As seen in the profile, prominent knickpoints are formed within the gorge reach. The presence of multiple knickpoints within the gorge, points to tectonic uplift causing the river to erode downward.

The profile shown in Fig. 4.8c is of unnamed stream to the west of Jara river. The stream arises at the base of the Jaramara scarp and flows northward incising through the relatively low level rocky topography of the Jara dome. The river shows two closely spaced knickpoints. The overall profile shows strongly concave up nature suggesting that the stream has responded to long-term tectonic uplift.

The Jumara stream arises at the crest of the Jaramara scarp and flow northward through the Jumara dome. The profile shows prominent concave up geometry which is primarily a reflection of the steep gradient of the river when it flows down the Jaramara scarp. The river does not show any large knickpoints, however the gradient of the river profile is very steep. The profile of the Jumara stream is in conformity with its setting in a tectonically active area that has undergone long-term tectonic uplift.

The longitudinal profiles clearly show the rejuvenated nature of the drainages. As the area is hyper-arid with very little rainfall, the formation of multiple knickpoints and steep channel gradients are attributed to sustained long-term tectonic uplift. The longitudinal profile of Nara River shows three streams meeting in the upper reaches of the basin from the hilly terrain and flows towards Great Rann sub-basin (Fig. 4.4b). The Khari river is concave-up, steep to moderate slope and shows several knickpoints.

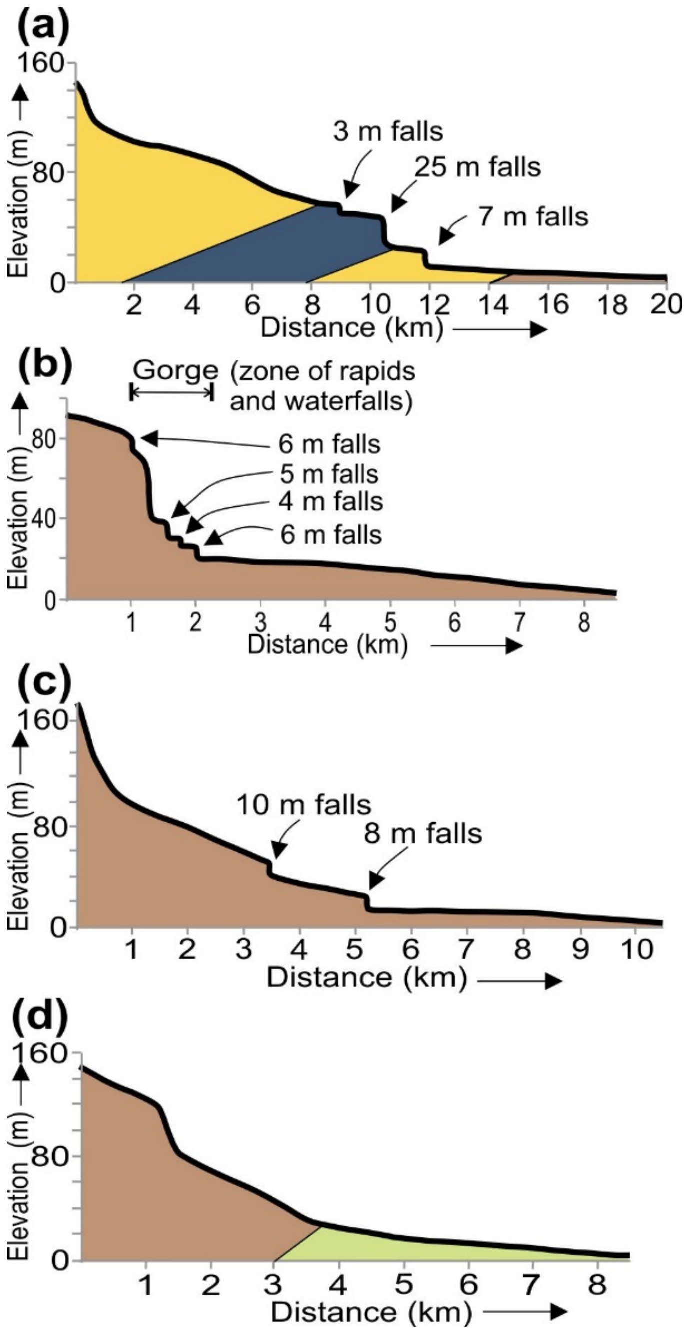

Fig. 4.8. Longitudinal profiles of the major rivers flowing through the western part of the NHRFZ. (a) to (d) Longitudinal river profiles of Gandi river (a), Jara river (b), stream west of Jara river (c) and Jumara stream (d). Note the prominent knickpoints and steep profile of Jara river in gorge reach with several falls. The lower part of the longitudinal profiles corresponds to the incised channels in the low hilly topography of Jumara and Jara domes.

The river discharges from the Gugriana hill range with steep to moderate slope observed to the upstream of Gugriana Fault zone. The Bhukhi river shows concave-up shape profile with very steep slope and a huge fall near the stream where Gugriana Fault is exposed. The Photwari river shows concave up profile with several knickpoints in the upland hilly region. The NW trending GUF crosses the main stream of Khari River and Bhukhi River. The prominent knickpoints in all the streams observed in the rocky plain zone which is between two major fault zones. The drainages here are controlled by the structural features and the profile shows distinct variation.

The longitudinal profile of the Makdawali River shows concave upward curve in the upland zone, undulating curve in the rocky plane area and straight channel in the SE fringe of Nara dome and saddle zone (Fig. 4.7b). The variation in the profile shows that is undergoing rejuvenation due to uplift of the structural and tectonic features in the basin. The upland zone shows almost smooth steep curve and high relief because of the Gugriana hill range. The river flows from the hills and changes the channel trend due to the presence of highlands. The channel receives the tributaries from the southern area of the basin draining from the Gugriana hill range. The maximum drainage frequency is observed at this zone. These tributaries merge the main trunk stream further in the rocky plain.