

1 **Assessment of Relative Active Tectonics in Parts of Aravalli**
2 **Mountain Range, India: Implication of Geomorphic Indices, Remote**
3 **Sensing and GIS**

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13 Running title: Assessment of relative active tectonics in Aravalli Range, India

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23 **ABSTRACT:** Aravalli Mountain Range is an example of erosional mountains, trending NE-SW,
24 shows numerous faults and lineaments. Udaipur area, situated south-east part of the mountain, is
25 considered as tectonically active. So the main objective is to study relative tectonic activity of the
26 Ahar watershed of Udaipur, Rajasthan, India. To assess relative tectonic activity of the area,
27 geomorphic indices such as stream length gradient index (SL), asymmetry factor (Af), basin shape
28 (Bs), valley floor width to valley height ratio (Vf), mountain front sinuosity (Smf), hypsometric
29 integral (Hi), hypsometric curve and transverse topographic symmetry factor (T) is applied. DEM
30 (SRTM), Google earth image and enhanced image of Landsat TM (2008) is used to extract linear
31 features. Result of these geomorphic indices of each sub-watersheds are used to divide area from
32 low to high relative tectonic activity classes, expressed as relative tectonic active index (Iat) and
33 according to Iat value the sub watershed UDSW2, 3 and 4 is tectonically relatively more active
34 than remaining part of the area. Field validation associated with evidences highlighted by using
35 geomorphic indices as well as stream deflrction and lineament analysis reveals that the Ahar
36 watershed of Aravalli Range, particularly the north-western flank, is most affected by tectonic
37 activity.

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39 **Keywords:** geomorphic indices; relative active tectonics; stream deflection; lineament; Aravalli
40 range

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46 1. INTERODUCTION

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48 The study area is located in the northern part of Udaipur district of Rajasthan (fig 1). The
49 GPS measurements of 2007–2011 suggest that the Udaipur block moves at a rate of about 49
50 mm/year towards northeast (Bhu et al., 2014) indicating tectonically this area is active. The main
51 Ahar river passes through in this region and as the drainage network is very much influenced by
52 tectonic activity, so morphotectonic study of Ahar watershed is important to assessment the
53 tectonic activity in this area. Morphotectonic is the study of landforms produced by tectonic
54 processes. The quantitative measurements of landforms are accomplished on the basis of
55 calculation of geomorphic indices by the use of topography maps, digital elevation model, satellite
56 images, aerial photographs and field works (Toudeshki and Arian, 2011). Tectonic geomorphology
57 is one of the emergent disciplines in geosciences due to the advent of novel geomorphological,
58 geodetic and geochronological tools which aid the acquisition of rates (uplift rates, incision rates,
59 erosion rates, slip rates on faults, etc.) at variable time-scales (10^3 - 10^6 years; Burbank and
60 Anderson, 2001; Azor et al., 2002; Bull, 2007). This discipline is important because the results of
61 regional studies on neotectonics are significant for evaluating natural hazards, land use
62 development and management in populated areas (Pedrera et al., 2009). The study of tectonics
63 helps to understand about geomorphology, structural geology, stratigraphy, geochronology,
64 seismology, and geodesy. The study of the geomorphological features such as the drainage may
65 assist in understanding the landscape evolution and recognize active tectonic movements
66 (Riquelmea et al., 2003; Malik and Mohanty, 2007; Bathrellos et. al., 2009, Kamberis et al., 2012).
67 Tectonically active region influenced on drainage pattern, basin asymmetry, stream deflection,
68 river incision (Cox, 1994). The geomorphic indices are important indicators capable of decoding

69 landform responses to active deformation processes and have been widely used as a reconnaissance
70 tool to differentiate zones deformed by active tectonics (Keller and Pinter, 1996; Chen et al., 2003).
71 We use geomorphic indices of active tectonics, known to be useful in active tectonic studies (Bull
72 and McFadden, 1977; Azor et al., 2002; Silva et al., 2003; Molin et al., 2004; El Hamdouni et al.,
73 2008; Mahmood and Gloaguen, 2012; Elias, 2015; Fard et al., 2015;). But this method was not
74 applied before in the study area. The main objective is to calculate different geomorphic indices
75 to assess relative active tectonics of the area. In the study area the Ahar watershed is divided into
76 10 sub watershed. Each and every sub-watershed, whether it is possible, the geomorphic indices
77 has been calculated to understand the relative tectonics. Remote sensing and field data were used
78 to analyze lithology, structure, soil erosion in the tectonically active region of Zagros mountain to
79 evaluate natural hazards like landslide (Ali et al., 2003).

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81 **2. GEOTECTONIC FRAMEWORK**

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83 This region was an active zone of sedimentation, distinct tectonism and repetitive
84 magmatism. The Banded Gneissic Complex acted as the basement during the Precambrian times
85 for the Proterozoic basins like Aravalli, Delhi (Heron, 1936). The western part of the Udaipur
86 district shows undulating topography due to NE-SW trending series of Aravalli hill. The oldest
87 formation exposed in the area belongs to Bhilwara Super group of Arachean age. The younger
88 formations of Aravalli super group and Delhi super group of Proterozoic age is found in the
89 western side of the district. Bhilwara belt and the Udaipur-Jharol belt are two major adjoining belts
90 situated in Aravalli Supergroup. The Udaipur-Jharol belt is exposed as an inverted "V" shaped area
91 with tapering end near Nathdwara. N-S trending Rakhabdev lineament divides this belt

92 symmetrically. Four major lineaments passes through the area. NW-SE trend of Udaipur–
93 Sandarpur lineament forms the contact between Debari and Udaipur group of rock (Bakliwal and
94 Ramasamy, 1987), N-S trending Rakhabdev lineament intersect older and younger sequence of
95 Aravalli Supergroup indicating its reactivation during proterozoic and cenozoic (Bakliwal and
96 Ramasamy, 1987; Bhu et al., 2014), NE-SW trending Chambal-Jamnagar lineament cross cut
97 Rakhabdev lineament (Bakliwal and Ramasamy, 1987), Darwal to Jogiwan lineament traverses
98 parallel to Rakhabdev lineament through eastern contact of Balicha formation of Udaipur group
99 and morphotectonically it is defined by the angular discordance in the structural trends on the two
100 sides of the lineament (Saifuddin and Iqbaluddin, 2000).

101

102 **3. METHODOLOGY**

103

104 Stream network and watershed boundary was delineated using SOI toposheet 45H/10
105 (1:50,000) and SRTM DEM (30 meter) under GIS environment. Georeferancing of toposheet was
106 done by ArcGIS 10.2. Image processing such as Laplacian, shobel, false colour composite image
107 generation and shaded relief were done on landsat TM (2008) and DEM to recognise linear
108 features. The geomorphic indices such as Stream length gradient index (SL), Valley floor width to
109 valley height ratio (Vf), hypsometric integral (Hi), Mountain front sinuosity (Smf), Asymmetry
110 factor (Af), Basin shape (Bs), Transverse topographic symmetry factor (T) was calculated in the
111 study are using DEM and google earth by the given formula (Table 1). After calculating the above
112 geomorphic indices sub watersheds were classified into three classes based on the index value. All
113 the indices were combined and divided the number of indices to classify every sub watershed

114 according to relative active tectonic (Iat). Stream deflection parameter, lineament map and field
115 evidences were used to support the result come from the analysis of above geomorphic indices.

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117 **4. RESULT AND DISCUSSION**

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119 **4.1 Analysis of Geomorphic Indices**

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121 Geomorphic indices including stream length gradient index (SL), valley floor width to
122 valley height ratio (Vf), hypsometric curve and hypsometric integral (Hi), Mountain front sinuosity
123 (Smf), Asymmetry factor (AF), basin shape (Bs) and transverse topographic symmetry factor (T)
124 has been analyzed and discuss on relative tectonic activity (Iat) by combination of all the
125 geomorphic parameters.

126

127 **4.1.1. Stream length gradient index (SL)**

128 Relative tectonic activity of an area can be appraised by using SL index. Deviation from
129 this stable river profile may be induced by tectonic, lithological and/or climatic factors (Hack,
130 1973). Soft rocks comprising high SL values is the indicators of recent tectonic activity, but low
131 values of SL in the area encompasses strike slip faults and streams are flowing through it may also
132 represent tectonically active (Keller and Pinter, 1996, Mahmood, and Gloaguen 2012). Rocks of
133 consistent resistance showing high value of stream length gradient index or fluctuation of SL
134 values indicates the area is tectonically active (Keller, 1986). The value of SL index over the study
135 area was calculated along the master stream of 10 sub-watersheds using google earth (Table 2).
136 The SL values were classified into three classes, where SL values more than 600 falls in class 1,

137 SL value in between 300 and 600 fall in class 2 and in class 3, the value of SL is less than 300 (El
138 Hamdouni et al., 2008).

139 Table 2 is about here

140 Figure 3 is about here

141 All the sub watersheds are fall in class 3 (Table 2). Relative study shows that sub watershed
142 UDSW2, UDSW3 and UDSW4 shows relatively higher SL value followed by UDSW5 and
143 UDSW8 which are relatively moderate SL value and remaining sub watersheds show low SL value
144 (Fig 5a). The relative value indicate that northern and western part of the Ahar watershed shows
145 relatively high and moderate tectonically active respectively. Eastern, southern and central part is
146 relatively tectonically less active. Places were marked where SL value relatively high and this high
147 value may be due tectonically uplifted or diverse erosion (Fig 3).

148 **4.1.2. Ratio of Valley Floor to Valley Height (Vf)**

149 The Vf index reflects the difference between V-shaped valleys that are down cut in
150 response to active uplift (low values of Vf) and broad-floored valleys that are eroding laterally into
151 adjacent hill slopes in response to base level stability (high values of Vf) (Bull, 1978). Deep V-
152 shaped valleys ($Vf < 1$) are connected with linear, active down cutting streams distinctive of areas
153 subjected to active uplift, while flat floored (U-shaped) valleys ($Vf > 1$) show an attainment of the
154 base level of erosion mainly in response to relative tectonic quiescence (Keller, 1986). Vf is
155 classified into three classes: class 1 ($Vf \leq 0.5$), class 2 ($0.5 \leq Vf \leq 1.0$), class 3 ($Vf \geq 1.0$) (El
156 Hamdouni et al., 2008). Master stream of sub-watersheds were used to calculate the Vf values of
157 the study area (fig.). Different researcher classified Vf index with different values (El Hamdouni
158 et al., 2008; Fard et al. 2015; Mahmood and Gloagaun, 2012). In this study area Vf index is
159 classified as Class 1: ($Vf < 0.5$), Class 2: ($0.5 \leq Vf < 1$) and Class 3: ($Vf \geq 1$). Although Vf value of

160 some area shows less than 1 but the average Vf value of all the sub watersheds is more than 1
161 falling Class 3, that is flat floored U shaped valley (Table 3), but some areas mainly along the
162 lineaments, faults and mountainous region where Vf value is less than 1 indicating 'V' shaped
163 valley.

164 Table 3 is about here

165 **4.1.3. Hypsometric Curve and Hypsometry Integral (Hi)**

166 Hypsometric curve is the area-altitude relation can be described as a proportion of area
167 above each proportion in elevation. The hypsometric integral (Hi) describes the relative
168 distribution of elevation in a given area of a landscape particularly a drainage basin (Fard et al.,
169 2015). The study of hypsometric curves as well as HI values provides important information about
170 tectonic behaviour of the watershed along with erosional stage of the watershed (Moglen and Bras,
171 1995; Willgoose and Hancock, 1998; Huang and Niemann, 2006). Convex-up curves having high
172 value of HI are representing youthful stage, smooth s-shaped curves crossing the center of the
173 diagram characterize mature stage, and concave-up with low HI values are indicator of old stage
174 (Strahler, 1952). Figure 4 shows the hypsometric curves of every sub watersheds. The value of
175 Maximum, minimum and mean elevation is directly taken from DEM by arc GIS software. To
176 check out the accuracy of the values particularly mean elevation data point sampling of more than
177 100 elevation values were collected from every sub watershed and computed by using DEM.

178 Figure 4 is about here

179 The value of HI index always ranges between 0 and 1 which is computed in number. Generally
180 high values of hypsometric integral shows convex hypsometric curve and low values are
181 responsible for concave curve. So on the basis of values and in respect of convexity and concavity
182 of hypsometric curve, Hypsometric integral can be classified into three classes. Class 1 ($HI > 0.5$

183) shows convex hypsometric curve. Class 2 ($0.4 > HI < 0.5$) shows concavo-convex or straight
184 curve and class 3 ($HI < 0.4$) having the curve of concave shape. Hypsometric integral is convex in
185 the lower portion or low elevated area may relate to uplift along a fault or perhaps uplift associated
186 with recent folding (El Hamdouni et al., 2008). High values of the index are possibly related to
187 young active tectonic and low values are related to older landscapes that have been more eroded
188 and less impacted by recent active tectonics. The HI value in the Ahar watershed ranges from
189 0.165 (UDSW9) to 0.461 (UDSW4) (Table 4). Classification based on relative tectonic activity
190 shown (fig 5b).

191 Table 4 is about here

192 **4.1.4. Mountain Front Sinuosity (Smf)**

193 Smf value can be computed through topographic map or aerial photography or satellite
194 imagery and the obtain value depends on the scale of the map. Small scale map produce
195 approximate values of Smf, while large scale topographic map and aerial photography have higher
196 resolution and are more appropriate for assessment of Smf (El. Hamdauni et al., 2008). Mountain
197 front sinuosity is defined as the ratio of the length of the mountain front along the foot of the
198 mountain to the straight line length of that front (Bull, 2007; Mahmood and Gloaguen, 2012). The
199 balance between erosion that tends to produce asymmetrical or sinuous fronts and tectonic forces
200 that tend to create a straight mountain front coincident with an active range-bounding fault is
201 presented by the above mentioned index (Kokinou et.al., 2013). On the basis of tectonically
202 activeness some researchers have classified this value with tree classes. Some studies have
203 proposed that Smf values lower than 1.4 are indicative of tectonically active fronts (Rockwell et
204 al., 1985; Keller, 1986; Burbank and Anderson, 2001; Silva et al., 2003; Kokinou et al.,2013), The
205 value of Smf was computed using Lmf and Ls value measured from SRTM data with spatial

206 resolution of 30 meter in the study area. The Smf value has been classified into three classes that
207 are class 1 in which $Smf < 1.1$, class 2 in which $1.1 \leq Smf < 1.5$ and class 3 when $Smf \geq 1.5$ (El
208 Hamdouni et al., 2008).

209 Frontal side of mountain with more than 800 meters in elevation and contour interval
210 between top of the hill or mountain and piedmont is more than 300 meter has been consider as
211 mountain front to analyse mountain front sinuosity. In the study area Smf value lies between 1.08
212 and 2.73. here sub watershed wise Smf value was consider. Instead of 1.08 of Smf value in
213 UDSW2 which is very tectonically active and fall in class 1 (El Hamdouni et al., 2008) but
214 UDSW2 has two mountain front and the average value is 1.11 (Table:) and this sub watershed fall
215 in class 2. Mountain front sinuosity of UDSW1 and UDSW6 fall in class 3 indicate tectonically
216 less active and UDSW 2, UDSW3, UDSW4, UDSW5, UDSW7 and UDSW10 shows tectonically
217 moderately active (Table 5: and Figure: 5c). The Smf value of mountain front located lower most
218 part of the sub watershed UDSW10 is 1.05 and this low value is because this front is align along
219 with fault.

220 Table 5 is about here

221 **4.1.5. Asymmetry Factor (Af)**

222 Tectonic tilting with direction of tilting of drainage basin can be evaluated by the analysis
223 of Asymmetry factor at the scale of drainage basin (Sharma, et al., 2013; Siddiqui, 2014; Kale et
224 al, 2014). This method was applied over a large area (Hare and Gardner, 1985; Sboras et al.,2010).
225 A_r (area of the right side of the master stream) and A_t (total area of the watershed) was measured
226 by Arc Map and to calculate these parameter, looking downstream of master streams of every sub-
227 watershed was considered. Af significantly greater or smaller than 50 shows influence of either
228 active tectonics or lithologic structural control or differential erosion, as for example the stream

229 slipping down bedding plains over time (El Hamdouni et al., 2008; Mahmood and Gluagoan,
230 2012). Inclination of schistosity or bedding allows for preferred migration of the valley in the
231 down-dip direction, producing an asymmetric valley (EL Hamdauni et al., 2008). The values of
232 this index are divided into three categories. 1: ($Af < 35$ or $Af \geq 65$) 2: ($57 \leq Af < 65$) or ($35 \leq Af$
233 < 43) and 3: ($43 \leq Af < 57$) (El Hamdouni et al, 2008). Af value in the study area ranges from
234 36.93 (UDSW4) to 59.59 (UDSW2) (Table 6). Sub watersheds UDSW2, UDSW3, UDSW4 and
235 UDSW7 falls in class 2 and the Af values of these sub watersheds indicates moderately tilting took
236 place in this area whereas remaining area falls in class 3 shows very less tectonic tilting or no
237 tilting took place in these area. Af value more than 55 and less than 45 are consider as asymmetry
238 basin and tectonic tilting were taken place towards left and right side of the basin respectively
239 while the value of Af in between 45 and 55 are considered as symmetry of the basin and the arrow
240 shows the direction of the tilting (Çağlar Özkaymak.,2015) (Fig: 5d). Tectonic tilting of UDSW3
241 and UDSW4 are west to south west direction, UDSW7 and UDSW10 towards southern direction,
242 UDSW2 and UDSW1 are towards north-eastern and east direction respectively.

243 Table 6 is about here

244 **4.1.6. Basin Shape (Bs)**

245 Drainage basins with elongated in shape indicates relatively young in nature in active
246 tectonic areas. With continued evolution or less active tectonic processes, the elongated shape
247 tends to evolve to a more circular shape (Bull and McFadden, 1977) As the value of width of sub
248 watershed vary in place to place, so average value was taken to calculate basin shape. High values
249 of Bs are associated with elongated basins, generally associated with relatively higher tectonic
250 activity and Low values of Bs indicate a more circular-shaped basin, generally associated with low

251 tectonic activity (El Hamdouni et al., 2008). Bs index can be classified as Class 1: ($Bs \geq 4$), Class
252 2: ($3 \leq Bs < 4$) and class 3: ($Bs < 3$) (El Hamdouni et al., 2008) (Fig: 5e).

253 Bs value ranges from 1.51 (UDSW1) to 4.71 (UDSW2) (Table: 7). Only UDSW2, UDSW4 and
254 UDSW9 have Bs index is just above 4 which reveals the watersheds is elongated in nature and
255 tectonically highly active. Bs index of UDSW3 is just above 3 and falls in class 2 indicates
256 elongated to sub elongated in nature and tectonically moderately active. Remaining part of the
257 study area has Bs value less than 3 or it can be say more or less close to 2, which indicates these
258 sub watershed shows more circular in nature and tectonically less active region.

259 Table 7 is about here

260 **4.1.7. Transverse Topographic Symmetry Factor (T)**

261 Neotectonic activity of an area can be identified by the study of drainage basin asymmetry
262 although the active structures are poorly exposed or covered by quaternary alluvium (Cox et al,
263 2001). If there is no tectonic activity occurs, then the main river will flow evenly from both sides
264 as a perfect symmetric basin and the value of T will be zero. The T value varies from 0 to 1
265 depending upon the intensity of the tectonic activity. Values near to 1.0 indicate that the river flows
266 closely to the margins of the basin, a result probably produced by intensive and recent tectonic
267 activity. Values of T were calculated to assess the migration of streams perpendicular to the
268 drainage basin axis (Keller & Pinter 1996).

269 Table 8 is about here

270 The value of T for all the sub watersheds is determined and the results are presented (Table:
271 8). Position of the T value which has been calculated is also shown (Fig: 5f). A number of segments
272 in each sub watershed has been considered to determine T value and average value is taken to
273 understand asymmetrical behaviour of sub watershed. T value ranges from 0.05 (almost symmetry)

274 to 0.47 (asymmetry). Transverse topographic symmetry factor can be classified into three classes
275 such as Class 1 for $T > 0.4$, class 2 for T between 0.2 and 0.4 and class 3 for $T < 0.2$ (Mosavi and
276 Arian, 2015). Sub watershed situated western part of the study area has T value more than 0.4 (fig
277 5f) showing asymmetry in nature indicates these area falls under tectonically highly active.
278 UDSW7 and UDSW8 of the western part of the study area has T value 0.18 (class 3) and 0.32
279 (class 2) respectively indicating tectonically less active and moderately active. UDSW6 falls in
280 class 2 with T value 0.32 and T value of UDSW1 has 0.18 and falls in class 3.

281 Figure 5 is about here

282 4.1.8. Discussion on Relative Tectonic Activity (Iat)

283 Aravalli is an example of erosional mountain. Udaipur is situated south-east part of the
284 mountain, is consider as tectonically active. So here the main objective is to study relative tectonic
285 activity of the study area. Several studies describe about relative tectonic activities by the use of
286 combination of Smf and Vf indexes in such a manner that the Vf values are plotted with the Smf
287 values on a same diagram in order to produce a relative degree of tectonic activity and recognition
288 of three different classes (Bull and McFadden, 1977; Silva et al., 2003; Kokinou et al., 2013).
289 Several studies shows the relative tectonic activity (Iat) with the help of seven geomorphic indices
290 (Sl, Vf, Smf, HI, Af, Bs, T) which is applied here (El. Hamdouni et al., 2008; Fard et al., 2015;
291 Elias, 2015; Mosavi and Arian, 2015). Every geomorphic indices has been classified into three
292 classes in which class 1 and class 3 represents high and low tectonically active respectively.

293 Table 9 is about here

294 Iat is obtained by the average of the different classes of geomorphic indices (S/n) and
295 divided into four classes, where class 1 is very high tectonic activity with values of S/n between 1
296 and 1.5; class 2 is high tectonic activity with values of $S/n \geq 1.5$ but < 2 ; class 3 is moderately active

297 tectonics with $S/n \geq 2$ but < 2.5 ; and class 4 is low active tectonics with values of $S/n \geq 2.5$ (El.
298 Hamdouni et al., 2008). The average value of class of geomorphic indices of the active tectonics
299 (S/n) and the relative tectonic activity index value (I_{at}) are summarized (Table: 9). I_{at} index class
300 of UDSW2, UDSW3 and UDSW4 is 3 which reveals that northern part of the study area shows
301 moderately tectonic active area, whereas rest of the study area where I_{at} index class is 4 falls under
302 comparatively less tectonic active area (Fig: 6a). Within the study area 89.89 Km^2 i.e. 20.56% of
303 the total area is class 3 measured by I_{at} which is moderately tectonically active. 347.41 Km^2 or
304 79.44% of the area is class 4 measured by I_{at} is tectonically less active.

305 Figure 6 is about here

306 4.2. Stream Deflection

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308 Sudden change of stream flow direction is atream anomaly occurs may be due to tectonic
309 geomorphology such as fault or fold or may be due to sub surface structure or lithological change.
310 Thus stream network analysis is a fundamental tool in tectonic geomorphology (Deffontaines and
311 Chorowich, 1991). Defflection of channel occurs when it crosses through fault because the
312 variation of erosion took place in fault zone.

313 Encircled area showing anomalies i.e. deflection of the flow direction of stream channel (Fig: 6b).
314 In the encircled area of sub watershed UDSW10, stream suddenly changed its direction from SE
315 to NE with angle of 85° due to fault is present there. In the area A3 and A4, the stream flows
316 towards NNE and suddenly changed its direction towards NE and towards east making angle 65°
317 and 70° respectively. At point encircled A1 stream has changed its direction from SE to towards
318 east with an angle 67° . In the area A2, stream flow towards south parallel to mountain front and
319 changed its direction and suddenly changed its direction with 120° and moves towards NE along

320 the Chambal-Jamnagar lineament. Interestingly 3.8 Km apart from the point of deflection towards
321 NE (same direction of the stream after changed its direction) there is a fault and the trend of the
322 fault is NE-SW. Encircled A2 and A3 shows after deflection the stream moves towards NE and
323 making nearly linear or curvilinear with the fault. .

324 The stream capture and beheaded streams, features are widely recognise as a typical geomorphic
325 illustration of tectonic structure such as fault or fold (Schumm, 1977) are observed at many places
326 and has been used to draw an extensive fault (Shabir et al., 2013). So further study is needed to
327 say that either the fault is extended upto the western point of the lineation or not. Stream
328 deflections are identified in the mountain front zone which are may be the occurrence of possible
329 geological structure and the sharp bends are used as evidence of presence of tectonic structure.

330

331 **4.3. Lineament**

332

333 Lineament mapping is valuable component to understand the tectonic behavior of the area
334 (Kassou et al., 2012). Dominant lineament direction can give the idea about the regional fracture
335 pattern of an area (McElfresh et al., 2002, Casas et al., 2000, Koike et al., 1998). Linear geological
336 structures of seismogenic compressional setting were identified through FCC, edge enhancement
337 filters and DEM derived product to understand tectonic behavior of the area and evaluate the
338 compressional direction (Ali and Ali, 2017). The high density lineament observed towards western
339 side of the area (Fig 7a). Rose diagram shows that the orientation of lineament distribution of the
340 area (Fig 7b). The main direction is N-S followed by NE-SW and NW-SE. small amount of E-W
341 direction is also present. The lineament map also indicate that the present day stream network is
342 influenced by the lineament direction (fig 7c).

343 Figure 7 is about here

344

345 **FIELD EVIDENCES**

346

347 Abundant evidence of vertical displacement and numerous rock deformations observed
348 here but interpretation of active tectonic is difficult due to lack of absolute date of displacement.
349 Mainly Archean and Proterozoic rocks are covered the whole area but Quaternary and recent
350 alluvium overlies in isolated patches, along river courses and in the shallow depression (CGWB
351 report, 2013). A major crack or may be fault has been found in the field but did not identify the
352 movement (Fig 8a). In zoom in position of that figure, roots without plant can be seen along the
353 crack because by removing of mass, plant also has been removed. This figure reveals that the crack
354 has been developed after plantation which is quaternary or recent geological age. Sudden
355 deflection of river channel of nearly right angle (fig 8b), straight river course (fig 8c), triangular
356 facet (fig 8d), soft rock deformation (fig 8e), displacement and movement of lineament (fig. 8g),
357 straight mountain front (fig 8h) are some evidences that express as active tectonic. Fig 8f shows
358 straight river course and at the position of yellow circle the river got high meandering. This
359 meandering may be due to tectonic upliftment indicating active tectonics.

360 Figure 8 is about here

361

362 **CONCLUSION**

363

364 Study of seismic event confirms that Udaipur district falls under seismically low damage
365 risk zone. SL value and Vf value shows all the sub watershed falls in class 3 indicates tectonically

366 less active. But in some places along the master streams of sub watershed belongs to the western
367 side of the study area shows V-shaped valley and also high SL value as more than 1000.
368 Fluctuation of SL value in the western side indicates tectonically relatively more active than
369 eastern side. Values of HI, AF and Bs show that UDSW2, UDSW3 and UDSW4 are tectonically
370 more active relative to others. By the study of Smf and T value, western part of the watershed is
371 tectonically more active. Comparing all the geomorphic indices or Iat value indicates 20.56% of
372 the total area mainly north western part of the study area is tectonically more active than remaining
373 79.44% area. Field evidences of abnormal geomorphic impression, high lineament density and
374 sudden change of stream direction found on the western side of the watershed which strongly
375 supports the above statements.

376

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501 **LIST OF TABLES AND FIGURES**

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524 **Table 1.** Formula of different geomorphic indices

Parameter	Formula	References
Stream length gradient Index (SL)	$SL = (dH/dL)*L$	Hack, 1973
Ratio of valley floor to valley height (Vf)	$Vf = 2Vfw / [(Eld - Esc) + (Erd - Esc)]$	Bull, 1977, 1978
Hypsometry integral (HI)	$HI = (Elev_{mean} - Elev_{min}) / (Elev_{max} - Elev_{min})$	Pike and Wilson 1971
Mountain front sinuosity (Smf)	$Smf = Lmf / Ls$	Bull and McFadden, 1977
Asymmetry factor	$AF = (A_r / A_t) \times 100$	Hare and Gardner 1985
Basin shape (Bs)	$Bs = Bl / Bw$	Bull and McFadden, 1977
Transverse topographic symmetry factor (T)	$T = Da / Dd$	Cox, 1994

526 **Table 2.** Sub watershed wise average SL value with class

Sub watershed	SL (avg.)	Class	Sub watershed	Average SL value	Class
UDSW1	78.67	3	UDSW6	27.52	3
UDSW2	232.6	3	UDSW7	77.96	3
UDSW3	232.54	3	UDSW8	108.61	3
UDSW4	238.81	3	UDSW9	46.69	3
UDSW5	132.19	3	UDSW10	88.06	3

527

528 **Table 3.** Vf value with classification of sub watershed

Sub watershed	Vf (avg.)	Class	Sub watershed	Vf (avg.)	Class
UDSW1	1.5	3	UDSW7	3.77	3
UDSW2	1.92	3	UDSW8	1.63	3
UDSW3	1.90	3	UDSW9	3.79	3
UDSW4	1.68	3	UDSW10	1.81	3
UDSW5	1.74	3			

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530

531 **Table 4.** Sub watershed wise Hi with classification

Sub watershed	Hypsometric integral	Class	Sub watershed	Hypsometric integral	Class
UDSW1	0.27567568	3	UDSW6	0.17280453	3
UDSW2	0.4054878	2	UDSW7	0.2887538	3
UDSW3	0.44932432	2	UDSW8	0.38321995	3
UDSW4	0.46101695	2	UDSW9	0.16519174	3
UDSW5	0.336	3	UDSW10	0.28162291	3

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533

534 **Table 5.** Sub watershed wise Smf value with classification

Sub watershed	Lmf (KM)	Ls (KM)	Smf		Class
UDSW1	4.34	1.83	2.73	2.03	3
	4.15	3.11	1.33		
UDSW2	2.74	2.40	1.14	1.11	2
	1.38	1.27	1.08		
UDSW3	3.12	2.17	1.44		2
UDSW4	7.23	5.09	1.42		2
UDSW5	6.07	5.06	1.19		2
UDSW6	13.96	8.69	1.60		
	8.39	4.59	1.82		
	4.19	2.88	1.45	1.65	3
	3.76	2.54	1.48		
	2.02	1.06	1.90		
UDSW7	3.25	2.59	1.25		2
UDSW10	4.46	3.08	1.45	1.25	2
	4.35	4.11	1.05		

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537 **Table 6.** Sub watershed wise AF value with classification

Sub watershed	$AF=(Ar/At)*100$	Class	Sub watershed	$AF=(Ar/At)*100$	Class
UDSW1	54.38	3	UDSW6	51.78	3
UDSW2	59.59	2	UDSW7	41.57	2
UDSW3	42.83	2	UDSW8	50.97	3
UDSW4	36.93	2	UDSW9	52.35	3
UDSW5	49.16	3	UDSW10	44.18	3

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540 **Table 7.** Sub watershed wise Bs value with classification

Sub watershed	Bs=BI/Bw	Class	Sub watershed	Bs=BI/Bw	Class
UDSW1	1.51	3	UDSW6	1.95	3
UDSW2	4.07	1	UDSW7	1.98	3
UDSW3	3.07	2	UDSW8	2.01	3
UDSW4	4.71	1	UDSW9	4.09	1
UDSW5	1.95	3	UDSW10	1.67	3

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542

543 **Table 8.** Sub watershed wise T value with classification

Sub watershed	T=Da/Dd (avg.)	class	Sub watershed	T=Da/Dd (avg.)	class
UDSW1	0.18	3	UDSW6	0.32	2
UDSW2	0.42	1	UDSW7	0.18	3
UDSW3	0.41	1	UDSW8	0.32	2
UDSW4	0.47	1	UDSW9	0.05	3
UDSW5	0.47	1	UDSW10	0.41	1

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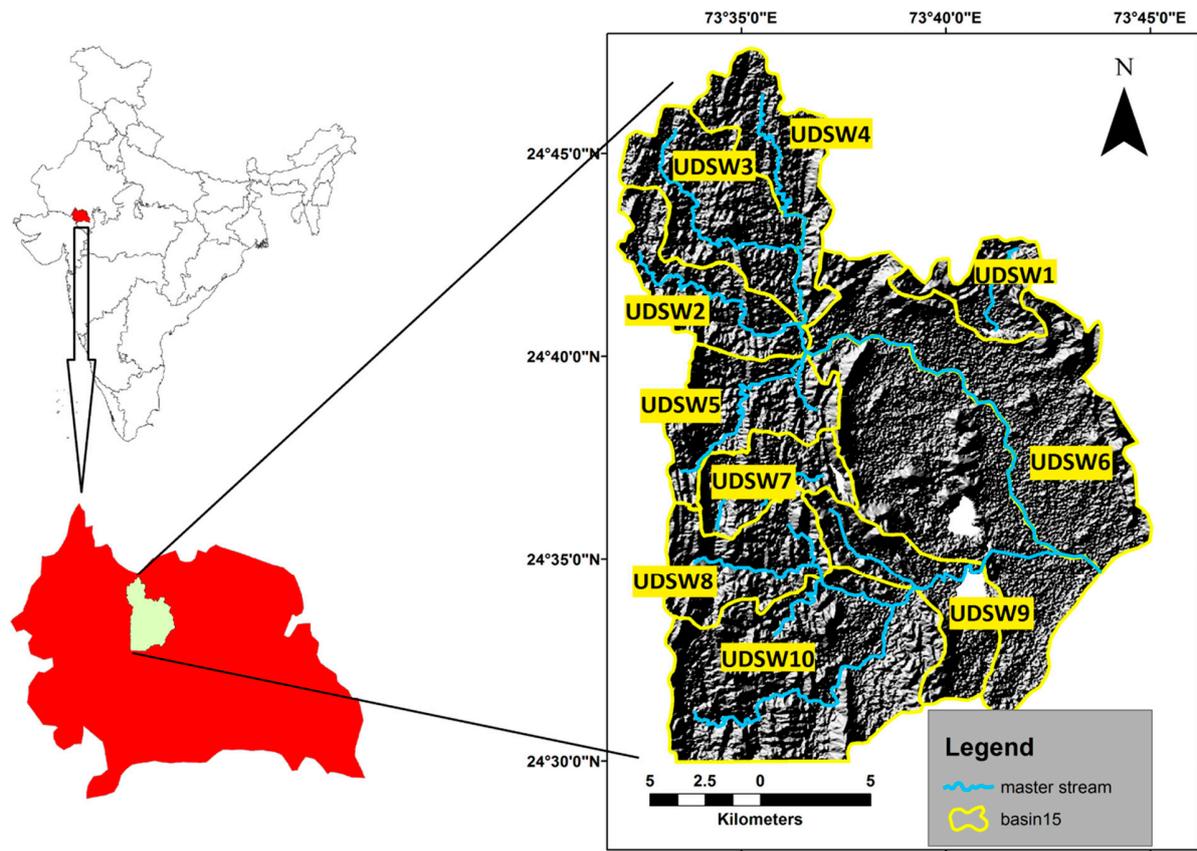
546 **Table 9.** Relative tectonic activity classification

Sub- Watershed	Area (Km2)	SL	Vf	Smf	Hi	Af	Bs	T	Iat=S/n	Iat Class
UDSW1	15.72	3	3	3	3	3	3	3	3	4
UDSW2	25.61	3	3	2	2	2	1	1	2	3
UDSW3	36.94	3	3	2	2	2	2	1	2.14	3
UDSW4	27.34	3	3	2	2	2	1	1	2	3
UDSW5	27.95	3	3	3	2	3	3	1	2.57	4
UDSW6&7	153.30	3	-	3	3	3	3	2	2.83	4
UDSW8	19.04	3	3	3	2	2	3	3	2.71	4
UDSW9	27.19	3	3	3	-	3	3	2	2.83	4
UDSW10	27.78	3	3	3	-	3	1	3	2.67	4
UDSW11	76.43	3	3	3	-	3	3	1	2.67	4

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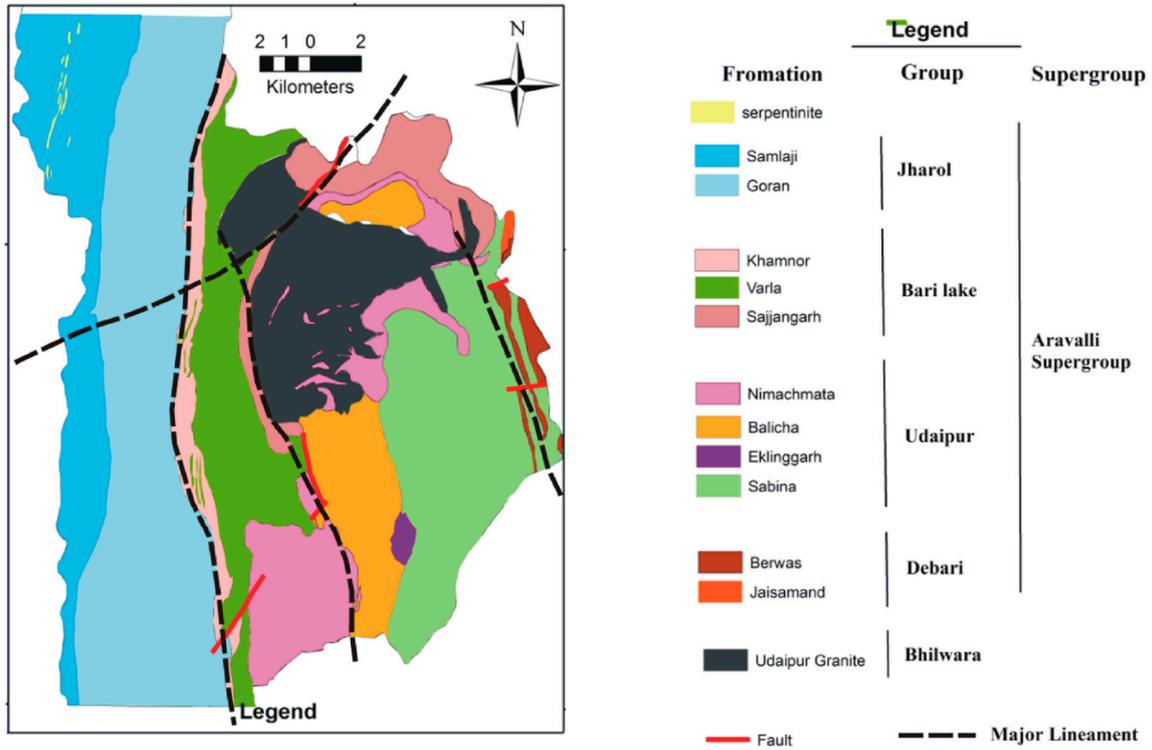
549 **Fig. 1.** Location map of the study area



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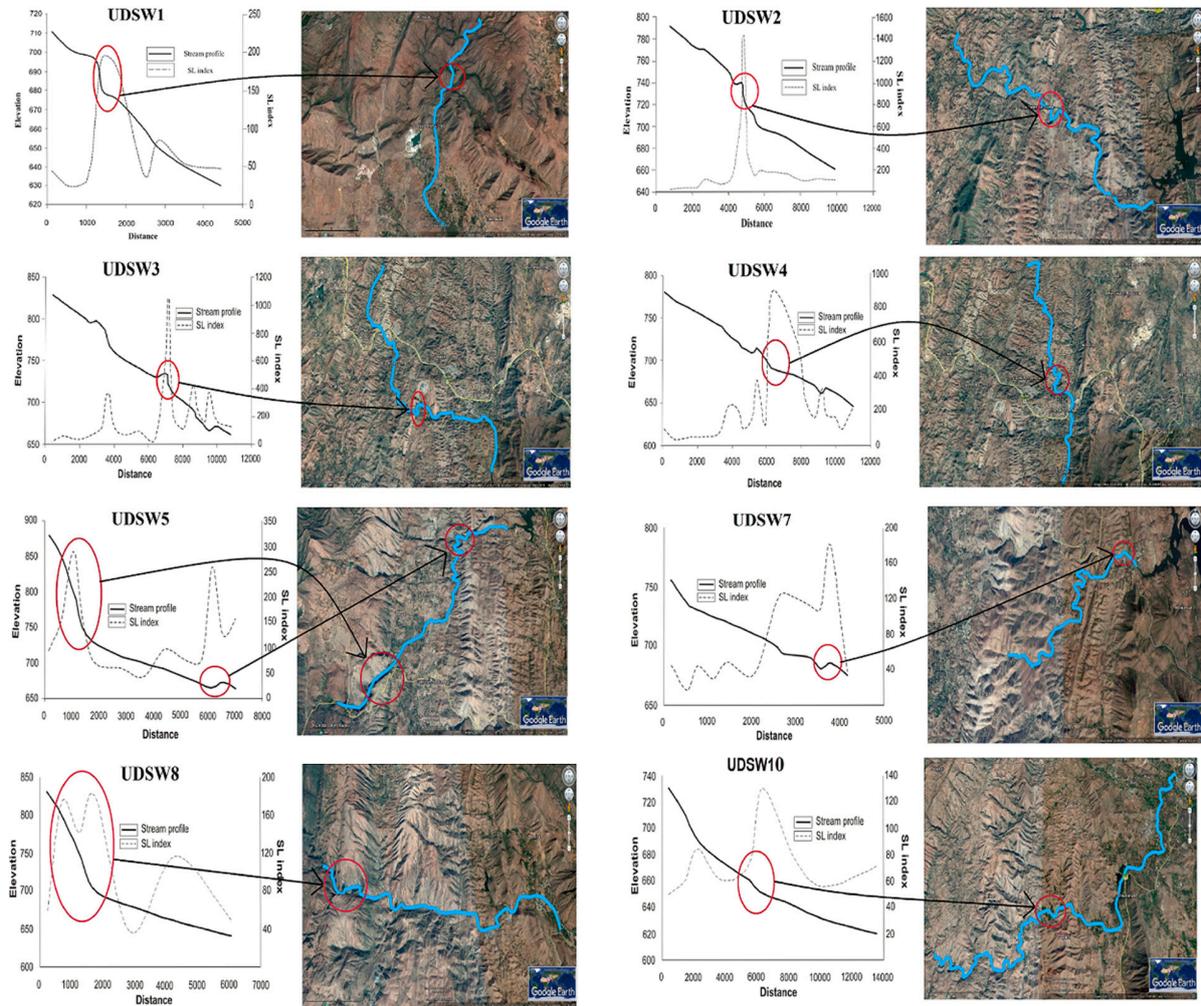
552 **Fig. 2.** Geological map of the study area.



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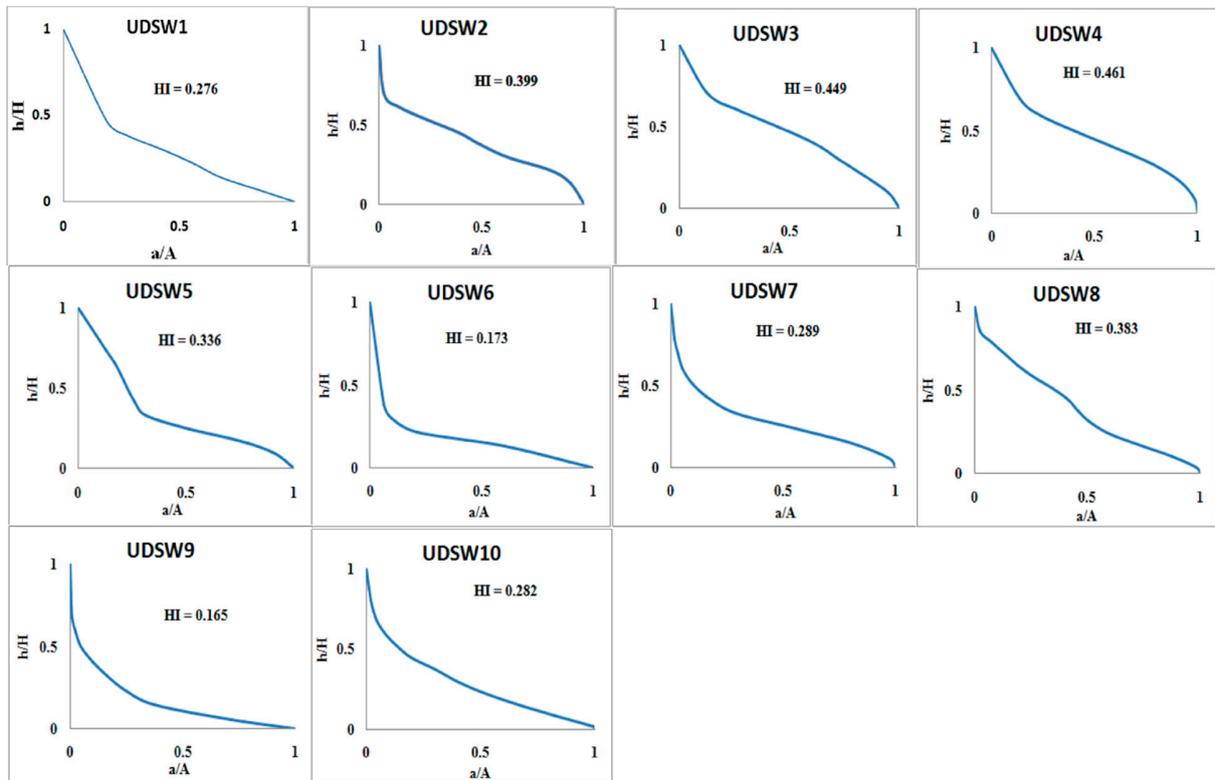
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555 **Fig. 3.** Graph showing SL index with respect to stream profile and the exact position of anomalies
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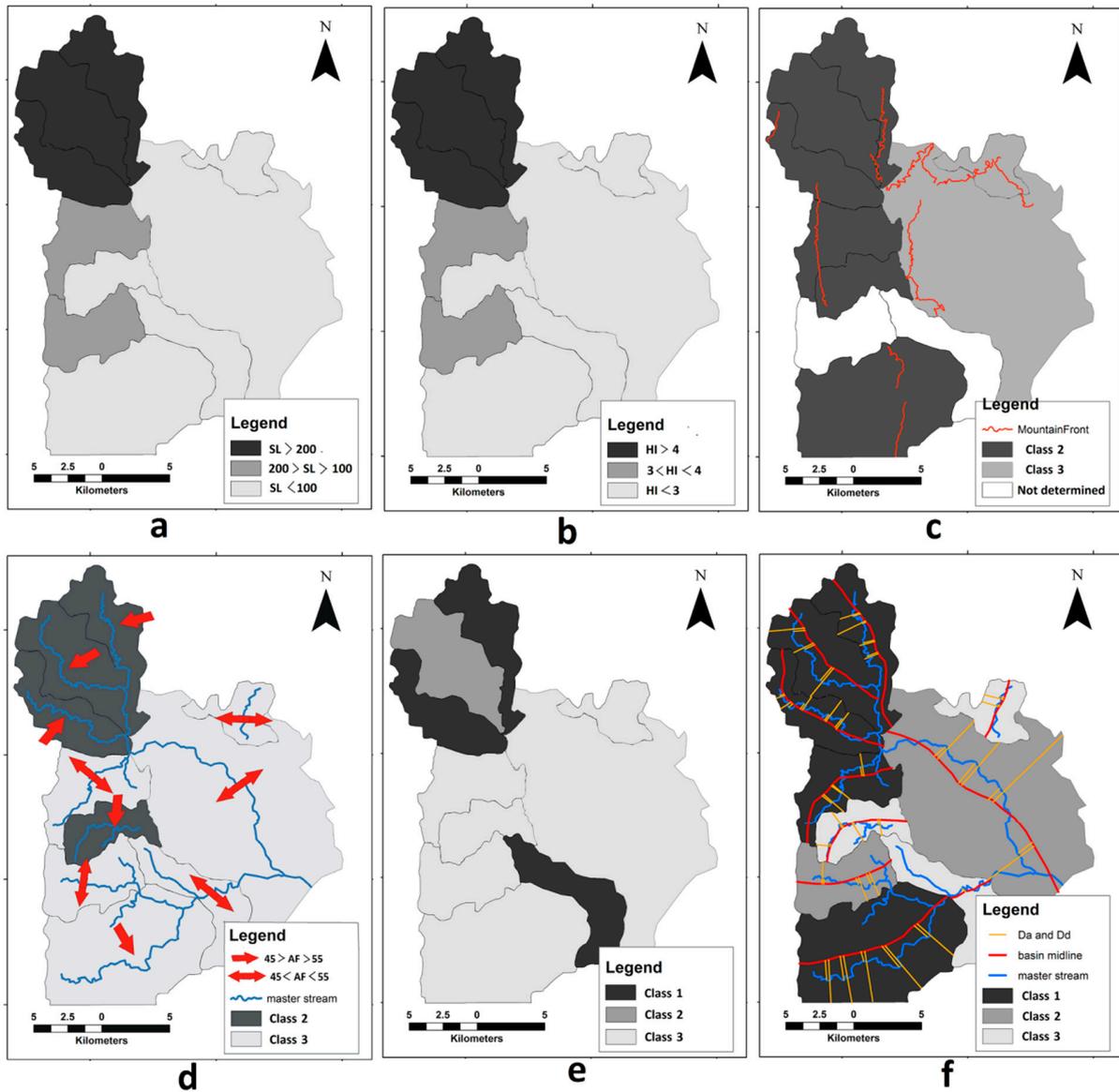
559 **Fig. 4.** Sub watershed wise Hypsometric curve

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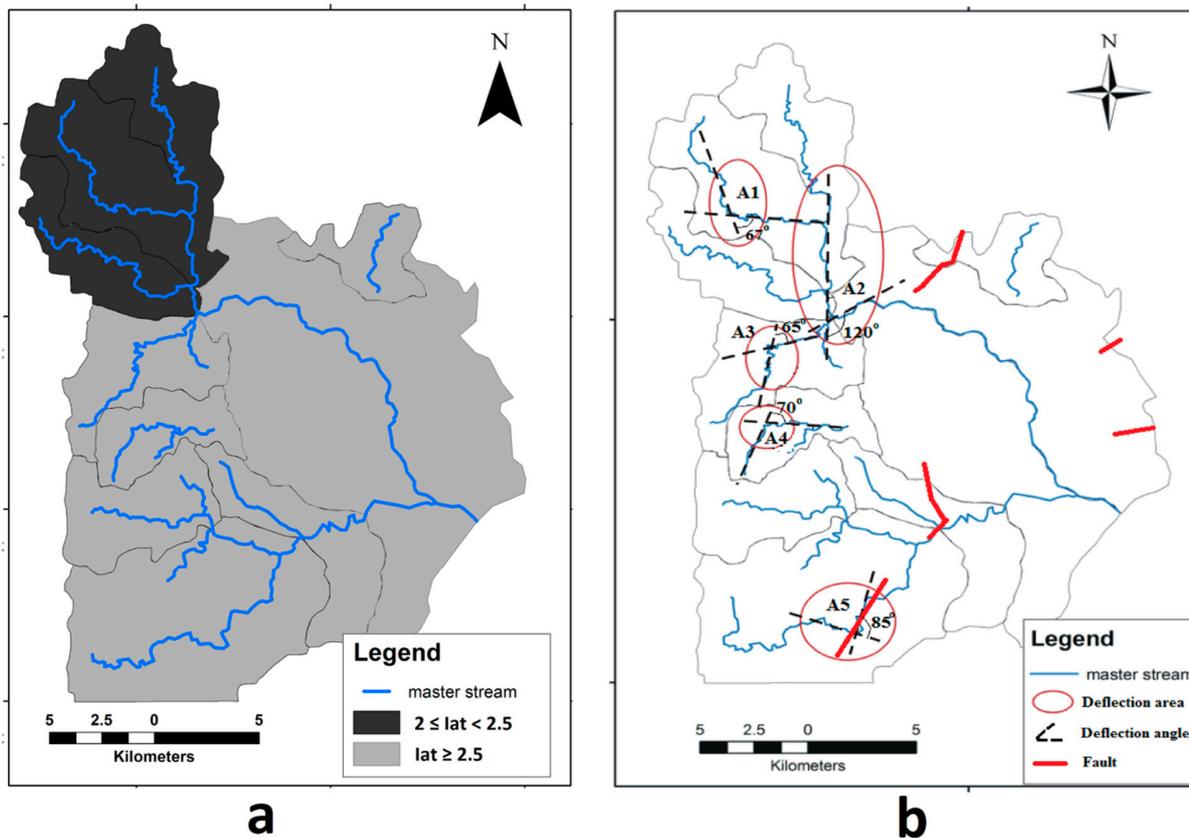
563 AF (e) Bs (f) T



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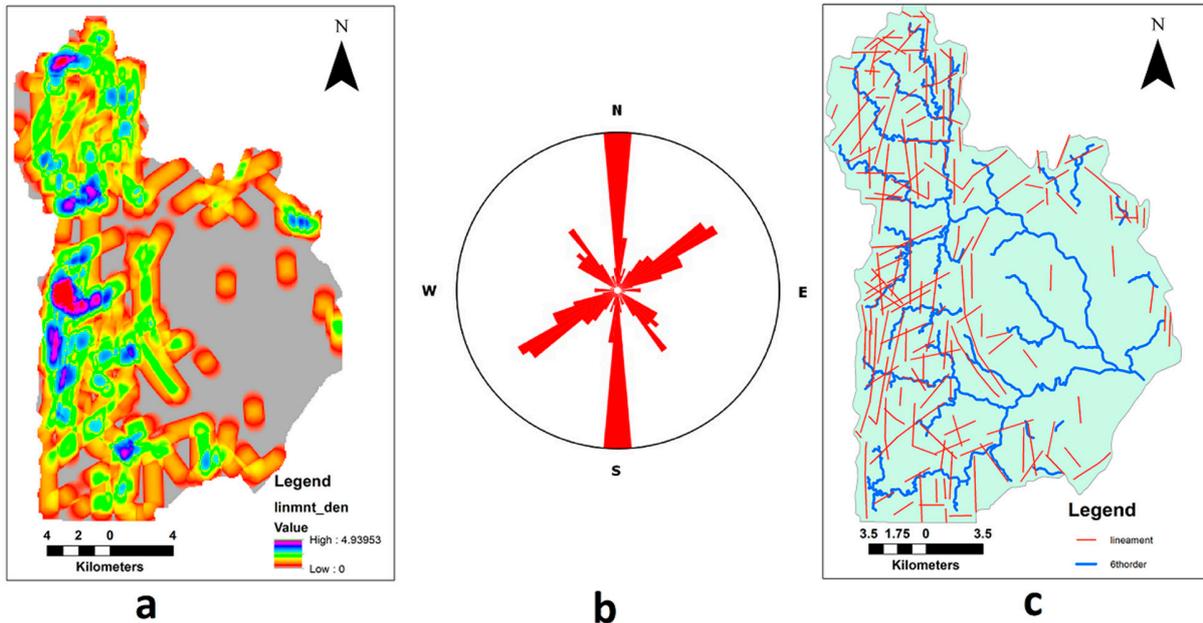
566 Fig 6. (a) Relative tectonic activity (b) Stream deflection



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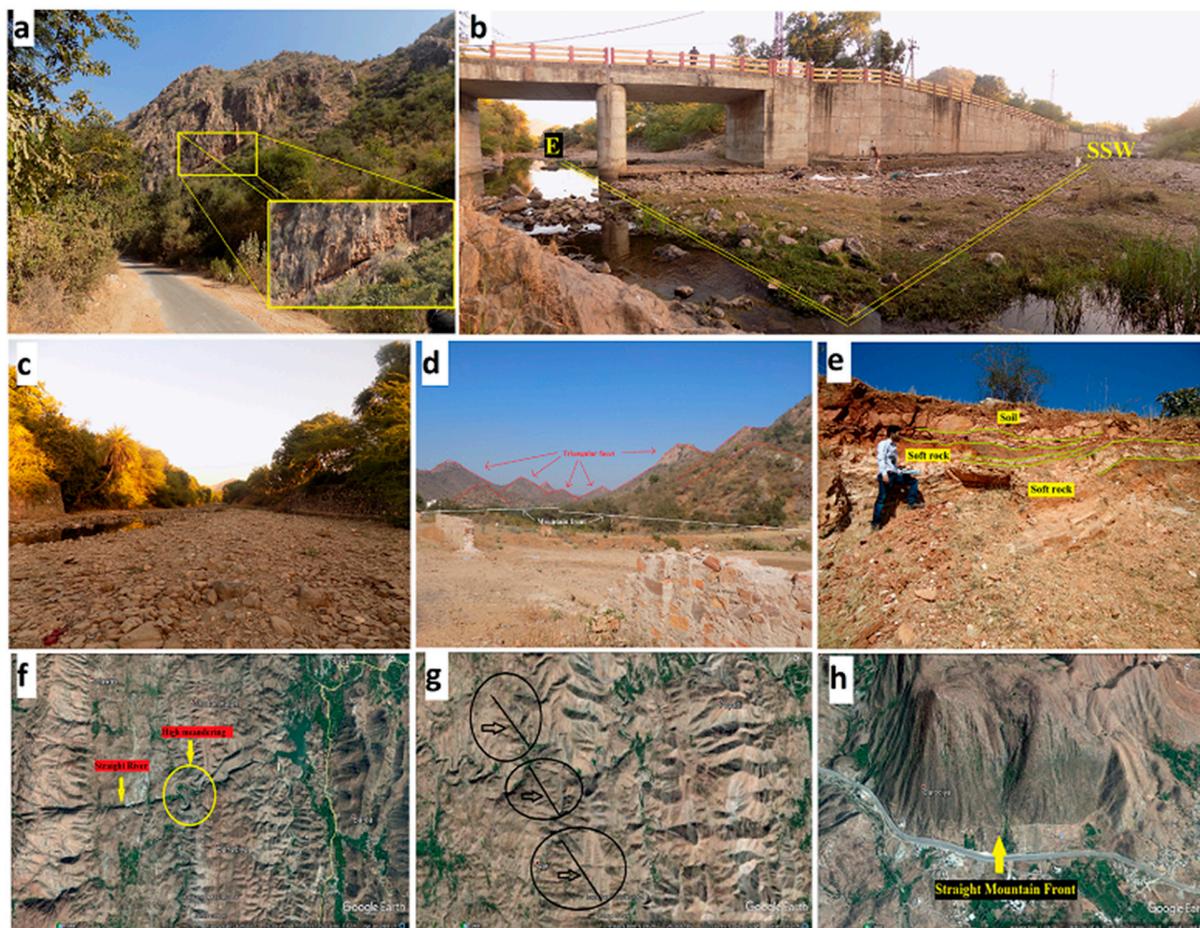
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