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Remote Sensing and GIS Based Extensive Morphotectonic Analysis of Tapti River Basin, Peninsular India

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Abstract: **The present study on Morphotectonics of the Tapti basin using remote sensing (RS) data and Geographic Information System (GIS) technique is an important input in deciphering the association between drainage morphometry and tectonics of the area. The basic structural elements like the established faults and other linear features of the study area were identified on the digitally processed remote sensing data and drainage pattern/morphometry was derived from the available Shuttle Radar Topography Mission, Digital Elevation Model (SRTM DEM) (90m) data. The various morphometric characters of the Tapti river basin were studied in detail. The drainage model of this area is a coarse sub-dendritic, trellis, and rectangular. The results of the preliminary morphometric analysis have been correlated with tectonic and seismotectonic characters exhibited by the study area. Overall, the morphometric and morphotectonic analysis revealed the area has periodically experienced tectonic and low order seismic instances.**

Index Terms: **DEM, Drainage Morphometry, India, Morphotectonics, Remote Sensing and GIS, Tapti River Basin.**

I. INTRODUCTION

The study of short and long-term external evidence of tectonic activities is considered as Morphotectonics (Singh and Singh, 2011; Nongkynrih and Husain, 2011; Magesh et al. 2011; Nagare, 2014). The morphotectonic analysis of a river basin explains the geomorphological and hydrological processes working on the basin scale. Climate, topography, and geology are the major controlling parameters of drainage patterns (Thomas et al. 2012). The surface features of the tectonic activities are represented by relative movement such as uplifting, subsidence, and translation of the crust (Strahler, 1957; 1964). The drainage basin and its relationship with the structures are the most susceptible parameter which controls the river courses (Miller, 1953; Altaf et al. 2013). The formations of landforms are the manifestation of the controls of tectonics which are lead by the processes of weathering and erosion (Singh and Singh, 2011; Thomas et al. 2012).

Remote Sensing technology is an important input in deciphering the relationship between drainage morphometry and tectonics of the area (Altaf et al. 2013). GIS techniques provide an analytical tool for quantitative analysis in such studies (Cholke, 2018; Barman et al. 2020). The study of SRTM DEM of the area demonstrates the presence of a large number of lineaments (some are established faults) and fractures across which distinct elevation changes are seen. The Morphotectonics features are observed and mapped using advanced remote sensing and digital image processing techniques (Nongkynrih, and Husain, 2011). Basin elongation ratio (Re) and Asymmetric factor (AF) are important parameters for morphotectonical investigation (Miller, 1953; Schumm, 1956; Rawat et al. 2011; Waikar, and Nilawar, 2014; Cholke, 2018; Barman et al. 2020). River Profile sections are used to identify the evidence of active structures in the area (Copley et al, 2014). In areas, where the rate of tectonics is low, indication comes from the morphotectonic investigation, whereas in the present, the rate of tectonics is substantial resulting in field indications being directly observed.

The present work is done on the Tapti River (also known as Tapi River) which is one of the major rivers of peninsular India originating from Multai in the Betul district of Madhya Pradesh

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with a length of around 764.569 kilometers (Jain et al. 2007; Copley et al. 2014).

II. STUDY AREA

In the northern part of the Deccan plateau, over an area of 63725.02 sq. Km. Tapti river basin is extended (Raja et al. 2010; Giri et al. 2020). The Tapti river basin (Fig.1) lies between longitudes of 72º 38' to 78º 17' and latitudes of 20º 5' to 22º 3' (Jain et al. 2007; Copley et al. 2014; Sharma et al. 2019). It is enclosed by the hill ranges from three sides. Satpura range, in the north, Mahadeo hills, in the east, the Ajanta range and the Satmala hills, the on the south and the west by the Arabian Sea. Around 25% of the area of the Tapti river basin is covered by forest (Jain et al. 2007; Raja et al. 2010; Copley et al. 2014; Giri et al. 2020). The Tapti river basin typically is a basaltic landscape (Jain et al. 2007; Copley et al. 2014)

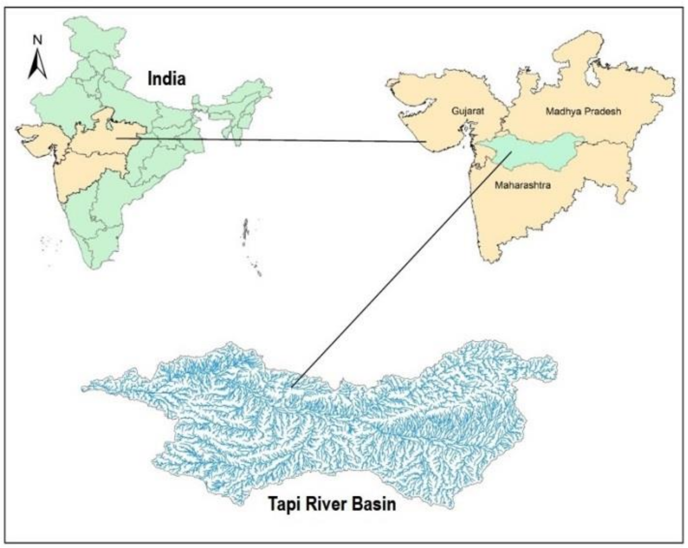

Fig.1: Location map of the study area showing the Tapti/Tapi river basin.

III. METHODOLOGY

This study is based on the quantitative investigation of geomorphic indices using SRTM DEM (90M Resolution). The periphery of the Tapti river Basin was delineated over the topographical maps and mosaic were created of satellite images and ArcGIS and Earth Resource Development Assessment System (ERDAS) Imagine software was used for georeferencing (Yadav et al. 2014). The rectification and resampling to a Universal Transverse Mercator (UTM) projection having World Geodetic System (WGS) 1984, Zone 43 North, as the datum was also completed. Some pre-processing function techniques to normalize the data were used to correct data error and noise. The sinks were removed by filling SRTM DEM data from the dataset (Giri et al. 2020).

Digital elevation model with 90m resolution was used for making Hill shed map overlay by contour lines with 100m intervals, slope map, aspect map. The morphometric parameter is used for landscape shape which accessing the tectonics of the area. Morphotectonic parameters such as basin elongation ratio (Re), Asymmetric factor, and study of longitudinal river profile section are useful for characterization of the topography and landforms features (Nongkynrih, and Husain, 2011; Thomas et al. 2012). The results obtained could be verified with the actual fieldwork carried out in the area.

IV. RESULT AND DISCUSSION

A. Hill Shed Map Overlay by Contour Lines

Hill shed map overlay by contour gives better comprehension of the topography. It can greatly enhance the visualization of the surface for analysis or geographical display, especially when using layer transparency (Schumm and Hadley, 1961; Waikar, and Nilawar, 2014). Most of the area exhibits elevation ranging from 100 to 300 m (Fig. 2). The NNW fringe of the area and the eastern and the northeastern part of the area exhibit comparatively higher elevation ranging from 500 to 1000 m (Giri et al. 2020).

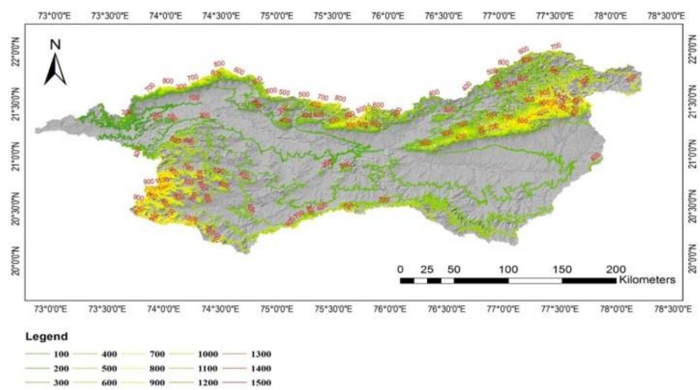

Fig. 2: Hill shed map overlay by contour lines of the Tapti river basin.

B. Slope Map

A slope map is a helpful tool for the identification of structural disturbances (Schumm and Hadley, 1961; Thomas et al. 2012; Waikar, and Nilawar, 2014). A slope map is constructed with the help of a surface tool utilizing a spatial analyst tool, highlighting the presence of fault scarps, tilting of strata, etc (Schumm and Hadley, 1961; Singh et al. 2021).

According to this slope map, regionally area has a gentle slope varying from 0^0 to 3^0 (Fig. 3). The north-northwestern fringe of the study area and the eastern–northeastern part of the area reflects 17^0-25^0 to 25^0-59.80^0 variations which have probably experienced tectonic disturbances. The scarp face of the Gavilgarh fault zone and Tapi north fault zone is characterised by a 3^0-5^0 slope (Giri et al. 2020).

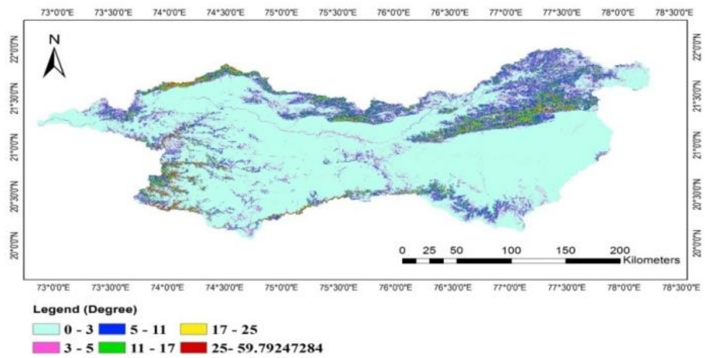

Fig. 3: Slope map of Tapti river basin.

C. Aspect Map

Aspect is used for recognition of the steepest downslope direction of each cell to its adjacent cell (Schumm and Hadley, 1961; Waikar, and Nilawar, 2014). The SRTM DEM has been used for the generation of the "Aspect map" of the area (Fig. 4) (Thomas et al. 2012; Giri et al. 2020).

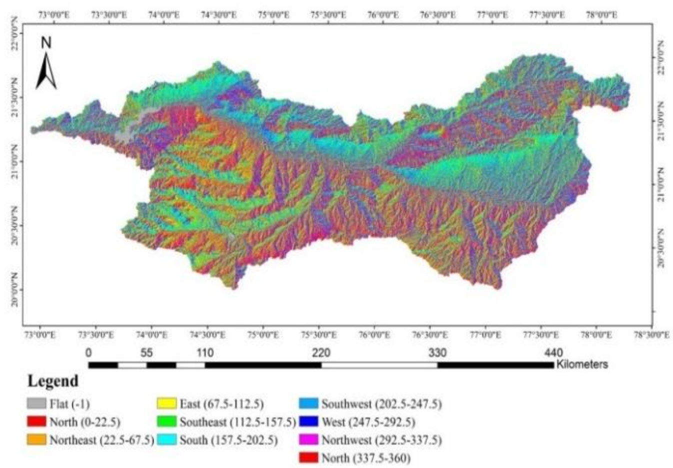

Fig. 4: Aspect map of Tapti river basin.

D. Geomorphological Map

Geomorphology is the systematic study of landforms concerning the climatology, geological and structural aspect (Schumm and Hadley, 1961). Landforms and drainage are the prime parameters in deciphering the geomorphology of an area. The geomorphological record best describes the landforms, plains, and plateau (Schumm and Hadley, 1961; Thomas et al. 2012).

Broadly areas can be classified in a variety of plateaus and plains (Fig. 5). Dissected, denudational plateaus and flood plains are dominant in this area. Denudational plateaus are the exposure of deeper rock structures by the erosion of the land surface, while dissected plateaus are characterised by the cutting of ravines, gullies, or valleys, especially by the stream (Schumm and Hadley, 1961; Thomas et al. 2012; Giri et al. 2020).

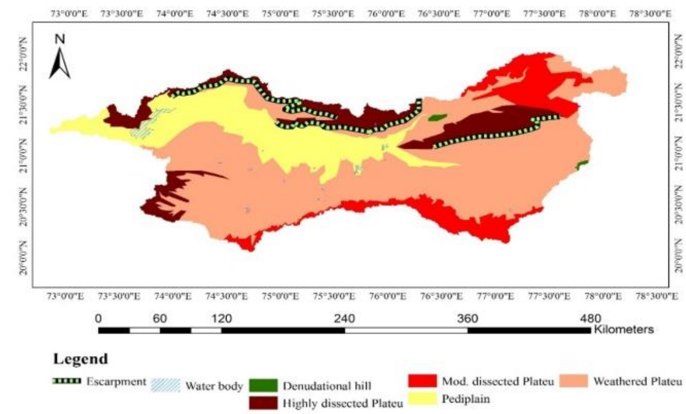

Fig.5: Geomorphology map of Tapti river basin.

E. Lineament map

Lineament is a linear feature that is thought to reflect the crustal structure, viz, Fault line, and straight stream courses. Lineament Mapping is the prime step that directly provides information on the tectonics of the area (Schumm and Hadley, 1961; Thomas et al. 2012; Singh et al. 2021). A structural plot of the area reveals the story of the tectonics of the area. There are several lineaments with some major & minor faults. Lineaments are haphazardly spread all over the Tapti river basin but when observed carefully they represent a crisscross pattern. Mostly a horizontal, vertical, NE-SW, and NW-SE were observed, often cross-cutting each other. There are four major faults, the NE-SW trending Tapti river fault, NE-SW trending Tapi north fault, E-W Gavilgarh fault, and SE-NW trending Purna fault (Fig. 6). Some minor faults were also observed having NE-SW and NW-SE trends (Nongkynrih, and Husain, 2011; Giri et al. 2020).

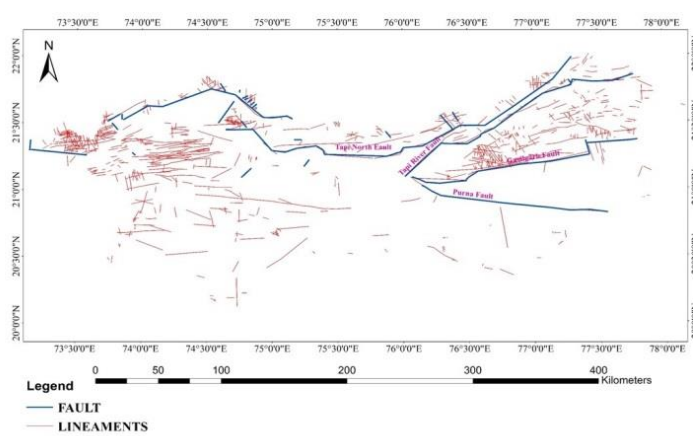

Fig.6: Structural map of Tapti river basin.

V. MORPHOMETRIC ANALYSIS OF BASIN

A. Relief Aspects

1) Relief Ratio (Rh)

The Rh value of the Tapti river basin is 0.002944, indicative of moderate relief and moderate slope (Waikar, and Nilawar, 2014; Giri et al. 2020).

2) Basin Relief

The term Basin relief (R) was given by Melton, 1957 (Fig. 7). Relief (R) (Table I) is 1558 m, indicative of moderate to a steep slope with high run-off (Schumm, 1956; Schumm and Hadley, 1961; Waikar, and Nilawar, 2014; Giri et al. 2020).
Basin Relief (R) is expressed as: $R= Hh$, Where H = maximum elevation (m), h = minimum elevation (m) (Giri et al, 2020)

Table I: Basin Relief (R)

Object Id	Shape	Major Stream Length in Km	Basin Area in Km^2	Maximum Elevation	Minimum Elevation	Basin Relief (Bh)
13982	Polygon	761.775	63725.0264	1559	1	1558

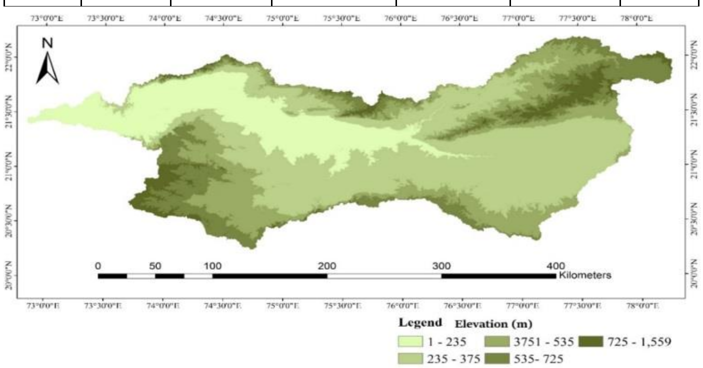

Fig.7: Digital Elevation Map (DEM) of the Tapti river basin.

B. Aerial Aspects

1) Drainage density (Dd)

Horton in 1945 introduced the term drainage density (Dd). The Dd (Table II) of the area is 0.439 km/km2 indicative of Low drainage density, signifying high porous soil and moderate vegetative cover (Giri et al. 2020).

Table II: Drainage density of all streams.

Full basin	Object ID	Basin area (Km^2)	The total length of all stream order(Km)	Avg. drainage density
Polygon	13982	63725.0264	27967.844887667	0.439

2) Stream Frequency (Fs)

The Fs for the basin (Table. III) is 0.0883 km2 (Schumm and Hadley, 1961; Altaf et al. 2013; Waikar, and Nilawar, 2014; Giri et al. 2020).

Table III: Stream frequency of the study area.

Object Id	Shape	Shape Area in km2	No. of stream	Stream Frequency/km2
13982	Polygon	63725.0264	5630	0.0883

3) Texture Ratio (T)

The Drainage texture ratio (T) of the area is 0.452 (Giri et al. 2020).

4) Form Factor (Rf)

The (Rf) of the area is 0.1098, indicative of an extended basin with lower peak flows (Schumm and Hadley, 1961; Altaf et al. 2013; Waikar, and Nilawar, 2014; Giri et al. 2020).

5) Circulatory Ratio (Rc)

The Rc value of the area is 0.1862, indicative of moderate to low relief (Waikar, and Nilawar, 2014; Giri et al. 2020). The high value of the circularity ratio signifies The late maturity stage of topography.

6) Elongation Ratio (Re)

The elongation ratio (Re) in the area (Table IV) is 0.3740 indicative of moderate to a slightly steep ground slope, signifying an elongated shape (Altaf et al. 2013; Giri et al. 2020).

Table IV: Form factor, circulatory ratio, elongation ratio of the basin area.

Major Stream	Object ID	Stream Length(Km)	Form Factor	Circulatory Ratio	Elongation Ratio
Polyline	238	761.775	0.1098	0.1862	0.3740

C. Drainage Asymmetry Factor (Af)

The drainage asymmetry factor (AF) is used to estimate the extent of tectonic tilting at the scale of the drainage basin or relatively large area (Schumm and Hadley, 1961; Alaei et al. 2017; Giri et al. 2020).
Drainage asymmetry is defined by Hare and Gardner, 1985;
$AF = Ar / At * 100$
Where Ar = Area of the basin to the right side of the stream
At = Area of the drainage basin
The area of the left part of the basin is greater than that of the right part, showing the effect of active tectonic or differential erosion or tilt (Fig. 8). If the AF of both parts of the basin is equal, then it indicates the presence of no or little tilting. An asymmetry factor

(Table V) of 22.66 indicates that the river basin is undergoing a probable active tilt in the northerly direction (Giri et al. 2020).

Table V: Drainage Asymmetry Factor of the Tapti River Basin.

Object Id	Shape	Grid code	Major Stream Length in Km	Basin Area in Km^2	Area of the Right Side Basin in Km^2	Drainage Asymmetry Factor
13982	Polygon	6	761.775	63725.0264	14441.998355 8	22.66

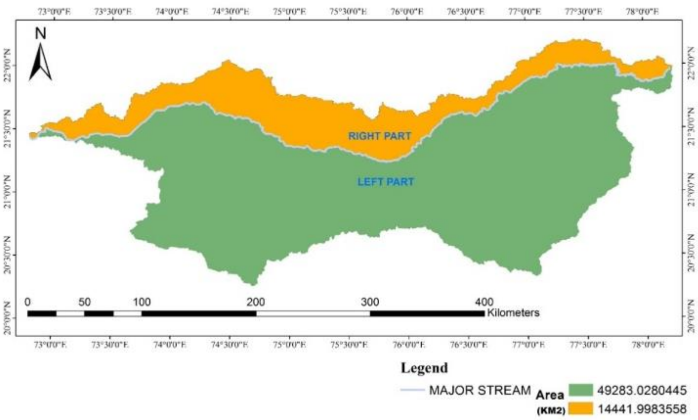

Fig.8: Drainage asymmetric map of Tapti river basin

VI. STUDY OF PROFILE SECTION

In morphotectonic studies, the digital elevation model can provide longitudinal as well as the cross profile of mountain ranges and active faults (Fig. 9). The longitudinal profile may display the youthfulness of the landform, highlighted by the presence of v-shaped valleys (Schumm and Hadley, 1961; Giri et al. 2020).

Also, such profile can be used to recognize structural features like major & minor faults, lineaments, V-shaped valley, dissected plateau, change in elevation along stream channel, evidence of differential block movement, etc. (Fig. 10)

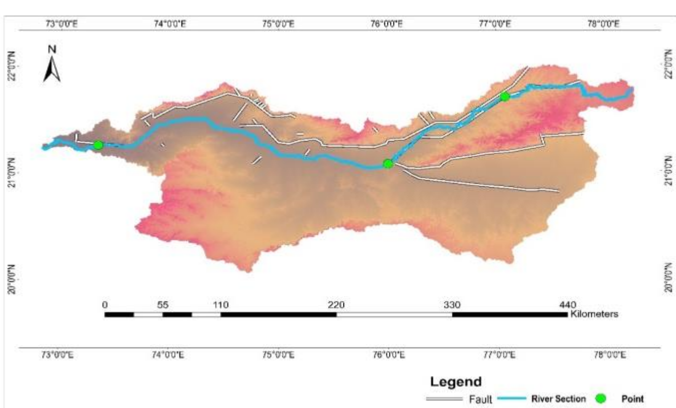

Fig.9: Map showing river section along which digital profiling has been done in the Tapti river basin.

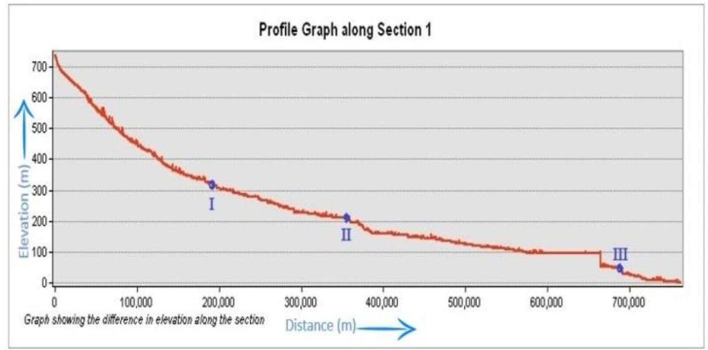

Fig. 10: Profile Graph of Tapti River section

Point I: Point I shows a sudden drop in elevation which co-relates with straight stream course. This convergence of evidence tallies with the previously established Tapti river fault.

Point II: In the central part of the Tapti drainage basin there is a sudden change in the route of the river which is also related to the drop in the elevation of about 20m. This location probably marks the intersection of the well-established NE-SW trending Tapi river fault & the nearly E to W Gavilgarh fault causing sudden flexure in the overall drainage characteristics of the area.

This is further substantiated by the fact that from this location toward the upstream side there is a drainage divide which has bifurcated the basin into two distinct parts in the north-eastern and eastern part of the basin. The originating eastern part of the main river course is depicting a clear NE-SW trend, which nearly follows the NE-SW trending of the Tapi river fault (Giri et al. 2020).

Point III: In the downstream side of the basin, the stream orientation is often controlled by a minor structural feature that has been locally established as a fault. This is to further state that the orientation of the major stream of the Tapi river basin is almost parallel to the Tapi north fault, which might be indicative of the presence of structural features in the southern part of the area sympathetic to the Tapi north fault (Giri et al. 2020).

VII. SEISMOTECTONICS

Seismotectonics is defined as the study of the correlation of individual fault of the area and the active tectonics present in the area. It involves extensive analysis of regional tectonics, recently recorded events using the latest instrumentation techniques, geomorphological evidence, and history of earthquakes in the area.

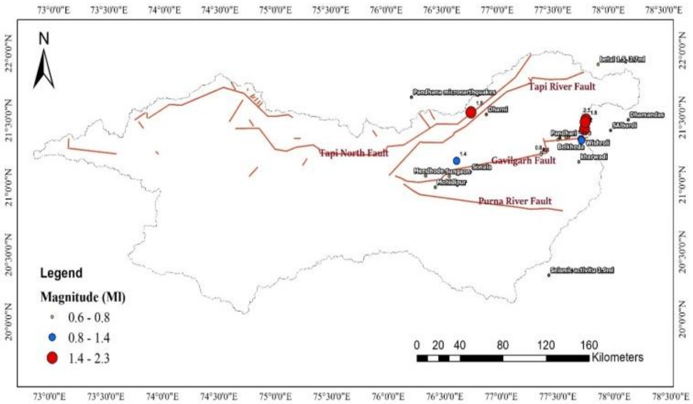

Fig. 11: Seismotectonic map of Tapti River Basin

Seismic events of 3.9ml magnitude on 10 march 2003 with epicenter south of Purna fault were recorded by GSI observatory (Fig. 11). One more event of magnitude 2.9ml at shallow depth was recorded with the epicenter near Dharni in Amravati district of Maharashtra on 1st April 2005 which falls south of the Tapti River fault. A seismic event with an epicenter north of Kharwadi has been recorded which is in close vicinity to the Gavilgarh fault. Few microearthquakes have also been recorded in the Pandhana area in the MP, north of Gavilgarh and Tapti north fault during 1998-1999 (Ghatak et al. 2009). Three distinct events of magnitude 2.3ml, 2ml, and 1.8ml have been recorded north of Belkund Dhana in a linear fashion which may be indicative of the existence of N-S structural entity in the eastern part of the basin cross-cutting the Gavilgarh fault. Two events of magnitude 3.7ml and 1.5ml have been notable near Betul which falls outside the basin in the northeastern part of the area. Few low order seismic events have been recorded near Daryapur, Wishroli, and Jambhal talav area (Ghatak et al. 2007; 2009; Copley et al. 2014;).

After examining the relationship between lineaments and seismic characteristics it can be interpreted, the area has experienced tectonic activities in its recent geological past (Sajadi et al. 2020). Careful observation shows that area is still experiencing tectonic activities as the morphology of the lineaments is changing and the area is continuing to experience low-level seismic instances (Jain et al. 2007; Copley et al. 2014; Giri et al. 2020). However, a thorough and detailed study on this aspect is quite essential to ascertain the prevailing seismic activity of the area and its relation to tectonics.

VIII. CONCLUSION

The Morphotectonic study of the Tapti basin with the help of RS and GIS technology established to be an important input in deciphering the relationship between drainage morphometry and tectonics of the area (Jain, 2007; Magesh et al. 2011; Altaf et al, 2013; Copley et al, 2014; Waikar, and Nilawar, 2014). The basic structural elements like the established faults and other linear feature of the study area were identified on the digitally processed remote sensing data and drainage pattern/morphometry as derived from the available DEM data (Nongkynrih, and Husain, 2011; Altaf et al. 2013; Waikar, and Nilawar, 2014). Since the present study pertains to use the freely available digital data using laboratory techniques, the results obtained need to be verified with the actual fieldwork carried out in the area (Giri et al. 2020).

The various morphometric characters of the Tapti, basin were studied in detail which suggested, that these basins, in general, are asymmetric and exhibit a northerly tilt. Gavilgarh fault zone and Tapti north fault zone are characterized by distinct scarp faces. The greater dissection of geomorphic landforms probably indicates the periodic structural disturbance the area has undergone. In general, the area is characterized by two dominant sets of lineaments viz. NW-SE and NE-SW. Also, a few NS and some EW lineaments have been found to cross-cut the regional trends. Based on the study of stream networks in the area, various morphometric characters were derived for the study area (Jain et al. 2007; Copley et al. 2014). The Relief ratio of the Tapti river basin is 0.002944, indicating moderate relief and moderate slope. The Basin relief is 1558 m which also indicates a moderate to steep slope. The low drainage density indicates the basin has highly permeable subsoil and moderate vegetative cover. The form factor for the Tapti river area is 0.1098, indicating the basin is elongated with lower peak flows of longer duration than the average. The high value of the circularity ratio shows the late maturity stage of topography. The elongation ratio of the study area is 0.3740, which indicates moderate to the slightly steep ground slope (Miller, 1953; Strahler, 1957; 1964; Schumm and Hadley, 1961; Altaf et al. 2013; Waikar, and Nilawar, 2014; Giri et al. 2020).

The Tapti basin exhibit high order of an asymmetric factor of the order 34% indicating the distinct effect of tectonic activity (Nongkynrih, and Husain, 2011; Giri et al. 2020). Study of various profile section indicated the effect of tectonic forces over the present-day geomorphic landforms in the form of a sudden drop in elevation (rapids) along with the river profile, offset of stream courses, sudden change in stream course orientation, change from depositional to the erosional regime, etc. (Schumm and Hadley, 1961; Waikar, and Nilawar, 2014). The low-level tectonic activity experienced by the area can be deciphered from the seismotectonic signatures noted in the area (Magesh et al. 2011). The area in general is characterized by few low-order seismic events. The relationship between seismicity and structural linears suggests that the area has experienced distinct tectonic activity in the geological past and continues to experience the same as indicated by the changes in the morphology of the lineaments in the study area (Raja et al. 2010). However, a thorough and detailed study is quite essential in the future to ascertain the prevalent seismic activity of the area and its relation to regional tectonics (Strahler, 1957; 1964; Schumm and Hadley, 1961; Giri et al. 2020).

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