International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 03 Issue 11 November 2020
DOI: 10.47191/ijcsrr/V3-i11-03, Impact Factor: 6.595
IJCSRR @ 2020
www.ijcsrr.org

Morphotectonic Analysis of Desang River Basin for Feasibility Appraisal of Micro Hydro Power and Diversion Based Irrigation

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Abstract: Desang River has a good deal of 'discharge' and 'elevation' in its course required for micro hydropower or diversion based irrigation projects. However, the region is known for its highly tectonic events at different points of time. The importance of morphotectonic analysis of the basin before undertaking any engineering geological project in its course is undisputable. Various morphotectonic parameters are studied in this paper to understand how tectonically active this basin is or how feasible to initiate any big investment for the public good in this basin.

Morphotectonic analysis has established that the basin is less active tectonically and is feasible to commence larger investment for micro hydropower and diversion based irrigation project with extremely low risk of failure due to tectonic eventuality.

Assam has one of the highest per unit electricity cost in the entire country and its irrigation potentiality created mostly based on expensive fossil fuel. Such an expensive bottom line is making micro, mini and small industries highly vulnerable and agricultural activity extremely cost prohibitive. In this backdrop, establishing micro hydropower and diversion based irrigation project could bring about a paradigm shift for the communities living in the vicinity of the Desang river basin.

Keywords: 'Desang River', 'Micro Hydropower', 'Diversion based irrigation', 'Morphotectonic', 'Assam'

Introduction

Desang River is a Tributary of the Brahmaputra River initiated in the Nagaland Hills and confluence with the Brahmaputra in Assam. Desang River basin covers an area of 2,029 Square Kilometer. The Basin boundary is measured to be 482 Kilometer long. Desang is an 11th Order River in the Strahler Order.

"Desang River estimated to have more than 7 billion cubic meter (7,547,297,184 Cu M) of annual discharge. This River has demonstrated a good deal of possibilities for micro hydropower and diversion based irrigation potentialities. The Average daily discharge of the river is estimated as 6,292,512 Cu M". (Hussain, T.A., 2017)

Further, "The study of the Desang River with 19 years discharge data establishes that it is a perennial River with 36.140 cumecs discharge at 90% exceedence level. The river course has shown different head conditions before reaching the low elevation land. Two potential combinations of intake and power house were assessed and found to have 38 meter head in one combination and 18 meter head in another. The first combination has the potentiality of generating 10.098 MW power without any storage and the second combination has the potentiality of 4.783 MW of electrical energy without any storage. Further field level investigation and ground truthing might provide more options for establishing economically viable hydropower plants in this river. There are various geologically conducive locations in the river course for building reservoirs to meet the peak load demand and increase the head further". (Hussain, T.A., 2018)

Preparation of Digital Elevation Model

Based on the SRTM data of 30M resolution, the Digital Elevation model is prepared. The SRTM data of the area is re-projected to WGS 72BE/ UTM Zone 46N Coordinate Reference System (CRS) of EPSG: 32646, for further processing and analysis. The channels of Strahler Order 7 and above are plotted here.

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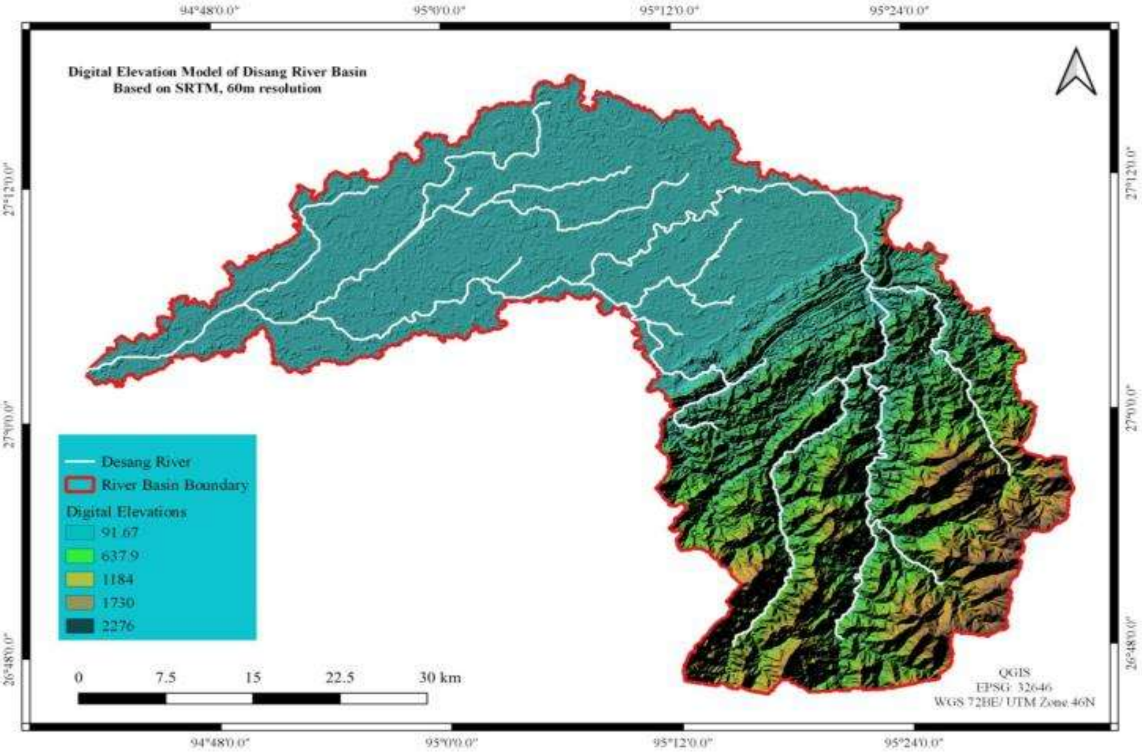

Fig. 1 - Digital Elevation Model of Desang River Basin

Avulsion of the Desang River meander belt

Avulsions, is the process of a channel course abruptly abandoning a portion of it and starting a new course. It is a very common feature in the study area with multiple impacts in the society hampering the human development process. "Given the impact of avulsions on society and their role in creating alluvial strata, it is surprising that so little is known about their origin. We still cannot predict the necessary and sufficient conditions that give rise to an avulsion, nor the evolution of the subsequent channel network". (Slingerland,R., et al, 1998)

However, study of historic avulsion events could through some light on the future of the low-head hydroelectric projects or diversion based irrigation projects.

The Desang River Basin had, at least, 3 distinct episodes of Avulsions in its course. The avulsion near Lakwa is the largest of all, where the channel course abruptly abandoned a portion of about 23 Km long and started a new course in the north of it. The episode of avulsion near Madhupur Gaon is around 11 Km long and have more than one smaller episodes before reaching the present stage. The avulsion near Sukani village is around 17 km long which is the result of multiple smaller events of avulsions.

The observation of avulsion process might help a low-head hydropower or diversion based irrigation project designer to estimate potential such changes in an around the project sites and take necessary precautions for any losses.

Mountain Fronts Sinuosity of Desang River

Mountain front sinuosity is an index that reflects presence of neo-tectonic activities in relation to the prolonged erosional activity of a stream. The mountain fronts that are undergoing active tectonic episodes with uplifting tend to be comparatively straight and demonstrate low S_{mf} value. Whereas, in the mountain fronts that have reduced uplifting or uplifting has come to an end, then erosional processes will be dominating by creating curvier mountain front, and S_{mf} will increase.

The assessment of the Mountain Front Sinuosity of the Desang River was carried out with the help of the Google Satellite Image, re-projected in UTM Zone 46N projection.

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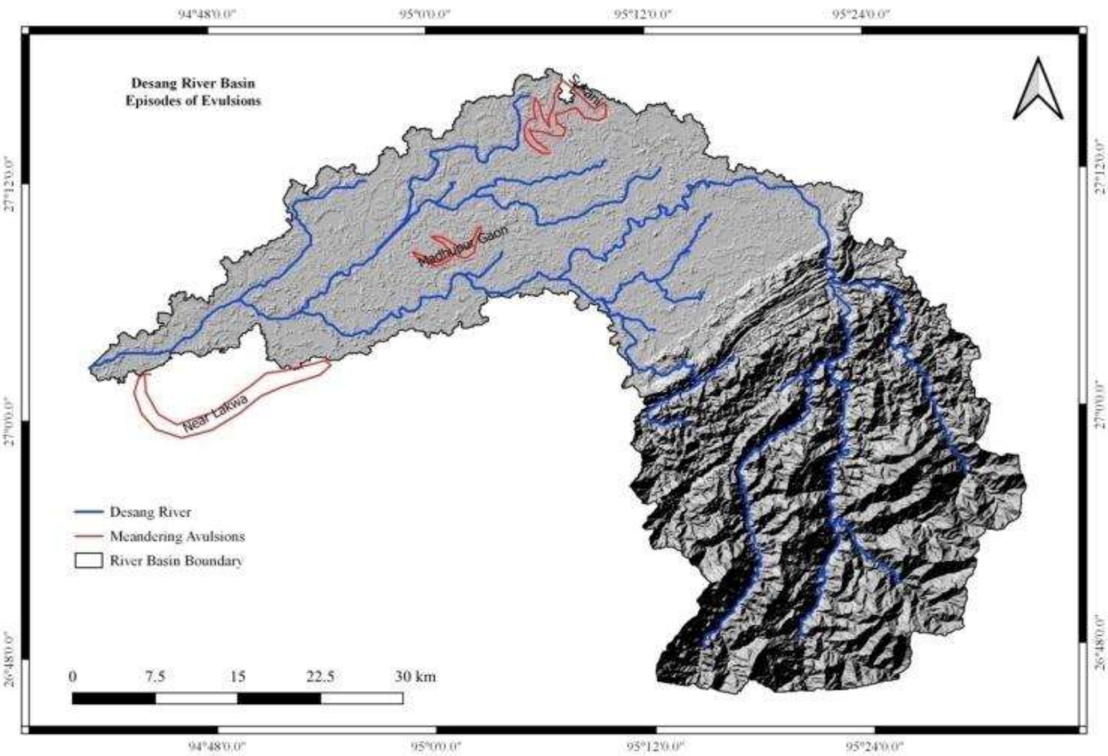

Fig. 2 - Major Avulsion Events in Desang River Basin

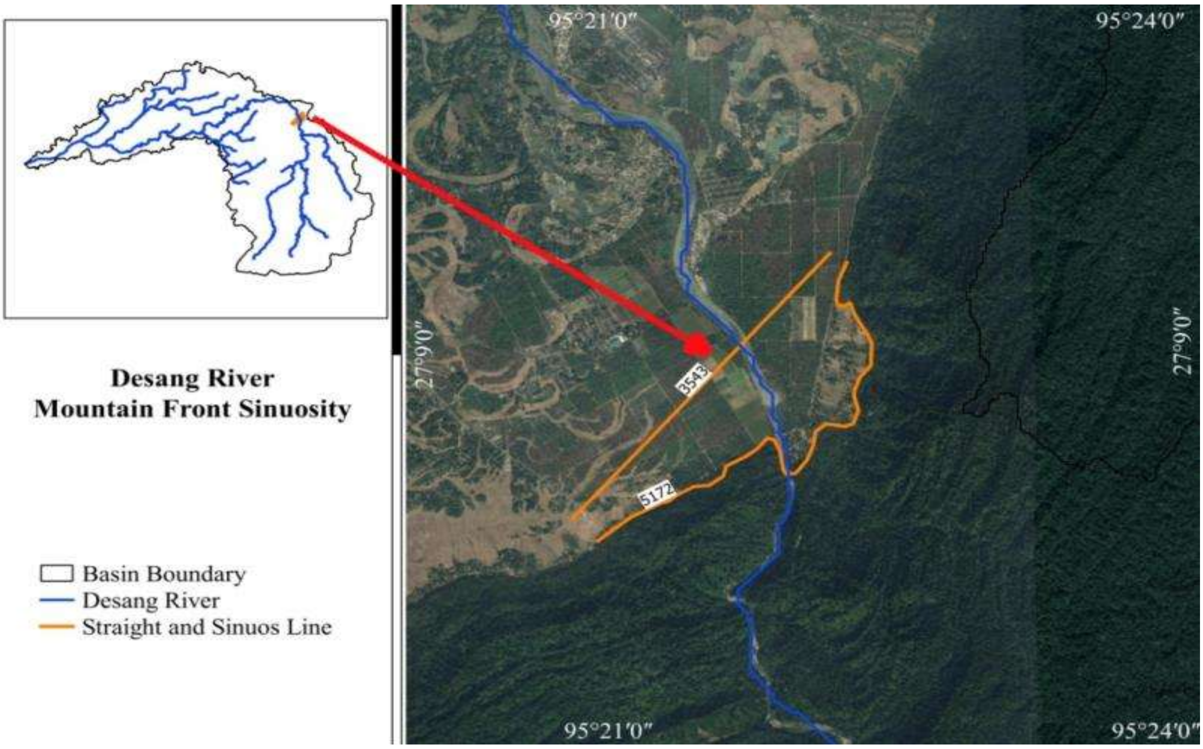

Fig. 3 - Mountain Front Sinuosity of Desang River

Here the length of the mountain front along the foot of the mountain (Lmf) is found to be 5,172 m, at the pronounced break in slope. Whereas, the straight line length of the mountain front (Ls) is measured as 3,543m. The Mountain Front Sinuosity Smf is calculated from the relationship to find the value 1.46.

$$S_{mf} = \frac{L_{mf}}{L_s} = \frac{5,172}{3,543} = 1.46$$

It falls in the Class-2 category of the Bull and McFadden (1977) classification, 'Less Active' category of Rockwell et.al. (1984) Classification and Wells et.al. (1988) Classification too.

Ratio of Valley Floor width to valley height of Desang valley

The ratio of the valley floor width to valley height (V_f) differentiates between broad-floored canyons, with relatively high values of V_f, and V shaped valleys, with relatively low values. Low values of V_f reflect deep valleys with streams that are actively incising, commonly associated with uplift.

The equation used for the purpose is denoted by the equation where V_{fw} is the width of the valley floor, E_{ld} and E_{rd} are the elevations of the left and right valley divides, respectively, and E_{sc} is the elevation of the valley floor. Valley floor index for the Desang River Valley is calculated as

$$V_f = \frac{2V_{fw}}{[(E_{ld} - E_{sc}) + (E_{rd} - E_{sc})]}$$

$$= \frac{2 \times 62.04}{[(165 - 132) + (172 - 132)]}$$

$$= \frac{124}{73}$$

$$= 1.7$$

High values of V_f are associated with low uplift rates, so that streams cut broad valley floors. In this case Valley Floor Index is high indicating low uplift rates.

Asymmetric Factor in Desang Drainage Basin

In a stable setting drainage basin, Asymmetric Factor is equal to 50. However, with the advent of any tectonic event, the drainage tends to shift to either side of the basin.

The asymmetry factor (AF) of Desang Drainage Basin is estimated with the equation

$$AF = 100 \left(\frac{A_r}{A_l}\right)$$

$$= 100 \left(\frac{1355}{684}\right)$$

$$= 198$$

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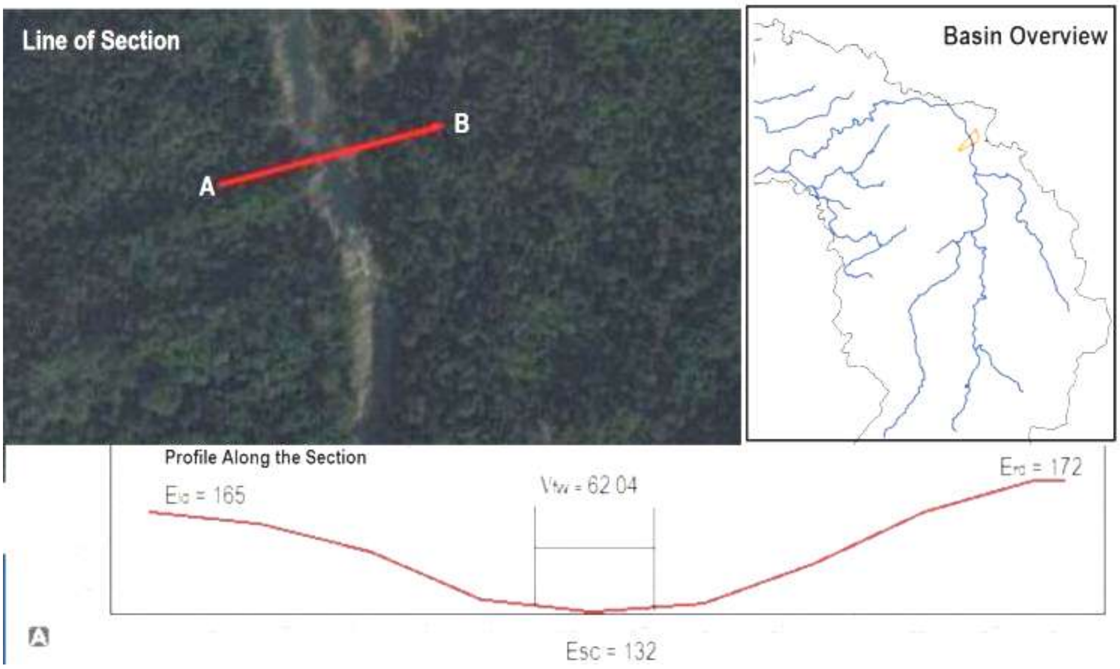

Fig. 4 - Ratio of Valley Floor width to valley height of Desang River

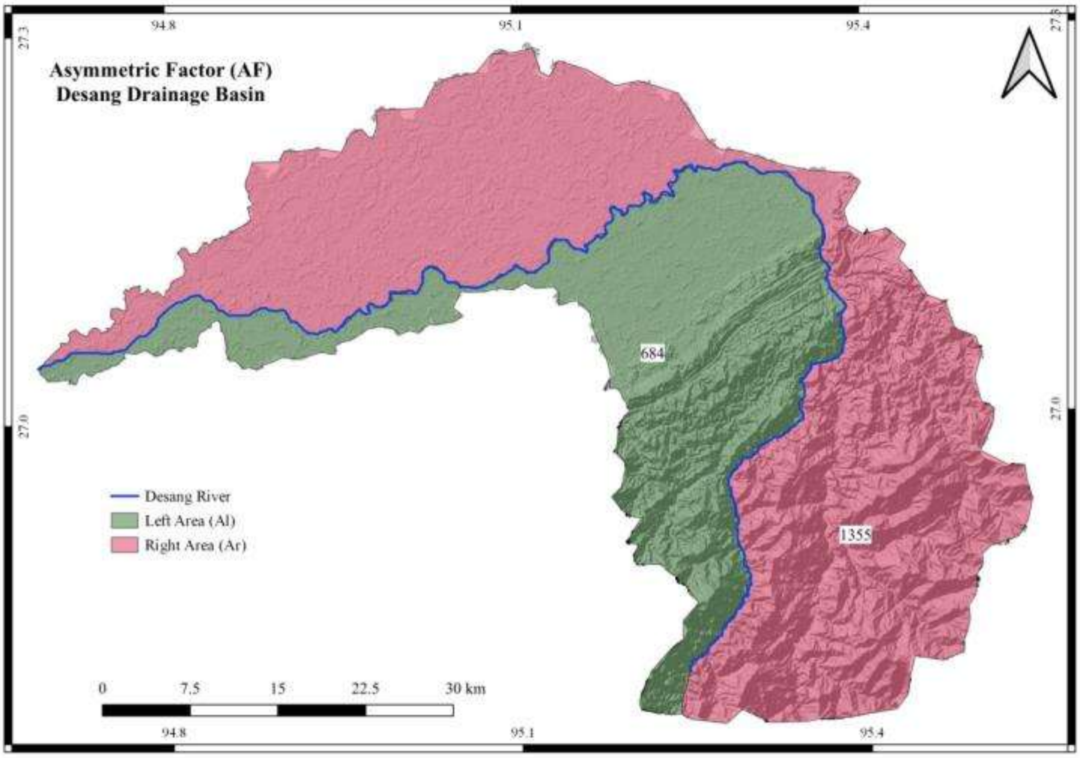

Fig. 5 - Asymmetric Factor of Desang Drainage Basin

Here, A_r is the area of the right basin facing downstream and A_l is the area in the left basin. In a north flowing stream, like Desang, where the eastern tributaries are longer than the western tributaries and shows the AF > 50, it indicates that the Desang

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Drainage Basin is tilted to the west due to the tectonic activities. However, higher the AF value; lower the recent tectonic activity. In case of Desang Drainage Basin, AF value is very high indicating tectonic stability in the basin.

AF is more conclusive in 4 conditional assumptions. (1) There is no variation of the rock type in the other side. (2) There is no other lithological control like dipping of the sedimentary layers in both side and (3) there are no micro climatic variations in terms of the vegetation difference between north and south facing slopes. (4) Finally, there is no down steep regional slope as the tributaries to streams that flow down steep regional slopes may be asymmetrical without active tilting.

Transverse Topographic Symmetry Factor (T) of Desang River

Transverse Topographic Symmetry Factor (T) is an important quantitative component to understand the morphotectonic condition of a stream. The Transverse Topographic Symmetry Factor (T) could be estimated by

- Creating the basin divide
- Delineating the basin midline of a drainage basin,
- Identifying the active meander belt of it and
- Plotting the midline of the meander belt along with
- Measuring the distances and azimuth in a section perpendicular to the drainage basin axis.

The equation used for the measurement of T is, $T = \frac{D_a}{D_d}$. Where, D_a is the distance from the midline of the drainage basin to the midline of the active meander belt, and D_d is the distance from the basin midline to the basin divide.

Channel network and drainage basin algorithm of SAGA was used in the SRTM layer of the area to delineate the Basin Divide before drawing the basin midline. Google satellite imagery was used for the delineation of the meandering belt in the downstream of the mountain front. A midline of the meandering belt was drawn for further processing and calculation of D_a and D_d. Vector calculator was used for the estimation of bearing and length of each section line from A to F.

Transverse Topographic Symmetry Factor (T) do not provide direct evidence of tilting, however, it facilitate rapidly identification of possible tilting. The index also reflects the migration of the stream segments perpendicular to the principal axis of the basin, due to either of internal forces or external processes (Keller and Pinter, 2002; Salvany, 2004).

The Desang Drainage basin has a Transverse Symmetry Factor (T) value near Zero indicating low asymmetry and bearing mostly towards NE-SW.

Basin Shape Index of Desang River

The Basin Shape Index calculation for Desang River Basin was carried out with the help of Channel Network and Drainage Basin analysis tool of QGIS. The Desang River basin is composed of four smaller sub basins. The basin length (B_l) and basin width (B_w) are measured to find the Basin Shape Index (B_s) from the formula given by Ramırez-Herrera (1998) as:

$$B_s = \frac{B_l}{B_w} = \frac{159 \text{ Km}}{34.9 \text{ Km}} = 4.56$$

As the value of B_s is more than 4, it is associated with elongated basins and therefore with relatively higher tectonic activity. Basin Shape Index measurements are subjective and therefore not repeatable.

Section	Dd	Da	T = Da/Dd	Bearing	Symmetry Towards
A	12637	2111	0.167	480	NE -SW
B	9339	1551	0.166	400	NE -SW
C	11027	1690	0.153	290	NE -SW
D	9532	1886	0.198	20	NE -SW
E	10561	1742	0.165	3490	NW-SE
F	8227	1923	0.234	3440	NW-SE

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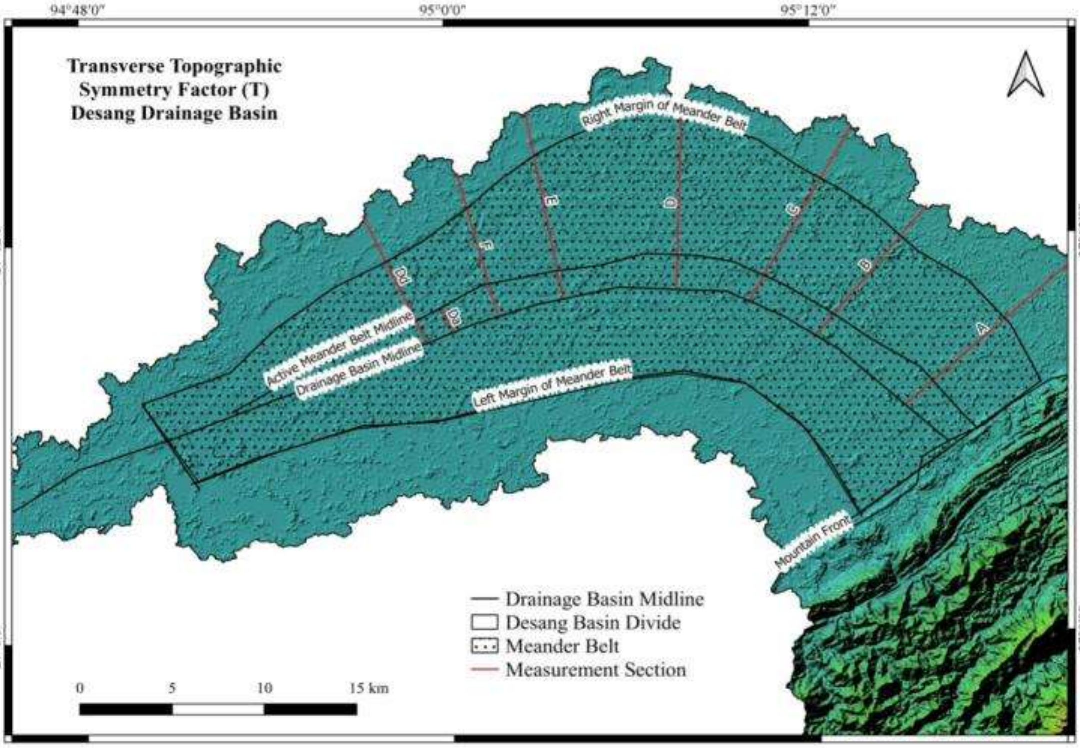

Fig. 6 - Transverse Topographic Symmetry Factor of Desang River

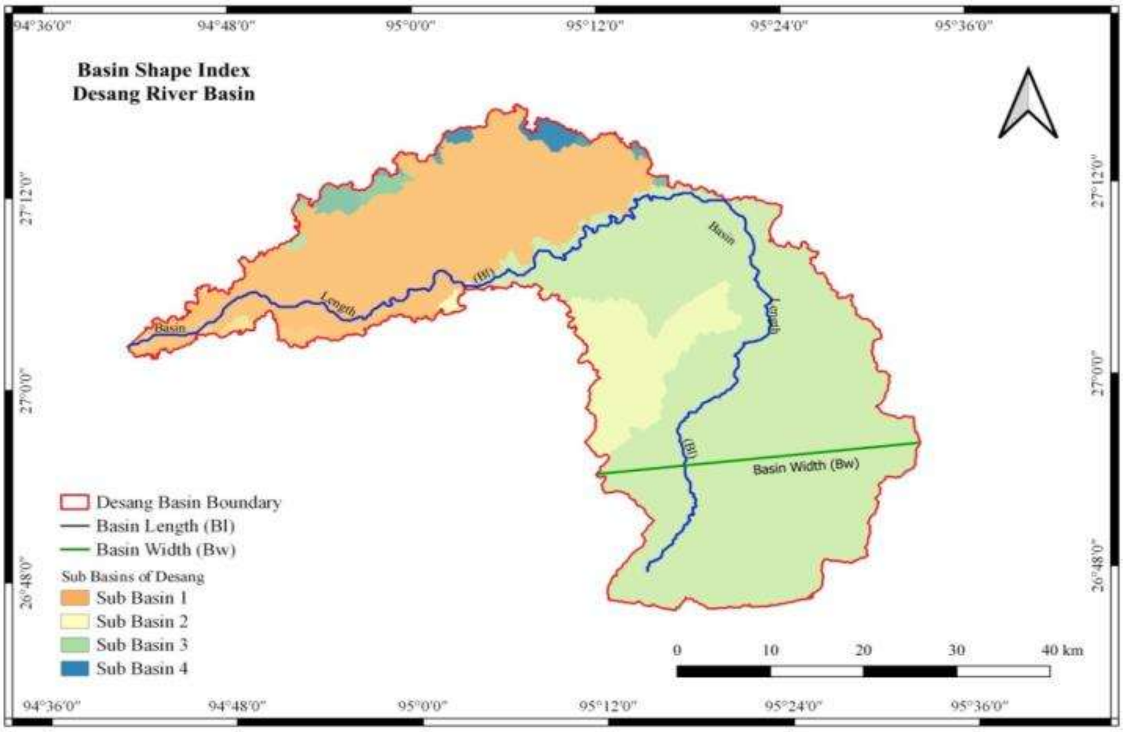

Fig. 7- Basin Shape Index of Desang River Basin

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Circularity Ratio Desang Basin

The Circular Ratio (Rc) is calculated for the Desang River valley by measuring the Basin Area (A) which is found to be 2,029 Sq Km and the Basin Perimeter (P) estimated here as 482 Km.

As per the equation given by Miller (1954), the basin circularity ratio for the Desang River Basin is calculated as shown below.

$$R_C = \frac{4\pi A}{P^2} = \frac{4 \times 3.14 \times 2{,}029 \text{ sq km}}{(482 \text{ km})^2}$$

$$= \frac{25{,}484.24 \text{ Sq Km}}{23{,}2324 \text{ Sq Km}} = 0.1097$$

The Circularity Ratio (R_c) is found to be a dimensionless number. The value of R_c in the Desang River Basin is near zero indicating chances of higher runoff than that of a basin of the same size with bigger R_c value.

Stream Length Gradient Index of Desang River

The Stream length-gradient index (SL index) is prepared after running the Flow Direction algorithm in the SRTM data of the Basin area. Main channel was already delineated with the help of channel network and drainage basin tool and dissolved the various segment of it.

The 'Profile Tool' of QGIS was used to extract the stream elevation profile from the first point in the hilltop to the last point of the stream up to the confluence with the River Brahmaputra. However, it was not considered enough as we were to find out the segment wise elevations of the stream to determine the SL index of each segment for the anomalous values to determine the tectonic activities.

Q Chainage processing tool was used to make segment of the entire river course in to segments of 10 Km long each. The 'Point Sampling Tool' was used to determine the elevation value of end points of each of the sections.

The attribute table of the layer containing the sample points with the length and Z value of each segment were exported to the excel sheet for further processing.

The Stream length-gradient index (SL index) is calculated for a particular segment of interest by the following formula:-

$$SL = \left(\frac{\Delta H}{\Delta L}\right)L$$

Where ΔH is the change in elevation of the reach, ΔL is the length of the segment, and L is the total channel length from the midpoint of the segment of interest upstream to the highest point of the channel.

Segment	Distance	Elevations (m)	L (m)	ΔL	ΔH	SL
1	10,000	94.0	143,827	10,000	0.1	1.4
2	20,000	95.0	133,827	10,000	1	13.4
3	30,000	102.0	123,827	10,000	7	86.7
4	40,000	102.1	113,827	10,000	0.1	1.1
5	50,000	106.0	103,827	10,000	3.9	40.5
6	60,000	110.0	93,827	10,000	4	37.5
7	70,000	114.0	83,827	10,000	4	33.5
8	80,000	116.0	73,827	10,000	2	14.8
9	90,000	119.0	63,827	10,000	3	19.1
10	100,000	162.0	53,827	10,000	43	231.5
11	110,000	192.0	43,827	10,000	30	131.5

12	120,000	241.0	33,827	10,000	49	165.8
13	130,000	345.0	23,827	10,000	104	247.8
14	140,000	505.0	13,827	10,000	160	221.2
15	148,827	716.0	4,413	8,827	211	105.5

The major anomaly in the SL index is observed in between the 9th and 10th Segments. It is representing the tectonic changes in the plate boundary. Other anomalies could also be attributed to different tectonic and lithological variations in the basin.

Hypsometric Curve of Desang Basin

The hypsometric curve gives us an estimation of what percentages of area in a basin have less than a specific height. The SRTM layer is used within the catchment polygon for the hypsometric curve. The processing tool called 'Raster Terrain Analysis' was used in 50 steps to prepare the hypsometric curve. The algorithim basically provides a table with percentage of area available in the basin below a specific altitude. It shows 100% area under the highest elevation.

This CSV (Comma Separated Value) is imported to the QGIS platform for preparing the hypsometric curve with the help of 'Data Ploty' plugin. The curve envisages that 2286m is the maximum altitude of the basin and 100% area of the Basin has the elevation less than this. The lowest elevation of the basin is 86 m from the mean sea level and around 17 percent of the basin area has elevation less than 87 m. The curve is basically the representation of the proportion of total basin height against the proportions of total basin area. The total height (H) is the relief within the basin that represents the difference of the maximum elevation to the minimum elevation. The hypsometric curve is independent of difference in basin size and relief.

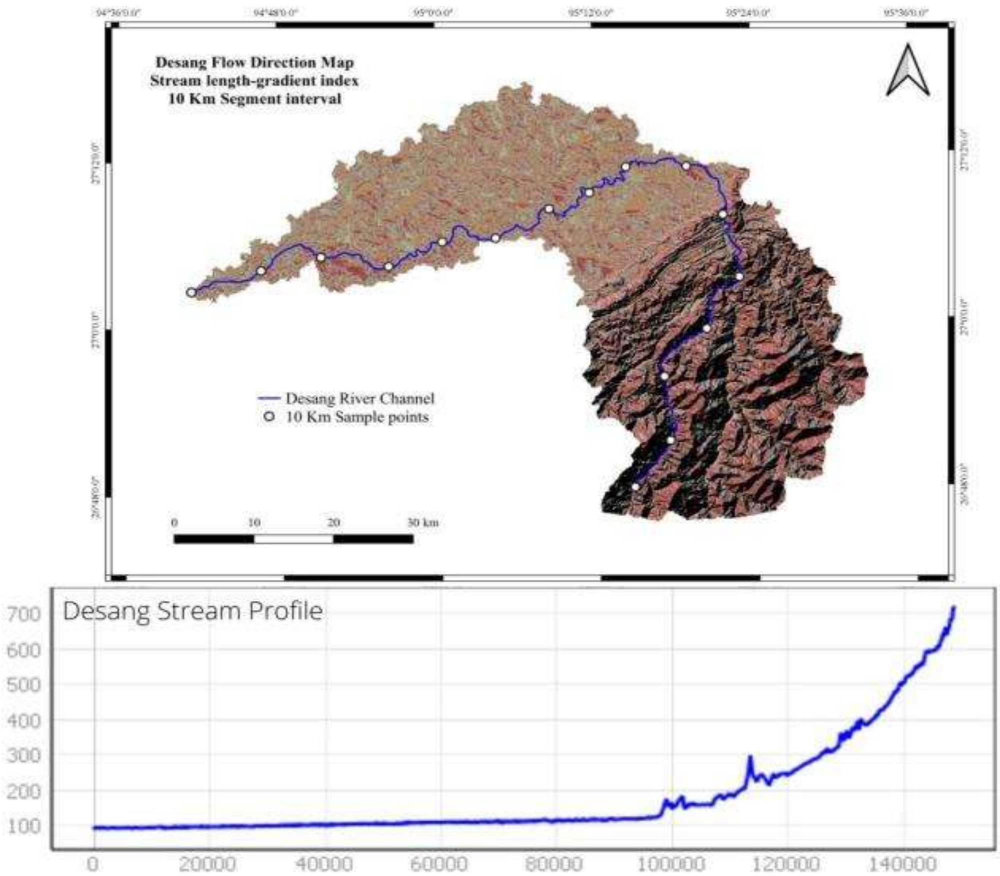

Fig. 8 - Stream Length Gradient (SL) Index of Desang River Basin

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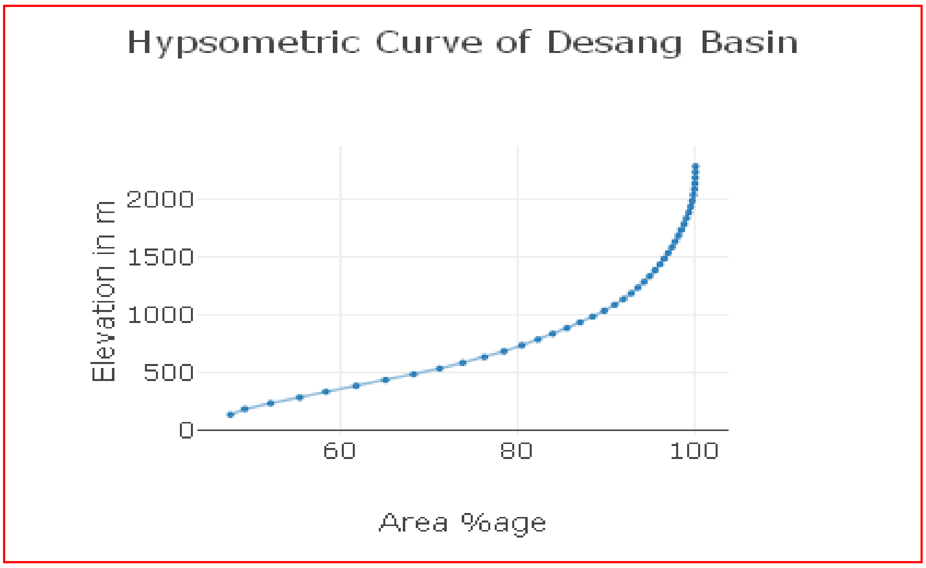
Hypsometric Integral of Desang Basin

The Calculation of hypsometric integral (Hi) provides a substantial indication of the area covered under a specific elevation. The hypsometric integral (Hi) for Desang Basin is calculated as follows:



$$H_i = \frac{\text{Mean Elevation} - \text{Minimum Elevation}}{\text{Maximum Elevation} - \text{Minimum Elevation}}$$

$$= \frac{417 - 86}{2286 - 86} = \frac{331}{2200}$$

$$= 0.15$$

The Minimum, Maximum and Mean Elevation values are derived from the SRTM layer with the help of Raster Calculator. High hypsometric integral indicates relatively young topography. Medium and low hypsometric integrals are the representation of mature and old topography successively.

Tectonic Setup Indicated By the Earthquake Epicenters

Earthquakes are the result of the energy released on the process of stresses accumulated in the tectonic movements. Plates or the blocks of the crust are continuously moving in a very low velocity, which could be resembled with the velocity of the nail growth, i.e. few millimeters per year. The huge blocks of the crust moving in a rough surface accumulate massive energy due to the resistance caused by the friction of the surfaces. Such energy accumulates for years up to a point where the surface could withstand no more stress but to release the energy to come into the equilibrium. The release of this energy is massive enough to shake the surface of the crust in different intensity based on the amount of energy released and its depth of occurrence.

On an average, Magnitude 2 and smaller earthquakes occur several hundred times a day worldwide. On the other hand, major earthquakes, greater than magnitude 7, are found to happen more than once per month. The 'Great earthquakes', with magnitude 8 and higher, are recorded almost once a year globally.

The earthquakes are the acid-tests for the earth-scientists to identify the tectonic movements and also to help interpretation of the morphotectonic events. In this research earthquake information are collected from the National Center for Seismology (NCS), Ministry of Earth Sciences, the nodal agency of the Government of India, and from the Incorporated Research Institutions for

Seismology (IRIS) that maintains details record of the earthquakes from the USGS source and also from the other mixed sources with high precision. With the help of QGIS the information so collected are presented in maps for further interpretation.

The area of interest (AOI) of the research is situated within the Latitude $26^0$30' to $28^0$00' and Longitude $94^0$30' to $96^0$30'.

Earthquake epicenter information is collected from the National Center for Seismology (NCS) for a period of 100 years from 1920 to 2020. Total 55 earthquakes are found to have epicenter in the study area in last 100 years. The epicenters of the earthquakes are ranging from 0 Km to 150 Km in the area. The earthquake occurred on 30^{th} April, 1990 at 07:26:17 IST is found to have the deepest epicenter of 150 Km with 4.6 Magnitude. Shallow earthquakes with less than a Km depth of epicenter are found in 10 numbers. Around 80% of the earthquakes with epicenters in the study area have depth less than 50 Km.

The magnitude wise analysis of the earthquake of the study area envisages the earthquakes with epicenters in the study area ranges up to Magnitude 7. The Earthquake of 26^{th} August, 1950 at 12:03:06 IST have recorded the highest magnitude of 7 within the study area in last 100 years. However, more than 80% of the earthquakes with epicenter in the study area have magnitude 5 or less.

The ability of an earthquake to make morphometric changes are directly proportionate to the magnitude of it and are inversely proportionate to the depth of it. In a nutshell, Shallow earthquake with high magnitude could make the most, in terms of morphotectonic changes, in a River basin.

Open source IRIS Earthquake Browsing method is used to extract the relevant earthquake records from the IRIS database and total 13 earthquake events' records are extracted from the database for the period starting from the year 1992 to 2012 with epicenters located in the study area. One earthquakes recorded by the IRIS have depth of epicenter less than 1Km and one earthquake has the depth of 100 Km. All other earthquakes recorded by IRIS have depth of epicenters less than 50 Km.

Magnitudes of these earthquakes are found to be varying between the range of 3.1 and 4.9 in the Richter scale. Only 2 earthquakes out of these 13 are having more than 4 magnitudes.

The records of Earthquakes gathers from NCS and IRIS have no resemblance and repetition. So long the morphotectonic study is concerned, any information of earthquake matters and hence, all these records of both the agencies are used in the study area. Why there is no resemblance of the earthquake records of both the premier agencies is a matter of concern. However, as this is not the focus of the research, the exploration of answers of this question of variations is ignored and skipped.

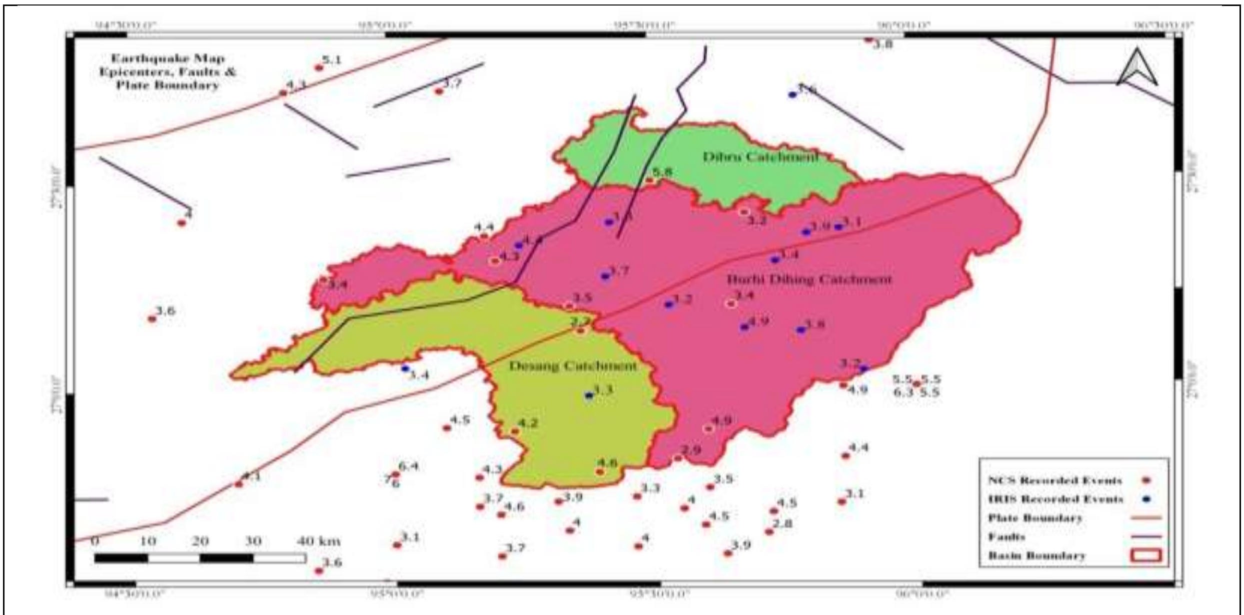


Fig. 6.1 Map showing Major Drainage Basin along with earthquake epicenters

Faults and Plate Boundaries

National Center for Seismology (NCS), Government of India, has published georeferenced faults lines of various parts of the country and its neighboring areas. The relevant faults are extracted and plotted in the study area for better comprehension of the morphotectonic conditions of the area. It is to be noted that the fault lines recorded here are not necessarily only the fault lines available in the area. There might have more faults and tectonic lineaments of different dimensions that are not being included here. Further study and observations may unfurl more facts related to the tectonic activities and its demonstrations in the area.

Deviation of Desang Basin

South to North flowing Desang River has a deviation of its entire basin towards the NE direction up to the Plate Boundary. Immediately after the Plate Boundary, the River started flowing towards the NW direction to meet the Brahmaputra. This Morphotectonic variation could be attributed to the tectonic movements along the Plate Boundary.

Faults and Epicenters

Many of the earthquake epicenters are found to be in the close proximity to the fault lines mapped by the National Center for Seismology (NCS), Govt. of India. It is apparent that the earthquakes that are far from the given fault lines or from the Plate Boundaries are also have some or other relationship with the tectonic arrangements of the area. Some such tectonic activities have surface manifestation like folds, faults or joints and the others are operating in the subsurface without any visible traces.

Conclusion

Hydrologically, the Desang River has a very good amount of river flow and geologically, the stream has significant elevation for sustainable development of micro hydropower and diversion based irrigation project in its course.

Morphotectonic analysis, discussed in this paper, has reaffirmed that any engineering project in the course of the river is tectonically safe from the near future eventualities.

The digital elevation model has ensured required head for micro hydropower and diversion based irrigation potentialities. Analysis of different avulsion episodes in the stream flow has drawn fair degree of precautions to be taken before commissioning of such engineering projects.

All the morphotectonic parameters including Mountain front sinuosity, ratio of valley floor width to valley height, asymmetric factor, transverse topographic symmetry factor, basin shape index, Circular ratio, stream length gradient index, hypsometric curve and hypsometric integral have confirmed that the basin is not active tectonically in the recent past and it is safe to go ahead any engineering project in the basin.

Detail analysis of the earthquake epicenters in and around the Desang basin has not shown any indication of tectonic risk in the basin for an engineering geological project.

Initiating diversion based irrigation projects in the basin will not only enhance productivity of the crops but also provide low cost competitive market relevance to the farmers. Setting up micro hydropower in the basin might change the living standard of the communities around it along with providing economic certainties to the micro, mini and small scale industries of the area.

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