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Assessing the slope of channels using Python and Linux algorithms: A case study on the central Indian drainage system to infer neotectonic activity

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Abstract

Fluvial geomorphology provides important insights into neotectonic activity because river systems respond sensitively to crustal deformation through changes in channel geometry and slope. In this study, channel slope and steepness of river networks in the Jabalpur region of Central India, located along the Son–Narmada South Fault (SNSF) within the Central Indian Tectonic Zone (CITZ), are analysed to evaluate possible neotectonic activity. Channel steepness indices and chi analysis were calculated using three approaches: a traditional manual method and two automated algorithm-based tools—LSDTopoTools (Linux-based) and LandSpy (Python-based). Digital Elevation Model (DEM) data were used to extract drainage networks and construct longitudinal river profiles. The results demonstrate that the drainage networks derived from all three methods are largely consistent, although minor variations in flow paths occur in the LSDTopoTools output. Channel steepness maps reveal a clear spatial contrast across the study area, with rivers south of the SNSF exhibiting higher steepness values compared to those in the northern block. This asymmetry suggests differential uplift and supports the interpretation of neotectonic reactivation along the fault system. Although LandSpy produces steepness values approximately 5000 times higher than those obtained by the other methods, the relative trends remain consistent after normalization. Among the tested approaches, LSDTopoTools provides the most efficient and reliable results for regional-scale geomorphic analysis. The study highlights the usefulness of automated geomorphic algorithms for rapid assessment of tectonic activity and demonstrates the significance of river profile analysis for understanding neotectonic processes in stable continental regions.

Keywords: Channel Steepness Index (K_{sn}), Chi Analysis, LSDTopoTools, LandSpy (Python Geomorphic Algorithms), Neotectonic Activity, Son–Narmada Fault System

INTRODUCTION

Geomorphology is a crucial approach for investigating the neotectonic activity since it entails the examination of the geomorphic records, which include landforms and Quaternary deposits that have developed over a time span ranging from a few thousand years to around 2 million years. It involves evaluating the geometrical as well as anatomical quantification of drainages and drainage basins, which is known as morphometric evaluation (Clarke, 1996; Strahler, 1969). It also encompasses morphotectonic analysis, which involves applying geomorphic concepts to assess recent tectonic activity. The phrase carries significance in its use, as it allows us to apply geomorphological ideas to evaluate the historical context, magnitude, and rate of tectonic processes. An in-depth analysis of the geomorphic records is crucial for understanding the role of active tectonics in shaping the landforms in the area under study.

The fluvial system, including river flow patterns and drainage systems, exhibit dynamic characteristics that vary over time and location due to factors such as geomorphology, geology, structural components, and vegetation, ((Rekha et al., 2011) and continuously shaped by various process (Knighton, 2014). Fluvial systems are indeed dynamic systems that flow over the Earth's crust. The active crustal block also serves as a dynamic system. One dynamic system influences the other dynamic system and produced anomalies. The any Earth's crust movement due to tectonic forces influences the behavior of the dynamic fluvial system situated above it.

Tectonic activity plays vital role in the development of drainage basin morphology. Analysis of a drainage basin in response to the tectonic processes can provide an insight into the past and recent deformational events of the region. Drainage networks are the most active and sensitive elements which can be used as a powerful tool to understand the tectonic activity of an area. Morphotectonic deals with the landscape morphology, which has evolved as a result of the tectonic activity. An analysis of active structures can be done by using morphotectonic indices, which are sensitive to rock resistance, climatic changes and tectonic processes resulting into landscape evolution.

The longitudinal profile of the bedrock river is utilized for determining tectonic activity, temporal deformation, and is also used for developing erosion models. A longitudinal profile of rivers is a graphical representation created with the plot elevation on the Y-axis against the distance down the river on the X-axis. The river channel steepness index (Ks) is an important parameter of longitudinal river profiles as it measures quantitatively the relative uplift rate. Several methods exist for calculating channel steepness, with continuous advancements in new approaches (Flint, 1974; Gailleton et al., 2019; Hack, 1957; Mudd et al., 2014; Perron & Royden, 2013; Whipple & Tucker, 1999). The Chi analysis is a reliable method for assessing river profiles to determine the transient stage of the river (tectonically activeness). It involves transforming the dimensional horizontal length coordinate into a non-dimensional Chi value (χ). This method was developed by Perron and Royden in 2013 and originally proposed by the Royden et al., in 2000. Also mapping of tectonic upliftment in the region can be accomplished by use geomorphic proxies such as the chi integral, as demonstrated by Perron and Royden (2013) and Willett et al., (2014).

Steady state Bedrock River Profile

The longitudinal profile of the bedrock river is utilized for determining tectonic activity, temporal deformation, and is also used for developing erosion models. A longitudinal profile of river is a graphical representation with elevation on the Y-axis and the distance along the river on the X-axis (Figure 0-1). Mature river profile generally attains a parabolic shape if it is in steady state. In this case river have maintain the hydraulic stability means maintain their geometry, flow rate, velocity, sediments transportation remain constant.

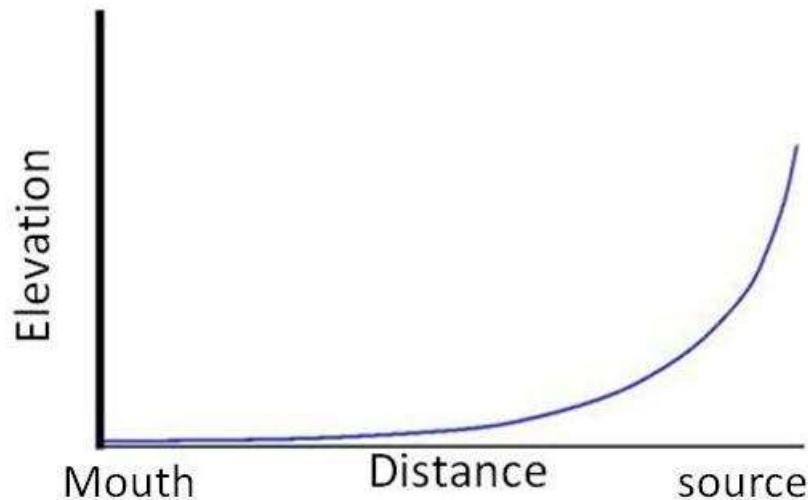


Figure 0-1: Figure showing smooth longitudinalriver profile of a typical steady state river.

How can we practically extract a river profile?

River profile can be extracted from two ways

- I. Field study (with collection of the river bed elevation along the downstream).
- II. Remote sensing study (using DEM)

In Field study by going to field and note down the elevation of the river by SONAR survey at different point along the river then draw the river profile. This method is very tedious and expensive. This empirical method is not suitable for the large number of river and area that under the observation.

Using Digital Elevation Model (DEM); remote sensing data collected through space borne satellite platform, (without going field) in laboratory by different GIS software (ArcGIS, QGIS, Global Mapper, etc.) to draw the same profile which takes very less time as compared to field study.

Deviation in parabolic long profile is caused by varying tectonic activity, lithology and climatic condition. Apart from these in practical, when we extract river profile by using DEM, we also see stair stepping path in river profile it may be observed due to DEM resolution effect. We can't differentiate the contribution of the above said factor towards the deviation in smooth profile to a stair stepping path. So, observing the profile deviation from the long profile will leads to vague interpretation of underlying dynamics. (Figure 0-2)

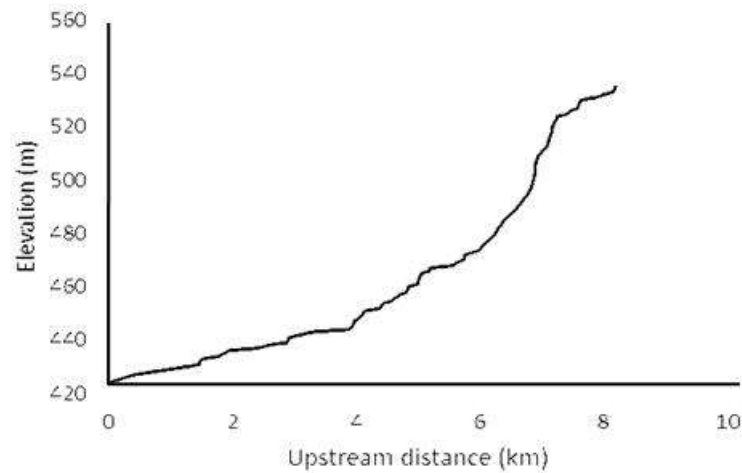


Figure 0-2: Showing stair stepping in river profile that contracted through data extracted by the DEM.

PREVIOUS WORK

Stream Power and River Channel

Stream power of a river is said to be the energy of the stream of water along the channel need to do all the work such as erosion, transportation of the sediments against the gravitational force. For a detachment-limited system (i.e. bed rock river), it has been found that the rate of erosion (E) bears a power-law relationship with stream power per unit area [multiplying shear stress (τ_b)] with flow velocity (V) i.e. $(\tau_b V)^a$. The basic stream power erosion model is given by

$$\Rightarrow E = k_b (\tau_b V)^a \quad (1)$$

From above equation a is positive constant and k_b is the dimensional constant which depends upon the rock mass quality (lithology, jointing, and weathering), sediment influx and the process of erosion (Whipple & Tucker, 1999).

From several mathematical and analytical studies, it is presented as the erosion rate also depends upon the ratio between sediment influx q_s and the sediment transporting capacity q_c . Empirically, the rate and process of incision can be regulated by this ratio. When the ratio has value <1 , incision rate accelerates due to availability of more tools to erode away the bed rock and value >1 provide a retardation to incision rate due to the covering up the river bed with excess of sediments. This ratio is mostly depending upon the climate, rate of upliftment, the position of drainage basin of the river. These two physical entities can be introduced to equation 1 in a way that,

$$k_b = k_e f(q_c, q_s) \quad (2)$$

k_e Represents the dimensional constant

The combining equation of equation 1 & 2 can inform about the flow hydraulics, channel geometry, and basin hydraulics.

Taking the flow hydraulics in account, we can relate the discharge of the river with the flow velocity V , depth of channel (D), width of channel (W). From conservation of mass (water) equation:

$$Q = VDW \quad (3)$$

Shear stress is given by (steady state flow equation)

$$\tau_b = \rho g D S = \rho C_f V^2 \quad (4)$$

Where C_f is the hydraulics constant

From channel geometry

$$W = k_w Q^b \quad (5)$$

$$\text{And} \quad Q = k_c A^c \quad (6)$$

k_c & k_w are the dimensional constant, b and c are positive dimensionless constant. k_w and b is dependant of rock quality, erosional process, sediment load whereas c and k_c depends upon the climate.

From combinations of the above equations from 1 – 6, we get

$$E = K A^{2ac(1-b)/3} S^{2a/3} \quad (7)$$

The simplified form of the equation is

$$E = K A^m S^n \quad (8)$$

The equation 9 is stream power erosion model for river profile evolution. Area is introduced as a proxy for discharge. K is the dimensional constant and coefficient of erosion rate often termed as Erodibility, m and n is the empirical positive constant (Howard & Kerby, 1983).

The evolution the river profile can be equated by considering the conservation of mass (bed rocks)

$$\frac{dz}{dt} = U(x, t) - E(x, t) \quad (9)$$

From equation 8

$$\frac{\partial z}{\partial t} = U(x, t) - K(x, t) A(x, t)^m \left| \frac{\partial z}{\partial x} \right|^n \quad (10)$$

The above equation is the stream power model for the evolution of the river in which z , x , t represents elevation, upstream distance, time respectively. Channel slope S is replaced by $\frac{\partial z}{\partial x}$ and U is denoted for the rate of upliftment.

To derive the slope area relation from stream power equation, it has to be considered both **U** and **K** uniform and steady state river profile i.e. $\frac{\partial z}{\partial t}$ has to be zero. Hence the equation will

$$U = KA^m \left| \frac{\partial z}{\partial x} \right|^n$$

$$\text{Or, } \left| \frac{\partial z}{\partial x} \right|^n = \frac{U}{K} A^{-m}$$

$$\text{Or, } \frac{dz}{dx} = \left(\frac{U}{K} \right)^{1/n} A^{-m/n} \quad (11)$$

The equation 11 describe a power law relation between slope and drainage area of the river and it is limited for the rivers in steady state

Slope-Area Analysis

Slope area analysis is widely used method to study the river profile evolution. The analysis has been governed by the equation (11). The slope area analysis requires calculation of specific catchment area (drainage area divide by flow width) and the local channel slope at every point along the river.

It has been presented that in slope area plot the values nearly follow two trend lines, one with increasing slope and other has decreasing slope. The former one represents the debris flow region in river indicating the younger stage of the river where the sediments tend to move downward along the hill slope under the action of gravity and the fluvial process is not active apparently (Figure 0-1). The later one shows the fluvial process where the slope gradually reduced with increasing drainage area. The area value from which slope starts to reduce in slope area plot is the *critical area*. The intercept of the trend line gives the value of $\left(\frac{U}{K} \right)^{1/n}$ often termed as *steepness index* (Wobus et al., 2006).

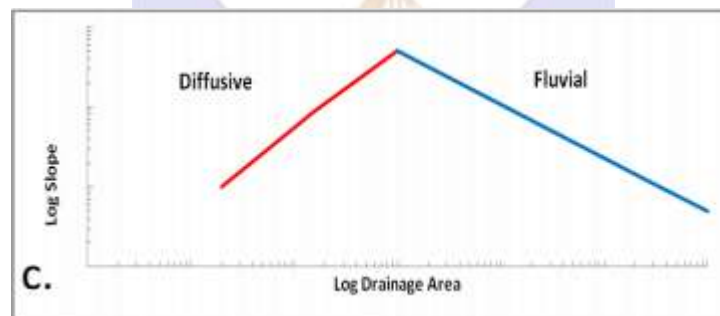


Figure 0-1. Figure showing log- log plot slope verses drainage area.

Chi analysis

Chi analysis involves the calculation of chi, new parameter which can be derived by integrating upstream drainage area with the upstream distance. It incorporates coordinate transformation, where distance is replaced by Chi (χ) (Perron & Royden, 2013).

Derivation of chi can be obtained performing integration on both side of equation 11

$$\int dz = \int \left(\frac{U}{K} \right)^{1/n} A^{-m/n} dx \quad (12)$$

Integrating equation from base i.e downstream endpoint (x_b) to the observation point i.e upstream end point (x), because the total river profile has to be integrated

$$\int dz = \int_{x_b}^x \left(\frac{U}{KA^m} \right)^{\frac{1}{n}} dx \quad (13)$$

Since river is in steady state with uniform upliftment and erodibility, $(U/K)^{\frac{1}{n}}$ will be constant

$$\int_{z_b}^z dz = (U/K)^{\frac{1}{n}} \int_{x_b}^x \frac{1}{A^{\frac{m}{n}}} dx$$

Or, $\int_{z_b}^z dz = (U/K)^{\frac{1}{n}} A_0^{\frac{m}{n}} \int_{x_b}^x \left(\frac{A_0}{A} \right)^{\frac{m}{n}} dx \quad (14)$

$$\text{Or, } z = \left(\frac{U}{KA_0^m} \right)^{\frac{1}{n}} \int_{x_b}^x \left(\frac{A_0}{A} \right)^{\frac{m}{n}} dx + z_b$$

$$\text{Or, } z = \left(\frac{U}{KA_0^m} \right)^{\frac{1}{n}} \chi + z_b \quad (15)$$

$$\text{And } \chi = \int_{x_b}^x \left(\frac{A_0}{A} \right)^{\frac{m}{n}} dx \quad (16)$$

In equation 15, a reference area A_0 , arbitrarily chosen area is introduced to integrand to obtain balance between dimensions on both side of equation. Chi plot comprises value of chi and elevation along its abscissa and ordinate axis respectively. Chi is calculated from equation 17 and has same unit and dimension as distance has.

In chi plot, a steady state river profile (parabolic) turns into linear because of equation 16, a linear equation where intercept Z_b is the lowest elevation i.e. elevation at x_b downstream end point and slope of the straight line gives ratio of rate of upliftment (U) to the erodibility (K); for $n=1$ (Royden et al. 2013).

In equation 19 by taking different m/n ratio straight lines with different are obtain from chi plot of a river, since the slope of line in chi profile also includes the value of m/n . So the mn ratio is the key in conversion of river profile into a straight line. The river profile attains linearity for the best suited m/n ratio.

OBJECTIVE

1. To find if the LSDTopotools and the LandSpy code manage to yield similar result as the Manual method?
2. Measurement of river steepness of the drainages around pristine Son-Narmada South Fault (SNSF), in the vicinity of Jabalpur, using these three methods and drawing inference about Neo-tectonics stability of the area.

PRINCIPLE & METHODOLOGY

Principle

Transformation of river profile

The Chi (χ) analysis is a method used to convert the long profile of a river into a straight-line graph introduced by (Perron & Royden, 2013). (Figure 0-1)

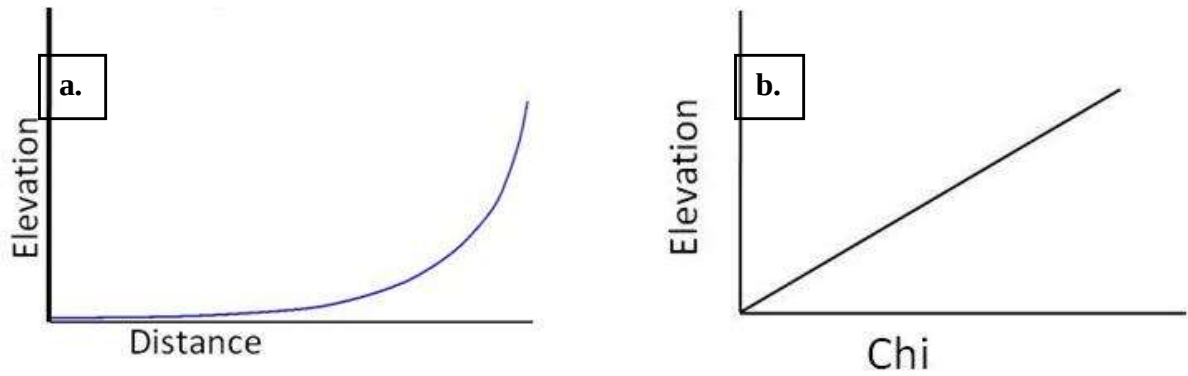


Figure 0-1: showing a. longitudinal river profile, b. chi profile

For a steady state chi profile will attain a straight line. As it is a straight line and having a constant slope any deviation can be identified easily. Such deviation in the slope of chi profile attributed to transient river profile in response of tectonic/climatic variation.

Principle of Chi Analysis

By using the fundamental stream-power equation

$$\frac{dz}{dt} = U(x, t) - K(x, t)A(x, t)^m \left| \frac{dz}{dx} \right|^n \quad \dots\dots 1$$

(Howard, 1994; Howard & Kerby, 1983; Whipple & Tucker, 1999)

Equation (1) represents that the relation between change in elevation through time is equal to the upliftment rate minus erosion rate scales with either stream power per unit area of the bed as a function of distance (x) and time (t).

Where U, K, z, and A are stands for rate of upliftment, erodibility coefficient, elevation and drainage area respectively.

For fluvio-dynamics steady state we are assuming elevation does not change with time

$$\text{i.e. } \frac{\partial z}{\partial t} = 0$$

Rearranging and solving equation 1;

$$\left| \frac{dz}{dx} \right| = \left(\frac{U}{K} \right)^{\frac{1}{n}} A(x)^{\frac{-m}{n}} \quad \dots\dots 2$$

Equation (3) can be expressed in form of empirical relation between river slope and drainage area proposed earlier by Flint, 1974; Gilbert, 1877; and Hack, 1957.

$$\frac{dz}{dx} = K_s A^{\frac{-m}{n}} \quad \dots\dots 3$$

$$\text{(Here } K_s = \left(\frac{U}{K} \right)^{\frac{1}{n}} \text{)}$$

Rearranging and integrating both side of equation (3);

$$\int_{z_b}^z dz = \int_{x_b}^x k_s A^{\frac{-m}{n}} dx \quad \dots\dots 4$$

$$z - z_b = \int_{x_b}^x k_s A^{\frac{-m}{n}} dx \quad \dots\dots 5$$

$$z = z_b + \frac{k_s}{A_0^{\frac{m}{n}}} \int_{x_b}^x \left(\frac{A_0}{A} \right)^{\frac{m}{n}} dx \quad \dots\dots 6$$

Arranging equation (6) in linear equation form, $Y = C + m \cdot X$

$$z = z_b + \frac{k_s}{A_0^{\frac{m}{n}}} \chi \quad \dots\dots 7$$

When we take $A_0 = 1$, K_s is the slope ('m') in chi profile

$$\chi = \int_{x_b}^x \left(\frac{A_0}{A} \right)^{\frac{m}{n}} dx$$

Hence from chi profile it is able to find the surface disturbances.

How to generate chi profile

Traditional method has been used vastly to prepare chi profile using GIS software like (ArcGIS, QGIS, etc.) but this method is very tedious and time taking. As it works on a single river at a time. To understand the surface behavior over a region, a maximum number river should be analyzed.

Therefore, here we have adopted two different computer code based algorithms.

LSDTopoTools method

LSD method is a Linux based developed by Mudd et al. 2014. LSD method has a number of tools for performing Chi analysis. This method is well reviewed code and has been used in earlier published literature (Mudd et al., 2014).

LandSpy method

LandSpy is a Python based open source Code for geomorphic analysis. This method relatively new to topographic analysis such as extraction of drainage network, calculation of Chi-map, create channel from a polyline shape file. No published literature is available using this method.

Comparison

Table 1: showing comparison of three methods

Manual	LSD	LandSpy
1. Significance of threshold value >>>>		
• Threshold value signifies the minimum number of flow accumulation required to form a channel.	Same as Manual Method	Threshold value signifies the minimum basin size in pixel.
2. Execution of chi analysis >>>>		
- Carried out with a single river at a time. Chi calculation of all the rivers is tedious. Hence, few representative rivers are chosen. Basin wise different concavity value is enforced based on the maxima test and collinearity test.	- Carried out on multiple rivers at a time. Therefore, chi analysis takes less time w.r.t Manual method. - A unique concavity value is applied for whole area under observation and basin wise different value can't be chosen	Same as LSD
3. Calculation and determination of K_{sn} >>>>		
K_{sn} is determined from slope of regression line fitted to the chi elevation profile of the river. Individual river yield a single K_{sn} Value	K_{sn} is determined by fitting multiple segments to the chi elevation profile of river. k_{sn} value is given for each cell of an individual river.	Same as Manual Method

CASE STUDY AND RESULT

The Jabalpur region situated under the EWE-ENE trending Central India tectonic Zone (CITZ) bordered by the Son Narmada North Fault (SNNF) in the north and Central India Shear Zone (CISZ) in the south. In between SNNF and CIS boundary lineaments Son Narmada South Fault (SNSF), Balrampur Fault (BLF) and Tan Shear Zone (TSZ) occurs from north to south respectively. This lineament is believed to be a major Precambrian deep crustal feature and a possible intra-plate paleo-rift, with evidences of reactivation. The most striking feature of the Son Narmada Lineaments (SNL) is its clear surface expression extending from west to east across central India. The region is seismically one of the most active in the Indian shield.

General geology of the area

There are several different types of rock formations in the Jabalpur region, ranging in age from Archaean-Proterozoic to recent alluvial deposits. The Mahakoshal group of rocks, are ages ranging from Archaean to Paleoproterozoic, are the oldest exposed rocks in the area. These are chiefly metamorphic rocks, which are folded, faulted and sheared. The Madan mahal Granites occur as intrusive within the Mahakoshal group and are coarse-grained holocrystalline rocks of late Proterozoic age. The Deccan Traps are among the world's largest volcanic flows of Paleocene age, predominantly overlying the Jabalpur region. The Lameta Group is made up of sedimentary rocks that lie beneath the Gondwana strata and are primarily exposed on the southern side of Narmada River.

The study area experienced three phases of deformation.

The Central Indian Tectonic Zone (CITZ) was formed by the collision of the North Indian Block (NIB) and the South Indian Block (SIB) in the Proterozoic era (Bhowmik et al., 2012). This collision resulted in the uplift and deformation of the rocks in the region.

Gondwana basin formed due to the renaissance of the pre-existing intra-cratonic continental rift of the Proterozoic age by extensional tectonic setting (Veevers & Tewari, 1995).

Reactivations of the pre-existing fault/shear zones are responsible for the occurrence of recent seismicity event over the Stable Continental Region (SCR) (Acharyya & Roy, 2000). The Cenozoic deformation phase leads to the active tectonic activities (Bhattacharjee et al., 2016; Copley et al., 2014). In present study we analyze the neotectonic status of the SNSF around the Jabalpur.

Channel network using LSDTopoTools

First, we take threshold contributing pixel 10000 and get few large rivers that are not sufficient for our analysis. (Figure 0-1)

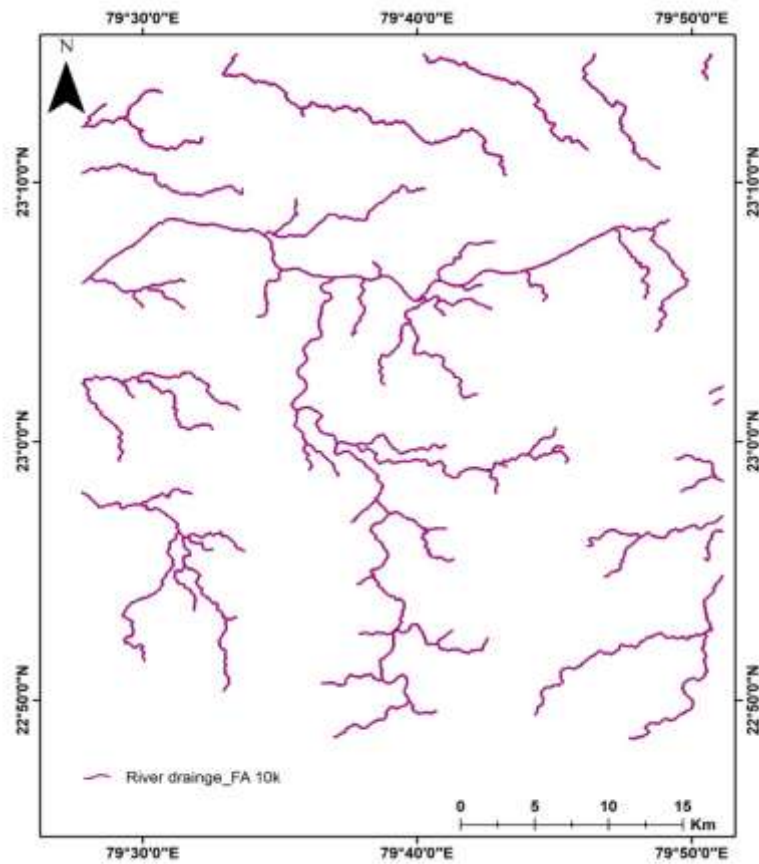


Figure 0-1: channel network for threshold pixel 10000

So we decrease threshold contributing pixel value to check the drainage density. Now we are changing threshold contributing pixel to see the differences in channel network. (Figure 02).

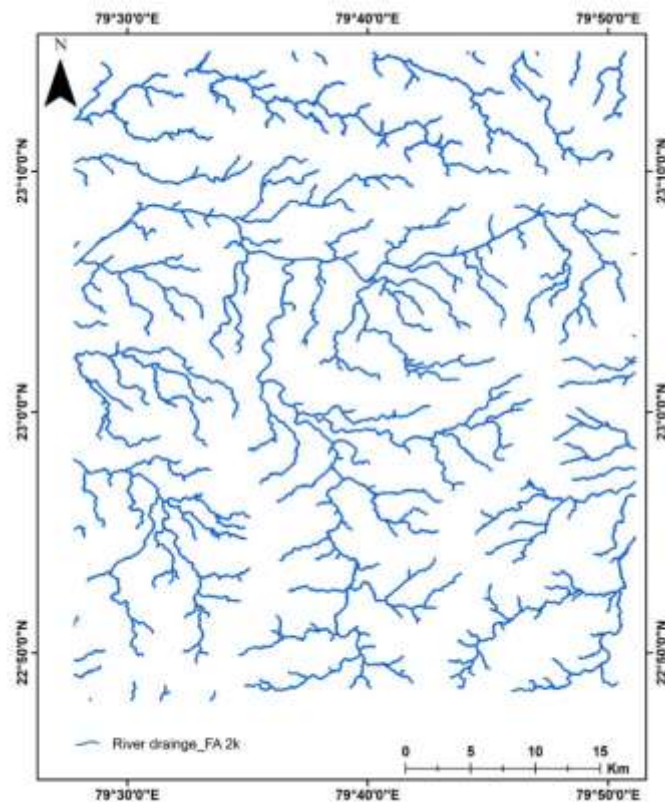
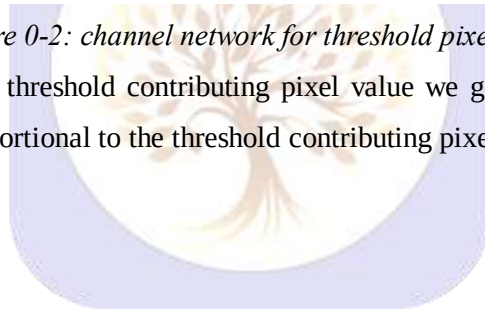


Figure 0-2: channel network for threshold pixel 2000

As we decrease the value of threshold contributing pixel value we get denser channel network. So the channel network is inversely proportional to the threshold contributing pixel.



For extraction of channel network using LSDTopoTools we considered threshold contributing pixel 1000 to get continuous river which are suitable for our analysis. (Figure 0-3).

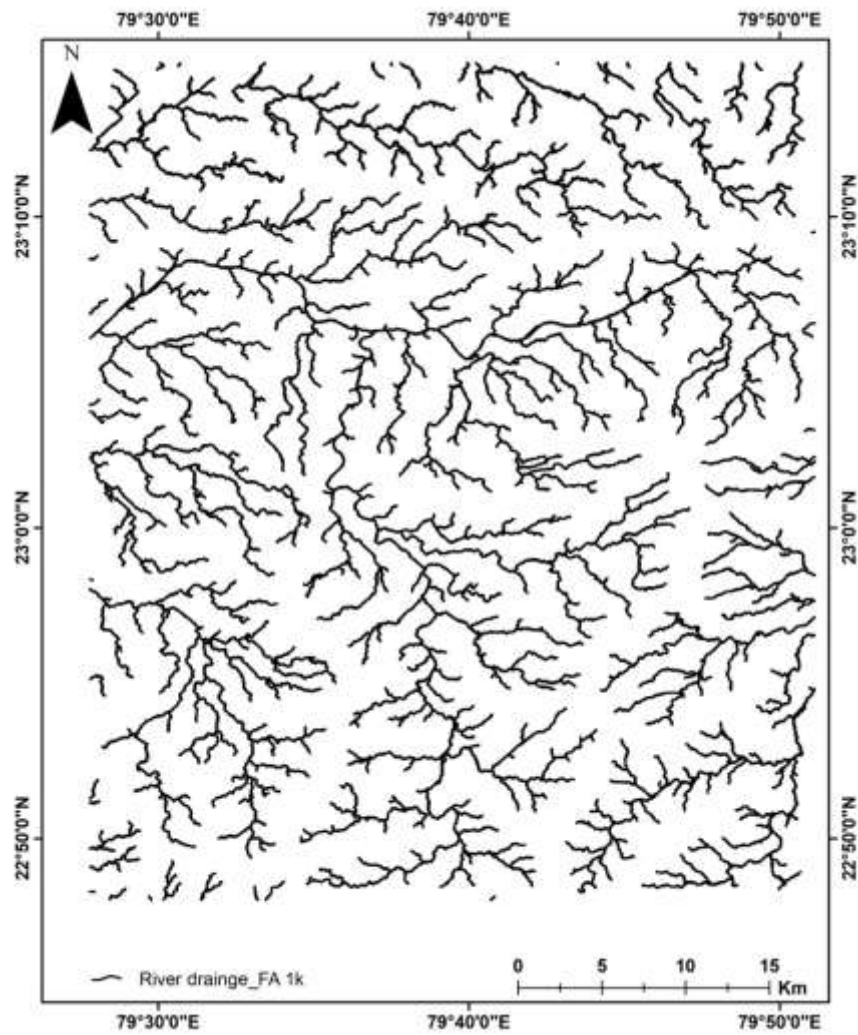


Figure 0-3: channel network for threshold pixel 1000

Channel network using Landspy

In Landspy a threshold value that signifies minimum basin size. Any drainage has basin size less than threshold value will not consider as river drainage. For extraction of channel network by Landspy we take threshold value 1600 (Figure 0-4).

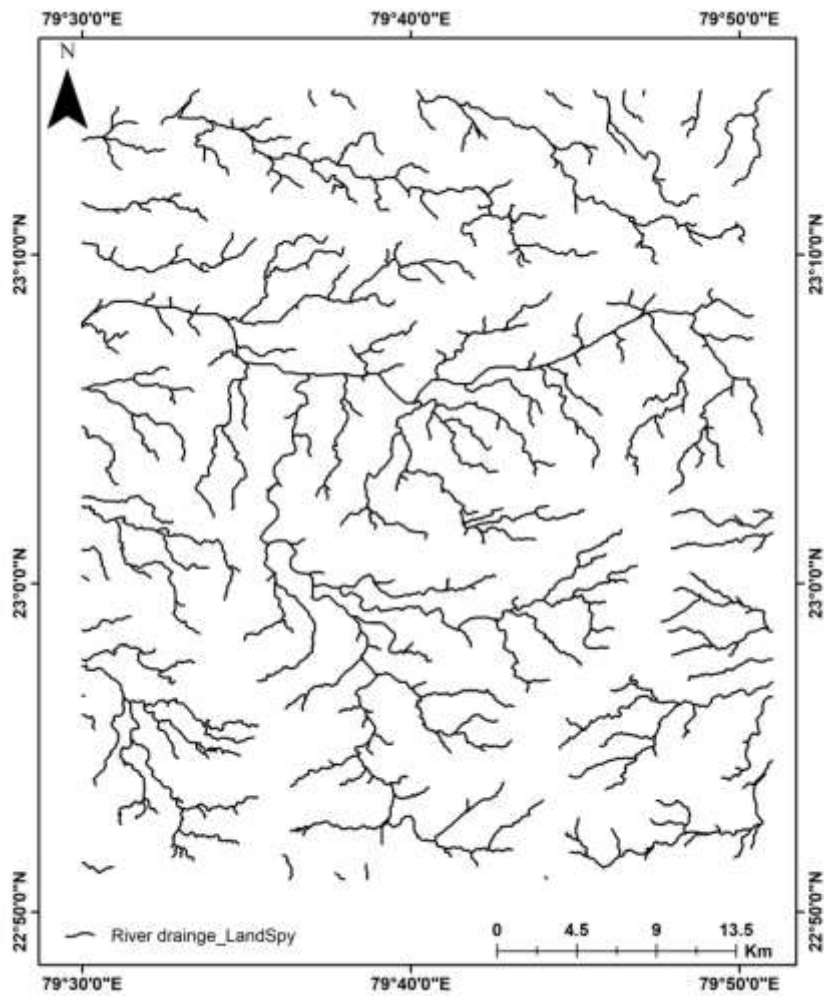


Figure 0-4: showing channel network of study area using LandSpy

Channel network using Manual method

For this analysis, drainage basins were extracted by taking different flow accumulation values. The drainage density is inversely proportional to the flow accumulation value. We considered flow accumulation 1000 suitable for our analysis, the drainage pattern generated with this value shown in the (Figure 0-5).

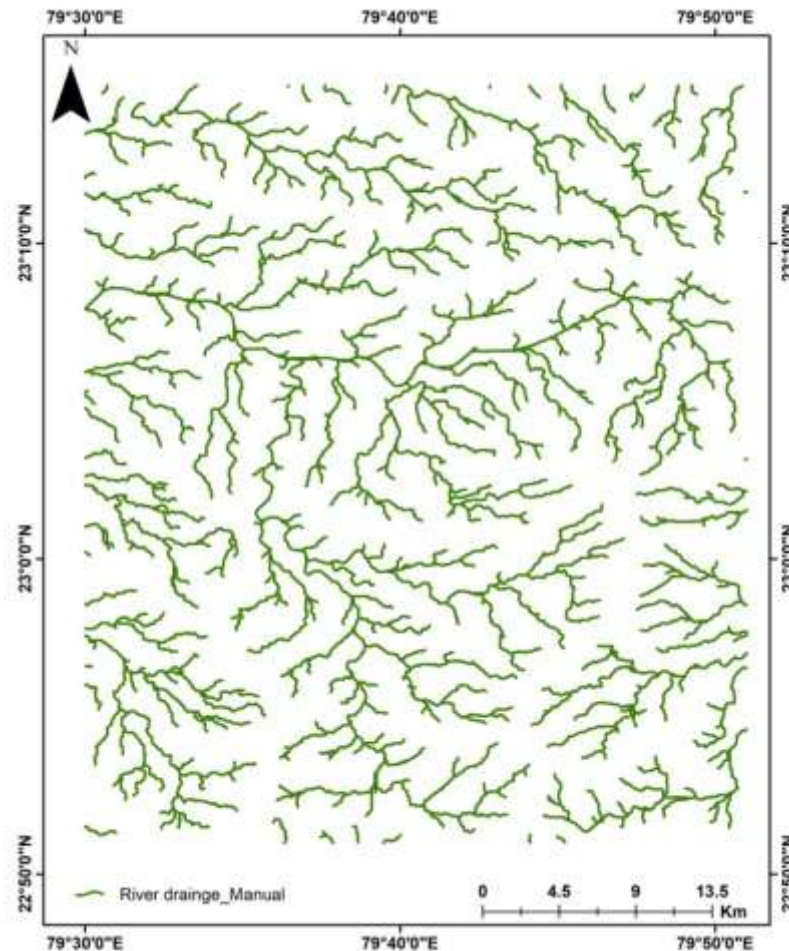


Figure 0-5: showing Drainages of study area using Manual method

Comparing channel network obtained from Manual, LSD and LandSpy

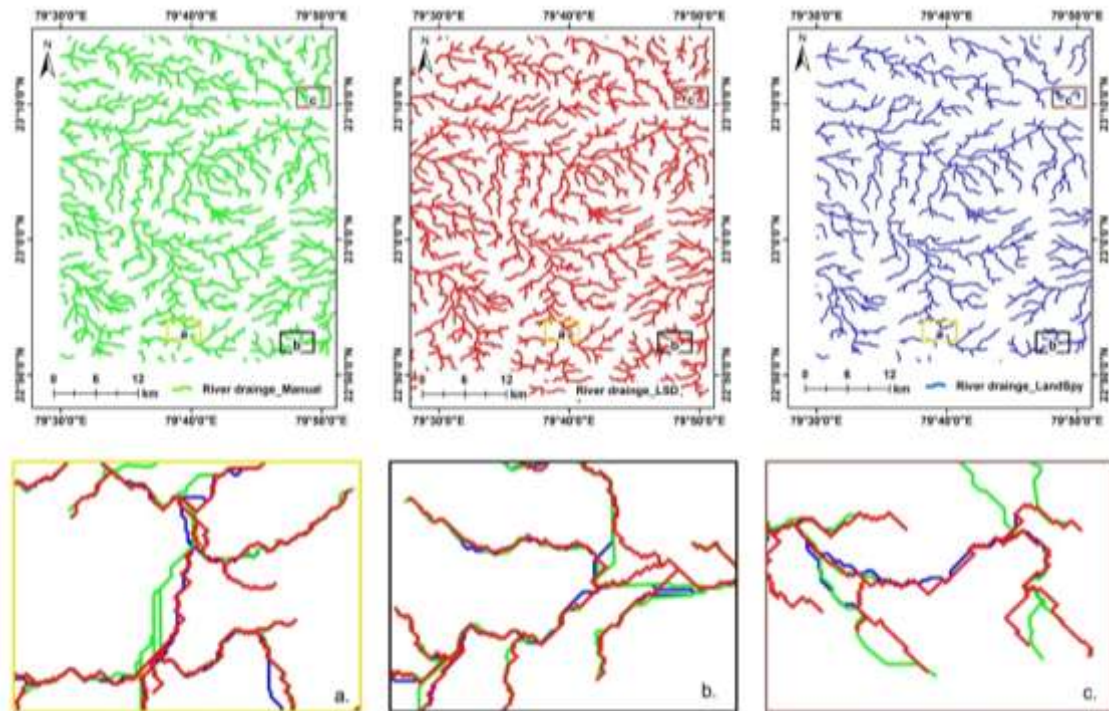


Figure 0-6: showing compassion of channel network

Channel network obtained from 3 methods shows almost similar. LandSpy channel network identical as in Manual method and coincides with the Manual channel networks in most places where, at few places the LSD flow path is found slightly different than LandSpy and Manual method error within limit can be acceptable for our study area.. (Figure 0-6)

Extraction of channel steepness map using LSDTopoTools

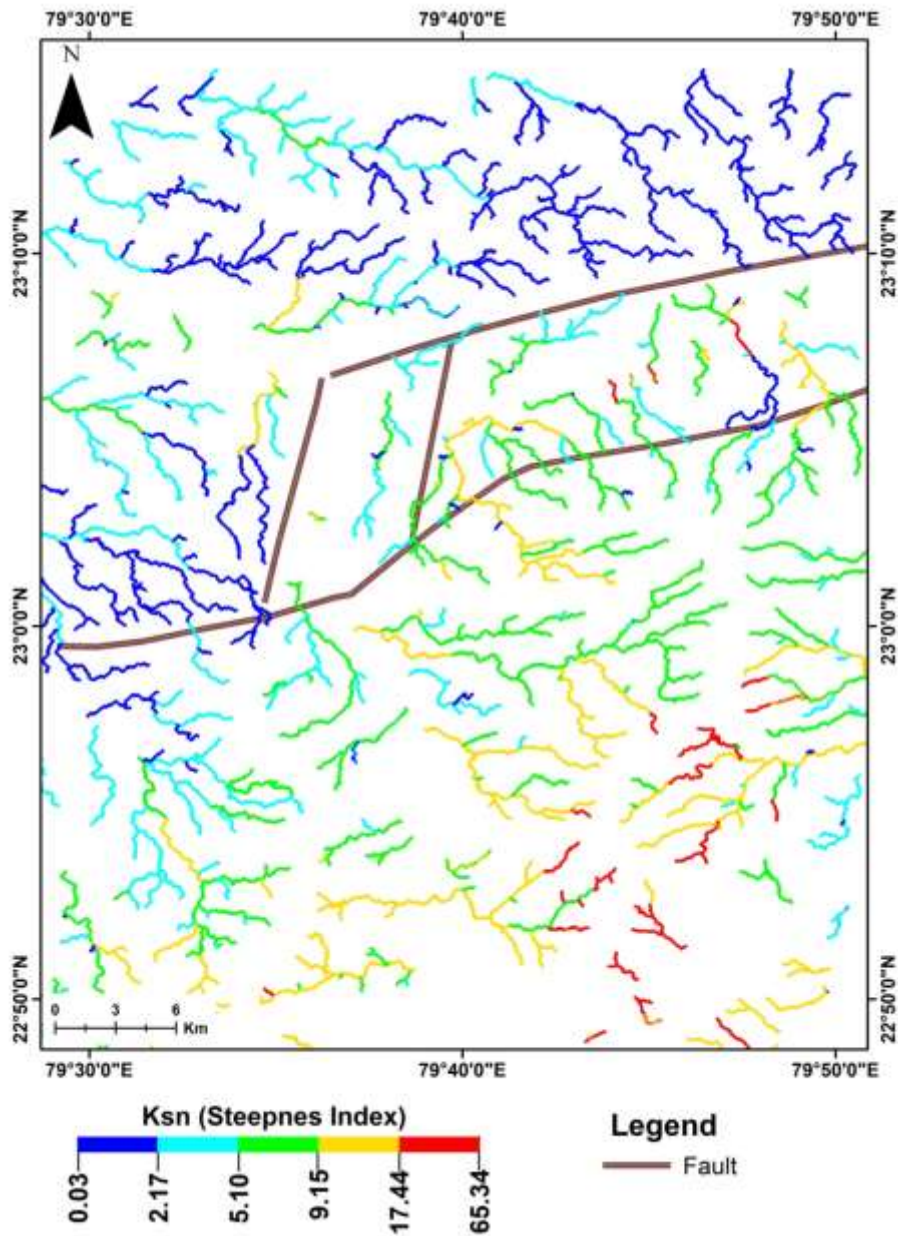


Figure 0-7: showing channel steepness map using LSD

This steepness map showing in (Figure 0-7) the block above the fault line is lower river steepness and the block below the fault line higher river steepness. Higher the steepness value indicates steeper is the channel and lower the steepness value indicates gentler is the channel.

Extraction of channel steepness map using Landspy method

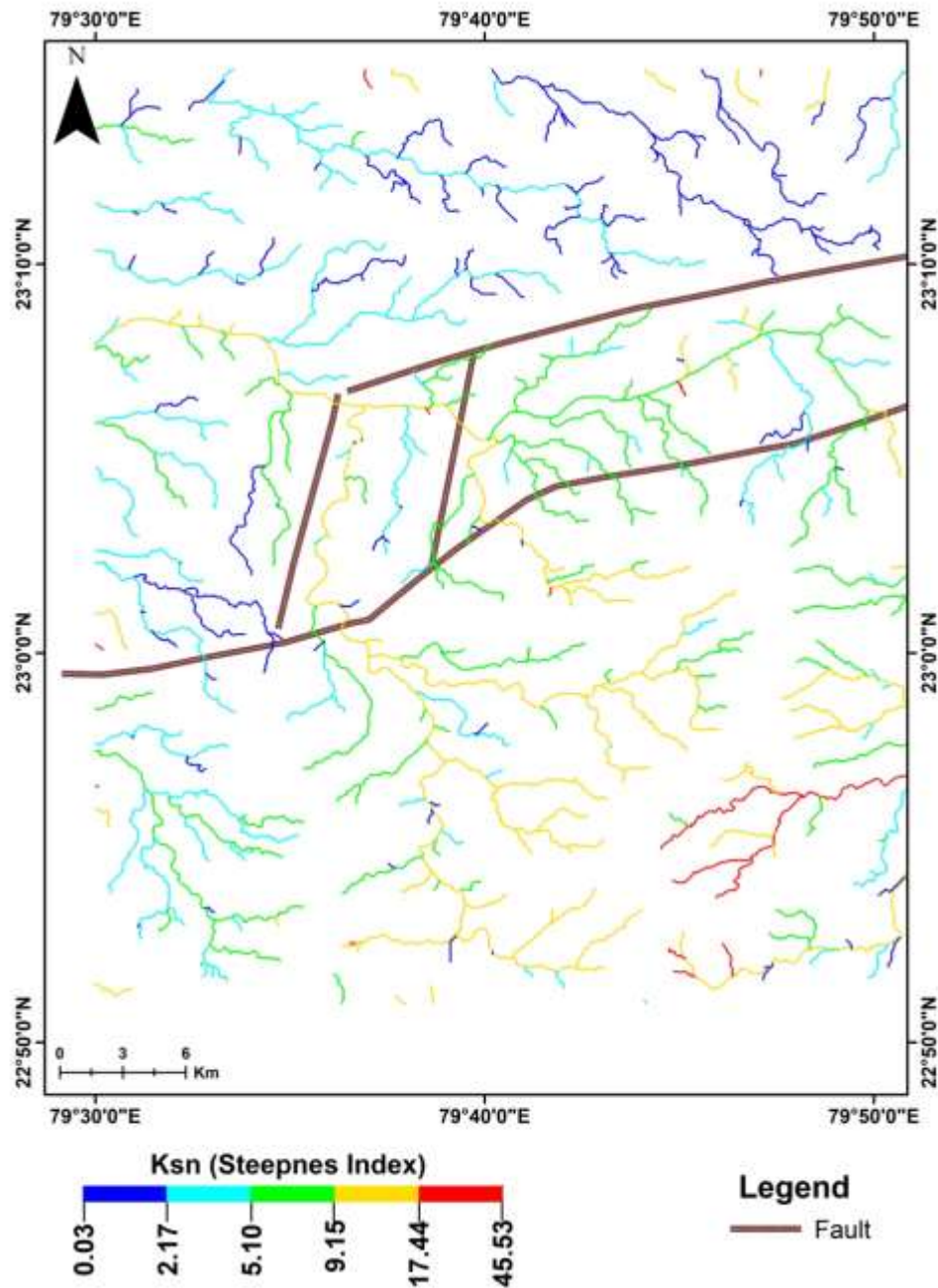


Figure 0-8: showing channel steepness map in Landspy

The river channel steepness values of southern river shows higher and northern rivers show lower steepness values. (Figure 0-8)

Extraction of channel steepness map using Manual method

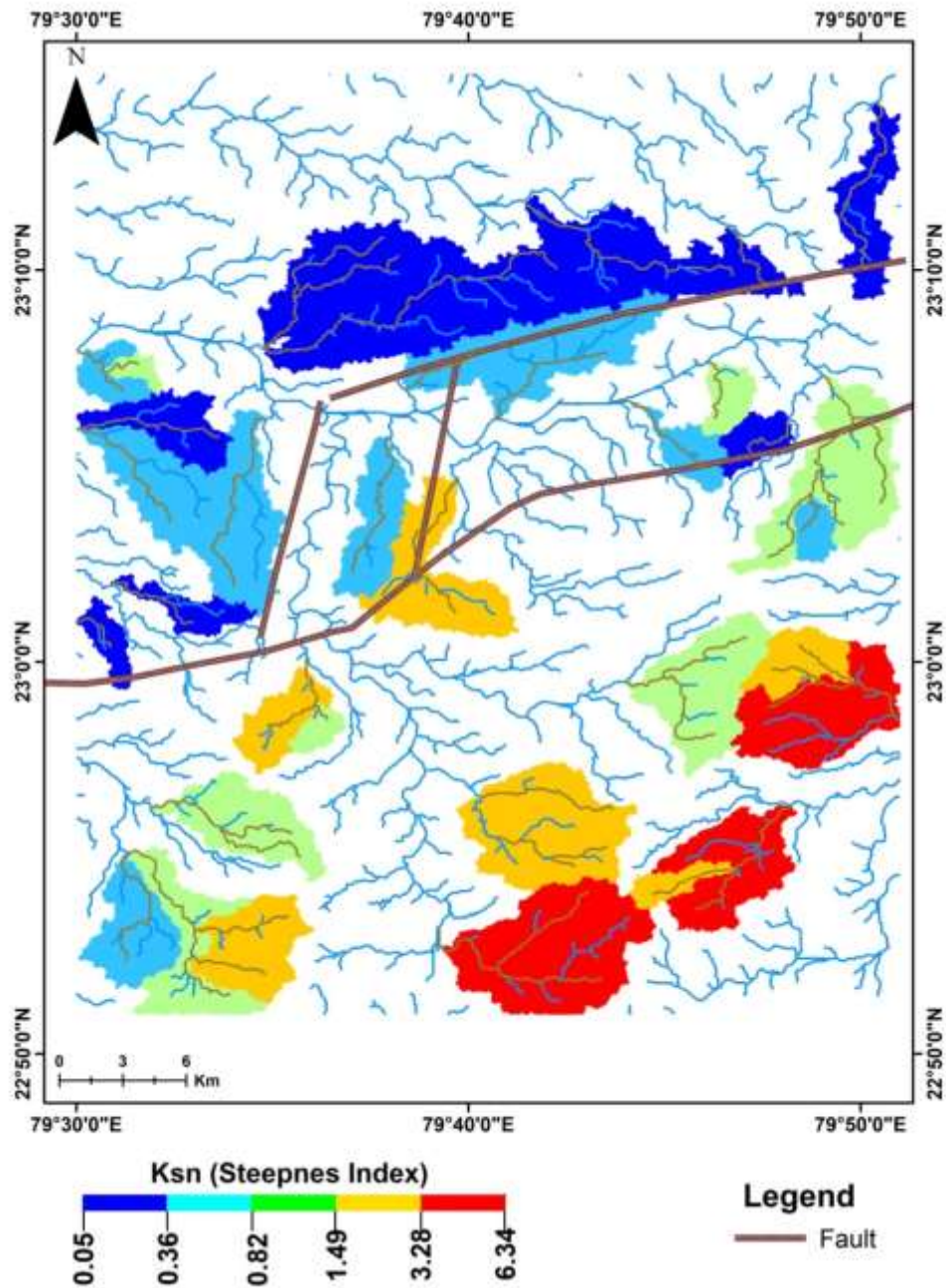


Figure 0-9: showing channel steepness map in Manual

Here we calculate river channel steepness of few selected river of our study area show higher steepness in southern part and lower steepness in northern part are shown in (Figure 0-9).

Selected river with their drainage basin

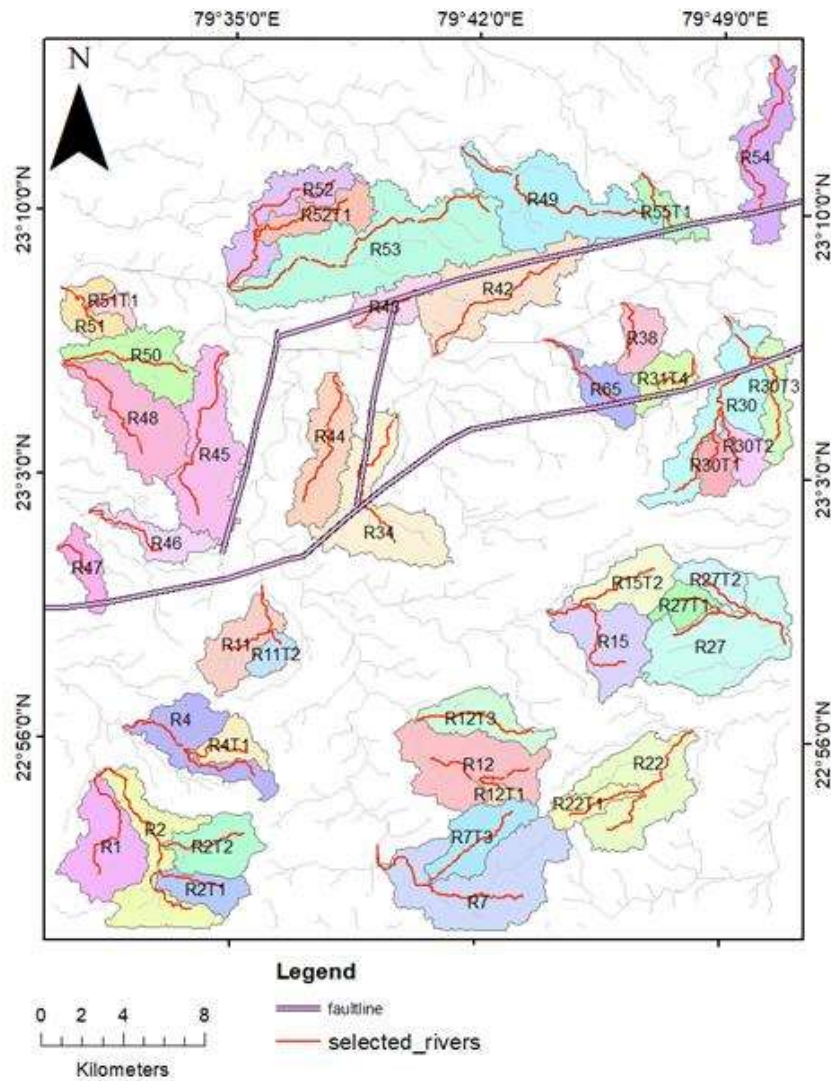


Figure 0-10: showing selected rivers with their drainage basin

This map showing selected river of our study area which are used to calculate channel steepness with three different methods are shown in the (Figure 0-10).

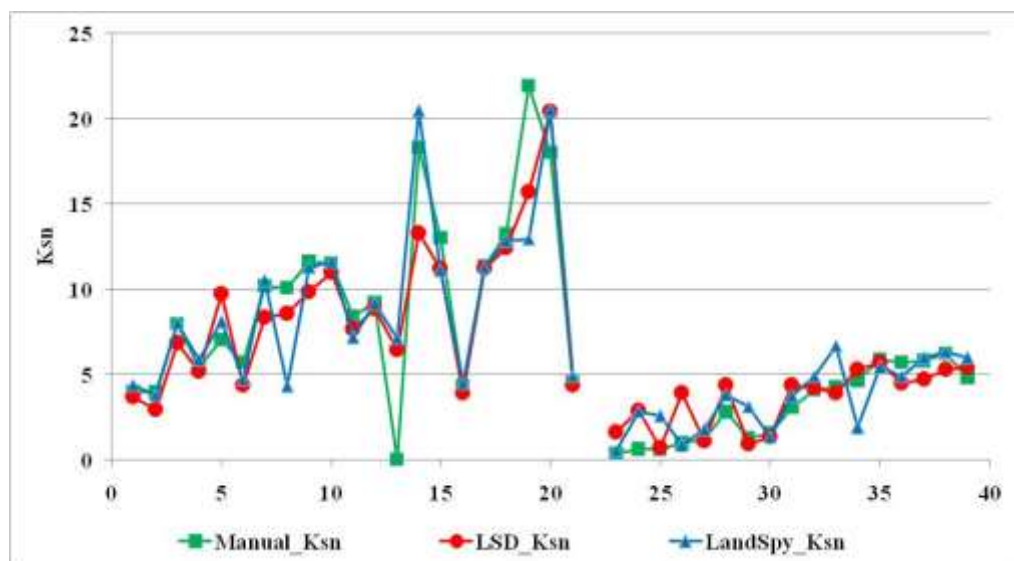


Figure 0-11: showing comparison of Ksn graph plot

Graph shows in (Figure 0-11) almost similar trend of channel steepness index (K_{sn}) of selected river obtains by LSD, Landspy and Manual method. Landspy gives channel steepness value 5000 times greater than LSD and Manual method. After dividing 5000 with Landspy K_{sn} value the trend of graph coincide with LSD and Manual method.

Comparing channel steepness obtained from Manual, LSD and LandSpy

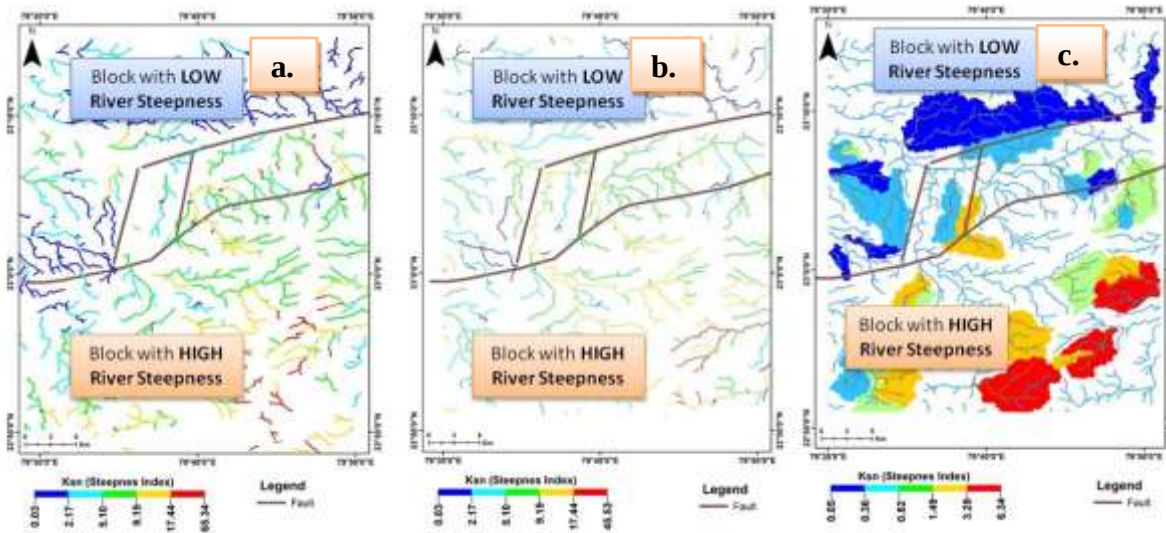


Figure 0-12: showing comparison of channel steepness a. LSD, b. LandSpy & c. Manual

These maps are showing in (Figure 0-12) river channel steepness of our study area, which are obtained using LSD, LandSpy and Manual methods respectively. These three methods show similar channel steepness of our study area where northern rivers show lower channel steepness values and southern rivers shows higher channel steepness values.

Discussion& conclusion

Analyzing the longitudinal profile of a river is crucial for predicting tectonic activity in the region. By utilizing DEM data, we can readily derive the river profile. However, the presence of stair steps on the longitudinal profile may be attributed to the spatial resolution of approximately 30 meters and a vertical resolution of 1 meter in our case. High-resolution data enables the formation of a smooth longitudinal profile.

The channel steepness of a river is a useful metric for assessing whether the slope of the river channel is unusually steep or gentle in comparison to the size of its drainage basin. The abnormal steepness index is caused by climatic variations in the region, variations in lithology, and tectonic activity. Chi analysis of a river is useful for determining the channel steepness and transforming the parabolic longitudinal profile into a straight profile, based on a specific concavity m/n value. The Chi profile of a steady state river is a linear function, where the rate of upliftment and erodibility along the river channel results in a consistent U/K value. When a river is in a transient stage, the U/K value varies across different segments of its profile. The slope of the Chi profile, as described by equation 7, quantifies the degree of steepness in the river channel.

We utilized a manual method as well as two automated computer code based algorithms, namely LSDTopoTool and LandSpy methods, for the extraction of drainages and calculation of the Chi and steepness index. In the manual method, we have the option to select the concavity value for each basin individually. However, this approach is time-consuming and laborious. In the software programs LSDTopoTool (compatible

with Linux) and LandSpy (written in Python), the steepness index is calculated for the entire region using a single concavity. This results in a normalized steepness index. The Manual and LandSpy methods provide a single steepness index value for a single river channel, while the LSDTopoTool assigns multiple steepness values for different segments of the same river channel. It is worth noting that the LandSpy tool has not undergone peer review and has not been used in any published research articles to date. However, its code is available on the open-source platform GitHub.

The channel networks obtained from three distinct methodologies demonstrate comparable outcomes within acceptable margins of error. The channel network produced by LandSpy closely corresponds to the river channels constructed manually, exhibiting alignment with the manually created channels in the majority of locations. Nevertheless, in certain regions, the LSD flow path diverges slightly from both LandSpy and the manual approach. However, these discrepancies fall within the acceptable range for our study. LandSpy notably yields channel steepness values that are 5000 times higher than those obtained through the LSD and manual methods. When graphing the channel steepness values of specific rivers from our research area using these three techniques, the patterns seem nearly identical and align when the LandSpy steepness values are divided by 5000.

Upon comparison, it is evident that the manual method is relatively time-consuming and sluggish, as it can only manage one river at a time. On the other hand, LSDTopoTool and LandSpy offer quicker outcomes and have the capability to analyze numerous or all river drainages in the specified region. Nevertheless, LandSpy tends to yield markedly higher values in comparison to the manual and LSDTopoTool methods. Our analysis indicates that LSDTopoTool is the superior choice due to its current superiority in terms of speed and precision.

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