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Research Article

LANDSLIDE SUSCEPTIBILITY ANALYSIS FROM MORPHOMETRIC PARAMETER ANALYSIS OF RIYONG KHOLA BASIN, WEST SIKKIM, INDIA: A GEOSPATIAL APPROACH

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ABSTRACT
Morphometric analysis of Riyong Khola basin is attempted to know the basic landscape configuration of the basin and prepare a Landslide susceptibility zone map with the help of GIS platform to pursuit a cartographer’s performance in real world mapping. The channel morphometry seeks to imply fundamental knowledge of geometric analysis of a landform through proper modeling to attempt a visual interpretation. GIS environment can store, retrieve, manipulate ,classify and finally produce digital maps from which the identification of proper landforms from Geomorphological point of view can be done so gracefully and proper comments can be made on the basic landscape configurations like relative relief, dissection index, drainage density, ruggedness index etc. For detailed study, the author has used digital elevation model (using ASTER DEM data), and GIS related tools have also applied for proper understanding of the basic linear, areal and relief aspects of the morphometric analysis. The present author has tried to establish quantitative relationship among various morphometric aspects of the drainage basin that is useful for identifying their relational effectiveness to promote landslide occurrences. Finally, we have attempted simplified Fuzzy-logic method on the prepared digital maps of various morphometric parameters to identify probable landslide susceptibility zones from distinctive tonal differences of the maps.

Keywords: *Morphometric Analysis, Quantitative Measurement, Landslide Susceptibility, Geometric Sequence, Positive Correlation, ANOVA*

INTRODUCTION
The science of morphometry is concerned with quantative measurement and generalization of land surface geometry (Chorley *et al.,* 1984). Riyong khola carries considerable amount of silts and gravels with the flood discharges. Measurement of the shape or geometry of any natural form may be it is a plant, animal or relief features is termed as ‘Morphometry’ (Strahler, 1969). But in geomorphology morphometry may be defined as the measurement & the mathematical analysis of the configuration of the earth surface & of the shape & dimension of its landforms (Clarke, 1970). In fact Morphometry incorporates quantitative study of the area, altitude, volume, slope, profiles of the land, and drainage basin characteristics of the area concerned (Singh, 1972). Geographical information system is used as powerful tools for studying basin morphometry and continuous monitoring. In the present paper an attempt has been made to i) find out characteristics of basin morphometry and ii) the probability of slope failure.

The Study Area
The exact location of Riyong khola is at the toe of the west Sikkim just beside Sambare, a local township. The basin has a geo-coordinate of 27°10’26.1065”N to 27°09’56.6781”N and 88°08’11.28”E to 88°09’59.03”E, finally meets with Rigbong khola at the south. The river is flowing over a very undulating terrain from north-west to south by bifurcating into a number of small tributaries to represent a dendritic pattern. The climate of the state has been roughly divided into tropical, temperate and alpine zones. The maximum temperature is highest in August (27.7°c) and minimum is experienced in December (7.6°c). The state as a whole gets 80% to 90% of the rainfall from monsoonal condensation. The basin is mostly covered by Proterozoic-Precambrian metamorphites of low to medium grade (Daling group), high-grade gneisses (Darjeeling gneiss and Kanchanjungha gneiss), *Chungthang* Formation (Quartzite, Calc-silicate

rocks, marbles, Graphite schist and occasionally amphibolites) with intrusive granites (Lingtse Granite gneiss) and Phanerezoic rocks including *Gondowana* and *Tethyan* rocks.

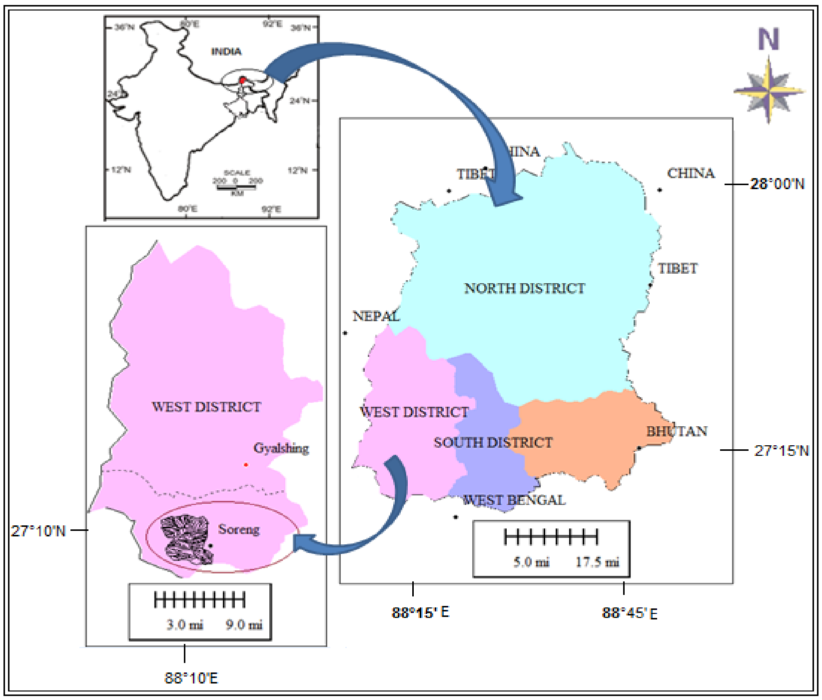

Figure 1: Location Map of the Riyong Khola Basin

MATERIALS AND METHODS

To prepare the Landslide Susceptibility map and for morphometric analysis special assistance of geoinformatics is considered as a good tool of study. A pilot geomorphological field investigation, secondary sources (Basin plan forms from unpublished dissertation work & free source ASTER DEM data 30m resolution, ASTERDEM-30m:METI and NASA) and simplified Fuzzy-Logic method (Vahidnia *et al.*, 2009) based on tonal differences of the digital maps have been taken into consideration. The visual inspection on the basis of tonal variations of the digital maps has been done for understanding the susceptible zones of Landslide hazard under GIS environment. The analysis of data and maps have been completed, corrected, evaluated and the characteristics of existing pattern, topographic aspects, and morphometric components have been represented by using GIS Platforms like Global Mapper 13.0, Map Info Professional 8.0 (Lab. of Dept. of Geography) and Google Earth (using SIO, NOAA, U.S. Navy, NGA, GEBCO data) for accomplishment of the work.

RESULTS AND DISCUSSION

Basic Landscape Configuration of the Basin

The basin is a typical tertiary mountainous terrain bearing a drainage significance set in the nexus of several distinct tectonic zones of various characteristics and associations of varied landscape elements. The landscape presents a complex mixture of fluvio-glacial and fluvial processes set in the axial and parts of inner morphotectonic belts in Sikkim above 9000 ft.The rock structure carries the evidence of tectonic incidents. In this basin, the process and stage are perhaps of more important in determining the main outlines of this landscape. The fluvial-morphometry is also supported by the particular modes of formation of the riverine topography primarily under fluvial environment. The landform of this basin is the outcome of 'altering –pleistocene morphogenetic systems' (Mukharjee, 1982). The typical lithomorphic expression of the Riyong basin has been evolved by the conditional interplay between weathering and erosion.

Drainage System

Riyong khola is the tributary that join the *Rigbong khola* valley from left and right-hand sides respectively at *Bhoutong*, from the wider lower *Talung* valley with comparatively gentler gradient mainly because of the accompanying invigorated lateral planation relating to the augmentation of discharges downstream from their confluence zone (Mukharjee, 1982). The Riyong khola represents a dendritic drainage pattern and numbers of channels get merged with the main channel by maintaining slope pattern. A vast area drained is composed of convex to concave arrangement of slope. Number of small drainage outlets get mixed into the next higher order channel and thus presents a gorgeous hierarchic pattern of stream ordering.

Laws of Drainage Network & Composition - Linear Aspects

Drainage network & composition is the relationship between order, relief of the drainage basin, slope of the drainage basin, shape of the drainage basin etc. of the basin.

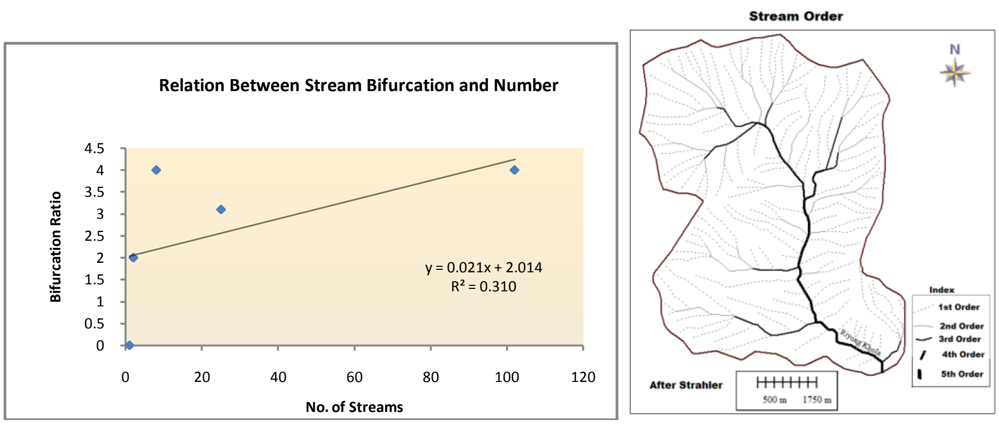

Figure 2: Stream Ordering & Relational Analysis between Morphometric Variables

Stream Ordering

Order is the composition of the embracing system of the drainage network. Stream ordering is the ordering or position of the different segments of the streams. It is the quantitative measurement of the stream & hierarchies of the segments of the tributaries have its own position. The most widely used scheme was adapted by Strahler in 1964.

He gave a simple scheme of ordering, in which fingertip channels are specified as order (u) or l & where two fingertip tributaries joined each other. Then they form 2nd order stream segment. In this basin it has been found that the highest order is 5th.

Total no of first order stream is 102, where as the 2nd, 3rd, 4th & 5th ordered streams are 25, 8, 2 & 1 respectively. It is observed that the maximum frequency is in the case of first order streams and that there is a decrease in stream frequency as the ‘stream order’ increases. The amount of soil erodibility from summital part of the basin is reflected from ordering.

Bifurcation Ration

According to Schumn (1956) the term Bifurcation ratio may be defined as the ratio between the total number of streams of an order & next higher order. It is dimensionless property of the drainage basin supposed to be controlled by drainage density, lithological characteristics, stream entrance angle, basin shape and area etc (Savindra Singh, 2007).

Lower R_b values are the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern (Nag, 1998). It varies from different physiographic & structural unit. The Rb_m of Riyong basin is 2.88 which also bear the characteristics of hilly terrain where high stream branching denotes high amount of Rb_m (figure 2). The geological structure of the basin does not distort the drainage pattern.

Stream Length Ratio (r_l)

Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number. Generally the total length of stream segments, maximum in first order streams & decreases as the streams order increases. It involves measurement of the length of the different rank / order of streams in a drainage basin. Changes in r_l from one order to another indicate the late youth to mature stage of the geomorphic development (Singh and Singh, 1997).

Mean Stream Length (L_{sm})

According to Strahler (1964), the mean stream length (L_{sm}) is a characteristic property related to the drainage network & its associate surfaces. The mean stream length is calculated by dividing the total stream length of each order & number of streams of each order. Generally, there is a positive relationship between stream order and Mean Stream length. The calculation of Mean Stream length ratio of *Riyong khola* basin is represented in the table below:

Table 1: Empirical Formulas for Computation of Morphometric Parameters

Sl. No.	Morphometric Parameter	Formula	Reference	Result
1	Stream Order (Nu)	Hierarchical rank	Strahler (1964)	5^{th} Order
2	Stream Length (km)	Lu = L1+L2 ……Ln	Strahler (1964)	GIS
3	Mean stream length (km)	Total stream length divide by total number of streams	Strahler (1964)	GIS
4	Mean Bifurcation Ratio (Rbm)	Rbm= Average of Bifurcation ratio of all orders	Schumm (1956)	2.88
5	Drainage Density (Dd) km/km2	D_d =Lu/Au Where Lu =total length of stream segments cumulated for each stream order, Au= Basin area	Strahler (1964)	3.30
6	Stream Frequency (F)	F = Nu/Au where Nu=total number of stream segments of all order, Au=Basin area	Horton (1945)	2.56
7	Dissection Index (D_i)	$D_i=R_R$ x $100/H_x$ Where, $R_{R=}$ Relative Relief, H_x=Highest Altitude	Dov Nir & Miller (1949)	79.77
8	Drainage Texture (T)	T= Dd x F Where Dd= Drainage Density, F= Stream Frequency	Smith (1950)	8.45
9	Circulatory Ratio (R_c)	$R_c=4\pi A/\ P^2$ Where, R_c= Circularity Ratio, A= Area of the Basin (km²), P = Perimeter (km)	Miller (1953)	0.632
10	Elongation Ratio (R_e)	Re=2√(A/π) /Lb Where, Re=Elongation ratio Lb= Length of basin (km), A = Area of the basin (km²)	Schumm (1956)	0.747
11	Compactness Constant (Cc)	Cc = 0.2821 P/A*0.5* Where A = Area of the basin (km²) P = Perimeter of the basin (km)	Horton (1945)	0.343
12	Length of Overland Flow (Lg)	Lg = 1/D*2 Where, Lg = Length of overland flow D = Drainage density	Horton(1945)	0.15
13	Constant of Channel Maintenance (C)	C=1/D Where, C= Constant of Channel Maintenance & D= Drainage Density	Schumn(1956)	0.30
14	Ruggedness Number(R_n)	Rn=RR*Dd/1000 Where, R_R=Relative Relief, D_d= Drainage Density	Strahler (1957)	7.90
15	Infiltration Number (I_f)	I_f = Fs * D_d Where, Fs= Stream Frequency, D_d= Drainage Density	Faniran (1968)	8.45
16	Form Factor Ratio (R_f)	$R_f = A / L_b^2$ Where, L_b=Maximum basin length, A= Area of the basin	Horton (1932)	0.44
17	Lemniscate (K)	$k = L_b^2/ A$ Where, L_b=Maximum basin length, A= Area of the basin	Chorley (1957)	2.28

(Computed by the author and Base Reference is taken from Doornkamp & King, 1971; Nayar and Natrajan, 2013, modified)

Morphometric Analysis– Aerial Aspects

Drainage Density

Drainage density refers to the total stream length per unit area. Horton (1945, 1970) defined it as the ratio of total length of all stream segments in a given drainage basin to total area of that basin. Drainage Density study of the basin has been done to understand the erosional status of the basin and to correlate it with the landslide susceptibility. Erosional terrain commonly represents a series of complex Geometrical surface (Chorley *et al.*, 1984). It is the good indicator for infiltration or runoff. Complexities of the surface runoff can be well shown. Here high Drainage density 3.30km/km^2 leads to create fine drainage texture.

Stream Frequency

Stream frequency or drainage frequency is the measure of number of stream segments of all orders per unit area (Horton, 1945). An important geomorphic concept is drainage texture or stream frequency which also measures the relative spacing at drainage lines. It is a measure to understand the occurrence of number of streams per unit area which helps in understanding the texture of the landscape. High drainage density associated with high frequency means highly drained. Drainage frequency zones in the Riyong khola River Basin reveals that very high frequency is found in the middle and middle left part of the river basin. The Stream Frequency of the Riyong Khola basin is 2.56 that indicate the runoff is faster, and therefore, Landslide vulnerability is more likely in the basin with a high drainage and stream frequency.

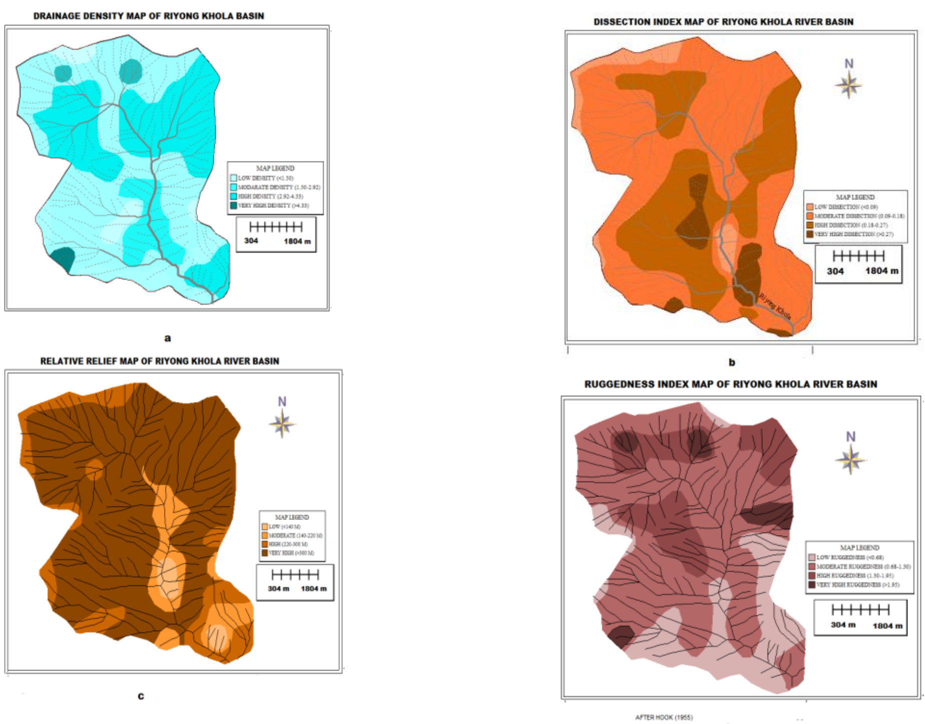

Figure 3 a, b, c, d: Morphometric Mapping of Riyong Basin

Ruggedness Number

Roughness index is leads to the better understand of the configuration of the landscape. Roughness index is more advanced than the average slope & dissection index as because it reflexes the combined effect of evolutionary rhythmic processes. Evolutionary processes are involved with different phases or stages. Its combined effect & rhythmic processes results different Roughness Index. This parameter was proposed by Strahler (1957). The value of Ruggedness Number of the basin is 7.90. Therefore, this region is infested by numerous rills and gullies. This type of landform can be expressed as a very significant terrain parameter in relation to landslide susceptibility.

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Infiltration Number (I_f)
Infiltration number of a drainage basin is the product of drainage density and stream frequency. The higher the infiltration number the lower will be the infiltration and higher will be the run-off (Rao *et al.*, 2011). The infiltration number of Riyong basin is 8.45. So, the amount of run-off in form of sheet flow is quite high in this basin. The presence of hard metamorphic rock hinders the infiltration of water in this basin.
Length of Overland Flow (L_g)
It is defined as the length of flow path, projected to the horizontal, non channel flow from point on the drainage divide to a point on the adjacent stream channel. This term refers to the length of the run of the rainwater on the ground surface before it is localized into definite channels (Horton, 1945). It is quiet synonymous with the length of sheet flow to a large extent. The value of this parameter is very low (0.15). Though the length of non-channelized flow is quite low but the frequency is very high. So, the volume of non-channelized discharge is also high.
Constant of Channel Maintenance (c)
Schumm (1956) used the inverse of Drainage Density as a property termed Constant of channel maintenance. Specifically, the constant C tells the drainage area required maintaining one unit of channel length and it is a measure of watershed erodibility. The value of C on permeable rocks with thick forest cover and high infiltration rate is always tending to be high. But, the value of C of Riyong khola basin is low (0.30). This is indicative of high magnitude of erodibility of surface topography.
Morphometric Analysis– Geometric Aspects
Elongation Ratio (R_e)
The elongation ratio reveals the shape of a drainage basin which is the ratio of the diameter of a circle of the same area as the basin to the maximum basin length (Schumn, 1956).
The value of elongation ratio is varied between 0.0 to 1.0 and 1.0 are the typical regions of very low relief, whereas value ranged between 0.6 and 0.8 are associated with high relief and steep ground slope (Strahler 1964).
After calculating the Elongation ratio, it has been clear that the river basin is ‘moderately elongated’ in shape. Because, it has the elongation ratio value of ‘0.747’.
Circularity Ratio (C_r)
It may be defined as the ratio of basin area to the area of circle having the same perimeter as the basin (Miller, 1953). Circularity ratio is dimensionless index which provides the outline form of basin. The value of circularity ratio varies from 0.0 (a line) to 1.0 (a circle).
As per Miller (1953), Circularity Ratio is affected by length, frequency & gradient of streams of different orders as well as the lithological characteristics of the basin. Circularity ratio bears an inverse relation to the basin area (Zavoiance, 1985). The basin has the circularity value of 0.632.
Form Factor Ratio (R_f)
Horton (1932), form factor may be defined as the ratio of basin area to square of the basin length. The value of form factor would always be less than 0.754 (for a perfectly circular watershed). The form factor ratio of Riyong basin is 0.44.
Lemniscate (k)
Chorley (1957), express the lemniscates value to determine the slope of the basin. The lemniscate (k) value for the Riyong khola basin is 2.28.
Relief Aspect
Hypsometric Curve Analysis
Hypsometry is related to the measurement of basin altitude and area to know the stage of erosion at which the basin is shaping up by water incision.
The hypsometric integral (HI) denotes the percentage area (40.6%) under the dimensionless curve is a good indicative of the basin erosional status or the surface decay. Whereas the erosional integral (59.4%) is the area proportionate to the area above the curve. The HI value denoting the active erosional youthful stage of the basin with minimum decay of valley floor as composed of hard *Daling* gneiss. The area-

height curve is an indicative of the spread of various tectonic upliftments and the proportion of terrain under active erosion. But, this type of curve doesn't represent the actual valley cross-profile.

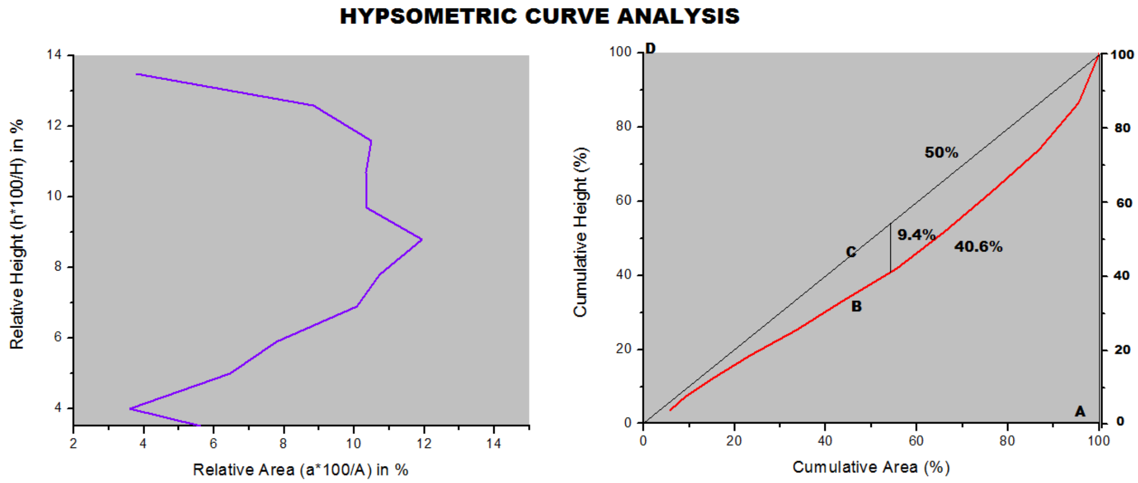


Figure 4: Areas vs. Height Proponent Analysis through Hypsometric Curve

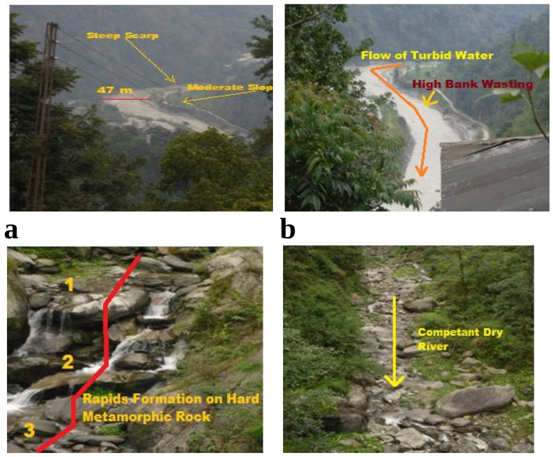
Demarcation of Third Ordered Sub-basins

For the sake of micro-morphometric analysis we have divided the total basin into 7 third ordered sub-basin. This sub-basin will provide various attributes through which we can easily determine the relationship of those attribute through which we can easily determine the relationship of those attributes with each other.

Table 2: Numerical Counts of Third Order Basin Parameters

No. Of 3rd order sub-basin	**No. Of channel**	**Sub-basin width (km.) A**	**Sub-basin length (km.) B**	**Sub-basin area (km^2.) C**	**Sub-basin perimeter (km.) D**	**Channel length (km.) E**
1	15	2.65	3.47	6.23	9.69	124.12
2	15	1.94	3.16	4.63	9.34	81.20
3	13	1.53	2.75	2.77	7.07	63.13
4	17	1.76	3.40	4.17	8.63	80.98
5	7	1.23	3.00	2.12	7.36	46.67
6	14	1.95	4.52	6.47	11.33	116.96
7	13	1.56	3.51	4.13	9.01	78.89
Mean	-	1.80286	3.40143	4.36	8.91857	84.56429
Standard Deviation	-	0.45	0.56	1.61	1.44	27.58
Standard Error of Estimate	-	0.170	0.213	0.610	0.546	10.426
Range	-	1.42	1.77	4.35	4.26	77.45

(Computed by the author)



c d

Plate 1: a-Sinuous Course of the Channel with steep Vegetated Valley side Scarp, b-High Bank wasting at the right & Turbid Water, c- formation of Rapids on Hard Metamorphic rock, d-Competent Dry Channel Bed

Pairwise Relationship of the Morphometric Variables

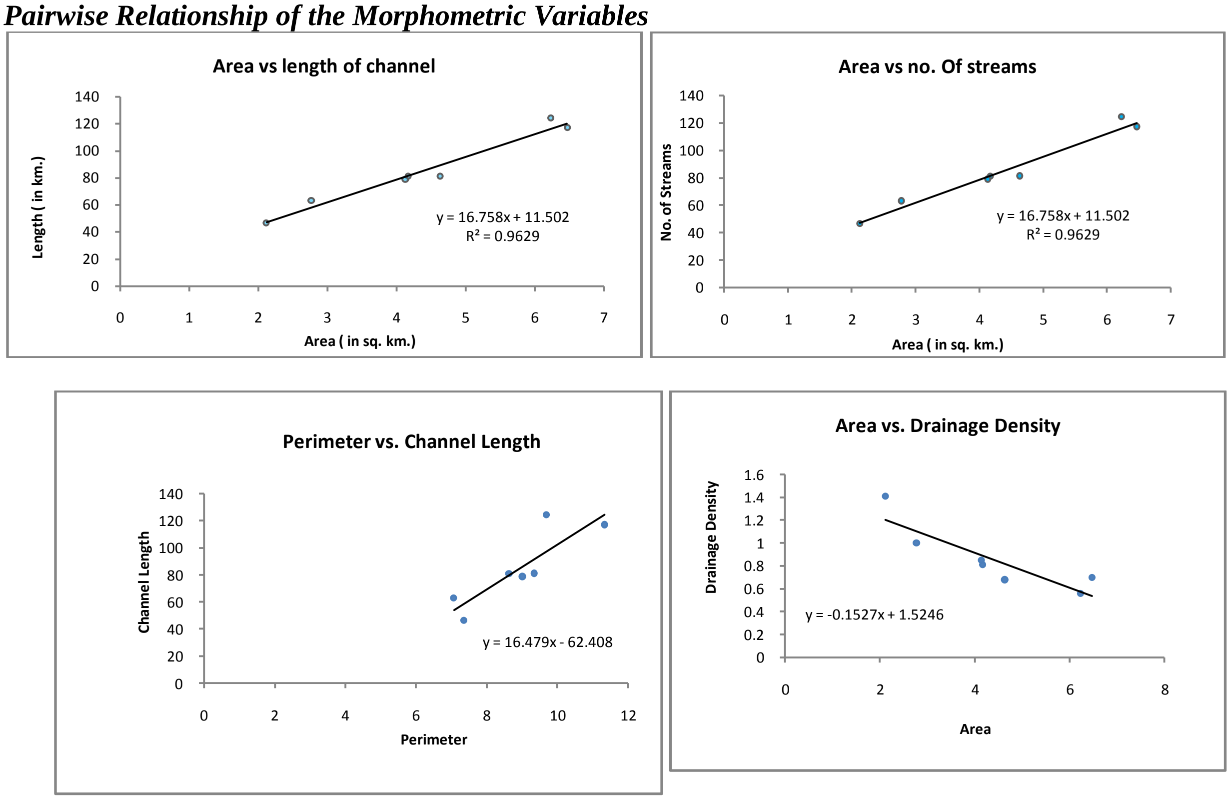


Figure 5: Pairwise Analyses of Morphometric Variables

A. First regression is attempt on **area** and **length** of each stream within the 3rd order sub-basin. The trend of the best-fit line of the linear regression denotes moderately high positive correlation between the two variables. Scatters are tending to stay with very close vicinity with the best-fit line, but the points are widely dispersed along the trend line. Thus, we may comment that over the area, the channels are well spaced and thus create a good drainage network. All the streams within a drainage basin especially the first order streams which supply the greatest amount to the total length of the drainage network, despite the fact that the mean length of the first order streams is less than that of any other order.

B. The second regression analysis is on **area** vs. **no. of streams**. The trend line here also represents a high positive correlation. This relationship bear logical examination and are consistent with the view that drainage basin tends towards a state of internal order and organization. The variables don't follow progressive correlation.

Table 3: Pair wise Identification of Results of Variation & Hypothesis Testing

Sl No.	Comparative pair of parameters	Degree of Freedom	F	Result of variation
1.	Area vs. Length	(1,12)	58.97	Variation Between Samples=83.09% Variation within Samples=16.09% R^2=+0.963 r=+0.981
2.	Area vs. No. of Channel		45.83	Variation Between Samples=79.25% Variation within Samples=20.75% R^2=+0.963 r=+0.981
3.	Perimeter vs. Channel Length		52.49	Variation Between Samples=81.39% Variation within Samples=18.60% R^2=+0.745 r=+0.863
4.	Area vs. Drainage Density		100.91	Variation Between Samples=89.37% Variation within Samples=10.63% R^2=-0.772 r=-0.879

(Computed by the author)

C. The third regression analysis is on sub-basin **perimeter** vs. **channel length**. The trend line here also represents a very high positive correlation. The value of F-ratio (52.49) also nullified the 5% chance of negative proportional relationship between variables. There is a significant relationship between perimeter and channel length.

D. The last regression analysis on sub-basin **Area** and **Drainage Density** has established a high negative correlation between the variables. It means that the two variables vary in opposite direction. The indication is that the area required to maintain a channel length is not sufficient and also supported the low value of C (Table no.1). But, the variations of sample means are significant.

Landslide Susceptible Analysis & Discussion

Riyong Khola sub-catchment is an important tributary of River *Tista* in West Sikkim. The occurrences of landslides in large magnitude are identified by the present author that has severe impact on the social life of the local communities. Landslides are among the great destructive factors which cause lots of facilities and financial losses all over the world (Shshabi *et al.*, 2012). The identification of a large landslide scar on the right bank of the river encourages the author to carry out a work by analyzing various morphometric parameters and finally produce a landslide susceptible map of the entire basin by fitting together all the findings come out from the analysis in GIS platform. Vernes (1984) said about the mapping areas of landslides within a specific period of time. It is a way to attempt a landslide susceptible mapping by using simplified Fuzzy logic method (Vahidnia *et al.*, 2009). It is purely a way of visual inspection that relies on identification of 'large value' carrying zone on the morphometric maps prepared under GIS environment.

The assessment of the susceptibility of the terrain for a slope failure, in which the susceptibility of the terrain for a hazardous process expresses the likelihood that such a phenomena occurs under the given terrain conditions or parameters. Here the author tries to correlate four basic morphometric areal parameters like- Stream frequency, Dissection index, Ruggedness index and slope of the terrain. The underground lithology is mainly composed of metamorphic silicate rocks with various hardness and permeability. The higher value of I_f number (Table: 1) reveals the fact more preciously. But, the effect of gully formation is so effective on the slopes directed towards the main consequent channel**.** Identification of most vulnerable sites of Landslide occurrences using the colour intensity variations on the same map and superimposition of highest intensity colour patches are taken from one single map (like-Drainage Frequency) and imposed it on the rest of three maps i.e. Ruggedness, Dissection and Average slope.

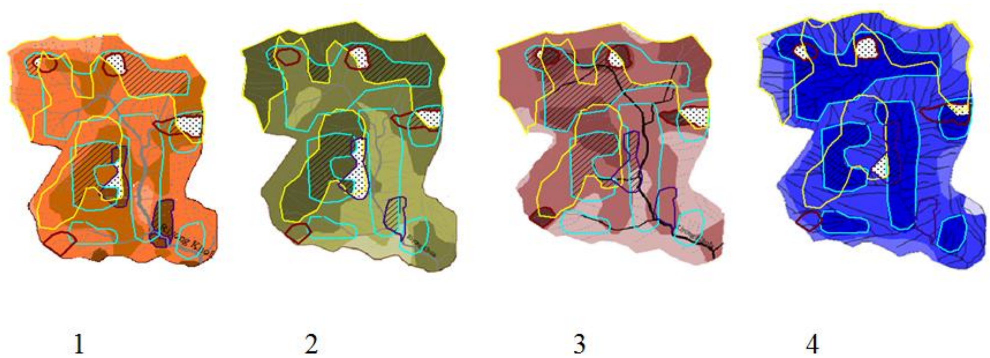


Figure 6: Identification Technique of Landslide Susceptibility Zones with Index Identities

Note:

=High susceptible area(Demarcated by the overlapping of three consecutive area patches)

=Moderate susceptible area (Demarcated by the overlapping of two consecutive area patches)

=Low susceptible area (Demarcated by the non-overlapping patches)

The author has taken into account the fact of superimposition of the 'large value' marked zones of each parameter on each other and finally produced the Landslide susceptible map. By overlaying landslide inventory maps with each causative factor, the statistical relationship can be measured between categories and past landslides based on landslide density in each category (Vahidnia *et al.*, 2009). The basic notion is that where the slope of the terrain is high, if the under laying rock of the segment is hard i.e. low amount of infiltration and high frequency of small channels with high intensity of sheet wash and valley incision. Such intensity can make the terrain a high dissected one with separated valley-ridge formation and obviously the segment on slope has high ruggedness values (Table 1). If all the high values of the selected parameters are found to be superimposed on each other that generated new area will have to be a zone where the chances of slope failure will be high. The target region where the mapping of several morphometric factors has been done to find out the relative correlation between slope instability and basin geomorphology. In Multilayer visual perception task, Landslide susceptibility mapping can be done so gracefully and it has the ability to handle the fuzzy informations.

The introduction of the legacies form the past i.e. the imposition of the present landslide scars (digitized area feature) on the prepared Susceptibility zone map has rightly fitted on the 'Very High Susceptible' zone. As the author has able to match the past occurrences with the present that can reveal the right probability of such hazard occurrences with his established calculations and mapping techniques. The final reproduction of the visual inspection in GIS platform is the Landslide Susceptibility zone map with lots of tonal variation as indicated in the legend. After preparing the Susceptibility zone map, the author simply superimposed all the present landslide scars of the basin taken from satellite imagery as 'area

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features' in KMZ/KML file format on the Susceptibility zone map. All the scars have suitably fitted on the map, especially over the high susceptible zones and proved the notion of the author as write.

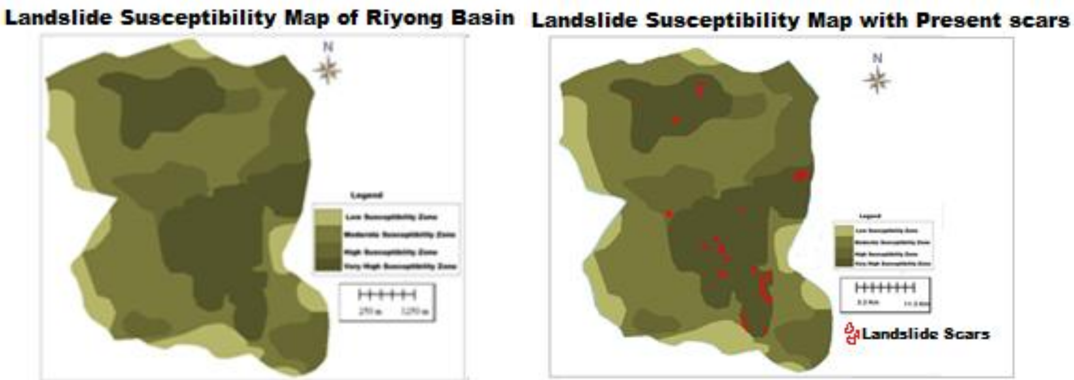

Figure 7 a, b: Final Landslide Susceptibility Map of Riyong Basin with Superimposition of the Present Landslide Scars

From the overall analysis, we can make sure about one thing that as the present Landslide phenomena has clearly fitted to the calculated and visual axioms by the blessing of Geographical Information System, so the calculated and visual technique of landslide hazard zonation mapping from simple geomorphological inventory notion can further be expanded for the future prediction of the occurrence of such large geo-ecological hazard. But, some effective lithological field observation and analysis can able to provide much strong and accurate results to know the probability of slope failure on such hilly terrains.

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