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Characterisation of Landslide of Shiv Khola Basin Based on Slope Profile Morphometry

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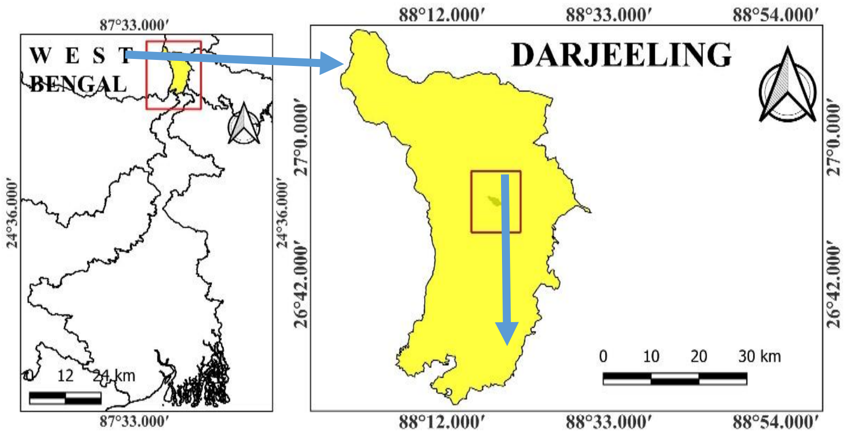
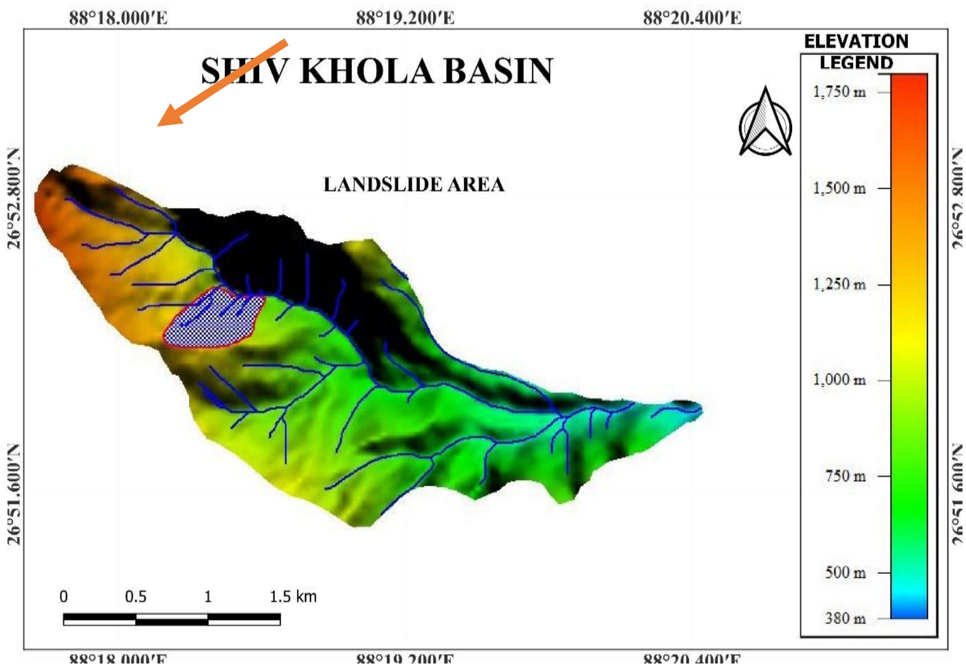
Introduction

Landslide is a wide variety of processes that result in downward and outward mass movements of slope forming materials (rocks, debris, soils and vegetation). The present paper is dealt with the Morphometric analysis of mass-movementof land failure region of the upper Shiv Khola basin (called Paglajhora)of Darjeeling Himalaya. This Morphometric outline controlled by geologic structure and reshapedby the hydro-geomorphic processes which is active in the terrains are characterised by high energy of instability and variability of the masses.High intensive rainfall on the impervious metamorphic rocks Gneiss allow the overland flows to slump and trigger the shear stress that makes the slope unstable.The slope profiles present the irregular formation consist with convex – concave association. In this context five morphometric indices are used for measurement the degree of slope movement.

Study Area

The slope failure region in and around Paglajhora i.e. influence area about of 1.67 sq. km and extends between 26^{0}51’45” N to 26^{0}52’30” N and 88^{0}18’00” E to 88^{0}18’45” E, situated right bank of the upper Shiv Khola. Upper Shiv Khola basin which is the right side tributary of the Mahanadi, lies near Tindharia town in the Kurseong sub division of Darjeeling district. The extension of Shiv Khola basin between 26^{0}51’26” N to 26^{0}52’55” Nand 88^{0}17’38” E to 88^{0}20’25” E and covers an area about 5.39 sq.km.The focused area has a Steep slope (above 20 degree), narrow valley with steep, rocky walls along the lower slopewith a river running along their bottom, moderate to high relative relief (300 to above 450 m). This affected region is bounded by 800 m and 1400 m contours heights.





Objectives

The main objectives of this paper are as follows:

- To understand and analyse the distribution and the diversity of involved material in landslide.
- To identify the process group and measurement the quantity of the slope forming material for determination of the morphological analysis with the help of the five morphometric indices.
- To present the comparative quantitative studies of the slope morphometry of 2004,2011, and 2019.

Database and Methodology

All these data are based on mainly secondary sources. Landslide area has been identified and measured from Google Earth and the contour map has been prepared based on SRTM data from USGS with 10 m contour interval. Each year contour map has 3 different

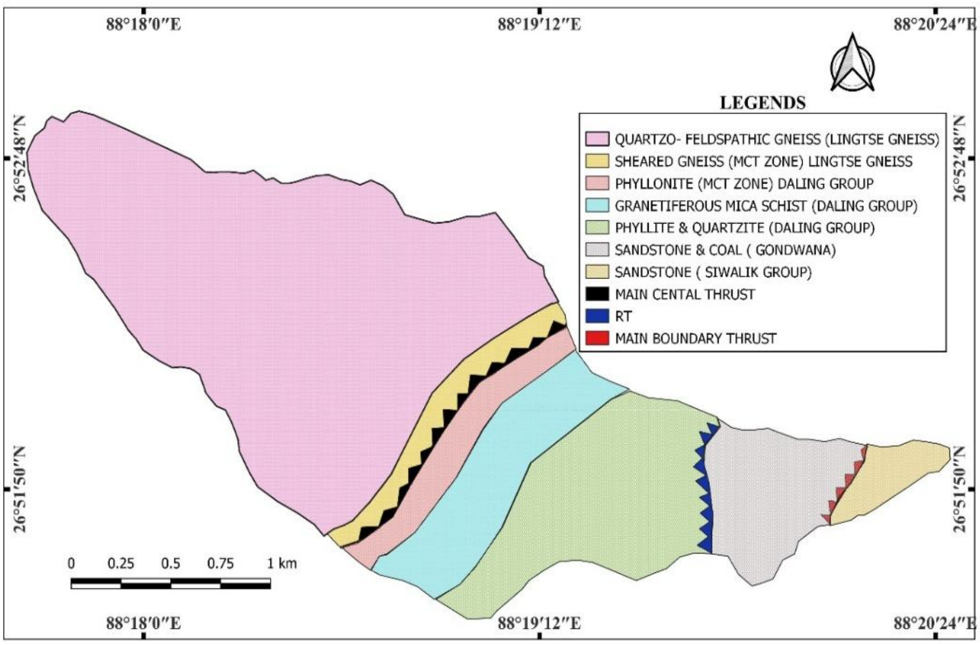
ISSN PRINT 2319 1775 Online 2320 7876
 UGC CARE Listed (Group -I) Journal Volume 10, Iss 9, 2021

positional section line,on that basis the three longitudinal and composite slope profiles are drawn and morphometric measurement are done with five different indices developed by Crozier. Geological map has been extracted from the site of Bhukosh of Geological Survey of India and the drainage network map has been created by SRTM DEM, and Global Mapper version 21.0.

Geological Setting

In the higher reaches of the Darjeeling hill areas, the Daling series gradually grade into the more metamorphosed rocks, which is known as Darjeeling Gneiss. The study area covered by mainly rocks of Darjeeling gneiss which are highly foliated& jointed due to metamorphism. The rocks comprise golden-silvery mica schist and coarse-grained gneiss. In some areasFeldspars and Quartz layers are found lying alternate to each other. The area exposes the highly tectonically sheared gneissic rocks close to Main Central Thrust (MCT) belonging to the Darjeeling and Daling Groups, which are separated with each other by the Main Central Thrust (MCT). This impermeable hard gneiss rock formation allows the surface flow and slope instability during the monsoon.

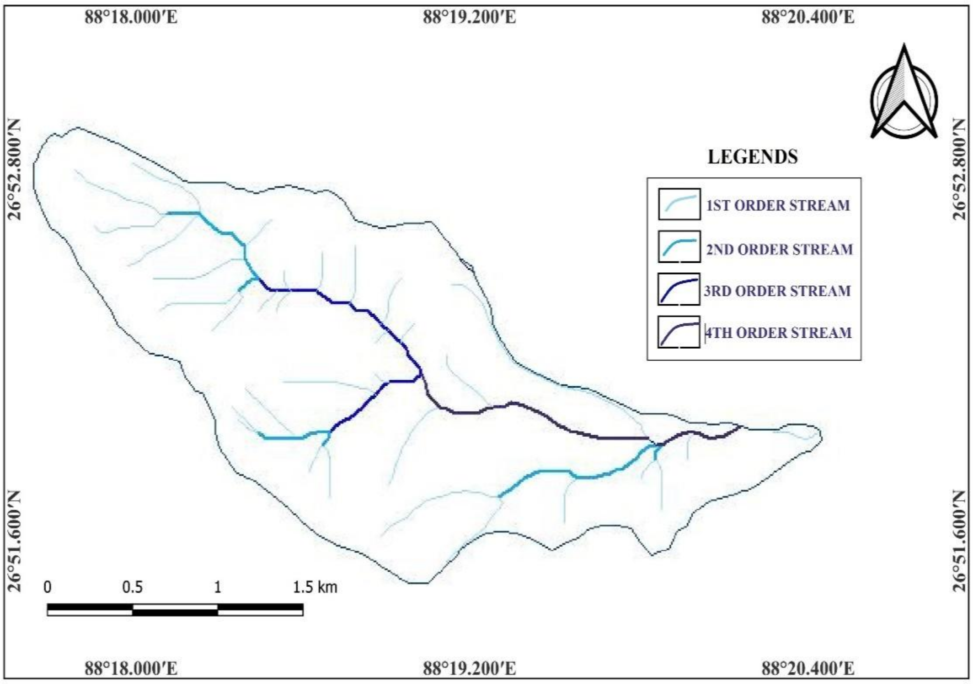
GEOLOGICAL MAP



Drainage

The area under study, are mainly drained by Mahanadi river (91.70 km) in the hill, andoriginates from the Mahaldiram hills of the Darjeeling Himalaya. The river flows in a southeast direction receiving a few sizable right side tributaries among which the Shivkhola river is the most important one. The amplitude of the Shiv Khola basin is 1,765 m (2,045 m at the source in Mahaldiram ridge and 280 m at the sub-basin mouth). The length of the master stream is 8.84 km and thus the average slope of the Shiv Khola River has been estimated to be 11.8°. The total basin area is 5.39 sq. km. The Darjeeling Himalaya is a very fragile terrestrial system, which is much often disturbed by various environmental catastrophes. The steep, narrow ridges and spurs are separated by water channels locally known Jhoras and Kholas. The different order of streams creates narrow and steep "V" shaped valley. A number of small streams are ephemeral while higher order streams are perennial, which are cut the colluvial slope. The drainage pattern is, in general, dendritic. Paglajhora landslide area comes under the moderate drainage density and exhibit more surface runoff and that lead to excessive erosion and have a tendency to landslide in this area.

DRAINAGE MAP



Slope Morphometry Indices

The quantitative morphological analysis presented in this study is based on five morphometric indices (Classification, Dilation, Flowage, Tenuity &Displacement Index), developed by Crozier.It has been used to identify the slope movement processes that is responsible for such morphological configuration. Here three slope profiles along AB, CD,& EF section line of one landslide area with three different years (2004,2011,2019) were drawn. Here three (Fluid Flow,Slide Flow, Rotational slide) types of slope movement processes, commonly observed in the study area.

ISSN PRINT 2319 1775 Online 2320 7876
 UGC CARE Listed (Group -I) Journal Volume 10, Iss 9, 2021

Morphometric Index	Formulas	Description
Classification Index	$\frac{D}{L}\times 100\%$	the ratio of maximum depth (D) of the displaced mass to the overall length or maximum length (L) measured up the slope,
Dilation Index	$\frac{Dx}{Dc}$	the ratio of maximum height of convex part (Dx) to the maximum depth of concave part (Dc)
Flowage Index	$\lvert\frac{Dx}{Dc} - 1\rvert\frac{Lm}{Lc}\times 100\%$	where Lm is the length of displaced material or convex part and Lc the length of concave part.
Tenuity Index	$\frac{Lm}{Lc}$	The ratio of the length of displaced material (Lm) or convex part to the (Lc) length of concave part.
Displacement Index	$\frac{Lr}{Lc}$	The ratio between surface length of rupture (Lr), exposed in the concave part, and Lc, length of concave part. A value of 100% for this ratio, indicates the most stable situation due to entirely removed material from the concave part.

Morphometric Indices

Morphometric Index	Section Lines	Different Years								
		2004-2011	Process Group	Class of Movement	2011 - 2019	Process Group	Class of Movement	2004 - 2019	Process Group	Class of Movement
Classification Index (%)	AB	1.45	SF	Slump	3.92	RS	Earth and rock slumps	3.03	RS	Earth and rock slumps
	CD	2.35	SF	Slump	3.70	SF	Slump	1.00	SF	Slump
	EF	2.41	RS	Earth and rock slumps	3.68	RS	Earth and rock slumps	4.00	RS	Earth and rock slumps
Dilation Index	AB	2.73	FF	Debris flow	1.05	RS	Earth and rock slumps	0.75	SF	Slump
	CD	4.00	FF	Debris flow	0.38	SF	Slump	1.33	SF	Slump
	EF	3.00	FF	Debris flow	0.71	FF	Debris flow	0.70	FF	Debris flow
Flowage Index (%)	AB	233.6	FF	Debris flow	7.70	RS	Earth and rock slumps	40.25	SF	Slump
	CD	345.0	FF	Debris flow	41.54	FF	Debris flow	37.62	SF	Slump

ISSN PRINT 2319 1775 Online 2320 7876
 UGC CARE Listed (Group -I) Journal Volume 10, Iss 9, 2021

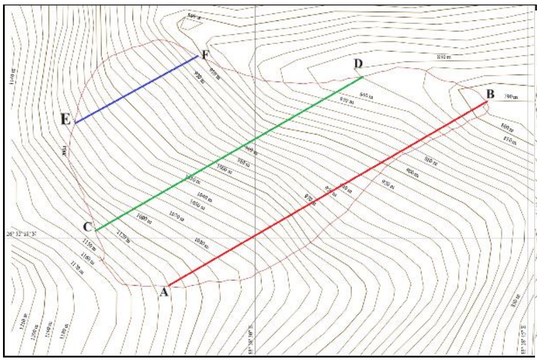
	EF	254.0	FF	Debris flow	37.7	FF	Debris flow	42.00	FF	Debris flow
Tenuity Index	AB	1.35	SF	Slump	1.54	RS	Earth and rock slumps	1.61	RS	Earth and rock slumps
	CD	1.15	FF	Debris flow	0.67	SF	Slump	1.14	RS	Earth and rock slumps
	EF	1.27	RS	Earth and rock slumps	1.30	RS	Earth and rock slumps	1.40	RS	Earth and rock slumps
Displacement Index	AB	0.24	SF	Slump	0.28	RS	Earth and rock slumps	0.48	RS	Earth and rock slumps
	CD	0.51	SF	Slump	0.56	SF	Slump	0.09	SF	Slump
	EF	0.39	RS	Earth and rock slumps	0.85	RS	Earth and rock slumps	0.27	RS	Earth and rock slumps

Statistical Summary of Morphometric Indices of Each Process Group year wise (Modified after Crozier)

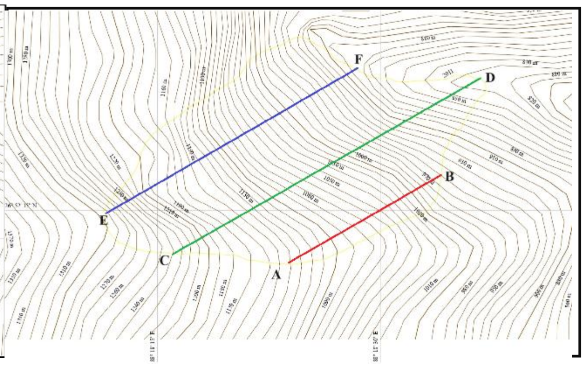
Morphometric Index	Different Years									
		2004-2011			2011-2019			2004-2019		
		RS	SF	FF	RS	SF	FF	RS	SF	FF
Classification Index	M	2.41	1.9	-	3.8	3.7	-	3.52	1.0	-
	S	0	0.45	-	0.12	0	-	0.49	0	-
	M+S	2.41	2.35	-	3.92	3.7	-	4.01	1.0	-
	M-S	2.41	1.45		3.68	3.7	-	3.03	1.0	-
Dilation Index	M	-	-	3.24	1.05	0.38	0.71	-	1.04	0.70
	S	-	-	0.55	0	0	0	-	0.29	0
	M+S	-	-	3.79	1.05	0.38	0.71	-	1.33	0.70
	M-S	-	-	2.69	1.05	0.38	0.71	-	0.75	0.70
Flowage Index	M	-	-	277.5	7.70	-	39.62	-	38.92	42.00
	S	-	-	48.43	0	-	1.92	-	1.32	0
	M+S	-	-	325.93	7.70	-	41.54	-	40.24	42.00
	M-S	-	-	229.07	7.70	-	37.7	-	37.6	42.00
Tenuity Index	M	1.27	1.35	1.15	1.42	0.67	-	1.38	-	-
	S	0	0	0	0.10	0	-	0.20	-	-
	M+S	1.27	1.35	1.15	1.52	0.67	-	1.58	-	-
	M-S	1.27	1.35	1.15	1.32	0.67	-	1.18	-	-
Displacement Index	M	0.39	0.38	-	0.57	0.56	-	0.38	0.09	-
	S	0	0.14	-	0.29	0	-	0.11	0	-
	M+S	0.39	0.52	-	0.86	0.56	-	0.49	0.09	-
	M-S	0.39	0.24	-	0.28	0.56	-	0.27	0.09	-

ISSN PRINT 2319 1775 Online 2320 7876
 UGC CARE Listed (Group -I) Journal Volume 10, Iss 9, 2021

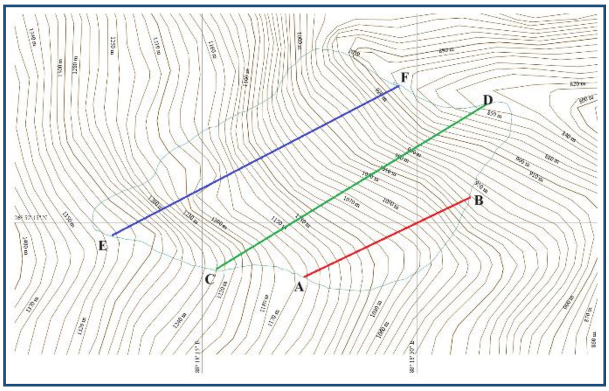
Contour Plan of Landslide Area of 2004, 2011 and 2019



2004

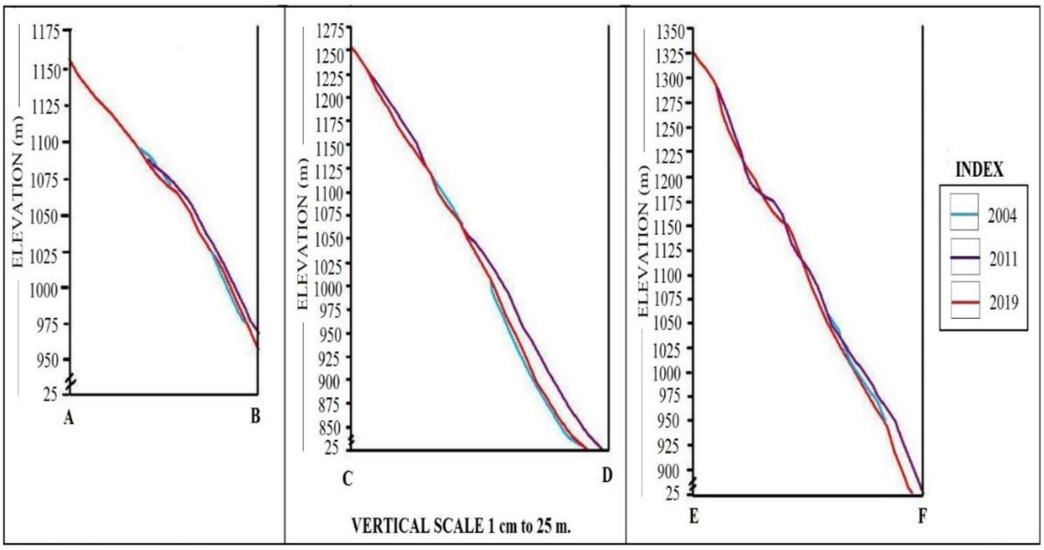


2011



2019

PROFILES OF THE "AB", "CD" & "EF" SECTION LINES ALONG VERTICAL PLANES IN DIFFERENT YEARS (2004, 2011 & 2019)

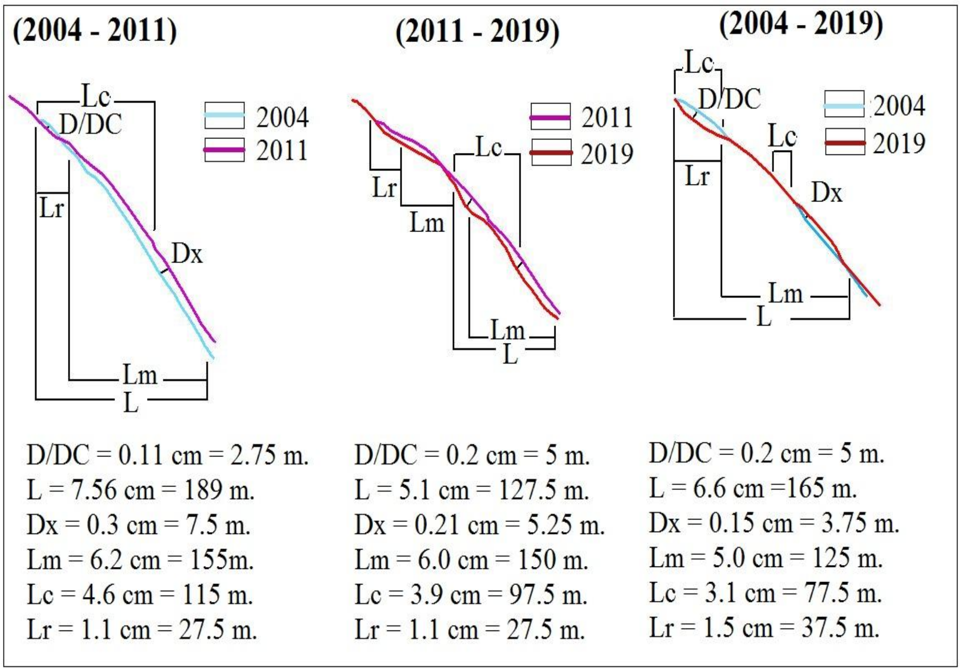


ISSN PRINT 2319 1775 Online 2320 7876
 UGC CARE Listed (Group -I) Journal Volume 10, Iss 9, 2021

The values of different morphometric indices have been taken from the sinuosity of the contour that is based on the slope of the previous year and also identify the process group.

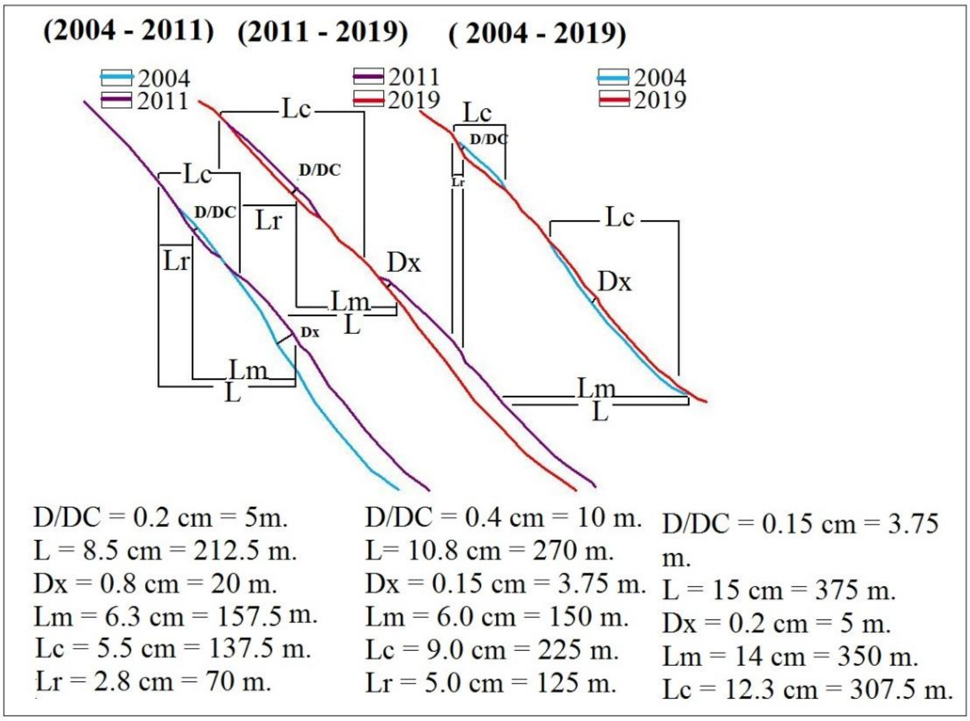
MEASUREMENT OF MORPHOMETRIC INDICES ALONG "AB" SECTION LINES

three section line as a whole. It is significant to note that, the same profile has been changes the process with relatable movement from top to bottom.



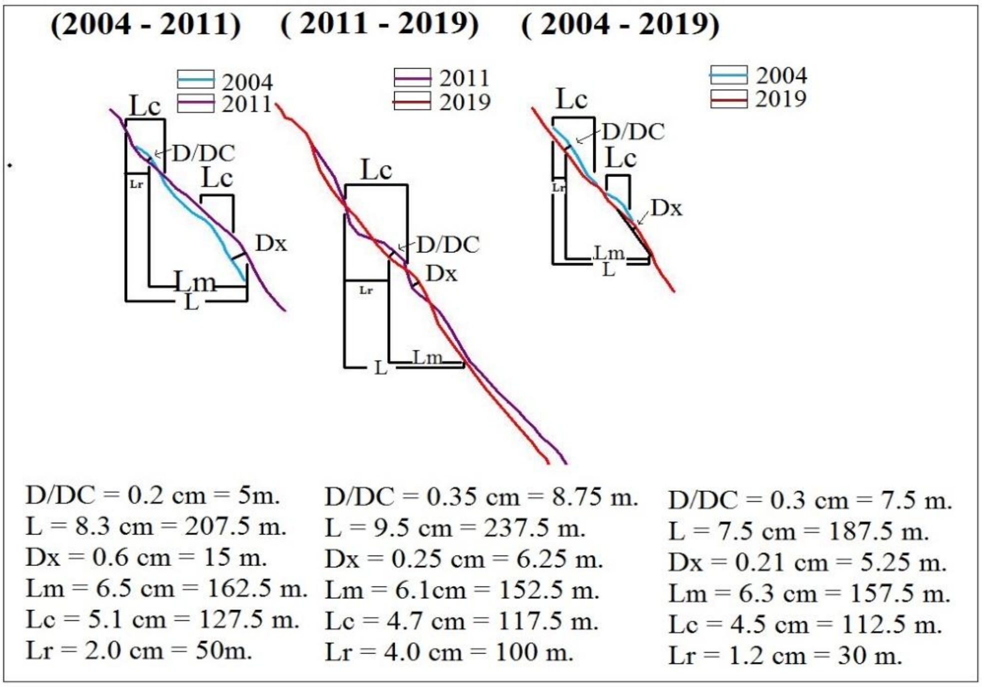
MEASUREMENT OF MORPHOMETRIC INDICES ALONG "CD" SECTION LINES

ISSN PRINT 2319 1775 Online 2320 7876
 UGC CARE Listed (Group -I) Journal Volume 10, Iss 9, 2021



It is evident that the profiles along three section lines (AB, CD, & EF) of three different years shown the landslide process in the upper part are mainly Rotational Slide (RS) or Slide Flow (SF) characterising Earth & Rock Slump and Slump type of movement respectively whereas the lower part of the slope of the profile majority is Fluid Flow (FF)

MEASUREMENT OF MORPHOMETRIC INDICES ALONG "EF" SECTION LINES



For the comparative study it is observed from the that, during the year 2004- 2011, 2011-2019, and 2004- 2019 the landslide ismainly Rotational slide (RS) with Earth and Rock

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Slump. This observation is based on the mean value of Classification Index, where Rotational Slide displaced the material deeply as a unit or block of material than the Slide Flow.The highest mean value of the process (RS & SF) are observed in the 2011-2019 among the three years and create more undulation on the slope by the movement of earth and rock slump.The maximum value of Dilation and Flowage index are shown during the year 2004-2011, developed by the Fluid Flow (FF). Here the profile represent that the movement of debris flow travelled much more distance downward and deposition of debris than the other processes.

The Tenuity Index has the potential of indicating the effect of slope inclination and the micro - relief features to channelling flow downslope and it is observed in the year of 2011-2019 dominated by the Rotational slide (RS).Then another important morphometric index is Displacement Index, which shows the values of each process group of three different years. It is used to determine the stability of the slope.From the statistical summary tables, it is clear that the low values of each year of each process group indicates the unstable slope condition due to partial removal of material from concave part. Especially during the year 2004-2011 where low amount of displacement developed by the SF & RS that’s increase the slope instability or failure and also increase the successive events or slope failure for the following years.

However, this type of morphological changes of above mentioned year effects on the river basin and river bed by changing the drainage system. Because the released material (colluvium product) moved downslope breaks the pre-existing structure and upheaval the river bed. During monsoon the product of the river bed washed out by water and blocking the course of the river and after that drainage became re-established.

Conclusion

The present detailed study on the slope failure or landslide of the Upper Shiv Khola basin (called Paglajhora) provide the identification of nature and condition of the slope movement process by the use of morphometric indices.Thus the slope movement is complex and reactivates by all three possible types of slope movement due to low values of displacement indices.From the above discussion, it is clear that the study area is affected by the slope movement of earth and rock slump for the upper part and gradually it changes the process by debris flow for the lower slope or toe of the landslide that is extend towards the river bed.

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