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Slope Stability Analysis: An Application of SHALTAB for Landslides on Toranmal Plateau

S.M. Bhamare[1], N M Kazi[2] and Vikram Agone[3]

[1]*Department of Geography, SSVPS Science College, Dhule.MS, India*
[2]*Dept. of Geography, SPDM College Shirpur, MS, India*
[3]*Project Fellow*
E-mail: [2]nmquazi@hotmail.com

Abstract—*Landslide is the main constraint of agriculture on Toranmal Plateau. It is responsible for shrinking of agricultural land. Landslide is geomorphic phenomena of mass movement of weathered material like rock fragments, debris, soils and plants down the slope. In simple word slope failure is called as landslide. The present topographic expression of the Toranmal plateau is the product of denudation processes on one hand and tectonic forces on the other. The steep escarpments confine the plateau from all sides. The boundary area of the plateau is intended by accelerating headword erosion of streams, recession of waterfalls and landslides. This part of Toranmal plateau is highly susceptible to the land slides. The plateau experience reduction of summit area from all sides. The agriculture land is thus shrinking from all sides. Therefore attention needs to be given towards the understanding of causes and consequences to mitigate these problems. The mapping of land slide affected area is essential for planning and management.*

The slopes are of two types one is natural slope and second engineered slope (Human influenced slope). The civil engineers always need to check the natural and engineered slopes. This check involves determining the shear stress developed along the most likely ruptured surface and comparing it with shear strength of the soil or slope material. This process is called as slope stability analysis. The stability of slope is analyzing by comparing the magnitude of the driving force to the resisting force.

The present paper attempts the analysis of slope stability with the help SHALTABmodel for Toranmal Plateau.

Keywords*: Landslide, Slope stability, Shear stress, Driving force, Resisting force SHALTAB,*

1. INTRODUCTION

Landslide is the main constraint of agriculture on Toranmal Plateau in Nandurbar District of Maharashtra. Since, agriculture land is shrinking after landslide. It is geomorphic phenomena of mass movement of weathered material like rock fragments, debris, soils and plants down the slope under the influence of gravity. In simple word slope failure is called as landslide. It is the natural phenomena, but also induced by anthropogenic factors. The most striking disastrous, ubiquitously occurring down slope process of mass movement including shear zone on escarpment, hill slope of plateau edges, which is a natural hazard that are commonly experienced in this region. The most susceptible part of the Toranmal plateau areas to landslides is surrounding escarpments. The plateau margins are relatively unstable and exposed to weathering and mass movement. Every year several landslides occur and agriculture land affected by it. The agriculture land is thus shrinking from all sides. Therefore attention needs to be given towards the understanding of causes and consequences to mitigate these problems. The mapping of land slide affected area is essential for planning and management.SHALSTAB is a slope stability model and used for mapping of relative potential landslide affected area.

2. OBJECTIVE

To assess the causes and consequence of landslides and mapping of affected area adopting the SHALTAB Model.

3. METHODS AND DATA SOURCE

SHALSTAB is may be used as a parameter free model. It is the ratio of the effective precipitation to soil transmissivity (q/T). The site with lowest ratio indicates instability of land surface and it is marked as landslide hazard area. The principle variables of q/T used in this study are;

i) **q** is effective rainfall.

ii) **T** is soil transmissivity or vertical indicator of saturated conductivity.

Satellite data is generated from digital terrain model.(DTM)

SHALSTAB has been widely used in different parts of world by earth scientists using digital elevation data to delineate potential slope stability over large areas.

4. LAND SLIDE FAVOURING CONDITIONS OF TORANMAL PLATEAU

The present topographic expression of the Toranmal plateau is the product of denudation processes on one hand and tectonic forces on the other. The steep escarpments confine the plateau from all sides. The boundary area of the plateau is intended by accelerating headword erosion of streams, recession of waterfalls and landslides. This part of Toranmal plateau is highly susceptible to the land slides. Every year hundreds of land slide occurs mostly in rainy season. The high altitude, steep slopes from all sides, heavy rainfall, intense weathering, deforestation, deliberate forest burning, shifting cultivations grazing of animals, construction of roads, soil erosion, soil leaching etc. are the favouring conditions for landslides on Toranmal plateau. The land slide hazards are at alarming rate due to anthropogenic interference in natural ecosystem. The plateau experience reduction of summit area from all sides.

5. OCCURRENCE OF LANDSLIDES ON TORANMAL PLATEAU

The most striking disastrous, ubiquitously occurring down slope process of mass movement including shear zone on escarpment hill slope of plateau edges, which is a natural hazard that are commonly experienced in this region. The most susceptible part of the plateau areas to landslides is surrounding escarpments. The plateau margins are relatively unstable and exposed to weathering and mass movement. This area is feasible to formation of fractures, joints, cracks and crevices due to release of overlying burden of weathered mass by denudation and gradual upliftment of the plateau. The rainwater seeps deeply through joints cracks and crevices. The chemical weathering penetrates deeply due to seeping water.

It loosens and dislocates the weathered mass from main stock of the rock. Thus landslides occur. The agriculture, settlements and roads on plateau summits in the vicinity of the escarpment area are mostly suffering from the landslides. The intensity of landslide is more in wet weather season. This is the prime agriculture practice season of the Plateau. The actual land slide sites have been observed during June 13-June 2014. The recent land slide occurrence sites have marked with GPS and landside events distribution map and attribute table prepared as shown in table no 5.2 and map no.5.1.

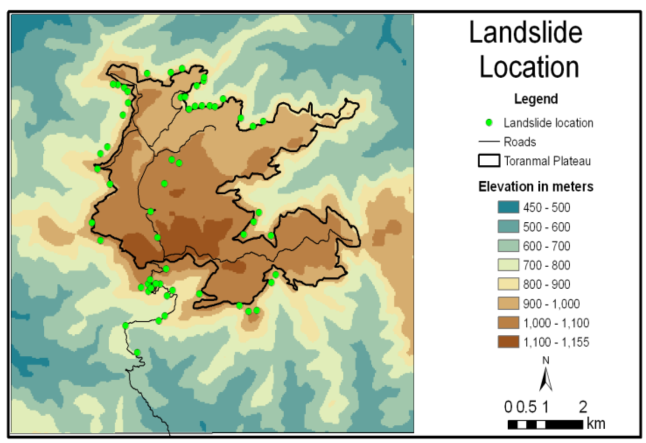
Table 5.2: Landslides observation During June 2013- June14

No	Landslide Location	No of Landslide	% of Total
1	Toranmal Plateau Summit	5	8.6
2	Toranmal Plateau (East Side)	4	6.9
3	Toranmal Plateau (West Side)	12	20.7
4	Toranmal Plateau (North Side)	17	29.31
5	Toranmal Plateau (South Side)	4	6.9
6	SatpayariGhats area	14	25.14
7	Bhander plateau	2	3.45
	Total	58	100

(Data generated from actual field observations of accessible sites.)

Table no.5.2 reveals that maximum landslides 17(29.31) % have observed on the northern side escarpment of the plateau and minimum 2 (3.45%) on Bhander plateau. Formerly the Bhander Plateau was an attached to Toranmal plateau. Now it is detached from the plateau by accelerated headword erosion of Kalapani River from Tapti basin and tributary of Zarkal from Narmada basin. This part is isolated and inaccessible one person is living on this plateau. The Satpayari Ghats on south is more susceptible to landslide. During the observation period 14 (25.14) landslides were noted. Though Eastern side of the plateau shows least landslide occurrences, but it is most inaccessible part of the Plateau and beyond the observations. The Awasibari part of this escarpment near the New Toranmal is the only accessible part on eastern side. The remaining part of escarpment is inaccessible. There may be the possibility of higher number of landslides. The map no.5.1 shows the distribution landslide sites during observation period.

Map 5.1 Distribution marked landslides of Toranmal plateau.



Considering the altitudinal variations maximum landslides were occurred between 1000-1155M elevations.

The probable previous five year data of landslide occurrence, their probable causes and damages have been generated considering this actual field observation and information collected from local people in surrounding area as shown in table no.5.3.

Table.5.3: Occurrence of landslides during previous five years (2009-10 to2013-14)

Intensity	Number of Land slide incidents	Type and nature	Location	Consequences

Very high degree of incidents	Less than 150	Slump-under cutting by river or streams. And the collapse of the free faces of the scarps from all sides.	Northern, Southern, Western, and Eastern sides of the plateau. Most effectively in western and western escarpment.	Damages to forest, agricultural land, roads, settlements. Belo the plateau. A stream from western side of the plateau was blocked and the stream channel course shifted to the northern side from its original course. Stream course shifts their directions. People migrate from affected areas. Traffic and Tourist affected
High degree of incidents	150-250	Rock slide-blocks of rocks dislodge rapidly move down the scarp & topples down	From all sides of the plateau. Most effectively on southern side	Dislodged of material destruction in Road, Bridge, and obstacle in communication. Traffic and Tourist affected
High to moderate degree of incident	250-350	Rapid fall of debris and, rolling of soil weathered mass with rock fragments and plants.	Northern, Southern, Western, and Eastern sides of the plateau.	Destructive slide creates lot of problems to cultivated land and settlements and roads. Traffic and Tourist affected
Lower degree of Incidents	More than 350	Chemically weathered debris, soil boulders fall	Northern, Southern, Western, and Eastern sides of the plateau.	Barriers to roads, destruction of crops, settlements. Traffic and Tourist affected

(Table generated from field observation and information from local peoples.)

Among the all escarpments from all side only southern escarpment is accessible by road.

The road is constructed through seven steps of Ghats and require considerable monetary amount for its maintenance after land side. The road is maintained by Building and ConstructionDepartmentGovernment of Maharashtra. The road distance is 24 kms from Ranipur to Toranmal. The remaining three sides of the plateau are almost inaccessible. Therefore no recorded data of landslide events, damages to live and property and affected area is available. The southern road becomes non motorable after heavy rain in rainy season. It is either blocked by landslides or flood damages. Because a road approaching to Toranmal crosses 19 times by single stream emerging from Kalapani waterfall draining into Tapti basin on southern slope of the plateau. When road is blocked all the transportation activities are stopped and Toranmal remain inaccessible. Transportation is the backbone of tourism. The tourism is collapsed and felt in financial loss. The landslide is the main constraint of tourism.

6. CAUSES OF LANDSLIDES:

Landslides are often caused by the processes that cause the increase shear stresses or shear strength of soil mass.(Abramson, Thomas, Sunil Sharma and Glenn. Boyce 2002). The most commonly process that act an increase in shear tress on hill slope are removal of support by erosion, mass movement likes fall, slides, anthropogenic activities like cuts, excavation and removal of material, overloading by natural (rain and accumulation of material) and human activities The common processes that cause a decrease in shear strength of slope material are inherent structure, composition and stratification, changes caused by weathering and physic-chemical activities like wetting and drying, hydration and removal of cementing material effect of pore pressures and change in structure due to degradation. All these activities are summarized in tableno.5.4 (A&B)The pre existing discontinuities such as fault, foliations, cleavages, sheared zone, joints cracks crevices soil dicks etc leads to lose the support of residual soils and weathered mass. The saturated residual soil often loses its strength. Faults bedding plains, cleavages and foliations have greater effect on rocks slope stability than soil slope stability. Theescarpments from all sides of Toranmal plateau are more feasible to the causes.

Table 5.4:(A) Factors That Cause Reduced Shear Strength in Slopes

Sr. No.	Factors	Rocks	Characteristics
1	Factors inherent to nature of Materials	Basalt	Structure, Compositions , Secondary structures, stratifications
2	Changes caused by weathering and physic-chemical activity	Rock Debris	Wetting and drying, hydration, removal of cementing agents.
3	Effect of pore pressures	Rock and soil mass feasibility	Cracks crevices joints and pore spaces in residual soil and weathered rock mass on slope.
4	Change in structure	Stress release,	Hydrous to anhydrous conditions.

(Source Slope Stability and Stabilization Methods -Abramson, Thomas, Sunil Sharma and Glenn. Boyce, 2002).

5.4: (B) Factors That Causes Increases in Shear Strength of Slopes

Sr. No.	Main activity	Processes	Agency
1	Removal of support	Erosion	By streams
			By successive wetting and drying
		Mass Movement by gravity	Soil creep. slump, slide fall subsidence etc.
		Human activity	Cuts, excavation, under construction of roads and settlements. deforestation
2	Overloading	By natural causes	Weight of precipitation, accumulation of weathered mass
		By human activity	Construction of fill, buildings and other overload in the crest. Deforestation.
3	Transitory effects	Earthquakes.	Sudden collapse and subsidence
4	Removal of underlying material	Bystreams incision	Cuts and incisions erosion by underground seeping
		By Weathering and anthropogenic activities	Removal of chemically weathered material. Loss of strength of underlying material. Burrowing activities of animals and human activity of quarrying
5	Increases of lateral pressure	By water	Water in cracks leads to crack widening, expansion of clay
		By heat	Thermal expansion and contraction of rocks

Source Slope Stability and Stabilization Methods - Abramson, Thomas, Sunil Sharma and Glenn. Boyce, 2002).

The Toranmal plateau is high elevated surface (1155M AMSL) composed of the basaltic rocks disposed horizontally and exhibits cracks ,crevices, fractures joints which allows deep penetration of water .The annual rainfall on the plateau is well above 1000mm. The physical weathering's like spheroidal weathering, exfoliation, block and granular disintegration and chemical weathering like hydration, hydrolysis solution, carbonation,oxidation etc are very common. The exposed rocks are disintegrated and decomposed into loose weathered mass. On saturation with water its mass increase and loose the shearing strength. Thus move under the influence of gravity on hill slopes and landslides occur.

7. SLOPE STABILITY

The stability of slope is analyzed by comparing the magnitude of the driving force to the resisting force. The driving force is the productweight of the material and its angle of down slope component. The resisting force is related to friction and cohesion. The slope stability is controlled by relief, strength of material soil water content, vegetation etc. The ruptured surface is a cricritical and has minimum safety factors. The natural slopes have remained stable many year may suddenly fail. This failure of slope or landslide is related to change in topography, seismicity, ground water flow loss of strength of material, change in stress and weathering. Before the slope failure, slope is in set of natural balance is known as stability of the slope. This state of equilibrium is assumed to exist when the shear resistance of the soil on failure slope surface equals to shear strength of the soil.At the state of equilibrium the factor of safety is equal to one or unity.The basic requirement of slope stability analysis is the determination of safety factor.

8. SAFETY FACTOR

The factor of safety is the ratio between resisting force and pulling or driving force. It is denoted by Fs and essential in analysis of slope stability.It can be expressed in several ways as follows:

Fs=Tf/Td------------------------------------ ---- (1)

Where Tf = average shear strength of the soil.

Td = the average shear stress developed along the potential failure surface.

Bishop, A. W. (1955) suggested following formula(3) for estimation of safety factor. This formula is most appropriate to Toranmal plateau.

$$FS = \frac{c' + hg\cos^2\theta(\rho_r - \rho_w m)\tan\phi}{\rho_r hg\sin\theta\cos\theta} \quad (3)$$

Where,

i) *C' is* the (effective) cohesion (as reduced by loss of surface tension)

ii) *h* is the thickness of the potential slide

iii) *g* is acceleration of gravity

iv)θ is the dip angle of the potential failure plane

v) *ρr* is the density of rock in the potential slide

vi) *ρw* is the water density

vii) *m* is the portion of saturated thickness of the slide *m* = 1 for a fully saturated slide and *m* = 0 for a completely dry slide

viii) tan *φ* is the angle of internal friction

Safety factor is also equal to the ratio between the angle of slope and angle of friction. When safety factor is less than 1(>1), the slope is unstable or slope failure occurs. Unity value of safety is critical and indicates onset of slope failure or landslides. The value of safety factor greater than 1(< 1) indicates stable slope.The slope material have a tendency to move due to shear stress in the soil by gravitational force, water fluid force, tectonic stresses seismic and human induced activities. Thus stability breaks and slope failure occurs. The stability of slope is the main concern of the landslides. The safety factor is the measure of slope stability. The safety factor of Toranmal plateau summit and surrounding plateauescarpments with basal area have been estimated with help of equation no.3 and parameters used to estimate safety factor are as shown in table no.5.5 and estimated values in table no.5.6.

Table 5.5: Parameters used in estimation of safety factor of Toranmal plateau.

No	Factor of Safety Parameter	Value
1	c is the (effective) cohesion (MPa)	70
2	h is the thickness of the potential slide (m)	2
3	g is acceleration of gravity m/s2	9.8
4	θ is the dip angle of the potential failure plane (radian)	Slope angle map
5	ρr is the density of rock in the potential slide	2.9 (Basalt Rock)
6	ρw is the water density (kg/m³)	999.97
7	m is the portion of saturated thickness of the slide	1
8	tan φ is the angle of internal friction (Degree)	33

The safety factor of Toranmal plateau summit area is also estimated as shown in table no.5.7. The safety factor less than one is 0.43 sq km or 43 hectares. It is about 2% of total Plateau summit area. It is slope failure zone or actually damaged area.. The critical zone covers 90 hectare of land. It is about 4.3% of total plateau summit area.

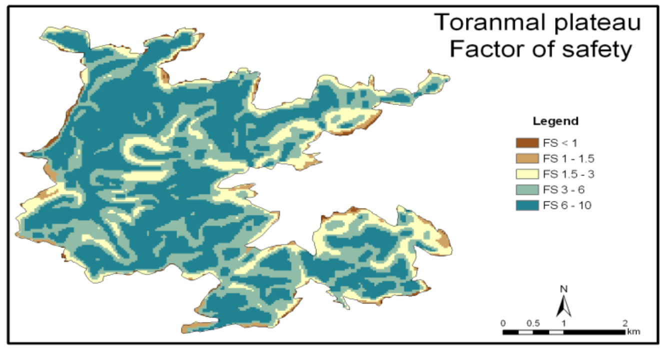
This zone is onset of slope failure. This area may be failed at any time and therefore most risky. The 449 (21.4%) hectare of the land of plateau summit belongs to third category of safety factor. It is not the safe area and needs to be protected. The fourth safety category area 620 hectares (29.4%) needs to be protected in near future. The remaining 829 hectares of land (42. %) Is safe from landslides.

Table 5.7: Toranmal Plateau Summit Factor of Safety

No	FS Class	Area in sq km	Area Hectare	Area in %
1	FS < 1	0.43	43	2.0
2	FS 1 - 1.5	0.90	90	4.3
3	FS 1.5 - 3	4.49	449	21.4
4	FS 3 - 6	6.20	620	29.6
5	FS 6 - 10	8.93	893	42.6
		20.95	2095	100.0

The distribution of safety factor on Toranmal plateau is shown in the map no have shown in map no.5.3.

Map no.5.3 Distribution of Safety factor of Toranmal plateau summit.



The peripheral area of the plateau from all sides shows safety factor less than one. This is the affected area of slope failure. The critical zone

9. SLOPE STABILITY ANALYSIS: AN APPLICATION OF SHALTAB FOR LANDSLIDES ON TORANMAL PLATEAU:

The slope stabilities have been analyzed by means of SHALSTAB slope stability model. SHALSTAB is GIS based deterministic model that runs in ARC VIEW environment. It is a coupled steady state and infinite slope stability model. It may be used in mapping the relative potential for shallow land sliding across landscape (William Dietrich and David Montgomery 1998). This model is based on coupled hydraulic slope stability equation expressed as:

$$q/T= Ps/Pw(1-\tan\theta/\tan\varphi)b/a \sin\theta--- \quad (1)$$

Where,

- **i)** **q**is the effective rainfall.
- **ii)** **T** is soil transmissivity or vertical indicator of saturated conductivity.
- **iii)** **Sinθ** is head gradient
- **iv)** **Tanθ** is slope of surface.
- **v)** **Tanφ** is angle of internal friction of soil mass at failure plane.
- **vi)** **a** is drainage area
- **vii)** **b** is the outflow boundary.
- **viii)** **ps** is soil bulk density.
- **ix)** **pw** is density of water.

The estimated parameters of SHALSTAB for Toranmal plateau are given in table no.5.7.

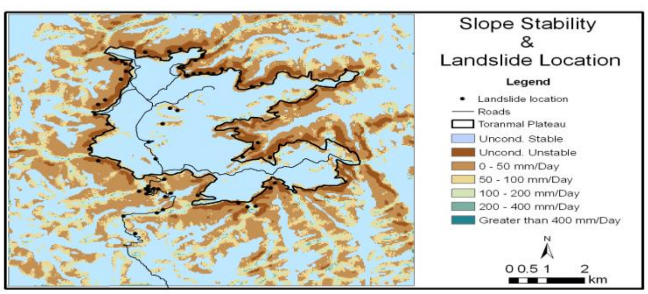
Table 5.7: SHALSTAB Model Parameters.

No	SHALSTAB Model Parameter	Average Value for Toranmal area
1	Soil bulk density (g/cm3)	1.6
	Density of water	1.0
2	Soil saturated conductivity (m/hr)	0.09
3	Soil thickness (m)	2
4	Friction Angle (Degree)	33
5	Soil bulk cohesion (MPa)	70

With this parameters slope stability values have been estimated and successive area calculated as shown in the following table.no.5.8 the spatial distribution map of slope stability have been prepared for Toranmal and surrounding area (map no. 5.4).

Table 5.8: Slope Stability Probability Classification of Toranmal Plateau:

No	Slope Stability Probability class	area in sq km	Area Hectare	Area in %
1	Uncond. Stable	58.30	5830.00	55.2
2	Uncond. unstable	5.05	505.44	4.8
3	0 – 50 mm/day	23.79	2378.97	22.5
4	50 – 100 mm/day	12.21	1221.48	11.6
5	100 – 200 mm/day	5.55	554.85	5.3
6	200 – 400 mm/day	0.71	70.83	0.7
7	More than 400 mm/day	0.02	1.53	0.0002
		105.63	10563.10	100.0



Map 5.4: Slope stability and Landslide Locations Map

The Toranmal plateau and its surrounding slope area is 105.63 sq km. This total area is divided into divided into seven slope stability classes. The first is unconditional stable area. It is 58.20 sq kms (58.30 hectares) and accounts 55.2% area of the total. It is the safe area and slope is stable in this area. The maximum area of summit belongs to this category but summit area is not totally safe or stable. The 5.05sq.km area is unconditionally unstable. It is about 5% of total area.

The instability at the rate of 0.0- 50 mm per day covers nearly 2379 hectares of land which covers 22.5% of the total area of the plateau. The rate of movement is slow. The rate of instability of the slope is moderate on 1221.5hectares of land It is 11.6% of total area of the plateau. The high and very high rate of instability is found over 5.3% and 0.7 % area of the plateau. The 1.53 hectares of the land of the plateau belongs to extremely high rate of instability. This is almost insecure area of the plateau.

10. REMEDIAL MEASURES TOWARDS THE LAND-SLIDING

Many scholars have suggested preventive measures on land-sliding. Hutchinson (1192) suggested that the terrain evaluation approach seemed the best way of extrapolating available subsurface data and ensuring that physical insights are fully considered in arriving at a land-slide hazard assessment

11. SLOPE STABILIZATION METHODS

The slope stabilization methods generally reduce driving forces and increasing resistive forces. The driving forces may be reduced number of ways like excavation of loose materials from unstable part of the slopes and manage drainage water to reduce hydrostatic pressure acting on the on unstable parts of the slope. Unloading is the process of removal of loose mass and by removal of big trees when root support becomes loose before falling trees on the roads. The driving force can be reduced by unloading technique likes removing weight from the upper parts of the slope. This is known as removal of head material, unstable or potentially unstable material, flattening of slopes. The flattening of the slope is the most widely and economical method of slope stability. Slope flattening increases the length of the failure surface. Benching slope, embankments, buttressing, and lightweight fillings and control of surface drainage are the other methods of slope stability.

12. CONCLUSION

The present topographic expression of the Toranmal plateau is the product of denudation processes on one hand and tectonic forces on the other. The steep escarpments confine the plateau from all sides. The boundary area of the plateau is intended by accelerating headword erosion of streams, recession of waterfalls and landslides. This part of Toranmal plateau is highly susceptible to the land slides. Every year hundreds of land slide occurs mostly in rainy season. The high altitude, steep slopes from all sides, heavy rainfall, intense weathering, deforestation, deliberate forest burning, shifting cultivations grazing of animals, construction of roads, soil erosion, soil leaching etc are the favoring conditions for landslides on Toranmal plateau. The land slide hazards are at alarming rate due to anthropogenic interference in natural ecosystem.

The slope stabilities have been analyzed by means of SHALSTAB slope stability model.

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The critical zone covers 90 hectare of land. It is about 4.3% of total plateau summit area. This zone is onset of slope failure. This area may be failed at any time and therefore most risky. The 449 (21.4%) hectare of the land of plateau summit belongs to third category of safety factor. It is not the safe area and needs to be protected. The plateau experience reduction of summit area from all sides. The agriculture land is thus shrinking from all sides. Therefore attention needs to be given towards the understanding of causes and consequences to mitigate these problems. The mapping of land slide affected area is References.

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