Slope Stability Analysis for Optimal Tree Density of Cedrus Deodar Tree in Kumaon Region of Uttarakhand State in India

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***Abstract*: The fragile Himalayan terrain of Uttarakhand state in India often face challenging and tough situation due to landslides, particularly in monsoon season. To cope up with these kinds of hazards, use of effective vegetation as Bio-Engineering is considered a good alternative as this management of ecosystem can provide benefits like stabilizing slope, medicinal resources and other environmental benefits.**

The present study analysed the mechanical effect of plant root system on slope stability. Root cohesion with surcharge effects were analysed and Factors of Safety (FOS) were evaluated for varied slope angles of two different types of soil collected from the sites of landslide area i.e. Kakri Ghat and Salri of Uttarakhand State in India. The extensive laboratory studies for varied plant densities showed the improvements in shear parameter and were used to calculate the Factors of Safety (FOS) from slope stability analysis by using two methods i.e. Swedish and Bishop's method for varied slope angles. Study shows that the variation between FOS and tree densities of Cedrus Deodar tree clearly indicate that there is an optimum tree density that will maximize the FOS for a particular soil type. The value of optimum tree density of Cedrus Deodar trees were obtained and recommended for the different slope condition (45° to 75°) and for soil types collected from the landslide sites Kakri Ghat and Salri Site from Almora and Nainital District respectively from Uttarakhand State, India.

The present work gives the methodology to ascertain the effect of root system vegetation in slope stability for particular soil types with certain limitation. It also quantitatively finds optimum value for plantation of Cedrus Deodar tree for particular slope types and prevents the slope failure caused by deficient vegetation as well as failure because of excess vegetation.

***Index Terms*: Slope Stability, Bio- Engineering, Root cohesion, landslides, Optimal Tree Density, Cedrus Deodar.**

I. INTRODUCTION

Uttarakhand has situated in the lesser Himalayan region around 64% of its landmass covered by Himalayan peak and Glacier. The lesser Himalaya at Uttarakhand in India predominantly consists of sedimentary and low-grade metamorphic rocks along with some crystalline rocks, which are soft, brittle and fragile in nature. These rocks are exposed to the adverse atmospheric conditions, which results in the occurrence of landslides frequently and have caused huge damage in human life. On 16 June 2013, divesting flood and landslides near Gobindat, Kedar Done, Rudraprayag district in Uttarakhand, becomes the country natural disaster.

The slope instability in upper Alaknanda valley Uttarakhand Himalaya, India was studied by Sajwan, K. S. and Sushil, K. [31] and explained that the Himalayan region landslide may occur due to many factors such as change in rainfall pattern, deforestation, construction on old landslide and quaternary deposit. Habitation and infrastructure development initiative in close proximity of streams and river as also our quaternary deposit and unplanned disposal of excavate the fury of both, landslide and flash flood in the region. Use of vegetation (grasses, shrubs and trees) has also been recognized and incorporated in engineering practice from as early as the thirteenth and fourteenth centuries for erosion control and stabilization of slope. Starting 1960s several researchers have investigated the role of the root system on soil reinforcement. Seeding or live planting (e.g., live poles and brush layer) is the main method used to establish the vegetation on slopes.

Vegetation helps to reduce erosion [35] and also to reduce the susceptibility to landslide due to the mechanical and hydrological effect it provides which influence the soil properties [22].

Two different types of tree species i.e., Pinus Radiata and Kanuka were used by Ekanyake *et al.* [8] to study the contribution of roots on soil strength in the east coast region of the north island of New Zealand, where a wide range of the landslide occurs. The result suggested that the contribution of each individual's roots to soil strength on a root cross-section area per unit shear area basis was independent of species for the two tree species tested.

Ekanyake *et al.* [9] used the energy approach model to develop the depth of the critical shear plane and may be used as a simple tool to choose most appropriate plant density to maximize the stability of a given hill slope.

Ali and Osman [1] studied four different types of plant species namely Vertiveria zizanoides, Leucaena leucocephala, Bixa orellana and Bauhinia Purpurea were planted in special boxes containing residual soil compacted to know density and they have found the shear strength of soil by using modified large shear box. A higher residual strength observed in the study also indicates a high contribution of the root system to soil-root reinforcement and root of all types of species, the contribution of roots enhances of soil shear strength and rapid growth of cohesion with increase in root length density.

Sati and Sundriyal [34] the studied and concluded that 14% landslide occur in poor vegetative slopes and 41% landslide occur in the cultivate land and roads etc. They took three types of vegetation (a) Pine (b) Alnus nepalensis (c) Other tree vegetation especially oak, they found that the uprooting of tree is common and it also cause the landslide. Alnus tree developed a short span increase the downhill force component which cause downward slide. On other hand oak tree causing rock mass failure. They observed the slope in Garhwal lesser Himalaya are thick in vegetation but they cause the landslides. Finally concluded that the all vegetation is not to increase the slope stability some of vegetation may cause of the failure of slope.

Mulyono *et al*. [23] discussed that in steep slope, the deep roots and large or dense fiber roots types increase the slope stability. Vegetation with high ability to absorb water from the soil and release into the atmosphere through a transpiration process will reduce the pore water stress and increase slope stability, vegetation with deep root anchoring and strong root binding was potentially more significant to maintain the stability of the slope.

Li, P. and Li, Z. [18] examined the importance of soil conservation on the basis of root distribution pattern and thick effects on soil erosion and revealed that a close relationship existed between root biomass and the amount of water–stable aggregate and soil organic matter content, and these factors greatly influenced soil erosion.

A wide variety of plant species (Bamboo, Cedrus Deodar, Teak, Semal, Khair, Artemisia Annua etc.) can be used for bio-engineering to reduce shallow landslide in landslide prone areas. Cedrus Deodar tree is a large evergreen, dioecious tree to 131ft – 165ft long. It is found in high altitude between 750m to 3500m. Its mean annual temperature is 12°c - 17°c. It is Native found in Afghanistan, Indian, Nepal and Pakistan. This is a fast grown tree and deep-rooted, that holds the soil masses and to increase the stability of a slope. Also control the soil surface erosion. Deodar is an important structural timber used for (building, beams and furniture, etc.) and also used for medicine purpose.

The vegetation not only stabilized the slopes but it is also found that the excess amount of vegetation adversely affects the slope stability on the critical slope. There is an adverse effect of excess vegetation on the stability of slope as the roots and stem increase the roughness of the ground surface and may increase the permeability of the soil. Also, the weight of trees acts as a surcharge on the slope and increase normal and downhill force components [24]. Therefore, we can easily understand that vegetation improves the stability of slope, but excessive vegetation reduces the slope stability because of its vertical normal load.

Thus, need for research proposed a study to find optimum number of plants that can be planted to achieve the maximum stability of slope and a parametric study has been carried out with variation in plant density on the varied soil slopes.

II. STUDY AREA

The study area is the Central sector of the Kumaon Himalaya, Uttarakhand which, constitutes a part of the Lesser Himalayan terrane. The sedimentary of the lesser Himalayan in Kumaon region are separated by two major tectonic trends, the Ramgarh Thrust (RT) and North Almora Thrust (NAT) (Mishra and Sharma). The site is located in west from Almora District for site 1 (Kakri Ghat) and East from Nainital District for site 2 (Salri site), Uttarakhand, between the coordinate 29º 32’ 47’’ N and 79º 31’ 39” E for site 1 and coordinate 29º 18’ 09” N and 79º 33’ 22” E for site 2.

Fig.1 Location and approach map of study area Kumaon Region of Uttarakhand (*Source :www.sewainternational.org)*

Fig. 2.0 Kakri Ghat NH 109 with vegetation before landslide in 2013 and after landslide in 2018 (*Source: Uttarakhand photos.blogspot.com)*

Fig. 3.0 Site View of Salri

The soil samples were collected from the above two sites and brought to the Soil Mechanics Laboratory of Department of Civil Engineering at G.B. Pant University of Agriculture and Technology Pantnagar, Uttarakhand for performing the laboratory test.

III. SELECTION OF SUITABLE PLANT FOR LABORATORY TEST

A suitable plant as similar as Cedrus Deodar in hill region was required for its plantation with varied plant density to conduct the laboratory tests, for studying the effect of root system on the shear parameter of collected soil samples from landslide sites. It was found that various species of plants such as Ocimum Tenuiflorum, Vetiver grass, Juniper, Artemisia Annua etc. can easily grow in the soil samples collected from sites. The species were compared for its correlation with Cedrus Deodar tree and on the basis of Roots spreading system, Height upon diameter ratio, density of tree. On comparison with Artemisia Annua to Cedrus Deodar tree it was found most suitable for this study.

Artemisia Annua has single main taproot, that grow downwards into the soil and from which number of smaller, more horizontal oriented lateral roots branch. The depth of root can penetrate into the soil can mirror the height of the aerial part of the plant and thus it provides excellent anchorage. Whereas, Cedrus Deodar has also deep root grown downwards into soil and has also wide lateral roots system. It can hold the soil masses and thus it provides excellent anchorage. The photographic comparison of root system is shown in figure number 4.0.

Fig. 4.0 Spreading of roots of Cedrus Deodar and Artemisia is similar

Table 1 Comparison Between Artemisia Annua and Cedrus Deodar (Agroforestry Database 4.0 (Orwa *Et Al.* 2009) and ISF Report 2017)

S.No.	Parameter	Artemisia Annua	Cedrus Deodar
1	**Diameter** (avg.)	0.95 cm	50 cm
2	**Height**(avg.)	3 ft. avg.	155 ft. avg.
3	**Weight** (avg.)	0.036 kg	5304.30 kg
4	**Density**	555.4 kg/m^3	560 kg/m^3
5	**Height/ Diameter**	96.301	94.56

A. *Artemisia Annua*

Artemisia Annua belong to the plant family of Asteraceae and is an annual short-day plant. Artemisia Annua is fragrant annual herb widely distributed in Asia, Europe and North America. This annual species grown rapidly in fertile, sandy and alluvial soils. It has single main taproot, that grow downwards into the soil and from which number of smaller, more horizontal oriented lateral roots branch. The depth of root can penetrate into the soil can mirror the height of the aerial part of the plant and thus it provides excellent anchorage.

This plant is used for medicinal purpose. The benefits of this plant are as: Anti- inflammatory, Anti- pyretic (fever reducer), Chemotherapeutic (kill cancer cell), Anti- microbial & Anti- fungal (kill bacteria, viruses and funguses), Anti- parasitic (kill parasites).

Fig. 5.0 Plants of Artemisia Annua

IV. SAMPLE PREPARATION AND EXPERIMENTAL PROGRAM

The representative soil samples were collected from the two sites (Kakri Ghat and Salri site) and were then brought to soil mechanics laboratory for soil testing. Forty- eight numbers of wooden boxes identical to the standard size dimension (30 cm x 30cm x 20cm) of large direct shear test (LDST) box were prepare for further preparation of samples and conduction of tests.

Forty- two wooden boxes were divided into equal area distribution with varying plant density and six of them were left undisturbed for the determination of soil shear parameter. to check the effect of roots system on shear parameter the area of sample surface was divided into seven equal parts and the Artemisia was planted at the approximately of the centroid of that area at equal density as shown in figure 6.

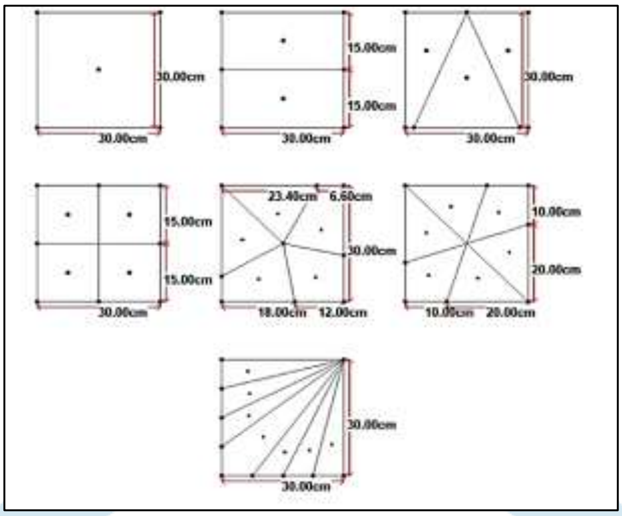

Fig. 6 Schematic diagram showing plantation of Artemisia Annua into soil sample

Fig. 7 plantation of Artemisia Annua into soil sample with varying plants density

The test specimens so prepared were subjected to 50 days of curing for development of desired root system. Thereafter, the stem of each plant was chooped –off for futher LDST test for finding the shear parameter of soil specimen.

Fig. 8 Speard of roots in soil sample after 50 days

In order to investigate the various geotechnical properties of soil, experimental programme was carried out as per IS standard procedures. Grain Size Distribution (IS: 2720 Part IV-1985), Bulk density tests were conducted on soil samples collected from the two sites (Kakri Ghat and Salri site) and Large Direct Shear Test (LDST) were conducted on the LDST Samples prepared with varied density of Artemisia Annua plantation.

(A)

Fig. 9 Performing Large Shear Box Test on soil samples prepared with varying plant density

It was observed that in specimen where two plants of Artemisia Annua were planted the root system develop after the curing of 50 days covered the whole soil mass without substantial overlap. Varied plant density of Artemisia Annua to be converted in to the equivalent tree density of Cedrus Deodar tree and if the root system two plant of Artemisia Annua planted in 30cm × 30cm *i.e.* 900 cm^2 area has contributed in the improvement in shear parameter of soil sample, the two Cedrus Deodar tree planted in 2A area (where root system is not overlapping substantially) will have the same effect. Cedrus Deodar tree roots can radially spread up to 4.88 m covering an area of 74.834 m^2 (U.S. Department of Agriculture Plant Hardiness) and two Deodar tree can cover the 150 m^2 area may (without substantial overlapping root system), which produce same effect as two Artemisia Annua plant in 900 cm^2 area.

V. SLOPE STABILITY ANALYSIS

Shear parameters of samples prepared from Kakri Ghat and Salri Site with varied plant densities were tested with Large Direct Shear Test. The curve variation shows gradual increase in the value of (c and ϕ) with increase the plant density up to five number of plant planted (*i.e.* Cedrus Deodar per 150sqm) and decreases for plant density six and seven (*i.e.* equivalent Cedrus Deodar as six Cedrus Deodar tree per 300sqm and seven Cedrus Deodar tree per 300sqm).

Table 2 Shear Parameter of Kakri Ghat and Salri Site with Varying Plant Density

Sl No.	Number of Plant	Kakri Ghat		Salri Site	
		c (kN/m^2)	Φ in degree	c (kN/m^2)	Φ in degree
1	Without plant	13.6	21°	12.67	24°
2	One	17.14	23°	14.36	22°
3	Two	19.35	22°	21.65	25°
4	Three	23.67	24°	24.73	25°
5	Four	25.37	26°	27.28	24°
6	Five	26.47	25°	26.37	25°
7	Six	24.94	24°	25.97	25°
8	Seven	23.86	23°	24.67	24°

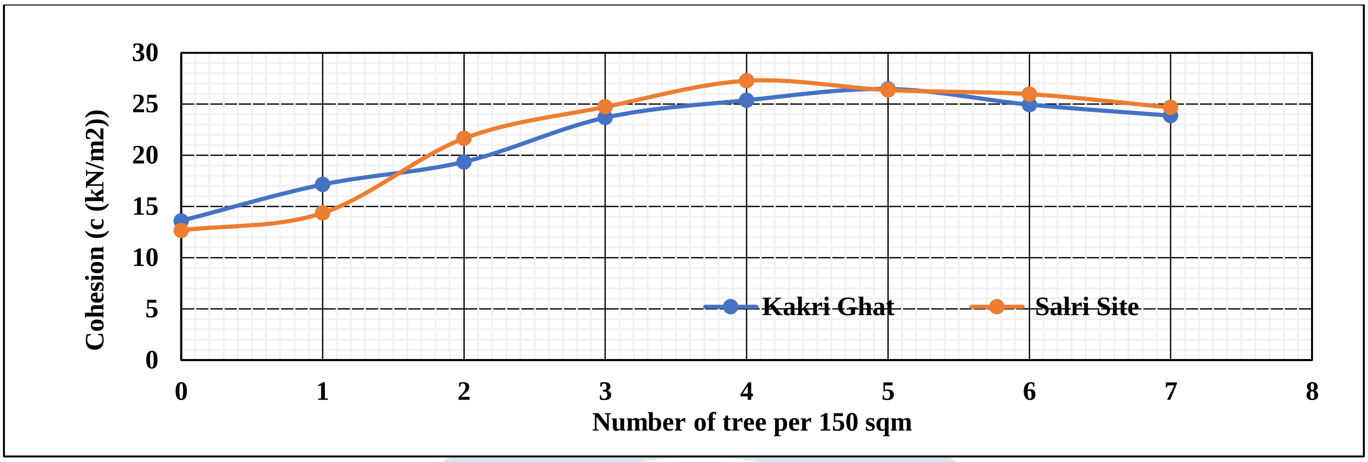

Fig.10 Variation of cohesion (c) of soil samples collected from Kakri Ghat and Salri Site with varying number of Cedrus Deodar tree per 150 sqm

Slope stability analysis was performed by Swedish Slip Circle method and Bishop's method to find optimum number of Cedrus Deodar that can be planted to achieve the maximum stability of the varied slope. The results obtained in determination of Factor of Safety (FOS) with varied slope are plotted to obtain the optimum tree density of Cedrus Deodar tree for the soil collected from two different landslide sites.

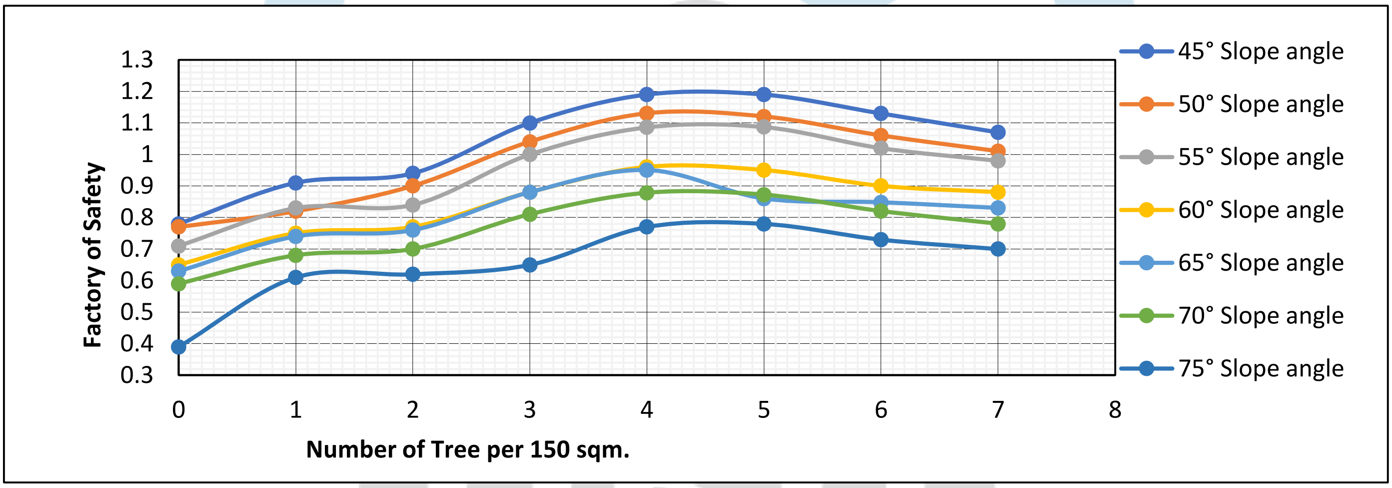

Fig. 11 Optimal Number of Trees Density in Different Angles by Swedish Method for well graded sandy deposits soil (Kakri Ghat Site)

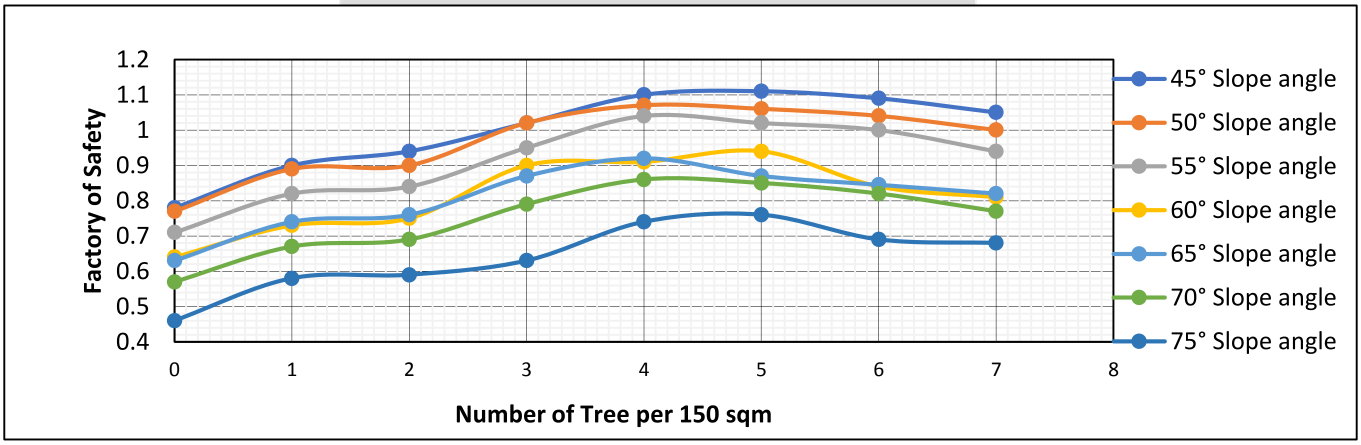

Fig. 12 Optimal Number of Trees Density in Different Angles by Bishop Method for well graded sandy deposits soil (Kakri Ghat Site)

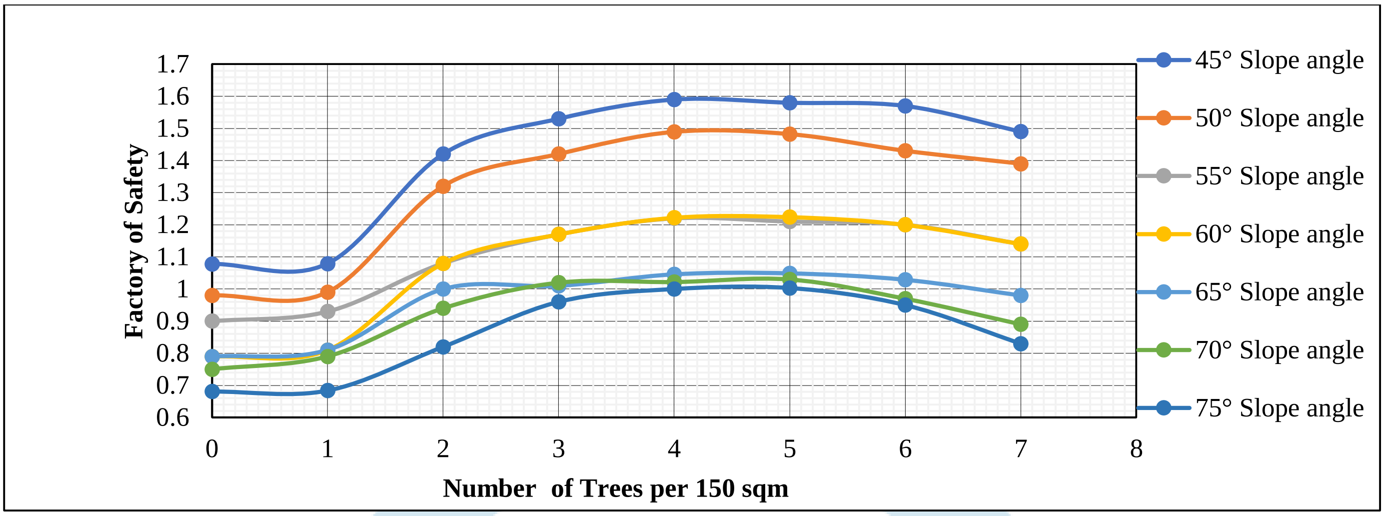

Fig. 13 Optimal Number of Trees Density in Different Angles by Swedish Method for poorly graded sandy deposits soil (Salri Site)

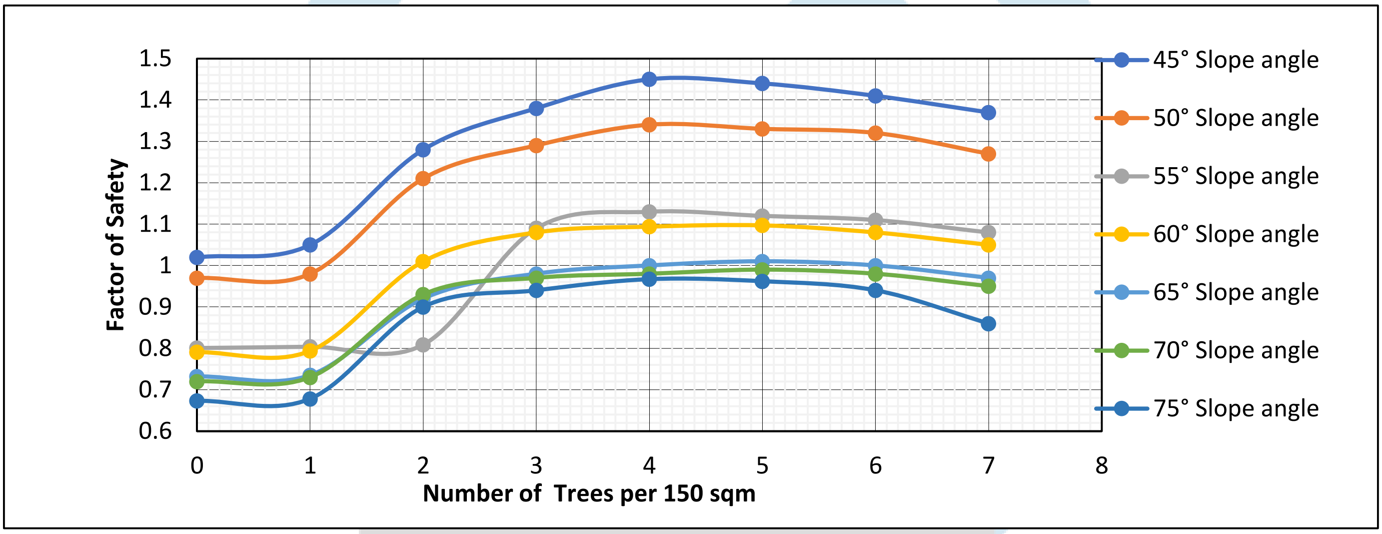

Fig. 14 Optimal number of trees density in different angles by Bishop Method for poorly graded sandy deposits soil (Salri Site)

Table 3 Comparative Analysis of Optimal Tree Density of Cedrus Deodar by Two Slope Stability Method for Well Graded Sandy Deposits Soil

Slope angle	Optimal Tree Density of Cedrus Deodar			
	By Swedish Method		By Bishops Method	
	Number of Tree 150 sqm. Area	FOS	Number of Tree 150 sqm. Area	FOS
45°	4.4	1.200	4.5	1.120
50°	4.4	1.120	4.2	1.090
55°	4.4	1.097	4.2	1.040
60°	4.3	0.989	5.0	0.940
65°	4.2	0.956	4.2	0.875
70°	4.2	0.890	4.2	0.850
75°	4.0	0.820	4.0	0.780

Table 5 Comparative Analysis of Optimal Tree Density of Cedrus Deodar by Two Slope Stability Method for poorly graded sandy deposits soil

Slope angles	Optimal Tree Density of Cedrus Deodar			
	By Swedish Method		By Bishops Method	
	Number of Tree in 150 sqm. Area	FOS	Number of Tree150 sqm. area	FOS
45°	4.10	1.598	4.20	1.460
50°	4.10	1.498	4.20	1.350
55°	4.10	1.240	4.40	1.130
60°	4.30	1.180	5.00	1.097
65°	4.50	1.062	5.00	1.010
70°	4.40	1.055	4.00	0.990
75°	4.00	1.005	4.00	0.967

VI. CONCLUSIONS

From the research work presented in this paper the following conclusions may be drawn:

1. Failure of Slopes are causing economical and human causalities in major parts of Uttarakhand states especially in monsoon reasons. The catastrophe caused by landslides have been reported as loss in revenue around Rs. 2000 million per year by Sate Disaster Management and Mitigation Department.
2. It is found that inadequate vegetation may not adequately stabilized the slopes but on the other hand excess vegetation may also cause the slope failure due to excess normal load on slopes. Therefore, there must be an optimum vegetation density for which the maximum slope stability may be attained.
3. For analysis the effect of root system in slope stability of two different types of soil collected from landslide area of Uttarakhand i.e. Kakri Ghat and Salri Site, Shear Box Testing were prepared with varied plant density. The selection of suitable plant Artemisia Annua is carried out with appropriate comparison with Cedrus Deodar tree. So that the effect of root system of Cedrus Deodar tree on the slope of Uttarakhand region may be represented effectively in the controlled laboratory conditions.
4. The extensive laboratory studies of around 48 sample of Large Shear Box Test for varied plant density shows the improvements in shear parameter with increase in tree density. It is obtained for the soil of Kakri Ghat (well graded sandy deposit) the value of c and ϕ is enhanced around 13.6 kN/m2 to 26.24 kN/m2 when the tree density were increased from Cedrus Deodar tree 0 to 5. Further the c and ϕ value is also observed to be decrease when the tree density is more than 5 tree/ 150sqm.
5. It is obtained for the soil of Salri Site (poorly graded sandy deposit) the value of c and ϕ is enhanced around 12.67 kN/m2 to 27.28 kN/m2 when the tree density were increased from Cedrus Deodar tree 0 to 4. Further the c and ϕ value is also observed to be decrease when the tree density is more than 4 tree/ 150sqm.
6. These improved value of shear parameters (c and ϕ) for calculated tree density of Cedrus Deodar tree (tree/150sqm area) are used to calculated the FOS from slope stability analysis by using two methods for varied slope angles.
7. Curve plotted between number of tree per 150sqm and FOS it is observed that the different slope angle the optimum number of Cedrus Deodar tree per 150 sqm, firstly increase for 45° slope angle and then decrease for slope angle of 75°.
8. The validation of calculated FOS is observed by using the GeoStudio 2019 (Slope/W) software and the calculated results of FOS for 60° is compared and found correct.
9. Finally, the optimum value of Cedrus Deodar tree for soil types may be adopted by Forestry Department and other Department. To plant the more tree on the slope where the tree density is less than optimum value as to curtail the excess tree density near to optimum value so that the maximum FOS may be achieve.

VII. LIMITATION OF STUDY

The study has significant results in terms of plant species that have a better performance stabilizing slope basically on landslides. However, the lack of direct date root area ratio, tensile strength *etc.* the result taken with caution because these types of factors are specific, even varying between the same species. The results can be taken indicative and an approximation of performance of plant species that have reported as useful in slope stabilization but for most of them no specific studies have been done.

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