IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 09, Issue 5 (May. 2019), ||S (I) || PP 19-25

Greening with Vetiver Grass to Reduce the Risk of Landslides and Slope Erosion (A Case Study on the Outer Ring Road of Gorontalo Province Indonesia)

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Abstract: Erosion and landslide on the outer ring road of Gorontalo Province were discussed among constructionists and geotechnical experts, especially slopes at station 13+600 which had steep slopes of 63^o and altitudes of 55.56 m. This research aims to determine the effect of vetiver vegetation on erosion that occurs and the relationship of erosion with land characteristics and the effectiveness of vetiver in controlling erosion and landslides. The results obtained from the analysis of vegetation suitability matrix with land conditions, showed that the use of vetiver in alluvial land with limestone deposits which have a water content of 15.47%, land density 2.68 and levels of Ph 9.7 were very effective growth. Empirical analysis of slope erosion with Universal Soil Loss Equation (USLE), it turns out that vetiver can reduce land loss by 22.5%. Vetiver root is effective against shallow avalanches, analysis with the Fellenius equation slice method using the rocscience slide 6.0 programs has no effect, but roots can only increase soil cohesion values.

Keywords: Erosion, Vetiver, Stability, Rainfall

Date of Submission: 23-04-2019 Date of acceptance: 06-05-2019

I. INTRODUCTION

Erosivity and landslides are challenges in the development of transportation infrastructure, if uncontrolled will have material losses for highway users. To minimize potential losses, erosion handling by vegetative methods should be carried out which is a simple, low-cost technology, utilizing plants for land and water conservation and environmental protection.

The combination of structural and non-structural engineering or vegetation is often more effective in preventing erosion and landslides. Greenway, (1987) argues that the application of bio-techniques in slope stabilization is useful as a prevention and control widely in engineering practice, while Gray and Sotir, (1996) to achieve desired engineering goals can use live plants and natural elements such as rocks and wood. The biotechnical method of using plants for traditional slope reinforcement methods is more cost-effective and environmentally friendly Zhu et al. (2017).

II. METHODOLOGY

Erosion estimation

Estimation of erosion (A) uses the USLE (Universal Soil Loss Equation) model Wischmeier and Smith (1978). This model is influenced by the characteristics of land erodibility, rain erosivity, slope length and angle, land management effort, and vegetation cover factor to reduce erodibility.

Land characteristics are internal aspects of slopes that must be measured as the basis for mechanical engineering of slope estimation, shallow landslides, undisturbed land is taken by drilling method and shear tests are carried out to obtain safe factor values, besides the drill test is carried out to identify land type and arrangement, and to ensure Vetiver root can grow naturally. Water content testing aims to see the oxygen source content for vegetation and as a mechanical parameter for land cohesion values, other parameters tested include specific gravity, grain size.

Vegetation Analysis

Vegetation can function as a live anchor and will function mechanically in holding the land through the value of root tensile strength and friction on the land produced. The use of root media as biological anchors can be done through selection of the type of root tensile strength (Mpa) of vegetation and the amount of influence produced for slope stability.

Safe factor

Fellenius explains that forces have parallel slope angles based on slices and safety factors with equilibrium moments. The principle of Fellenius's method for each collapse occurs through the rotation of a ground block on a circular landslide surface as the center of rotation, assuming that the normal force is considered to work in the middle of the slice and the resultant forces between slices are ignored.

Based on the Fellenius assumption stated above, then the analysis of security factors with the Mohr–Coulomb collapse criteria as in equation 1;

$$\tau = c' + \sigma' \tan \text{Ø}' \quad \ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

Where τ is the soil friction strength, c' is the cohesion value obtained from the direct shear test, σ' is the effective normal stress of the reduction in fixed normal stress (σ) with pore water pressure (u) while the normal stress and tan Ø' is the shear angle in the ground. Safety factor (SF) is stated from the results of the shear stress caused by landslides. If SF> 1.5 shows a stable slope, and if SF = 1.5 the slope is likely to be unstable and if the SF <1.5 slope is declared unstable and requires handling

Slope stability analysis uses the rocscience slide 6.0 programs to facilitate the calculation of forces acting on each slope. The measurement results of slopes were processed using slides based on the parameters of the weight, (Y) Kn/m^3, cohesion, (C) Kpa and the value of friction angle in the land (φ) in the layer, and analyzed based on Mohr-coulomb failure criteria. After the feed intake parameters were analyzed using the Fellenius slice method to obtain a landslide collapse image on each slice.

III. RESULTS AND DISCUSSION

Land characteristics

Uninterrupted land samples were taken from Huidu village, at station 13+600 ORRoGP precisely at the coordinates of 0°38'44.60"N - 122°56'45.91"E. Drilling was carried out to a depth of two meters, every 20cm depth was carried out by visual analysis. The result is that the size and color have similarities up to a depth of 200cm, the description of the land is alluvial brownish yellow, lithology of fine sandy land (gravel and loose) The grain size of land fraction according to the Unified Soil Classification System (USCS) is low to medium plasticity clay, contains gravel clays, sandy clays, silt clay, clean clay, the results of the sieve analysis are shown in Table 1.

Table 1. Grain size analysis

Analysis	Standard	Value
	Specific gravity	10,77
	Water content of the field %	15,47
Soil classification according to USCS standards	Liquid Limits (LL) < 50 %	33.90 %
	Plastic Limit (PI) >7 %	10,77 %
	Pass the filter 200	50,33 %
	Group symbol	CL
Test analysis	Coarse fraction (> 0,075 mm)	72,20 %
Grain size	Fine fraction < 0,075 mm)	27,80 %
	Arranged by	
	Gravel (>2 mm)	30,33 %
	Sand (0,075 – 2,0 mm)	33,00 %
	Silt (0,005 – 0,075 mm)	8,87 %
	Clay(< 0,002 mm)	27.80 %

Source: Data processing, 2019

Sliding Strength

Based on the results of the analysis of shear strength obtained by soil parameters as in Table 2;

Table 2. Direct shear test parameters

Load (kg) / Parameter	Unit	8	16	24
Wet volume weight (g_b)	(g/cm^3)	1,91	1,91	1,91
Dry volume weight, (g_d)	(g/cm^3)	1,71	1,71	1,71
Final moisture content (w)	(%)	18,65	20,77	18,28
Normal Voltage (s_n)	(kg/cm^2)	0,25	0,51	0,77
Shear parameter point 1				
Shear stress when collapsing (t)	(kg/cm^2)	0,350	0,712	0,906
Sliding changes when collapsing (d_h)	(%)	0,39	0,71	1,04
Inside friction angle (φ)			25 ^{o}	
Cohesion (c)	0,106 kg/cm^2 equivalent 10,36 kN/m^2			
Shear parameter point 2				
Shear stress when collapsing (t) (kg/cm^2)	0,350	0,673	0,906	
Sliding changes when collapsing (d_h) (%)	0,46	0,63	0,49	
Inside friction angle (φ)			25^o	
Cohesion (c)	0,092 kg/cm^2 equivalent 9,05 kN/m^2			

Source: Analysis Results, 2019

Slope safe factor

Analysis of landslide fields with the slice method produced a safe factor value of 0.272, including critical slopes (Ray and De smedt, 2009) requiring stability improvements, to obtain a safe factor <1.5 can be achieved if the range of angles is less than 17.5^o, as seen in Figure.1;

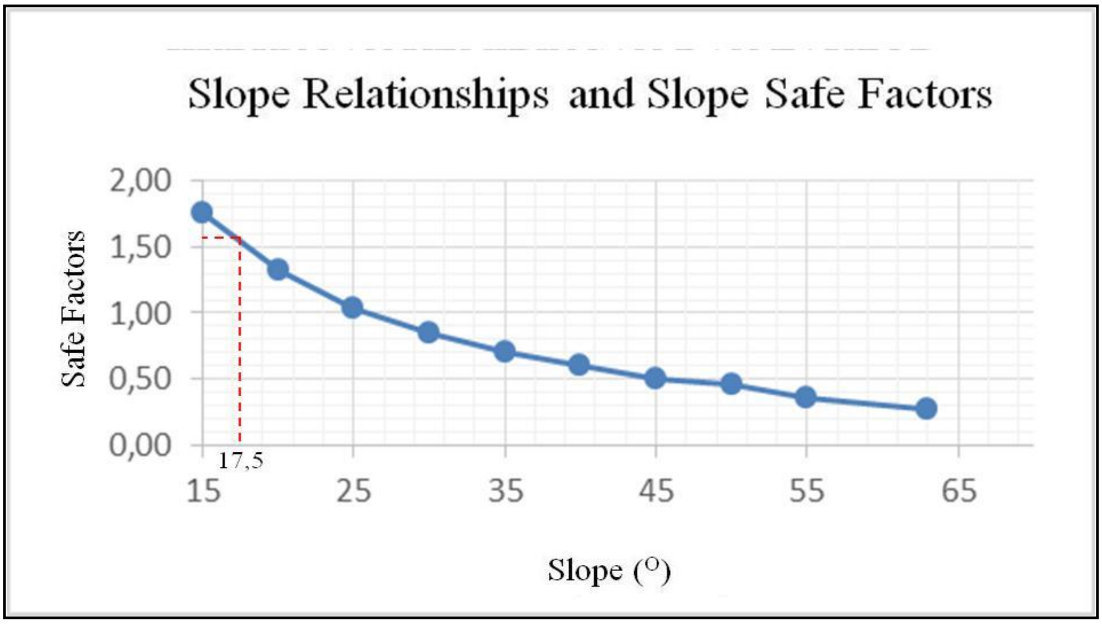

Figure 1. Slope relationship and safe factor

Relationship between rainfall and land erodibility

Rainfall has an effect on the slope erosivity process; the average rainfall in the last two years (2017 and 2018) of 1406 mm/year according to the 2013 Directorate General of Forestry Regulation can be classified as very low. Falling rain can not all be absorbed into the ground, some become surface runoff and carry fine grains of particles following the gravitational force, the average infiltration rate is obtained at 13.25 mm/hour, based on the standards of the Food and Agriculture Organization in Annex 2 Infiltration rate classifies the soil in ORRoGP contains clay.

The results of measurements of uncovered soil infiltration on the outer ring road of Gorontalo Province (ORRoGP) using a double ring infiltrometer, obtained an average water absorption of 19 mm/hour, according to the infiltration index Rickard and Cossens, (1965) in SCDT (2003) land infiltration included in the medium category, this condition is good for areas with very low rainfall, but it is very worrying for areas with high rainfall.

Moderate infiltration values and very low rainfall indexes produce balanced water infiltration before the land saturates. Lands that are saturated, convert rainwater into surface runoff and if not controlled can increase slope erosivity through surface flow, the value of land sensitivity to rainwater is known to be 2.70 included in the medium category, if the high rainfall intensity of the land is sufficiently active in response to rain and erosion. The results of the study indicate that if the land is left without cover it will have an impact on the average soil loss of 13.56 tons/year or 5.06 m^3, with the average rainfall occurring in the range of 1406 mm/year.

Relationship between land erosivity and vegetation methods

Land loss on an area of 322,914 m^2 or about 32.30 ha, can be seen from the estimation of slope erosion with vegetation and on without vegetation with equation 2

$$A = R.K.L.S.C.P \quad (2)$$

The relationship between land erosivity and vegetation is shown in Table 3

Table 3. Land loss without vegetation planting

Parameter	Symbols	Value	Unit	Information
Rainfall erosion index	R	47,907	ton/ha/cm	Medium
Land sensitivity index	K	0.27	%	Medium
Long and slope factor	(L.S)	6.125	m - %	Initial conditions
Without vegetation protection	C	0.5	-	Clear cut
	C^*	0.2		
Without Conservation Efforts	P	0.2	-	Without Conservation
	P^*	0.15		
The amount of land lost average every year	A	13.56	ton/ha/yr	With Conservation Geometric planning
The amount of land lost average every year	A*	3.05	ton/ha/yr	Geometric Planning
Effects of using vegetation Vetiver	(A-A*)	10.5	Ton/ha//yr	Erosion land that can be controlled

Source: Analysis Results C *, P *, A * are loss of land by planting vegetation

The erosion hazard level (EHL) on the vegetation-free slope of 1.63 is included in the medium scale, if the slope uses EHL vegetation of 0.37 including on a low scale, changes in EHL indicate the effectiveness of vetiver on the land. In the same rain land erosion is produced if the slope uses vetiver vegetation as a cover of 3.05 tons/ha/year or about 1.14 m^3. The effect of vetiver vegetation on soil erosivity is 10.5 tons/ha/yr, thus land loss due to erosion in the ORRoGP area of 32.30 ha can be controlled by 10.5 tons/ha/year or around 3.92 m^3.

Application of vetiver grass vegetation

The choice of vegetation type should consider the survival of post-planting vegetation, because not all types of vegetation are able to grow and adapt to land and environmental conditions on the outer ring road of Gorontalo Province (ORRoGP). The results of laboratory tests show that the Ph level of the land has a fairly high acidity level which is between 9.6 - 9.7, so that the suitability between the types of vegetation for both grasses and trees is needed as in Tables 4 to 5.

Table 4. Suitability of land conditions

Land conditions and research environment	Plant	vetiveria zizanioides (vetiver)	Paspalum notatum (Bahia)	Leucaena leucocephala (Lamtoro)	Acacia mangium (Akasia)	Pinus densiflora (Pinus)
Location altitude mdpl (m)	40- 90	0 -1100	0-2000	0 - 500	0-400	>1000 - 2000
Temperature (°C)	22-32	22 – 55	7.8 – 30	21 - 32	23 - 30	19 - 21
Availability of water						
Annual rainfall (mm/yr)	1477	250 – 5000	700 - 1200	700 - 1500	1300-2500	2500 - 3000
Duration of dry months (month)	2	15	2-3	3-4	2-3	1-2
Availability of oxygen (oa)						
Drainage	Slow	Good, Rather, Fast, Medium	baik	Good, Rather Fast, Medium	Good, Rather	Good
Nutrient retention (nr)	9.7	4.2 – 12. 5	4,0-6,5	7,0 - 8,0	7,0 - 7,5	5,5 - 7,0
Toxicity (nr)						
Salinity (mm hos/Cm)	0	4.2 - 12.5	<1	<4	<4	<2
Danger of Erosion (eh)						
Slope (%)	67	< 67	< 50	<8	<8	<8
Danger of erosion	Very low	High	Very low	Very low	Very low	Low
Land preparation (lp)						
Rocks on the surface (%)	<2	<3	<1	<3	<3	3-15
Land and roots						
*Land texture**	CL	L, SCL, SiL,Si, CL, SC,SiCl	S,L, C	L,SCL,SiL,Si, CL, SC,SiCl	SL, L, SCL, SiL, Si, CL, SiCL	SL, L, SCL, SiL, Si, CL, SiCL
Effective depth (Cm)		20 – 360	243 -304	> 100	>100	>100
Value of tensile strength (Mpa)		85.10	19.23	104.83	54.37	32

*) C= Clay, S= sand, L= clay, SL= Sandy clay, Si= Silt, SiL= Dusty clay
SiCl= Dusty clay, SC= Sandy clay, SCL= Sand clay , StrC= Clay Structure

Continued Table 4

Analysis of vegetation conformity shows the level of suitability of vegetation with land and environmental conditions on the road the outer ring of Gorontalo Province shown in Table 5;

Table 5. Level of vegetation and land suitability

Land conditions and research environment	Vegetation	vetiveria zizanioides (vetiver)	Paspalum notatum (Bahia)	Leucaena leucocephala (Lamtoro)	Acacia mangium (Akasia)	Pinus Densiflora (Pinus)
Location height (mdpl)	40- 90	++	++	-	++	-
Air temperature (°C)	22-32	++	++	++	+	-
Availability of water						
Annual rainfall (mm/yr)	1477	++	+++	++	++	--
Duration of dry month (Month)	2	++	++	++	++	++
Availability of Oxygen (OA)						
Drainage	Slow	++	+	+	+	+
Nutrient retention *(nr)*	9.7	++	-	-	-	-
Toxicity **(nr)**						
Salinity *(mm hos/Cm)*	0	++	++	++	++	++
Danger of Erosion **(eh)**						
Slope *(%)*	67	++	-	-	-	-
Danger of erosion	Very low	++	++	++	++	+
Land preparation **(lp)**						
Rocks on the surface (%)	2	++	+	+	+	++
Land and roots						
Land texture	CL	++	+	++	++	++
Effective depth *(Cm)*		++	++	++	++	++
Tensile value (Mpa)		++	++	++	++	++

Notation; (--) = Not exactly (-) = Less precise (+) = Suitable (++) = Most appropriate

Vetiver grass and slope stability

The application of vetiver grass considers the slope conditions and land erodibility values and slope angle The planting of grass is carried out at a distance of 10 cm and filled with two rows of vetiver spaced 15 cm, the distance between the vetiver grass groups filled by two rows is 40 cm apart, serves as a barrier water rate and channel for surface runoff. The results of the analysis show that the adaptation of vetiver grass to the nature of the land has a relatively high suitability compared to other vegetation. The mechanical effect of the composition of vetiver grass roots is very good for lands that function as biological anchors, as seen in table 6

Table 6. Parameters of root influence

Parameter	Values	Unit
Vetiver root diameter (d) (d)	0,66	mm
Assumption of root growth length	200 cm	cm
Vetiver Value of pressure and tension that is linear in vetiver grass (E), Hengchaovanich and Nilaweera (1996)	85.10	N/mm^2
Analysis of the effect of root tensile strength		
Vertical root area (A) = $\frac{1}{4} \pi d^2$	0,34	mm^2
Root Pull Strength (EA)	28.934	N
or equal to	0.028934	Kn/mm^2
Roots in 1 vetiver grass canopy have	200	Point
Vetiver grass produce (0.028934 * 200)	5.78	Kn/mm^2

Source: Analysis Results, 2019

The value of style (Kn) and root diameter (mm2) for one vetiver canopy, which is 5.78 Kn/mm^2, is used as the root function approach to land resistance and shear. The results of the rocscience slide 6.0 analysis program, using the assumption of vetiver as a live anchor with a parallel root style, indicate that vetiver grass is not able to increase the safe factor of slopes, because the slope is too high and the land carrying capacity is the main cause of the ORRoGP stability, but vetiver root can have an influence on the cohesion value (c) of the slope surface, which can be implemented in Mohr-Coulomb's collapse law by Wu (1979) as shown in equation 3;

$$\tau = (C + 1{,}2\, T_R \;\; RAR\,)_{+} (\sigma - u) \tan \phi \;\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

Where the value of soil shear stress (τ) soil cohesion value (C) value of root contribution to land cohesion (C_R), normal stress value (σ), pore water stress (u) and (φ) is the inner shear angle, (T_R) value root tensile strength and (RAR) ratio of root area (RAR) to depth (Z), can be calculated by equation

$$\{(1/400)\times(2\text{-}z)\}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The results of the analysis show an increase in the value produced by the root against the value of shear strength, as in Table 7.

Table 7. Effect of root vetiver grass on soil shear strength

z, Root depth (m)	Tr, Root tensile strength (Mpa)	$C_{R,}$ Root contribution Share cohesion values () (Kpa)	RAR, Root area and depth ratio	τ, Ground shear stress (kg/cm)
2	85.10	28.59	0.00028	30.164

IV. CONCLUSION

Estimation of slope erosion on the outer ring road of Gorontalo Province (ORRoGP) erosion especially in STA 13+600 shows the relationship of climate analysis with land characteristics, vegetation as land cover can be used as a controller for slope erosion. The land erodibility index is classified as moderate, indicating that the land tends to be active, especially if the rainfall scale is high and can increase the Erosion Hazard Level (EHL). The safety matrix shows that vetiver planting in alluvial land with limestone deposits with a water content of 15.47%, soil density 2.68 and levels of Ph 9.7 are very effective. The use of vetiver has a positive impact on reducing the amount of land loss per year by 22.5%, and vetiver root can increase the cohesion value to 28.59 Kpa.

ACKNOWLEDGMENTS

The author expresses his gratitude and appreciation to the Department of Public Works and Public Housing of Gorontalo Province, Regional Road Work Unit IX, BMKG Gorontalo Province, Department of Transportation Engineering, Hasanuddin University, which has facilitated the completeness of this research.

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IOSR Journal of Engineering (IOSRJEN) is UGC approved Journal with Sl. No. 3240, Journal no. 48995.

Rahmat Libunelo[1] "Greening with Vetiver Grass to Reduce the Risk of Landslides and Slope Erosion (A Case Study on the Outer Ring Road of Gorontalo Province Indonesia)." IOSR Journal of Engineering (IOSRJEN), vol. 09, no. 05, 2019, pp. 19-25.