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Geomorphic Variables Influential to Develop Erosional Characteristics*

Yoo-Jeong Hwang**

산지사면의 침식에 영향을 주는 지형인자에 관한 연구*

황 유 정**

Abstract : The goal of this study is to find the geomorphic variables contolling gully development on hillslopes following deforestation. Two possible geomorphic processes, surface erosion and mass movement were reviewed to compare the characteristics and geomorphic variables involved. The research objective in this paper is to find the variables and the statistical model which can explain gully density in the study area. Gully density was selected as a response variable. For log gully density, the best subset regression was found to have the variables such as area, surface length, and surface width. Log area is the most significant predictor. Even with several outliers, the normal probability plot of the residuals from this regression looks straight. So, area, surface length, and surface width explain half of the variance in gully density.

Key Words : geomorphic variables, hillslope processes, deforestation, gully development

요약 : 본 연구는 사면에서 식생이 제거된 후 침식지형이 발달하는 경우에 어떠한 지형인자가 영향을 줄 수 있는지를 알고자 하는 것이다. 지금까지 보고된, 사면에서 일어날 수 있는 지형형성작용에는 표면침식과 사면이동이 있으며, 본 연구 지역에서는 사면이동보다는 표면침식이 진행되었던 것으로 판명되었다. 연구지역에서 영향을 준 지형인자를 비교하기 위해서 사면의 면적과 사면의 길이, 너비, 사면의 경사, 사면의 형태, 사면의 방향 등이 지형인자로 고려되었다. 통계적인 모델링을 통하여 나타난 회귀모델은 사면의 면적과 사면의 길이, 너비가 표면 침식의 정도를 좌우하는 지형인자로 판명되었다.

1. Introduction

The extent of deforestation was quite substantial in Korea. For instance, in 1910, more than 40% of the national forest land was either deforested or partially reforested with seedlings (Forestry Statistical Yearbook, 1910). Land degradation could be found in any portion of the country until nationwide reforestation started in the 1960s. All layers of soil were removed from the hillslopes in some areas according to erosion control project records prepared in the 1920s (Chosun Chongokbu, 1926). The purpose of this study is to identify the geomorphic controls of erosion. Hillslope erosion and mass movements are two general types of geomorphic processes that might have resulted from deforestation in Korea. Using geomorphic variables suggested in these geomorphic processes, an anlysis of erosional landforms in a highly degraded area near Seoul will be done.

All hillslopes are subjected to natural forces that are opposed by inherent resistance within landforms. The principal sources of resistance on hillslopes are derived from (1) the structural strength of geologic materials, (2) the cohesiveness of soil mantles, and (3) vegetation cover (Selby, 1982). Collectively, these

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** Post-doc research fellow in the Institute of Korean Regional Studies, Seoul National University

constitute the shear strengths of hillslopes which oppose the shear stresses. The decrease in shear resistance may result either from internal or external causes. Internal causes involve some change in either the physical or the chemical properties of the material or its water content. External factors which lead to an increase in shear stress on the slope usually involve a form of disturbance that may be either natural or induced by man.

Whenever shear stress exceeds shear strengths, the materials involved are deformed or translocated and work is performed (Selby, 1982; Cooke and Doornkamp, 1990).

The effect of vegetation removal can be found in terms of less interception and less transpiration losses. Once vegetation is removed or the density of vegetation has been reduced, less cohesive and loose soils on the slope can easily be removed on the slope with the increase of overland flow. Once, forest land has been disturbed by tree removal, the hillslope environment begins to adapt to the changes of relationship between resistance and shear strength, and hillslope hydrologic condition can be altered drastically leading to erosion (Cooke and Doornkamp, 1990).

Hillslope erosion process consists of the detachment, entrainment, and downslope transportation of surface materials (Selby, 1982).

On the basis of hillslope hydrology and the driving forces, four categories of hillslope erosion can be designated (1) rainsplash, (2) sheet erosion, (3) rill erosion, and (4) gully erosion.

Another possible process involved on the disturbed forest land in Korea is mass movement. Factors and variables controlling different types of mass movement have been studied in various circumstances.

Velocity of movement, mechanism of movement material, mode of deformation, water content, and geometry of the moving mass distinguish the types of movement. Varnes's classification has been widely accepted; falls, slides, and flows (Selby, 1982).

2. Analysis of Hillslope Geomorphic Processes

An area north of Seoul as shown in Figure 1 (about 120 square km) was selected for analysis of factors controlling slope erosion following deforestation. This area was selected because the area is one of the most degraded area (Hwang, 1995) and the availability of aerial photos.

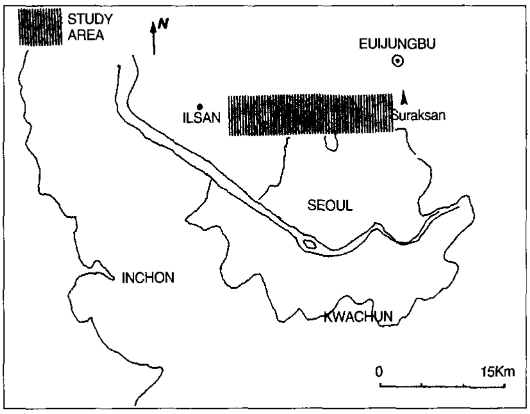

Figure 1. Study area

As this area is located next to the capital, it has been repeatedly deforested. Erosion control reports on this area describe the severity of degradation such as removal of soil layers and slope failures. Only twenty to thirty percent of forest land was covered with full grown trees (Chosun Chongdokbu, 1926). In the aerial photo interpretation(photos were taken from 1950-51), many gullies were recognized in the study area. Some of gullies are continuous and others are discontinuous. The texture of sediment near the gullies look coarse. Few deposits implying the evidence of mass movement found in the bottom of the slopes. The gullies appeared to be resulted from water erosion.

In detail, the research objective is to find the variables and the statistical model which can explain gully density in the study area. The analysis has been done to find the variables that are more significant than other in gully development. The unit of observation is a slope facet that can be identified as a unit on the aerial photos, which has a clear ridge line and uniform slope. The size of a slope facet ranges from 50,000 to 500,000 square meter.

Controlling variables were selected based on the literature review. Most of the studies selected variables such as slope length, slope gradient, slope form, and type to explain the processes on hillslope. In this study, slope length, slope width, slope gradient, slope aspect, area, the highest elevation, and the lowest elevation were measured on each unit facet by the surface analysis function in Arc/Info (Tab. 1). The type and form of slope were identified by overlay of contour layer and slope surface layer. A total of 101 slope unit facet were analyzed.

1) Slope form

The slope form is one of the major factors to be considered in explaining the spatial distribution of slope processes. Kemp (1990) explained that discharge and slope increase downslope leading to a progressive increase in the total amount of surface erosion on convex slopes. On the concave slopes, there is initially rapid increase in erosion downslope, but this levels out as the slope declines, and at the base of the slope, the rate of ground lowering begins to decrease. But Megahan and King (1985) concluded that concave slopes, whether based on plan view or slope cross section, are efficient landforms for concentrating soil water and can lead to more chance of erosion.

Table 1. Variables

Independent variables
Slope form
Maximum slope surface length
Maximum slope surface width
Area
Highest elevation
Lowest elevation
Elevation difference
Mid elevation
Slope gradient
Slope aspect
Dependent Variables
Length of gullies
Average gully length
Gully density
Tin density

2) Slope aspect

The aspect can give influence on the erosional process because reduced solar radiation on north-facing slopes can lead to increased soil moisture, and thus increased the chance of erosion.

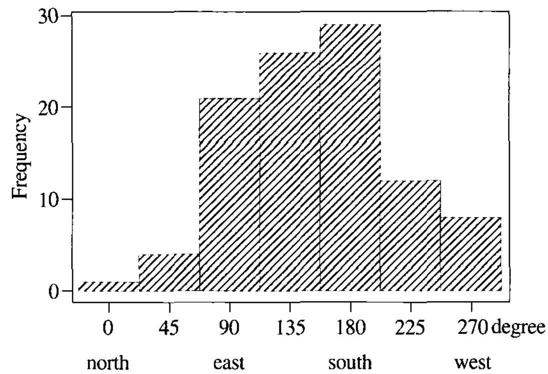

Figure 2. Slope aspect

3) Slope gradient

Slope gradient is used to predict the soil erosion in the Universal Soil Loss equation (Lal, 1994). In this study, slope steepness was calculated from the TIN data structure which is based on two basic elements; points and a series of edges joining these points to form triangles. TIN structure has been used to estimate slope steepness in many geomorphological modelling studies (Moore et al., 1993). Each sample point is connected with its two nearest neighbors to form triangle. In each TIN, the degree of steepness can be calculated in

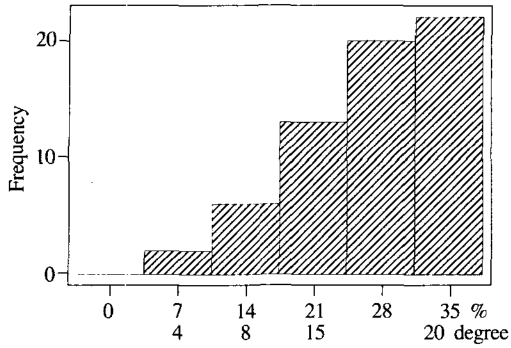

Figure 3. Slope gradient

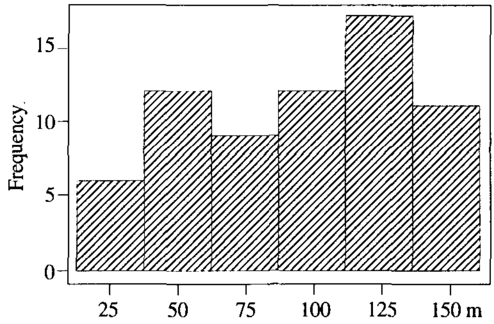

Figure 5. Slope width

ARC/INFO.

In this study, over ninety percent of the sample slope facets had more than 15 degree slopes implying that most sample facets are steep. Less than ten percent of the sample slope facets show less than eight degree (Fig. 3).

4) Slope length and width

The universal Soil Loss Equation also includes slope length as a variable (Lal, 1994).

In this study, slope lengths were measured to test whether slope length can influence the gully development. Before measuring slope length, highest and lowest point on each slope facet were designated. Surface length between highest and lowest point was calculated in ARC/INFO command. Over 65 per cent of the sample surfaces have surface length less than 100 m (Fig. 4). Surface width was measured by calculating surface length between two mid-elevation points on two ridge lines. Forty five percent of the sample surfaces have surface width between 100 and 200 m (Fig. 5).

5) Elevation

Elevation was measured in meters above sea level. The mountains in this study area ranges in elevation from 50 to 600 meter. Most of the slope facets (over 65%) have highest point between 50 and 100 m. Around 20 per cent of the sample slope surfaces have highest points over 150 m. This shows that most of the disturbed, deforested sites were located at low level of the mountains, easily accessible areas by footsteps. The difference between the highest and lowest points of slope facet was chosen as a variable with mid-elevation (Fig. 6).

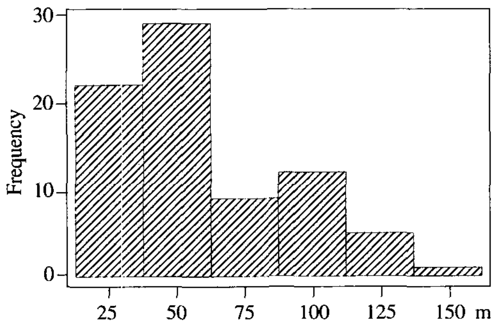

Figure 4. Slope length

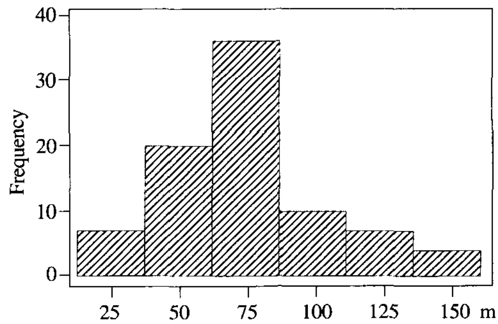

Figure 6. Mid elevation

6) Slope Facet Area

More than 85 per cent of the sample surfaces had a slope facet area less than 50,000 square meter (Fig. 7).

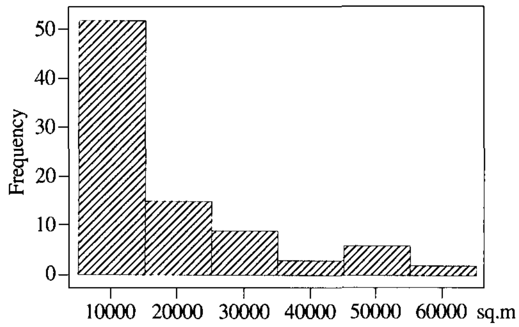

Figure 7. Slope facet area

3. Data Analysis and Results

The objective of the data analysis is to reveal the general relationships among the geomorphic variables, as well as to explore the particular relationships between variables that describe the extent of gullying and potential geomorphic controls. Data were collected on 101 slope facets using ARC/INFO software, and were analyzed using MINITAB.

A principal component analysis of response variables was done to examine the covariation among the response variables and to choose one of more variables for regression analysis. Principal component analysis of predictor variables was done to reveal the extent to which these variables measure the same thing. Finally, the best subset regressions for log gully density (dependent variable) were done, followed by then diagnostic analysis for the best model.

1) Steps in data analysis

The two sets of variables (predictor and response) were each examined using a combination of descriptive plots and analyses.

A. Distributions of and relationships among response variables

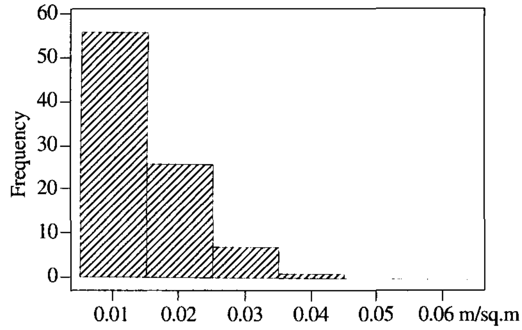

Figure 8. Gully density

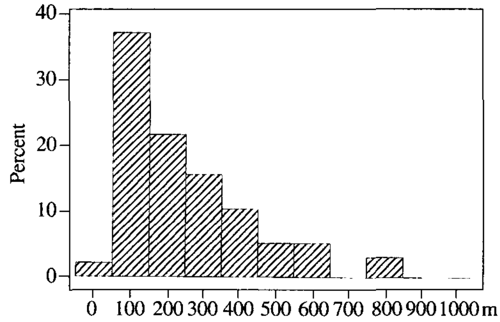

Figure 9. Gully length

Histograms of the response (gully extent) variables are shown in Figure 8-9. Most of the histograms showed skewed patterns. Therefore, variables were log transformed. Histograms of log transformed variables showed distributions that were more nearly normal (Fig. 10-11). The scatter plots of raw values are shown in Figure 12. These show weak and inverse relationships, for example, between gully density and average gully length. The scatter plots of transformed variables, however, look more linear (Fig. 13). For example, the figure reveals a more linear relationship between log transformed gully density and log transformed average gully length. Correlation coefficients that measure the strength of the linear

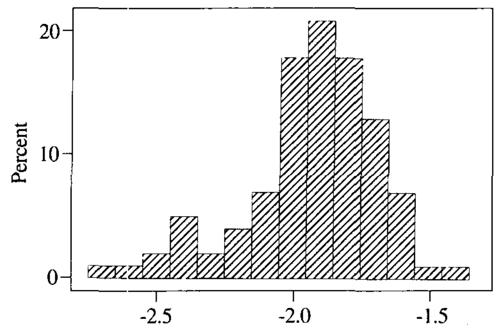

Figure 10. Log gully density

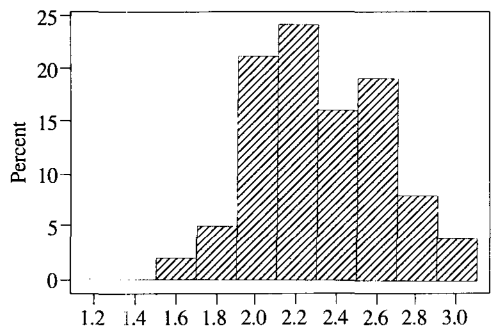

Figure 11. Log gully length

relationship among transformed response variables were significant (Tab. 2; p-values less than 0.05). The significant correlation indicates that the response variables are related to one another, and to some extent measure the same thing.

B. Distributions of and relationships among the predictor variables

The scatter plots of untransformed values of the predictor variables also show many non-linear relationships (Fig. 14), and like the response variables, the distributions of individual variables are skewed. For example, relationship between area and surface length is clearly non-linear. Therefore, area, surface length, surface width, mid elevation, and elevation difference variables were log transformed. The scatter plots of transformed variables showed linear relationships (Fig. 15).

C. Relationships between response variables and predictor variables

The draftsman plot of transformed response variables and predictor variables is shown in

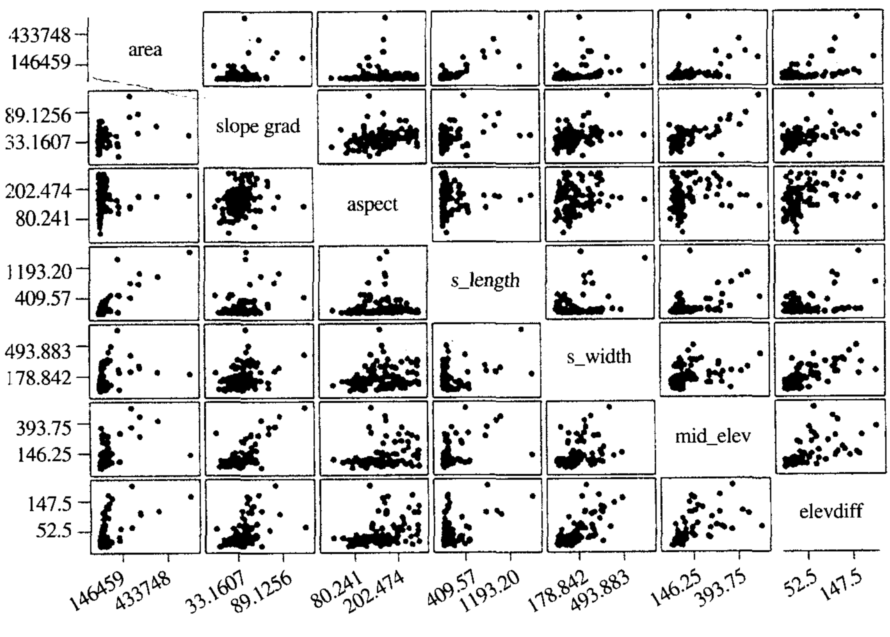

Figure 12. Scatterplot of raw variables

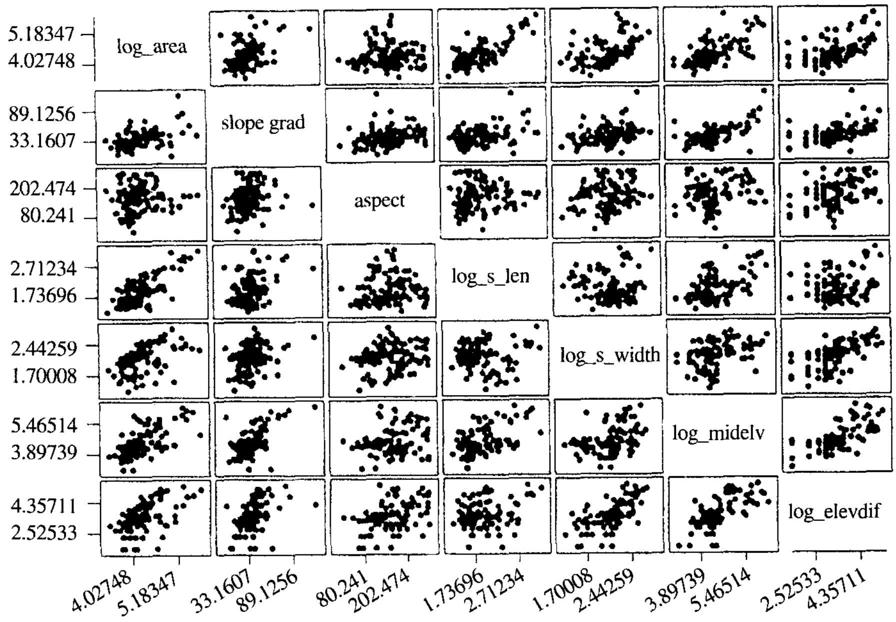

Figure 13. Scatterplot of transformed variables

Table 2. Correlation

	tot_g_le	log_avgl	log_g_de
log_avgl	0.708		
	0.000		
log_g_de	-0.254	-0.253	
	0.008	0.008	
tin_dens	0.273	0.210	-0.151
	0.004	0.030	0.120

Cell Contents: Correlation
P-Value

	log_area	slope gr	aspect	log_s_le	log_s_wi	log_mide
slope gr	0.468					
	0.000					
aspect	0.053	0.241				
	0.591	0.012				
log_s_le	0.761	0.398	0.042			
	0.000	0.000	0.667			
log_s_wi	0.458	0.328	0.232	-0.051		
	0.000	0.001	0.016	0.604		
log_mide	0.627	0.615	0.222	0.502	0.394	
	0.000	0.000	0.025	0.000	0.000	
log_elev	0.568	0.512	0.380	0.281	0.640	0.705
	0.000	0.000	0.000	0.004	0.000	0.000

Figure 16. The individual plots in this figure show several interesting relationships between the predictor and response variables. For example, the relationship between log gully density and log area is inverse linear. The relationship between slope gradient and tin density is linear.

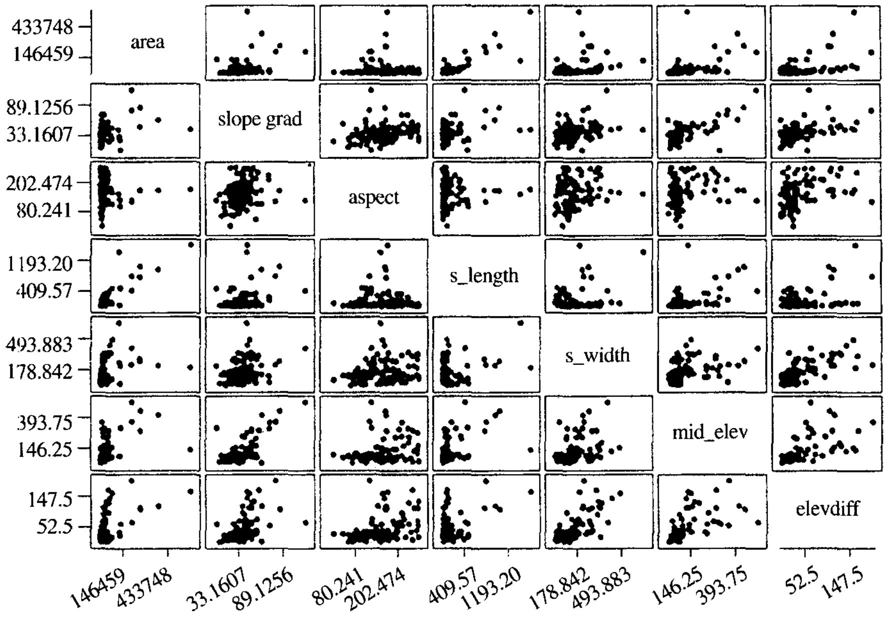

Figure 14. Scatterplot of predictor variables

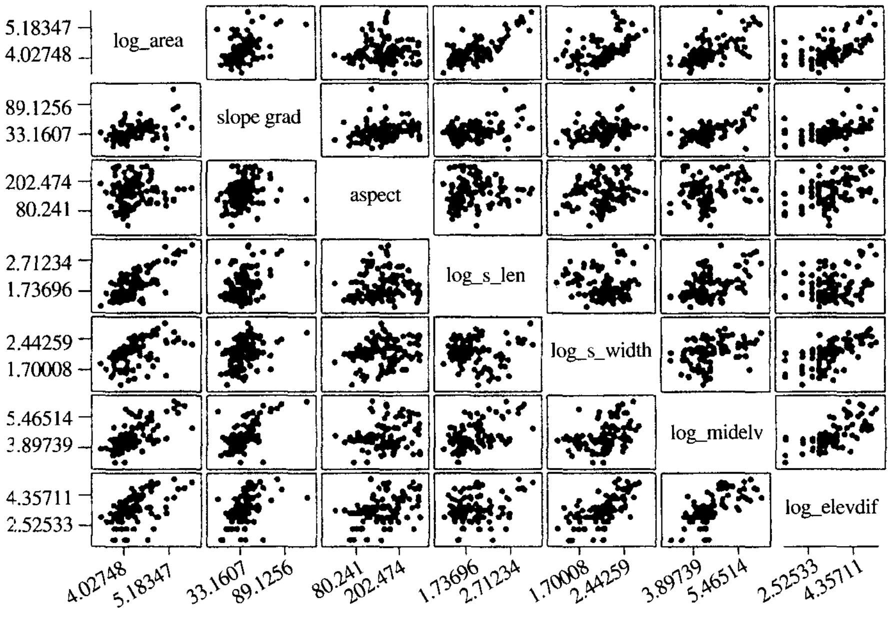

Figure 15. Scatterplot of transformed predictor variables

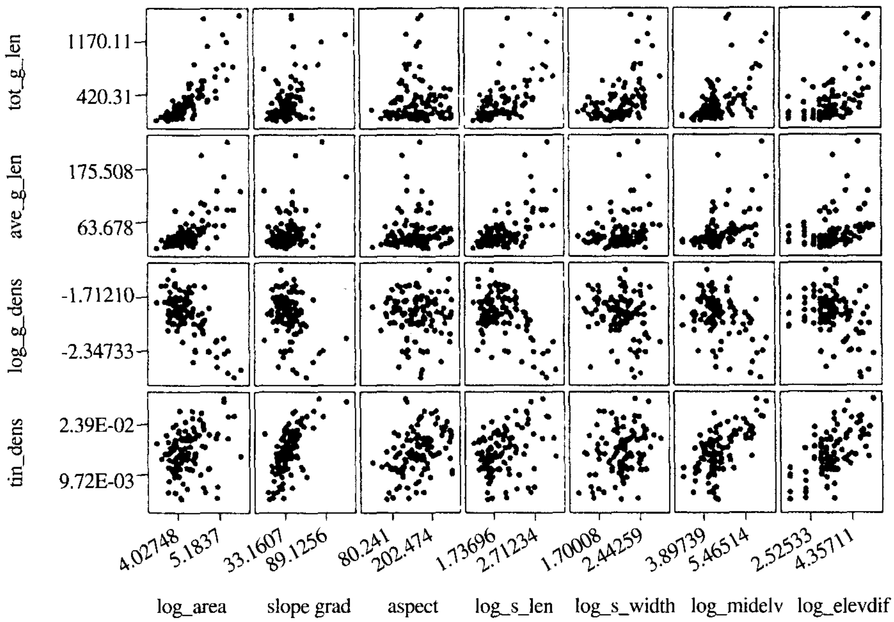

Figure 16. Transformed response and predictor variables

D. Principal component analysis of response variables

The objective of principal component analysis was to pick a single response variable for regression. The component loading (i.e. correlations between variables and components) and the eigenvalues of each showed that two components explain seventy one percent (Tab. 3). Principal component one is log gully density. Principal component two is tin-density. Log gully density was chosen as response variable for regression analysis.

E. Principal component analysis of predictor variables

To understand the relationships among the predictor variables, a second principal component analysis was done. Two components explain sixty nine percent of variance (Tab. 4). Principal component one is log area and log surface length. Both variables explain the size of the slope facet. Principal component two is surface width.

F. Best subsets regression

Log gully density was selected as response

Table 3. Response variables

Rotated Factor Loadings and Communalities Varimax Rotation						
Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
t gleng	0.888	0.153	0.088	0.336	-0.261	1.000
ave leng	0.441	0.121	0.153	0.876	-0.010	1.000
l gden	-0.067	-0.067	-0.989	-0.111	0.005	1.000
l gleng	0.943	0.122	0.045	0.251	0.175	1.000
tin den	0.145	0.982	0.068	0.095	-0.007	1.000
Variance	1.8978	1.0225	1.0165	0.9642	0.0990	5.0000
% Var	0.380	0.204	0.203	0.193	0.020	1.000

Table 4. Predictor variables

Unrotated Factor Loadings and Communalities

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Communality
l area	-0.840	0.286	-0.248	-0.309	0.166	0.026	0.166	1.000
s gradi	-0.771	0.009	0.159	0.551	0.179	0.212	0.013	1.000
aspec	-0.340	-0.535	0.725	-0.251	0.094	-0.034	0.024	1.000
l leng	-0.624	0.699	0.192	-0.234	0.051	0.053	-0.158	1.000
l wid	-0.567	-0.638	-0.448	-0.086	0.214	-0.072	-0.114	1.000
ele dif	-0.828	-0.298	-0.098	-0.101	-0.403	0.209	-0.006	1.000
mid ele	-0.868	0.123	0.063	0.230	-0.148	-0.391	0.012	1.000
Variance	3.5644	1.3669	0.8622	0.5870	0.3013	0.2516	0.0666	7.0000
% Var	0.509	0.195	0.123	0.084	0.043	0.036	0.010	1.000

Table 5. Best subset

Vars	R-sq	R-sq(adj)	C-p	S	s gradi	aspec	l leng	l wid	mid ele	ele dif	l area
1	44.2	43.6	4.3	0.18270							X
1	20.2	19.4	47.8	0.21839			X				
2	45.0	43.9	4.8	0.18222						X	X
2	44.5	43.4	5.6	0.18302				X			X
3	46.9	45.2	3.4	0.18006			X	X			X
3	45.7	44.0	5.6	0.18207			X			X	X
4	47.7	45.5	3.9	0.17957			X	X	X		X
4	47.1	44.9	5.0	0.18060		X	X	X			X
5	48.4	45.7	4.7	0.17934			X	X	X	X	X
5	47.8	45.1	5.7	0.18028		X	X	X	X		X
6	48.7	45.5	6.0	0.17964		X	X	X	X	X	X
6	48.4	45.1	6.7	0.18029	X		X	X	X	X	X
7	48.8	44.9	8.0	0.18060	X	X	X	X	X	X	X

variable. The best model for predicting this response variable can be identifies as one that has high R square and adjusted R square, and low Cp values (Tab. 5).

Variables such as log area, log surface length, and log surface width were frequently selected as important predictor variables in the analysis (Tab. 5). Log area was included in every model because it has very strong relationship. Log area takes care of the problem that gully density and tin-density were defined using area variable. Therefore, there is automatic relationship that might be expected between gully density and area that can be accounted for by including area as a predictor.

G. Regression diagnostic analysis and final model

The normal probability plot of the residuals for the model is straight line, indicating that the residuals are approximately normally distributed (Fig. 17). Residual scatter plot for the model does not have a discernable pattern (Fig. 18), indicating that other serious violations of the assumptions of regression analysis are not present. These plots tell that the model is good enough to predict the gully development with variables selected.

The final (best subset) regression includes the variables log area, log surface length, and log surface width. R square value tells us what proportion of the variance of the dependent variable is accounted for by all the predictor variables combined. In this model, 48 percent of the variance of the log gully density is explained by all predictor variables (log area, log surface length, and log surface width) combined.

4. Discussion of Model

It has been found that gully development was controlled by slope facet size as represented by area and surface length variables. Surface water erosion was thought to be the main process in drainage network expansion. Therefore, the larger slope facet area could collect more runoff than the smaller area, which could lead to more surface erosion upon deforestation. Some of variables such as slope form or slope gradient were expected significantly influence the differential degree of gully development, did not appear to show a significant relationships with the response variables. The reasons for this lack of significance will be investigated in future research.

Table 6. Final model

The regression equation is
1 gden = -0.462 - 0.575 1 area - 0.000323 mid ele + 0.246 1 leng + 0.263 1 wid

predictor	Coef	StDev	T	P
Constant	-0.4615	0.2235	-2.06	0.042
1 area	-0.5750	0.1017	-5.66	0.000
mid ele	-0.0003233	0.0002613	-1.24	0.219
1 leng	0.2458	0.1034	2.38	0.019
1 wid	0.2628	0.1095	2.40	0.018

S = 0.1796   R-Sq = 47.7%   R-Sq(adj) = 45.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	2.82302	0.70575	21.89	0.000
Error	96	3.09552	0.03224		
Total	100	5.91854			

Source	DF	Seq SS
1 area	1	2.61399
mid ele	1	0.00295
1 leng	1	0.02042
1 wid	1	0.18566

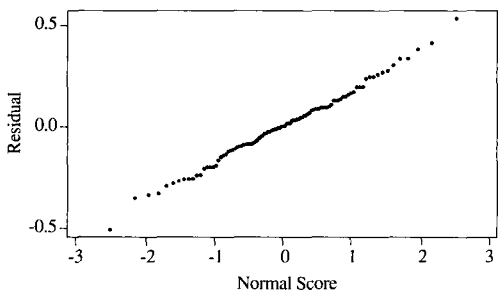

Figure 17. Normal probability plot

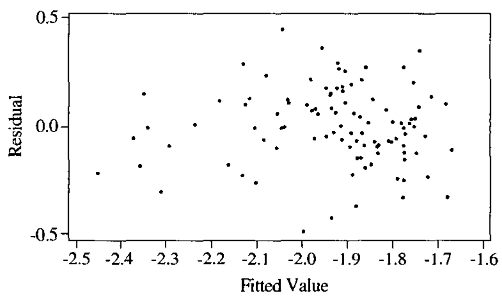

Figure 18. Residual scatter plot

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