地理學論叢 第32號(1998. 8), 43-49.

Effects of Forest Clearance on Drainage Network Development

Hwang,Yoo Jeong*

삼림지 훼손과 하계망의 발달

황 유 정 **

Abstract : This paper presented results of drainage network analysis in two study sites, one disturbed (deforested) basin and one basin that was protected from deforestation. The disturbed basin has slightly higher drainage density and significantly longer first and second order streams than the forested basin. Various processes of drainage network expansion were considered. The main process seems to be channel development by surface water erosion, and possibly by subsurface piping. Only minor mass movements were observed.

Key words : drainage network, forest clearance, geomorphic effects, deforestation

요약 : 본 연구는 대량적인 삼림훼손이 유역 하계망의 발달에 영향을 주었는가에 관한 것이며, 두개의 상이한 삼림지 관리의 역사적 배경을 가진 지역에서 비교 연구 되었다. 두 연구대상 유역은 동일한 식생대에 속하며, 거리에 있어서 근접해 있고 기반암의 특성도 유사하다. 삼림훼손이 있었던 유역에서는 저차수 하천의 평균길이가 길었으며, 하계밀도에 반영되어 밀도가 약간 높게 나타났다. 주요 지형 형성작용으로는 표면침식, 파이핑등이 고려되었다.

주요어 : 삼림벌채, 하계망, 하계 밀도, 표면침식, 식생피복

Ⅰ. Introduction

Geomorphic effects of land clearing or deforestation throughout a region can be found in the streams. The previous studies identified those effects such as enlarged stream, bank deposit overflowing, decreased pool frequency, and increase or decrease of sinuosity (Thornes, 1990, Hagans and Weaver, 1987). In this study, sediment choked streams were identified in the aerial photos of Koyang basin. But, without multi-dated aerial photos or topographic maps before and after deforestation, it was not possible to determine change of sinuosity or channel width in deforested basins. Rather than focusing on the change of channel morphology after deforestation in one area, the research was directed to answer the difference of drainage network composition between deforested and undisturbed basins.

Natural or man-induced changes imposed on a fluvial system tend to be absorbed by the system through a series of channel adjustments. The predominant difference between natural and

* Post-Doc Research Fellow, The Institute of Korean Regional Studies Seoul National University
** 서울대학교 국토문제연구소 연수연구원

man-induced changes is time scale. Channel adjustments caused by climatic changes or uplift may be very slow and progressive, practically imperceptible during man's period of observation. Conversely, large-scale channel modifications by man result in a sudden and significant shock to the fluvial system that causes observable changes (Simon and Hupp, 1990).

Prosser and Slade (1994) provided research on how vegetation cover leads to the susceptibility of valleys to channel incision in swampy alluvial flat meadows. In their study, the probability of channel incision reportedly increased with the loss of vegetation cover, or reduction of vegetation density. Their study suggests that where vegetation cover is cleared, drainage density increased.

As this research was designed to understand erosion following deforestation without intensive field work, mainly using aerial photos and GIS techniques, attention was given to the drainage network.

Ⅱ. Study area and Research Method

In this research, two areas which have quite different backgrounds in terms of forest practices will be analyzed to answer the question of whether tree removal has contributed to the increase of channels, leading to denser network. Two study areas (Koyang and Kwangneung) were selected to address the questions on drainage network development (Figure 1). Koyang basin(Changneung cheon) was substantially deforested by the early twentieth century while the Kwangneung basin(Bongseonsa cheon) has never been deforested except by natural fires and minor insect attack (Forestry Agency, 1988). Erosion control reports on Koyang basin prepared in the 1920s described the severity of forest land degradation in detail. Only twenty five percent of forest land was stocked with full grown trees. More than thirty percent of forest land was barren (Chosun Chongdokbu, 1926; 1928). There were wide-spread erosion problems. The main cause of deforestation in Koyang basin can be attributed its closeness to the capital (Hwang, 1995). Reportedly, fuelwood markets were set up in Koyang for merchants and citizens of the capital to purchase wood (Kim, 1983). Kwangneung was closed to entry in 1490s when it was set aside as a royal cemetery. Both regions have similar bedrock distribution and degree of relief (Table 1).

Analysis of drainage network characteristics was used to address the research question on the impact of vegetation removal.

TABLE 1. Bedrock Characteristics and Elevation

Basin	Bedrock	Elevation Range
Koyang	granite, granite-gneiss	200-600 m
Kwangneung	granite, granite-gneiss	100-590 m

The perennial channels and drainage basin boundaries were digitized on the topographic maps (1:5000 scale) published by National Geography Institute (Table 2). These channel maps were draped over the TIN models, constructed from contour coverages. The study drainage basins were clipped out from the TIN modes. The main goals of the analysis were to find out the number of channels, surface lengths of the channels, and surface area of the study basins. Surface length and surface area are different from planimetric length and area on the topographic maps because measurements are done in three dimensional models. Drainage density was calculated with drainage basin area and total length of first, second, and third order streams.

TABLE 2 Topographic Maps of Study Basins

Koyang Basin	
1:5000	SEOUL 028, 029, 030, 038, 039, 040
Kwangneung Basin	
1:5000	POCHON 077, 078, 087, 088, 097, 098

These two drainage basins were analyzed for drainage texture. Koyang basin showed higher drainage density and longer 1st and 2nd order streams compared with Kwangneung basins (Table 3)(Figure 1). Koyang basin also has higher a bifurcation ratio than Kwangneung basin. These properties can be explained based on characteristics reported in other studies and processes involved in drainage network development.

Ⅲ. Drainage Density and Disturbance Regime

A number of factors have been known to control drainage density. Drainage density is controlled by the amount and quality of water received at the surface. Therefore, climatic factors such as mean annual precipitation, precipitation intensity, and seasonality of precipitation have to be considered first. Secondly, bedrock characteristics like permeability and hydraulic conductivity can control the difference of drainage density. Less permeable rock types can be associated with high drainage density. Thirdly, species composition and percent cover of vegetation has to be considered in determining drainage density (Dunne, 1980; Knighton, 1984).

The two study basins analyzed here were selected to hold bedrock characteristics, climate, topography, and soil properties constant, focusing on differences in vegetation cover. In this study, as the two basins have similar lithologic and climatic characteristics, the major difference between the study basins is degree of human disturbance, specifically vegetation removal. The question is whether or not human disturbance by vegetation removal contributed to the development of more dense channel networks.

TABLE 3. Drainage Basin Properties

	Koyang(deforested)	Kwangneung(protected)
First order	138	62
Second order	38	18
Third order	9	2
Bifurcation ratio	3.631	3.444
Drainage Area	41.64 sq.km	51.39 sq.km
Length of streams	44.038 km	41.898 km
Drainage density	1.0575	0.8152
Ave.Length(First Order stream	420 m	191.38 m
Ave.Length(second Order stream)	868 m	217 m

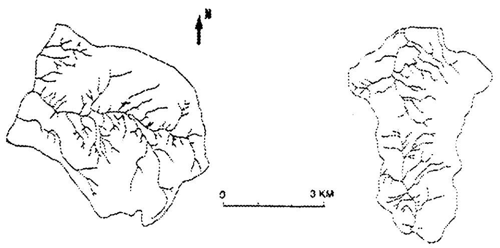

Figure 1. Koyang and Kwangneung Basin dense channel networks

Soils weathered from granite bedrock distinctly reflect the properties of the parent rock, and typically have low organic matter content. The soils derived from granite or gneiss, which is the bedrock in the study basins, are typically either loam or sandy loam (Park,1988). Granite tends to weather to sand which has high permeability.

Limited surface runoff and the dominance of throughflow are expected with vegetation cover.

Schumm (1997) cited Levish's analysis of drainage density in granite regions in California. Levish measured active channels with well-defined banks. He used 1:63,000 topographic maps and 1:20,000 scale aerial photographs. The average permeability of the weathered granite soils was 97 mm per hour. In granite basins the majority of runoff is transmitted by throughflow. Twenty four basins in Levish study showed drainage density in the range of 1.52- 14.92.

TABLE 4. Drainage Density Data

Basin	Precipitation	Area	Drainage Density
Nevada City	1,387 (mm)	4.6 (sq.km)	2.78
Tiger Creek	1,146	5.4	2.23
Calaveras	1,340	3.9	2.08
Grant Grove	1,070	4.2	2.56

(Source : Schumm, 1997)

Basins in California with 1000 mm precipitation (comparable to precipitation in the Korean study sites) showed drainage density from 2.09- 2.78, which is higher than the values shown in this study. It is probable that species composition and vegetation density in California results in higher drainage density compared with Koyang and Kwangneung basins. Even with same precipitation (1,000 1,300 mm), most of the California basins have relatively low density vegetation cover with shurubs compared to the two Korean study basins which have deciduous and coniferous forest cover. Lower vegetation cover in California is related to the mediterranean climate, which is characterized by summer drought. In Korea, the precipitation maximum occurs in summer, supporting denser vegetation.

Ⅳ. Results and Discussion

1. Disturbance and Channel Initiation

It was found that the disturbed basin (Koyang) has a slightly higher drainage density compared to the undisturbed basin (Kwangneung). The increase of drainage density can be expected upon disturbance (Prosser. I. P. and Slade, C. J. 1994). More first order streams were found in the disturbed basin in this study. This implies that disturbance regime help to develop more first order streams (Table 3).

Channels originate in a variety of ways. They may form on a recently exposed surface or during a phase of network expansion resulting from a change in environmental or base-level conditions (Selby, 1985). In this study, channel origination might be related with network expansion with increase of surface runoff. When forest cover was present, there was little surface runoff and little surface erosion especially as granitic soils have high permeability. Deforestation can increase the surface runoff leading to surface erosion. Granitic soils are non-cohesive, making them susceptible to erosion.

2. Sheetwash, Rilling and Gullying

Hillslopes subject to only sheetwash can remain unchannelled (Leopold et al., 1966) as sheetwash is unconcentrated flow. The presence or absence of rilling depends on the erosion rate. Rilling is a form of drainage capable of carrying more material than sheetwash flow. More surface erosion can lead to rills. In fact, rills were identified on the aerial photos of deforested basins of this research. Some of rills have enlarged to become gullies.

Most rills are straight and furrowlike (Higgins, et al, 1990). In contrast, gullies have steep sides and steep headcuts. They tend to have few, short branches. They grow headward by erosional undercutting or sapping of the headcut.

Although it is widely understood that rills simply develop into gullies by erosional enlargement, differences in their morphology suggest that they differ in genesis. Some studies claim that steep-walled gullies are developed by sapping and migration of their headcuts without prior existence as rills (Higgins,et al., 1990; Crouch,1990).

The next step in erosional development is to develop perennial channels, where water movement becomes sufficiently concentrated to cut a recognizable channel from rills or gullies (Figure 2). This means that initiation of perennial channels need a sufficient shear stress and time to develop on the hillslope after vegetation removal. The initial cut has to be maintained and enlarged to be a perennial channel. The onset of channelization requires another threshold to be attained, related possibly through the erosion rate to critical conditions of slope geometry, such as slope gradient, slope length, slope width, and slope surface area.

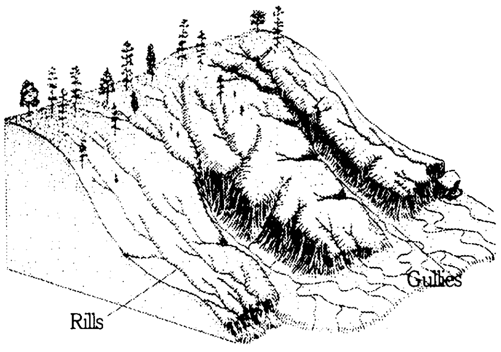

Figure 2. Rill and Gully (Source: Higgins et al.,1990)

The steps in development from surface erosion to perennial channel require a long time to develop in a drainage basin even with disturbance like vegetation removal.

3. Subsurface Flow and Slope Failure

Once vegetation is removed or the density of vegetation has been reduced, less cohesive and loose soils on the slope can easily be removed with the increase of overland flow, where shear stresses are great enough to lead discrete slope failure (Selby, 1985). Actually, in this study area, with careful interpretation of the aerial photographs, a few evidences of slope failure were found.

Erosion control reports also recorded the areas of slope failures in Koyang basin. But, it is not certain whether those slope failures led to initiation of the perennial channels in this study area.

Channel initiation can be done by movement of subsurface waterflow, too. Collapse of subsurface pipes can create channels. Under dense vegetation cover in granite weathered soils, the amount of subsurface flow can not be ignored. But, it is unlikely that subsurface flow was very active on cleared hillslopes that show clear evidence of erosion by surface runoff.

4. Impact of Tree Removal by Stream Order

Previous studies mention the effects of timber harvesting depending on the order of streams. King (1989) reported in a north-central Idaho study that streamflow responses to timber harvesting could be clearly identified in the lower order streams rather than higher order streams. This suggests that lower order streams can be modified easily upon vegetation removal. Ryan and Grant (1991) also reported that landslides and debris flows produced many low order tributaries after tree harvesting in Elk River in Oregon. But, in this study, though a few debris flow deposits were found at the base of the hillslope, it seems unlikely that the occurrence of debris flows led to development of more tributaries. Both the first and the second order streams in the deforested basin (Koyang) showed longer stream length compared with undisturbed basin (Kwangneung). The second order streams in the disturbed basin were four times longer than in the undisturbed basin (Table 3). In this regard, more studies are needed to explain the differences in these study basins.

As these study basins do not have sequential air photos covering multiple dates, it is not possible to determine which processes did increase the low order streams. Either hillslope surface erosion or slope failure such as landslides or flows may lead to development of more low-order channels after deforestation. The presence or absence of a specific geomorphic processes is influenced by the nature and constraints operating in a particular basin. Therefore, higher density and increasing number of low-order channels in the disturbed basin can be understood more thoroughly by the hillslope erosional processes.

Bibliography

Burrough, P.A., 1986, Principles of Geographical Informtion Systems for Land Resources Assessment, Clarendon press, Oxford.

Costa, J.E.,1975, Effects of Agriculture on Erosion and Sedimentation in the Piedmont Province, Maryland, *Geological Society of America Bull.* 86:1281-86.

Cooke,R.U. and J.C.Doornkamp,1990, Geomorphology in Environmental Management, 2nd Edition.

Crouch,R.J.1990, Erosion Processes and Rates for Gullies in Granitic Soils Bathurst, New South Wales, Australia, *Earth Surface Processes and Landforms,* l15: 169-173.

Faulkner, H., 1990, Vegetation Cover Density Variations and Infiltration Patterns on Piped Alkali Sodic Soils: Implications for the modelling of overland flow in semi-arid areas, Vegetation and Erosion, edited by J.B.Thornes, John Wiley & Sons Ltd.

Forestry Agency, Republic of Korea, 1988, History of Forest Land Devastation (written in Korean).

Hagans, D.K. and W.E.Weaver, 1987, Magnitude, Cause and Basin Response to Fluvial Erosion, Redwood Creek basin, northern California, in Erosion and Sedimentation in the Pacific Rim, Proceedings of the Corvallis Symposium, IAHS Publ. No.165.

Gray,Donald H.,and W. F.Megahan, 1981, Forest Vegetation Removal and Slope Stability in the Idaho Batholith, USDA, Forest Service, Intermountain Forest and Range Experiment Station, Research Paper, INT-271.

Higgins,C.G., B.R.Hill, and A.K.Lehre,1990, Gully Development in *Geological Society of America* Special Paper 252.

Horton,R.E.,1945,Erosional Development of Streams and Their Drainage Basins: hydrophysical approach to quantitative morphology, *Geological Society of America Bulletin,* 56 : 275-370.

Jee,Yong Ha, 1964, History of Korean Forestry Policies (written in Korean).

Hwang, Yoo Jeong, 1995, Spatial Pattern of Frest Land Degradation Early Twentieth Century, Jour of Geography,Seoul National Univ.25:19-33

Kemp, A.C., 1990, Towards a Dynamic Model of Gully Growth, in Erosion, Transport and Deposition Processes, Proceedings of the Jerusalem Workshop, March-April 1987, IAHS Publ. No.189.

Kim,H. 1983, The Fuel Problems in Chosun, *Andong University Bulletin* 5 (written in Korean)

King,J.G.1989, Streamflow Responses to Road Building and Harvesting:a comparison with the equivalent clearcut area procedure, USDA Forest Service Intermountain Research station Research Paper INT-401.

Kraak,M.J. and F.J.Ormeling, 1996, Cartography: Visualization of Spatial Data, Longman.

Knighton,David.1984, Fluvial Forms and Processes, Edward Arnold.

Lillesand, T.M. and R.W.Kiefer, 1994, Remote Sensing and Image Interpretation, John Wiley & Sons, Inc. 3rd edition.

Megahan,W.F., 1982, Channel Sediment Storage Behind Obstructions in Forested Drainage Basins Draining the Granitic Bedrock of the Idaho Batholith, in Sediment Budgets and Routing in Forested Drainage Basins by Swanson, F.J., R.J. Janda, T.Dunne, and D.N.Swanston, USDA Forest Service Pacific northwest Forest and Range Experiment Station, General Technical Report PNW-141.

Moore,I.D.,R.B.Grayson, A.R.Ladson, 1993, Digital Terrain Modelling ; A Review of Hydrological, Geomorphological, and Biological Applications, 7-34, edited by K.J.Beven, I.D.Moore, Terrain Analysis and Distributed Modelling in Hydrology, John Wiley & Sons.

Park, Dong-won,1988., Physical Environment in Korea Geographical Perspectives, Korean Educational Development Institute, Seoul, Korea

Prosser, I.P., and Slade, C. J. 1994. Gully formation and the Role of Valley-floor Vegetation, southeastern Australia, *Geology* 22:1127-1130.

Schumm,S.A.1997, Drainage Density, Problems of Prediction and Application, in Process and Form in Geomorphology, edited by D.R.Stoddart, London.

Seiby,M.J., 1985, Earth's Changing Surface, An Introduction to Geomorphology, Clarendon Press,Osford.

Thornes,J.B.,1990,(Ed) Vegetation and Erosion: processes and environments, John Wiley & Sons Ltd.

Thornes,J.B.,1990, The Interaction of Erosional and Vegetational Dynamics in Land degradation:Spatial outcomes, in Vegetation and erosion: processes and environments, John Wiley & Sons Ltd, p.41-53.

Zuidam, R.A.,1985, Aerial Photo-Interpretation in Terrain Analysis and Geomorphologic Mapping, ITC, Netherland.