UNIVERSITI PUTRA MALAYSIA

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM (GIS) IN SOIL EROSION PREDICTION: A CASE STUDY OF THE SG. HIJAU WATERSHED, FRASER'S HILL, PAHANG

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By

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Thesis submitted in partial fulfillment of the requirement for the Degree of Master Science in Tropical Forest Resource Management in the Faculty of Forestry, Universiti Putra Malaysia, Selangor.

May, 2003

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2003

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A study was conducted to assess soil erosion using Geographical Information System (GIS) and Universal Soil Loss Equations (USLE) for the Sg. Hijau watershed. The study area, located in Fraser's Hill, Pahang is 1.5 km^2 in size and lies between 1060 and 1350 m a.s.l. A GIS software, ARC/INFO version 3.4 was used to develop the database. Analysis was carried out using the ArcView Spatial Analyst Version 1.1 and ArcView 3D Analyst. Results obtained show that about 48% of the Sg. Hijau catchment falls under the slope gradient of 12^0-25^0 while 26% of the area under the slope of more than 25^0. Four empirical methods based on the applications of erosivity were used for soil erosion computation. They were from Roose (1975), Balamurugan (1990), Morgan (1974) and rainfall of more than 25 mm/hr adopted in this study. By comparison, Roose generated the highest erosion rate with 1.757 t/ha/yr followed by Balamurugan with 0.685 t/ha/yr, 25 mm/hr with 0.567 t/ha/yr and lastly, Morgan with 0.532 t/ha/yr. Erosion rates of less than 1 t/ha/yr were computed for most of the area in the study watershed: soil erosion rates ranged from 0.363 to 0.642 t/ha/yr. The results obtained were also comparable to measured soil loss from erosion plots in other studies under similar conditions. Most studies have shown that erosion seldom exceeds 1 t/ha/yr under forest conditions. This study showed that soil erosion rates could be calculated using USLE within the GIS environment. Apart from employing GIS as an easy-to-use database and toolkit for modeling, GIS techniques could be used to assess the uncertainty and validity of spatial erosion models. The use in catchment hydrological and erosion modeling offers considerable potential.

APPLIKASI SISTEM MAKLUMAT GEOGRAFIK (GIS) DALAM MERAMAL HAKISAN TANAH: SATU KAJIAN KES DI KAWASAN TADAHAN AIR SG HIJAU, FRASER'S HILL, PAHANG

Oleh

ANASTASIA NG SUAN KIM

2003

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Fakulti : Perhutanan

Satu kajian telah dijalankan untuk menentukan hakisan tanah dengan menggunakan Sistem Maklumat Geografi (GIS) di kawasan tadahan air Sg. Hijau. Kawasan tadahan air Sg. Hijau terletak di Fraser's Hill, Pahang, dengan saiz keluasan 1.5 km^2 dan terletak di antara 1060 hingga 1350 m pada paras laut. Perisian GIS, iaitu ARC/INFO versi 3.4 digunakan untuk membina pangkalan data. Analisis data dijalankan dengan menggunakan perisian ArcView Spatial Analyst Versi 1.1a dan ArcView 3D Analyst. Keputusan menunjukkan bahawa sebanyak 48% daripada Sg. Hijau berada dalam lingkungan cerun $12^0 - 25^0$ manakala 26% daripada kawasan Sg. Hijau berada dalam cerun lebih dari 25^0. Empat kaedah empirik berdasarkan kadar hujan telah digunakan dalam menentukan kadar hakisan tanah. Kaedah itu adalah dari Roose (1975), Balamurugan (1990), Morgan (1974) dan kadar hujan lebih dari 25 mm/j (R>25 mm/j) yang digunakan dalam kajian ini. Daripada keempat-empat kaedah empirik, kaedah Roose memberi kadar hakisam yang tinggi dengan 1.757 t/ha/thn diikuti dengan Balamurugan iaitu 0.685 t/ha/thn, 25mm/j dengan 0.567 t/ha/thn dan akhirnya, Morgan dengan 0.532 t/ha/thn. Kadar hakisan tanah kurang dari 1 t/ha/thn diperolehi di kebanyakkan kawasan Sg. Hijau dalam kajian ini, iaitu dalam kadar lingkungan 0.363 ke 0.642 t/ha/thn. Keputusan yang diperolehi juga adalah setanding dengan keputusan hakisan tanah yang diukur di petak hakisan dalam kajian lain dibawah keadaan yang sama. Kebanyakkan kajian menunjukkan bahawa kadar hakisan tanah jarang melebihi 1 t/ha/thn di dalam kawasan hutan. Kajian ini telah menunjukkan bahawa selain menggunakan perisian GIS sebagai alat yang mudah digunakan malah GIS mempunyai potensi untuk menaksir pangkalan data dalam hidrologi tadahan air dan model hakisan.

Specially dedicated to

My beloved Mother, Mary and my loving dad, Paul
My sister, Felicia
My brother & his family,
Leonard, Priscilla & Annie,
And to all my friends

Thank you for your love,
prayers, patience and encouragement,
Without your support,
I will not be where I am today,
I love you all

ACKNOWLEDGEMENTS

Firstly, I would like to thank the Almighty God for granting me the strength and confidence that I need to complete this thesis. I especially would like to express my deepest gratitude and appreciation to my supervisor, Assoc. Prof. Dr. Lai Food See for his invaluable help, dedicated efforts, guidance and patience throughout this study.

I am particularly grateful to Albert Tan for his kind assistance, knowledge and advice. Many thanks also, to my friends for their moral support and most of all, their invaluable friendship.

Finally, I would like to express my deepest love and gratitude to my family members for their unending prayers, support and encouragement during the course of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE

INTRODUCTION

1.1 General

Although soil is an essential natural resource it is being degraded at an unprecedented scale, both in rate and geographical extent. Soil degradation is caused by soil erosion through the process of detachment and transportation of soil material from one place to another through the actions of wind, water or action of rain. While numerous research have been done over the years throughout the world, the problem of soil erosion still persists and recent information indicates the soil loss rates may indeed again be on the rise (Carter, 1977).

When a vegetation or forest area is removed, the natural equilibrium between soil building and soil removal is disturbed. As a result, soil erosion will cause serious deterioration of hydrological conditions of all watersheds. Soil erosion not only hinders sustainable land management, but can also cause off site environmental problems such as siltation of lakes and reservoirs.

These days, with the growing importance of Information Technology and Geographical Information System (GIS), a computer-based tool has become an essential means in watershed management. Burrough (1986) defined GIS as "a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular purpose". GIS is a specialized computer software for handling, displaying and analyzing spatial data. The use of GIS can reduce technical constraints faced in field data acquisition and analysis process. With its high efficiency, numerous databases can be used to integrate and generate information that would have taken much time and difficulty in the past.

1.2 Problem Statement

Soil erosion has been traditionally computed based on plot studies of which the Universal Soil Loss Equation (USLE) is the most popular. This equation, composed after Wishmeier and Smith (1958), has been used in many parts of the world. The USLE has been widely used around the world because it seems to give acceptable results moreover, of its simplicity and flexibility in modification. Before computers were used extensively, soil erosion estimations were made based on manually derived topographic variables from topographical maps. With increasing availability of computer software, particularly in spatial analysis, USLE has been applied in conjunction with GIS software in some studies. While GIS has received great interest, there is much more to be done in spatial analysis and predictive work in the country. This study was conceived to estimate soil erosion based on topographical information and hydrology data for Sg. Hijau watershed, Fraser's Hill.

1.3 Objectives

The general objective of this study is to determine soil erosion under primary forest condition in the Sg. Hijau watershed, Fraser's Hill, Pahang using the integration of Universal Soil Loss Equation (USLE) and Geographical Information System (GIS).

The specific objectives of this study are:

i. To estimate the soil erosion rates of the study watershed under natural forest and thus generating digital soil erosion map.

ii. To compare soil erosion rates of other watershed studies, namely of hill forest watersheds with this study watershed which is of lower montane watershed.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Since the general public is ignoring the capacity of our biological system, deterioration that once took centuries is now being compressed into years by inexorable population growth. Forests have proved to be one of the most heavily exploited. Erosion is undermining soil productivity. A natural process, soil erosion as such is neither new nor necessarily alarming but when it out places the formation of new soil, inherent fertility declines. Soil loss under different land uses have been recorded and studied by many researchers i.e. Morgan (1974), Wischmeier (1978), Hudson (1981), De Roo (1993).

The increasing costs of soil loss in both environmental and monetary terms have encouraged both data collection and model development efforts, at a range of spatial and temporal scales. Soil loss, have been represented by models at many different levels of complexity and at varying spatial and temporal scales. They have been used widely as generators of quantitative predictions with the Universal Soil Loss Equation (USLE), for all its acknowledged limitations forming basis of many models. Recently, a more spatially distributed approach has been adopted in modeling work. The move to a more distributed approach has been supported by a better understanding of the variability of erosion processes, as well as increasing resources of digital map and sensor data. Computing technology in the form of Geographical Information System (GIS) has been developed specifically for handling spatial data. The integration of soil erosion models with the technology of GIS can effectively store, manipulate, and analyze the large amounts of spatial data demanded by soil erosion models and can effectively display spatial information, which is very useful for analyzing the findings.

2.2 Soil Erosion

Soil erosion is a physical process and refers to the wearing-away of the land surface by water and/or wind as well as to the reduction in soil productivity due to physical loss of topsoil, removal of plant nutrients, and loss of water.

Soil erosion is particularly problematic in tropical countries. It threatens developing tropical countries where agriculture is primary to development and the majority of the rural population depends on it for their livelihood (Enters, 1998). Soil erosion affects both upstream and downstream areas. Upstream, soil erosion leads to loss of productivity and loss of water storage capacity on eroded sites. Downstream sedimentation results in damage to downstream fields, river channels, and capital infrastructure such as dams, water system and irrigation channels, thereby imposing costs to downstream water users.

Soil erosion includes a range of phenomena such as sheet erosion (the removal of thin layers of topsoil from an eroded site), gully erosion (the formation of incised gullies in a hillside) and mass wasting (the structural failure of part of a hillside as in the case of a landslide). Although all of these types of erosion do occur naturally, man's use of watershed lands, particularly steep areas, can greatly increase the extent and rate of erosion. Activities such as agriculture, logging, and construction can lead to increased soil erosion. Soil erosion is therefore a complex phenomenon influenced by natural and socio-economic factors.

2.3 Types of Erosion

Erosion in all forms involves the dislodgement of soil particles, their removal and eventual deposition away from the original position. Soil erosion is a naturally occurring process on all land. The agents of soil erosion are water and wind, each contributing a significant amount of soil loss each year. Soil erosion may be a slow process that continues relatively unnoticed, or it may occur at an alarming rate causing serious loss of topsoil. Large areas of the earth are affected by accelerated erosion by water and wind.

Table 2.1: The global extent of land affected by wind and water erosion (Oldeman, 1991).

	Land Area Affected by Erosion (10^6 ha)	
Region	Water Erosion	Wind Erosion
Africa	227	186
Asia	441	222
South America	123	42
Central America	46	5
North America	60	35
Europe	114	42
Oceana	83	16
World	1094	548

2.3.1 Wind Erosion

Wind erosion is a serious problem in many parts of the world. It is worse in arid and semiarid regions. Areas most susceptible to wind erosion on agricultural land include much of North Africa and the Near East, parts of southern, central, and eastern Asia, the Siberian Plains, Australia, northwest China, southern South America, and North America.

Wind erosion, unlike water, cannot be divided into such distinct types. Unlike water erosion, wind erosion is generally not related to slope gradient. Occurring mostly in flat, dry areas and moist sandy soils along bodies of water, wind erosion removes soil and natural vegetation, and causes dryness and deterioration of soil structure. Wind erosion physically removes the lighter, less dense soil constituents such as organic matter, clays, and silts. Thus it removes the most fertile part of the soil and lowers soil productivity (Lyles, 1975).

The main factor in wind erosion is the velocity of moving air. Soil movement is initiated as a result of wind forces exerted against the surface of the ground. For each specific soil type and surface condition there is a minimum velocity required to move soil particles. This is called the threshold velocity. Once this velocity is reached, the quantity of soil moved is dependent upon the particle size, the cloddiness of particles, and wind velocity itself.

Suspension, saltation and surface creep are the three types of soil movement, which occur during wind erosion. While soil can be blown away at virtually any height, the majority (over 93%) of soil movement takes place at or below one meter.

2.3.2 Water Erosion

Water erosion is intense in most countries due to their erosive climatic conditions. Water erosion results from the removal of soil material by flowing water. The extent of erosion by water is affected by several factors, the length and steepness of slope, soil texture, the amount and timing of severe rains.

A part of the water erosion process is the detachment of soil material by the impact of raindrops. The soil material is suspended in runoff water and carried away. Generally, three kinds of accelerated water erosion are commonly recognized: sheet, rill and gully.

Sheet erosion is soil movement from raindrop splash resulting in the breakdown of soil surface structure and surface runoff. It occurs rather uniformly over the slope and may go unnoticed until most of the productive topsoil has been lost. Sheet erosion can be serious on soils that have a slope gradient of only 1 or 2 percent. However, it is generally more serious as slope gradient increases.

Rill erosion is intermediate between sheet and gully erosion. This erosion feature occurs as rainwater accumulates after rainfall event and it concentrates in depressions, than flows along the irregularities, causing the formation of rills. Due to the acceleration of the velocity of moving water, the detachment and transport of soil particles are both greater in rill erosion than in sheet erosion.

Gully erosion is the consequence of water that cuts down into the soil along the line of flow. Gullies form in exposed natural drainage way, in plow furrows, in animal trails, in vehicle ruts, between rows of crop plants, and below broken man-made terraces. In contrast to rills, they cannot be obliterated by ordinary tillage. Their presence is a strong indicator that erosion is out of control and that land is entering a critical phase that threatens its productivity (Laflen *et al*, 1997).

Roose (1994) described three processes of gully formation: (i) the formation of a V-shape gully where the weathered material from the gully sides is moved from the gully bottom and additional material is moved from the gully bottom due to hydraulic shear; (ii) a U-shaped gully due to gully wall failure due to the pressure of a watertable; and (iii) tunneling in soluble material or because of burrowing animals. Bradford et al. (1973) described gully erosion has having three phases: (i) failure of gully head and Gully banks, (ii) cleanout of the debris by streamflow, and (iii) degradation of the channel.

2.3.3 Water and Wind Erosion

There are significant similarities and differences between the processes involved in water and wind erosion. Both are understood as rate processes that depend on the speed of the wind or overland flow. While these speeds are measured in experimental studies, since lengthy time series are not generally available, extrapolation to longer time periods poses similar weather generation problems for both wind and water erosion prediction. Water erosion does not have the highly sensitive dependence on surface water content that is characteristic of water erosion. However, both types of erosion are strongly reduced by contact cover.

In water erosion, cover in such close contact with the soil surface that it impedes overland flow is generally much more effective than aerial cover, which provides protection only against rainfall impact (Rose, 1993). In wind erosion aerial cover is very effective, and the resulting substantial reductions in wind speed at the soil surface can lead to threshold wind speeds not being exceeded.

There is no direct analogy in wind erosion to rainfall detachment, though the surface bombardment by wind-driven saltating particles conjures up vague similarities. Deposition under gravity is the cause of return of saltating particles to the soil surface in both media. However, the speed of the particles involved in this return is much lower in the case of water erosion than for wind-driven sand, and is thought not to be a cause of erosion. Though terminal velocity is achieved with much less fall distance in water compared to air, the fall velocity on return may not be terminal in either medium except for small particles.

The distinction made between entrainment and re-entrainment in describing flow - driven water erosion has some relevance to wind erosion in that there is resistance to be overcome to remove dust particles against attractive forces, and even very low levels of moisture increase the attraction between sand size particles that threshold velocities may not be achieved. If saltation is prevented by capillary and matric forces due to water, then the main source of energy for the ejection of dust particles is unavailable.

2.4 Erosion Models

In attempts to better manage soil and water resources, computer modeling has received increasing attention, including development of numerous soil erosion models.

These erosion models have been used in investigative, evaluative, predictive and learning modes. These models have been developed to extend the understanding of physical process as well as for generating quantitative predictions of losses. The resulting models differ widely in their representation of processes, temporal and spatial scales. On the temporal scale, an erosion model can be classified as:

- A long term average annual model, such as the USLE (Wischmeier and Smith, 1978) and RUSLE (Renard *et al.*, 1991);
- A seasonal model, such as GAMES (Rudra *et al.*, 1986) and GAMESP (Rousseau *et al.*, 1988);
- An event model, such as WEPP (Laflen *et al.*, 1991), EPIC (Jones *et al.*, 1991) and ANSWERS (Beasly *et al.*, 1980) or
- A continuous simulation model, such as WEPP (Laflen *et al.*, 1991), EPIC (Jones *et al.*, 1991), CREAMS (Knisel *et al.*, 1980) and GLEAMS (Leonard *et al.*, 1987). Most of the continuous models can be used for an event.

On the spatial scale, an erosion model can be classified as:

- A hill-slope model, such as WEPP (Laflen *et al.*, 1991);
- A field scale model which aims to consider both hill slope and valley bottom, such as CREAMS (Knisel, 1980), GLEAMS (Leonard *et al.*, 1987) and EPIC (Jones *et al.*, 1991); or
- A watershed or grid model, such as GAMES (Rudra *et al.*, 1986), GAMESP (Rousseau *et al.*, 1988), ANSWERS (Beasly *et al.*, 1980) and AGNPS (Young *et al.*, 1985).