

UNIVERSITI PUTRA MALAYSIA

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM (GIS) IN SOIL EROSION PREDICTION: A CASE STUDY OF THE SG. WENG EXPERIMENTAL WATERSHEDS

ALBERT TAN THEAN WEI

FH 2002 16

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM (GIS) IN SOIL EROSION PREDICTION: A CASE STUDY OF THE SG. WENG EXPERIMENTAL WATERSHEDS

By

ALBERT TAN THEAN WEI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Master Science

August 2002



Abstract of thesis presented to the Senate of the Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM (GIS) IN SOIL EROSION PREDICTION: A CASE STUDY OF THE SG. WENG EXPERIMENTAL WATERSHEDS

By

ALBERT TAN THEAN WEI

August 2002

Chairman: Associate Professor Lai Food See, Ph.D.

Faculty: Forestry

A study was carried out to assess soil erosion under natural forest in watershed using the Universal Soil Loss Equation (USLE) model within a Geographic Information System (GIS) environment. The Sg. Weng Experimental Watershed, located within Hulu Muda Forest Reserve, Kedah, Malaysia was chosen for this study. The study area comprised four watersheds namely Watershed 1 (2.6 sq. km), Watershed 2 (8.4 sq. km), Watershed 3 (7.6 sq. km) and Watershed 5 (42.1 sq. km).

The USLE model consists of five factors namely rainfall erosivity (R), soil erodibility (K), length slope (LS), crop management (C) and support practice (P) factors. The R factor was obtained based on four methods namely Morgan (1974), Balamurugan (1990), Roose (1977) and rainfall equal or exceeding 25 mm/hr (this study). Using a regular grid of Digital Elevation Model (DEM), a method based on the maximum downhill slope and cumulative slope length was used for calculating the LS factor. K factor was obtained from Department of Agriculture, Kedah based



on five soil series. The C and P were combined into a single factor called vegetation management (VM). The values obtained for each parameter were later converted to raster layers for modeling the soil erosion.

Rates of erosion were found to be less than 1 t/ha/yr for most of the area in the study watersheds. Soil erosion rates ranged from 0 to 2.255 t/ha/yr in W1, 0 to 3.127 t/ha/yr in W2, 0 to 5.233 t/ha/yr in W3 and 0 to 4.118 t/ha/yr in W5. The LS and R factors were the major ones influencing soil erosion rates. The results obtained were comparable to measured soil loss from erosion plots and also predicted soil loss from USLE 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 can be calculated using USLE within a GIS environment. The use of GIS has facilitated the manual measurements of slope and slope length on topographic maps with automated procedures based on the used of DEMs. This has reduced significantly the time spent in analysis while at the same time gave some degree of accuracy needed for soil erosion prediction. The successful integration of USLE and GIS should be of tremendous use for studies that require simple and accurate soil erosion assessment.



Abstrak tesis yang dikemukakan kepada Senat University Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

APPLIKASI SISTEM MAKLUMAT GEOGRAFIK (GIS) DALAM MERAMAL HAKISAN TANAH: SATU KAJIAN KES DI KAWASAN TADAHAN AIR SG. WENG

Oleh

ALBERT TAN THEAN WEI

Ogos 2002

Pengerusi: Profesor Madya Lai Food See, Ph.D.

Fakulti: Perhutanan

Satu kajian telah dijalankan untuk menilai hakisan tanah bagi hutan di kawasan tadahan air menggunakan model *Universal Soil Loss Equation* (USLE) di dalam perseluitaran Sistem Maklumat Geografik (GIS). Kawasan Tadahan Air Sg. Weng yang terletak di Hutan Simpan Hulu Muda, Kedah, Malaysia telah dipilih sebagai kawasan kajian. Kawasan kajian ini terdiri daripada empat kawasan tadahan air iaitu Kawasan Tadahan Air 1 (2.6 km persegi), Kawasan Tadahan Air 2 (8.4 km persegi), Kawasan Tadahan Air 3 (7.6 km persegi) dan Kawasan Tadahan Air 5 (42.1 km persegi).

Model USLE terdiri daripada lima faktor iaitu rainfall erosivity (R), soil erodibility (K), length slope (LS), crop management (C) and support practice (P). Faktor R dikira berdasarkan empat kaedah iaitu Morgan (1974), Balamurugan (1990), Roose (1977) dan hujan yang sama atau melebihi 25 mm/hr (kajian ini). Dengan menggunakan Digital Elevation Model (DEM), satu kaedah berdasarkan cerun maximum dan panjang cerun kumulatif digunakan untuk mengira faktor LS.



K yang berdasarkan kepada 5 jenis tanah, didapati daripada Jabatan Pertanian Kedah. C dan P pula digabungkan kepada satu faktor iaitu vegetation management (VM). Nilai yang didapati bagi setiap faktor kemudian ditukarkan kepada lapisanlapisan grid untuk pemodelan hakisan tanah.

Kadar hakisan tanah didapati kurang daripada 1 t/h/yr di kebanyakan kawasan di tempat kajian. Kadar hakisan tanah yang didapati adalah dari 0 ke 2.255 t/ha/yr bagi W1, 0 ke 3.127 t/ha/r bagi W2, 0 ke 5.233 t/ha/yr bagi W3 dan 0 -- 4.118 t/ha/yr bagi W5. Faktor LS dan R didapati amat mempengaruhi kadar hakisan tanah. Keputusan yang didapati juga adalah setanding dengan keputusan hakisan tanah yang diukur di petak hakisan dan yang diramal dengan USLE di kajian lain di bawah keadaan yang sama. Kebanyakan kajian ini menunjukkan bahawa kadar hakisan tanah jarang melebihi 1 t/ha/yr di dalam kawasan hutan.

Kajian ini menunjukkan bahawa, kadar hakisan tanah dapat dikira menggunakan USLE dalam satu persekitaran GIS. Penggunaan GIS adalah untuk memudahkan pengiraan kecerunan dan panjang kecerunan dengan kaedah automatik berdasarkan kepada penggunaan DEM. Ini telah dapat mengurangkan masa dan kos perbelanjaan bagi analisis serta pada masa yang sama memberikan satu tahap ketepatan yang diperlukan dalam meramal hakisan tanah. Kejayaan dalam pergabungan USLE dan GIS akan menjadi sesuatu yang amat berguna dalam kajian yang memerlukan kaedah penilaian hakisan tanah yang mudah dan tepat.



ACKNOWLEDGEMENTS

First of all I would like to express my heartfelt gratitude and appreciation to my supervisor, Assoc. Prof. Dr. Lai Food See for his invaluable help, dedicated efforts, guidance, suggestions and constructive criticisms throughout this study. I am also very grateful indeed to my to two other supervisors, Encik Ismail Adnan bin Abdul Malek and Dr. Ahmad Ainuddin for their kind assistance, knowledge and advice. I am particularly grateful to Drainage and Irrigation Department (DID), Malaysia Hydrology Division, for financial assistant under the study project "Impact on logging on Muda-Pedu water catchment".

I would like to thank Ir. Mr. Low Koong Sing of DID, Malaysia Hydrology Division, for providing the hydrological data for used in this study. I would also like to thank Mr. Gerard McGuire of Department of Agriculture, Kedah for providing the information on the soil data and soil erodibility factor of the study area. My gratitude also goes to Mr. Baharuddin Kasran of FRIM for providing reading materials, guidance and assistance in this study.

I am particularly grateful to Teck Hock for his assistance, constructive discussions and ideas throughout the study. Many thanks to all 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 father, mother and sister for their prayers, support and encouragement during the course of this study. Above all, my humble praises to GOD who has made all this possible.



TABLE OF CONTENTS

Page

ABSTRACT	ii
ABSTRAK	iv
ACKNOWLEDGEMENTS	vi
APPROVAL	vii
DECLARATION	ix
LIST OF TABLES	xiii
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xix

CHAPTER

1	INTR	DUCTION	1
	1.1	General	1
	1.2	Objectives of the Study	4
2	LITE	ATURE REVIEW	6
	2.1	Introduction	6
	2.2	Definition of Soil Erosion	6
		2.2.1 Geological Erosion	7
		2.2.2 Accelerated Erosion	7
	2.3	Type of Erosion	8
		2.3.1 Rainsplash Erosion	9
		2.3.2 Sheet Wash	9
		2.3.3 Rill Erosion	0
		2.3.4 Gully Erosion	1
		2.3.5 Subsurface Erosion 1	1
		2.3.6 Mass Movement	13
	2.4	Distribution and Causes of Soil Erosion	14
	2.5	Erosion Models	8
		2.5.1 Type of Erosion Models	19
	2.6	Overview of Universal Soil Loss Equation (USLE)	26
		2.6.1 Rainfall Erosivity Factor (R)	27
		2.6.2 Soil Erodibility Factor (K)	31
		2.6.3 Slope Length and Steepness Factor (LS)	34
		2.6.4 Crop and Management Factor (C)	35
		2.6.5 Support-Practice Factor (P)	36
	2.7	GIS in Soil Erosion Modeling	38
		2.7.1 Digital Thematic Maps	39
		2.7.2 GIS and Erosion Model Linkages 4	40
		2.7.3 A USLE-GIS Based Approach in Soil Erosion	
		Evaluation	1 2
	2.8	Summary	47



M	ATERIALS AND METHODS
3.1	Introduction
3.2	Description of Study Area
	3.2.1 Climate
	3.2.2 Geology
	3.2.3 Vegetation
	324 Soil Characteristic
3 3	Data Acquisition
0.0	3 3 1 Base Man
	3.3.7 Ancillary Data
3 /	Hardware and Software
ן. כי	Data Processing and Management
5.5	3 5 1 Designing Detabase
	2.5.2 Deta Automation
	3.5.2 Data Automation
24	5.5.5 Data Recunction
3.0	Ordenerating the LS ractor
	3.6.1 Developing the Digital Elevation Model
	3.6.2 Cumulative Downnill Slope Length AMLs
	3.6.3 Grid-based Algorithm Description
	3.6.4 Slope Classification
3.7	Universal Soil Loss Equation
	3.7.1 Rainfall Factor (R)
	3.7.2 Soil Erodibility Factor (K)
	3.7.3 Vegetation Management (VM)
3.8	Soil Erosion Estimation
3.9	Summary
RJ	ESULTS AND DISCUSSION
4.1	Introduction
4.2	GIS Database
	4.2.1 Digital Elevation Model
Δ ?	Basin Slone Classification
Δ.	Rainfall Frosivity Factor (R)
ч	A A 1 Relationship between R Factor and Rainfall
4	Soil Series and Soil Frodibility Factor (K)
т Л (I enoth Slope Factor (IS)
7.0	4.6.1 Relationship between IS and Slope
1 -	V Soil Frosion Rates
4.	4.7.1 Frosion Classification
	17.1 Elusion Classification. Individual Easter and
	4.1.2 Relationship between individual ractor and Computed Soil Erosion
	472 Unputed Soli Elosionian Estimation
	4.7.3 rypouleucal Kainialis in Erosion Esumation
	4.7.4 Comparison of Soli Erosion Kates
	4.7.5 Comparison of Soil Erosion Rates with Other Studies
4	8 Summary
	-



5	CON	CLUSION	140
	5.1	Introduction	140
	5.2	Computation of Soil Erosion Rates	140
	5.3	Recommendations	143
BIB	LIOGR	АРНУ	144
VII	`A		152



LIST OF TABLES

Table		Page
2.1	Summary of erosion and sediment sources	17
2.2	Summary of the differences between USLE and RUSLE	20
2.3	Type of soil erosion models	22
2.4	Conditions required for natural runoff plot and rainfall simulation plot	32
2.5	C-factor values of the Universal Soil Loss Equation	37
2.6	P-factor values of the Universal Soil Loss Equation	38
2.7	GI	45
3.1	Watershed characteristics of the Sg. Weng Experimental Watershed	52
3.2	Mean monthly rainfall in Ulu Muda Forest Reserve, Baling Kedah (1990-1993)	53
3.3	Forest type of Sg Weng Experimental Watershe	55
3.4	Sources of data required	59
3.5	Primary layers of Sg. Weng Experimental Watershed	65
3.6	Slope classification of Sg. Weng Experimental Watershed	70
3.7	Annual rainfall of Sg. Weng Experimental Watershed	73
3.8	Annual rainfall with intensity equal and greater than 25mm/hr	75
3.9 ⁻	Soil erodibility factor, K (t.ha.h/ha/MJ/mm) of soil series of Sg. Weng Experimental Watershed	75



3.10	Vegetation management factor (VM) of Sg. Weng Experimental Watershed	76
4.1	Slope distribution of study watersheds	91
4.2	Rainfall records of study watersheds for five year (1996 – 2000)	97
4.3	Rainfall erosivity factor, R (MJ.mm/ha/h/yr) for study area based on four different methods for five years (1996 – 2000)	99
4.4	The erosive rainfall of the study watersheds (units in MJ.mm/ha/h/yr)	100
4.5	K (t.ha.h/ha/MJ/mm) distribution of study watersheds	103
4.6	LS distribution of the study watersheds	104
4.7	LS factor based on six slope classes	105
4.8	Stope length (m) distribution of study watersheds	105
4.9	Mean soil erosion rates (t/ha/yr) of study watersheds from 1996 to 2000	115
4.10	Soil loss classification for study watersheds	116
4.11	Comparison of mean erosion for study area based on four different methods of determining the R factor	1 29
4.12	Comparison of soil erosion rates conducted in tropical forest	132



	L	IST	OF	FI	GU	RES
--	---	------------	----	----	----	-----

Figure		Page
2.1	Stages in the gully initiation	12
2.2	Nomograph for computing K values (metric units) of soil erodibility for use in the Universal Soil Loss Equation	34
3.1	Location of study site, Sg. Weng Experimental Watershed	50
3.2	Map of study site	51
3.3	Symington's (1943) altitudinal forest zones and Lai (1993) elevation of catchment studies in Peninsular Malaysia	57
3.4	Soil series of study watershed	58
3.5	HP Workstation running of UNIX operating system	60
3.6	Digitizer table	61
3.7	Digitizer	61
3.8	Steps in building database	62
3.9	Combined steps in building the database using ARC/INFO software	65
3.10	Flowchart illustrating the process for calculating LS values from DEM	68
3.11	Graph for determining VM sub-factor	77
3.12	Guide for estimating density of bare soil, canopy and fine roots	78
3.13	Summary of the complete process in the methodology of the study	80



4.1	Topographic features and attribute tables of W1	82
4.2	Topographic features and attribute tables of W2	83
4.3	Topographic features and attribute tables of W3	84
4.4	Topographic features and attribute tables of W5	85
4.5	DEM of W1	88
4.6	DEM of W2	88
4.7	DEM of W3	89
4.8	DEM of W5	89
4.9	A 3D-perspective of elevation of study watersheds	90
4.10	Grid map representing slope classification of W1	92
4.11	Grid map representing slope classification of W2	93
4.12	Grid map representing slope classification of W3	94
4.13	Grid map representing slope classification of W5	95
4.14	A 3D-perspective of slope of study watersheds	96
4.15	Relationship between annual rainfall and R factor	101
4.16	Relationship between slope (a), slope length (b) and calculated LS in W1	106
4.17	Relationship between slope (a), slope length (b) and calculated LS in W2	107
4.18	Relationship between slope (a), slope length (b) and calculated LS in W3	108
4.19	Relationship between slope (a), slope length (b) and calculated LS in W5	109



4.20	LS factor of W1	110
4.21	LS factor of W2	111
4.22	LS factor of W3	112
4.23	LS factor of W5	113
4.24	Percentage area for five erosion classes in W1	117
4.25	Percentage area for five erosion classes in W2	117
4.26	Percentage area for five erosion classes in W3	118
4.27	Percentage area for five erosion classes in W5	118
4.28	Relationship between annual rainfall (a), R factor (b) and soil erosion in W1	120
4.29	Relationship between annual rainfall (a), R factor (b) and soil erosion in W2	121
4.30	Relationship between annual rainfall (a), R factor (b) and soil erosion in W3	122
4.31	Relationship between annual rainfall (a), R factor (b) and soil erosion in W5	123
4.32	Relationship between LS factor and soil erosion rates in W1	125
4.33	Relationship between LS factor and soil erosion rates in W2	125
4.34	Relationship between LS factor and soil erosion rates in W3	126
4.35	Relationship between LS factor and soil erosion rates in W5	126
4.36	Soil erosion rates based on hypothetical annual rainfall in W1	128
4.37	Soil erosion rates based on hypothetical annual rainfall in W2	128
4.38	Soil erosion rates based on hypothetical annual rainfall in W3	129
4.39	Soil erosion rates based on hypothetical annual rainfall in W5	129



4.40	Soil erosion rates of W1	134
4.41	Soil erosion rates of W2	135
4.42	Soil erosion rates of W3	136
4.43	Soil erosion rates of W5	137



LIST OF ABBREVIATIONS

GIS	Geographic Information System
DEM	Digital Elevation Model
TIN	Triangular Irregular Network
W1	Watershed 1
W2	Watershed 2
W3	Watershed 3
W5	Watershed 5
DID	Drainage and Irrigation Department
USLE	Universal Soil Loss Equation
MSLE	Modified Soil Loss Equation
MUSLE	Modified Universal Soil Loss Equation
RUSLE	Revised Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project
CREAMS	Chemicals, Runoff and Erosion from Agricultural Management Systems
GUESS	Griffith University Erosion Sedimentation System
EUROSEM	European Soil Erosion Model
LISEM	Limburg Soil Erosion Model
GRASS	Geographical Resource Analysis Support System
ILWIS	Integrated Land and Watershed Management Information Systems
ERDAS	Earth Resource Data Analysis System
AML	Arc Macro Language



CHAPTER ONE

INTRODUCTION

1.1 General

The rapid process of soil erosion is considered one of the most critical environmental problems facing our world today. Currently, it is widely recognized as a serious global problem. This phenomenon is caused by the immense pressure on land due to rapid development and population growth. In order to cope with this demand, vast areas of forest have been cleared. Much of the forested land in the world today has already been lost and is being replaced by agriculture, highway construction, urban development, housing and other land use activities. The consequences of these activities have resulted in accelerated erosion which has affected large areas of the earth.

The growing concern among relevant authorities, scientists, environmentalist and those affected by various land use changes has created the need for accessing the magnitude of erosion and how much of it has exceeds the acceptable tolerance limits. Based on the assessment of soil loss, different possible combinations of land use and management practices can be determined so that soil loss can be reduced and maintained within the prescribed limit. Before planning conservation work, it is helpful if the assessment can be transformed into a statement on how fast the land is being eroded. Therefore, what is required is a method of predicting soil loss under a wide range of conditions.



Basic mathematical models that combine fundamental principles, concept and relationships of erosion mechanics, hydrology, hydraulics, soil science and meteorology are effective tools for estimating soil loss. Various soil erosion models have been developed ranging from the lumped or empirical models which uses simple equation to the more advanced and complex models that use mathematical equations to describe the spatial and temporal distribution of mechanisms controlling erosion. These models can be used as a predictive tool for assessing soil erosion because through these models, conservation planner can determine how much, when and where the erosion is occurring. Through these models also, they will have better understanding of the erosion processes and their interactions before effective control program for soil conservation can be designed and implemented.

In recent years, Geographic Information System (GIS) has become an important and useful tool for handling spatial data. GIS can capture, store, manipulate, analyze, and display spatially referenced information which allows the development of spatial databases. These databases can be accessed, modified and updated in the future in line with the changing environment and situations. Since so much erosion is linked to the processes of the earth's surface, technology such as GIS can been integrated with many erosion and watershed models whereby the spatial phenomena (such as topography, soil, crop management and climate) can be handled in significantly improved fashion. GIS offers spatial data management and analysis tools that can assist experienced and skillful users in organizing, storing, editing, analyzing, and displaying spatial information.



The use of GIS in soil erosion assessment can be seen at various scales ranging from generation of thematic maps showing current or susceptible areas of erosion to development of spatial decision support system through the integration between GIS and soil erosion models. Combining the strengths of each will result in more powerful predictive and analytical tools in terms of efficiency, speed and accuracy of simulation results. GIS can also reduce the time and money invested in establishing a database system that can be used to support planning and monitoring.

1.2 Problem statement

This study attempts at watershed soil erosion assessment using Geographic Information System (GIS). In the study of erosion, it has been found that most of the physically based models (eg. WEPP, GRASS, CREAMS and others) from developed countries are not suitable for local use due to different environment conditions and data availability. These models are complex and may present difficulties for use. Mainly for this reason, this study adopts the Universal Soil Loss Equation (USLE) in estimating the soil erosion rates because of its simplicity and parameters are more easily available although some modifications can be made to adapt to local conditions. The simple form of the equation also makes it easier to be integrated within the GIS environment. Previously the slope length of the USLE is estimated rather than calculated for large areas. The use of GIS is also to facilitate the calculation of the slope and the length slope factor for use in the USLE so that the landscape will be more accurately described and erosion estimates will approach actual values.



In addition, earlier attempts at estimating soil erosion using USLE and more recently, with GIS, had been made. These studies (eg. Lok *et al.* (1991) in Upper Klang Valley, Roslan & Tiew (1996) in Cameron Highlands, Kamaruzaman *et al.* (1999) in Langkawi and others) had been successful in generating soil erosion information although some limitation such as methods of determining the parameters, quality of the data and reliability of the results were also addressed. This study attempts to consider these limitations with the aim to predict more accurately watershed erosion.

1.3 Objectives of the Study

The general objective of this study is to determine soil loss under forest conditions in the Sg. Weng Experimental watersheds using the Universal Soil Loss Equation (USLE) in combination with Geographic Information System (GIS) to generate digital soil erosion information.

The specific objectives of this study are: -

- i. To determine the slope length factor (LS) of the USLE equation using a digital elevation model (DEM).
- ii. To determine the other component of USLE (rainfall erosivity factor (R), soil erodibility factor (K), crop management (C) and support practice factor (P)) for conversion to digital or raster format.
- iii. To estimate the soil erosion rates of the study watersheds under primary forest and thus generating digital soil erosion map.



It is envisaged that reasonable information on the soil erosion rates could be reasonably generated in this study and the method used in this study could be applied to other areas with similar conditions in order to access the magnitude of soil loss. Furthermore, the information obtained will be valuable resources for decision makers to guard against land disturbances in high erosion risk areas.



