UNIVERSITI PUTRA MALAYSIA

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

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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

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Satu kajian telah dijalankan untuk menilai hakisan tanah bagi hutan di kawasan tadahan air menggunakan model *Universal Soil Loss Equation* (USLE) di dalam persekitaran 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 lapisan-lapisan 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.

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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.