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DEVELOPMENT OF TOOLS FOR SOIL EROSION RISK MAPPING FOR MALAYSIAN FOREST CATCHMENTS

SAIFUL ISKANDAR KHALIT

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By

SAIFUL ISKANDAR KHALIT

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia
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DEVELOPMENT OF TOOLS FOR SOIL EROSION RISK MAPPING FOR MALAYSIAN FOREST CATCHMENTS

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SAIFUL ISKANDAR KHALIT

September 2012

Chair: Professor Husaini Omar, PhD

Faculty: Engineering

Logging, road construction and heavy machine usage in forest activities are challenges faced when trying to minimize the impact on forest environment, especially land degradation and soil erosion and also contamination of water resources. Measurement of soil loss using a conventional method is time- consuming and expensive. Another problem posed by soil erosion during rainy season, flood occurred at the downstream at Kampung Pasir Raja and settle up the formation of sediment in the river which engaged with public concern. Climatic data was obtained by installation of Automatic Weather Station (AWS) which was carried out from August 2007 to August 2008 (water year cycle) to record daily data. A parameter modification was made to the modified soil loss equation (MSLE) which consisted of rainfall (R), soil erodibility (K), slope length (LS) and vegetation management (VM). This leads to an application of the MSLE which produces a soil erosion maps. The validation of the model is acceptable since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables more than 90 percent (%) confidence level in the STATGRPHICS Plus analysis. In other

hands, the validation also was done for two different sites at Blok 5 PITC, Temengor Forest Reserve, Grik, Perak and Bukit Tarek Forest Reserve.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN ALATAN UNTUK PEMETAAN RISIKO HAKISAN TANAH BAGI HUTAN HUJAN MALAYSIA

Oleh

SAIFUL ISKANDAR KHALIT

September 2012

Pengerusi: Professor Husaini Omar, PhD

Fakulti: Kejuruteraan

Aktiviti pembalakan, pembinaan jalan hutan dan penggunaan jentera berat merupakan cabaran untuk meminimakan kesan terhadap persekitaran hutan dan kualiti air. Pengukuran terhadap hakisan tanah menggunakan kaedah konvensional adalah lambat dan mahal. Semasa berlakunya musim tengkujuh, masalah penambakan timbunan pasir di Sungai Dungun timbul lalu mengakibatkan banjir di kawasan rendah di Kampung Pasir Raja. Beberapa kaedah yang telah dilakukan dalam penyelidikan ini yang meliputi kaedah pin hakisan dan unjuran ("modeling"). Selain itu, data iklim juga dicerap secara harian dari bulan Ogos 2007 sehingga Ogos 2008 (kitaran tahunan air) bagi merekodkan data bagi hujan dan tujuan permodelan. Untuk tujuan pembangunan pangkalan data "Modified Soil Loss Equation" model, beberapa parameter telah digunakan iaitu hujan (R), keterhakisan tanah (K), panjang cerun (LS) and perancangan tumbuhan (VM). Secara statisitknya, model ini memberi lebih 90 peratus ketepatan secara perbandingannya dengan menggunakan perisian STATGRAPHIS Plus. Selain itu, model ini divalidasi di dua lokasi kajian iaitu Blok 5 PITC, Hutan Simpan Temengor, Grik Perak dan Hutan Simpan Bukit Tarek, Mukim Kerling Selangor.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the Doctor of Philosophy. Members of the Supervisory Committee were as follows:

Husaini Omar, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Thamer Ahmad Mohammad Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ahmad Rodzi Mahmud, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date :

DECLARATION

I declare the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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SAIFUL ISKANDAR KHALIT

Date : 7 September 2012

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LIST OF ABBREVIATIONS

MSLE	Modified Soil Loss Equation
RUSLE	Revised Universal Soil Loss Equation
USLE	Universal Soil Loss Equation
FR	Forest Reserve
FRIM	Forest Research Institute Malaysia
R Factor	Rainfall Erosivity Factor
K Factor	Soil Erodibility Factor
LS Factor	Length of Slope and Gradient Factor
VM Factor	Vegetation Management Factor
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTION

1.1 General

Tropical forest is one of the world's richest ecosystems in plant and animal diversity (Jetten, 1994) but is also one that is threatened by human pressure (Park, 1992; Dale, 1997) where land use cover change is mainly driven by population increase (Sinha, 1997). A total of 12000 million hectares (ha) is world's forest in 1988, 3600 million ha is tropical forests and 50 % being located in South East Asia (Koning et al., 1998). Land use change plays an important role in this ecosystem when compared with natural events; it causes various kind of impact upon water quality, biodiversity, regional climate, and ecosystem degradation (Koning et al., 1998). The conversion of tropical forest to pasture and the subsequent succession of pasture to secondary forest have a significant effect on canopy cover, canopy height, species composition, and biodiversity (Reiners et al., 1994). Increasing food demand and changes in land management and land tenure have pushed forward the agricultural frontier in many tropical countries. Subsistence farmers are continuously being displaced and forced to clear new areas for cultivation on steeper slopes.

1.2 Erosion Processes

Erosion is probably the first environmental problem that affects human. A soil erosion study is essential in order to achieve sustainability of our natural resources

due to the increment of land development in Malaysia and one of the indicators of non-point source pollution. There are so many impacts from soil erosion such as sedimentation, shallower river bed and reduced soil fertility. While soil erosion is a natural process, human activities such as construction or vehicle disturbance can substantially increase the rates of erosion, sediment transport and deposition. Increased erosion and sedimentation can create hazardous conditions, destroy water quality and cause other environmental damage, requiring costly for repairs. Therefore, it is important to minimize the damage caused by disturbances by planning soil conservation measures. An early solution for the loss of topsoil was relocating to a different place and starting again. As the demanding of logging activities increased; this was no longer possible and humans became aware of the need to prevent erosion whereby the topsoil is saved to prevent streams from silting up. The most common long-term solution to erosion is the establishment of appropriate vegetation to hold the soil in place.

In forest management, engineering practices on forest activities are challenged by the task of minimizing the impact of forest environment which are emphasized timber production and forest road but also implementing a minimize destruction to sustain our water resource. On forest harvesting, topsoil is often removed and stockpiled to be used in the final configuration of the soil surface. The less fertile soil is exposed during the construction process, it can erode and causes problem to the environment. The soil that run off from the site might enter streams and effect aquatic life as well as silt up the channel and make it less attractive and navigable. The soil particles must, therefore, either be held in place or contained on the site.

On the 6th December 2008, tragedy struck for the residents of Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang (Figure 1.1). Five residents died in the landslide and 14 bungalow houses were damaged. It was the second landslide hazard after 17 years where there were 48 casualties reported. Moreover, one of the three Highlands Towers condominium block also collapsed during the tragedy. From the tragedy, public should not take for granted and should be more careful and aware during monsoon season especially in the highland settlement. However, to be more effective in providing experience and information to public, government should take proactive actions in public awareness, landslide and slope rehabilitation and safety.

12 Ahad, 5 Disember 2010

Advertorial

Metro

Mengapa tanah runtuh?

Kesedaran aspek keselamatan cerun mampu cegah bencana

TANGGAL 6 Disember 2008 pastinya memahat memori ngeri dan sayu. Gara-gara kejadian tanah runtuh di Taman Bukit Mewah, Bukit Antarabangsa, Hulu Klang, lima maut manakala 14 banglo musnah.

Angkara tanah runtuh juga, 17 tahun sebelum itu, 48 terkorban apabila satu daripada tiga blok kondominium Highland Towers, runtuh. Hakikatnya, bahaya tanah runtuh bukan perkara yang boleh dipandang enteng.

Justeru, bagi memberikan lebih pendedahan dan maklumat berguna berkaitan tanah runtuh kepada masyarakat, kerajaan mengambil langkah proaktif mewujudkan program kesedaran awam, pendidikan mengenai tanah runtuh dan keselamatan cerun.

gravity

POTENSI BAHAYA... tanah, batu dan runtuhan sentiasa di bawah pengaruh graviti dan akan bergerak ke bawah jika bebanan di atas cerun melebihi ketahanannya.

AWAS... tanah runtuh mudah terjadi pada lereng bukit

Figure 1.1: An article concerned about erosion issue in Malaysia (Harian Metro, December 2010)

1.3 Traditional Versus Recent Method in Erosion Estimation and Prediction

There are several methods to quantify erosion risk. On hill forest, the simplest technique is using pin erosion that can be measure at the hill slope. The difference in the length of the pins which made from iron was exposed indicates the amount of soil loss in a certain period. Over a large landscape such as in logged over forest, soil erosion can be measured in terms of sediment yield, which is the sum of suspended and bedload sediments discharged from a watershed (Baharuddin et al, 1999). The method of sustainable forest management is commonly practice in Peninsular Malaysia especially in protecting soil and water values in tropical catchment forest. It includes the ecological and economic values likely soil erosion occurs from disturbances such as forest roads, timber harvesting, or fire. These disturbances have major effects on both the vegetation and the soil properties. Elliot and Hall (1997) reported that soil erodibility depends on both the surface cover and soil texture. According to the study by Robichaud *et al*. (1993), the soil erodibility on a skid trail is greater than in the areas between skid trails. Hydrologic process such as soil erosion and runoff are complex in nature and all these processes depend on various factors such as watershed geomorphology, land use, distribution and duration of rainfall. Over the years several hydrological models ranging from empirical relationships to physical models have been developed for the prediction of hydrologic process. There is the recent tendency to move from using empirical erosion models (e.g. USLE, MSLE, and RUSLE) to more advanced models for conservation purposes. An ANN model to predict soil erosion is an alternative to the empirical models. Erosion prediction is useful in the evaluation of different

management practices, control techniques for the forested catchments and for the purpose of watershed conservation.

The advancement of today's technologies has enabled the use of Geographical Information System (GIS) in calculating soil erosion risk for varies research. In contrast, the availability in handling spatial data efficiently such as mapping soil erosion using the GIS would identify areas that are at potential risk of extensive soil erosion, provide information on the estimated value of soil loss at the logging areas. It allows the results to be displayed clearly using maps. Despite of it, GIS is also providing a more quantitative and objective analysis. In addition, it can provide answers to spatial queries, for instance whether the erosion is associated with specific factors such as the difference of rainfall intensity or the loss of continuous vegetation cover in the particular logging area. This information is very useful in decision making context to reduce soil erosion if logging at the hillslope were to continue.

The Modified Soil Loss Equation (MSLE) will be used with integration of GIS frame work to calculate the total erosion loss in forest areas. The study aims to assess the effect of natural canopy and forest harvesting on the soil loss in small catchment through field measurements, the impact of forest conditions on the river pollution and configuration of surface water through field measurement and laboratory works and develop a system for the validation of the MSLE in the tropical catchment by incorporating field data with spatial data and information. This new study has potential to replace the conventional method which has several problems which was time consuming and financially expensive in term of technical support and material.

1.4 Physical and Climatic Features

The State of Terengganu Darul Iman is located at latitude 3º 47' to 5º 57' N and longitude 113 º 49' to 115 º16' E of the east coast of Peninsular Malaysia. A total land area is 1,302,225.31 hectares (ha). This state is bordered by Kelantan and Pahang at the northwest and southwest of the state respectively, while facing the South China Sea at the east. Forest covers 62.80% of the inland while, rivers and wetlands dominate another 11.19%. The other landuse are built-up, cropland and paddy field (Figure 1.2).

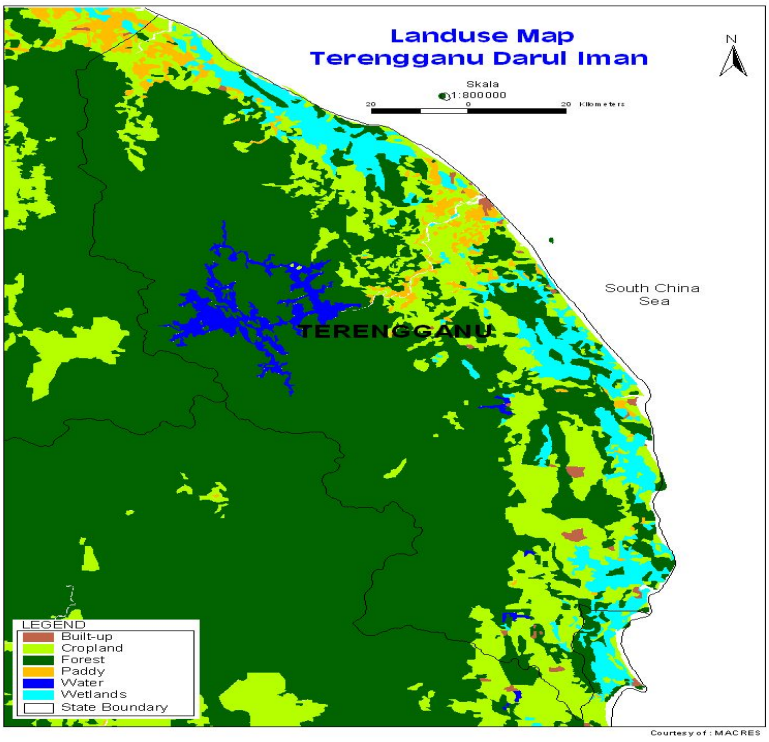

Figure 1.2: Land use map of Terengganu (MACRES, 2003)

The climate of Terengganu is equatorial monsoon with high temperature and rainfall throughout the year. This region is influenced by the prevailing northeast monsoon wind which produces heavy rainfall from November to January each year.

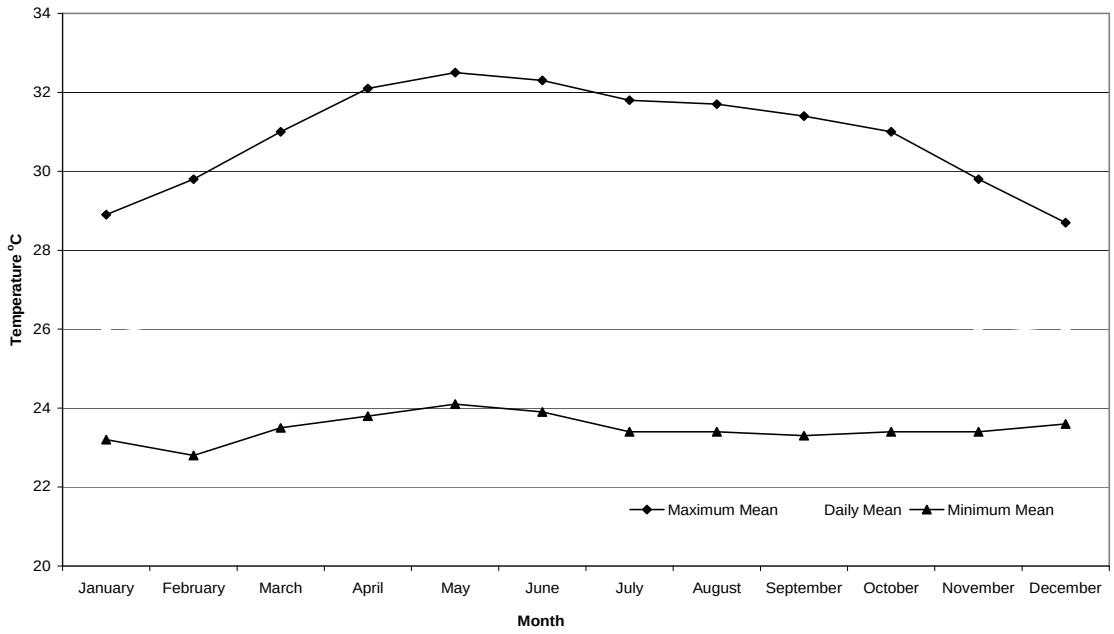

Figure 1.3: An average monthly temperature profile at Kuala Terengganu Airport station from 1982-1991 (DID, Dungun, 2007)

Temperature is relatively uniform throughout the year. Monthly mean was 26.7ºC while the monthly maximum was 30.9ºC and a monthly minimum was 21.6ºC. Highest monthly mean recorded was 27.6ºC in May while the lowest was 25.9ºC in December and January (Figure 1.3).

1.5 Topographic Analysis

Computation of Digital Elevation Model (DEM) and computation analysis is a crucial component in analyzing the preparation of topographic data for soil erosion. Spatial data was digitized from topographic maps while attribute data was obtained from several sources such as the Department of Agriculture and Department of Irrigation and Drainage. Images of three dimensional study areas were generated by GIS application. The integration between GIS and MSLE model will be used to evaluate erosion for a large area. The results are presented in attribute table and graphical forms. Such planning may seem difficult for large areas but geographic information systems (GIS) can provide the tools to assess the erosion risk, evaluate various disturbance alternatives and spatially optimize conservation measures. Cost effective of land maintenance and rehabilitation might be requires identification of logged over in forest area at greatest risk of soil erosion and deposition, as these areas should be as targeted as potential erosion preventions areas. Therefore, the needs of high quality process-based data should provide valuable tools for assessing the current erosion status and predicting erosion patterns for various land use and management requirements.

An area in the east coast of Peninsular Malaysia was selected due to it complex characteristics. It is also associated with high annual rainfall and the influence of the north-east monsoon and indicates of high potential for soil erosion. The annual rainfall is greater than 3000 mm and is strongly seasonally. The term tropical lowland forest is used to describe forest where there is little or no seasonal water shortage and where the climate is continuously warm and humid (humidity can reach

almost 100% at night). The topography is rugged mountainous and steep sloping area and the major soil is derived from weathered-limestone and granitic which is common in Peninsular Malaysia. These soils usually occur in upland conditions with soil profiles being shallower relative to form the Beserah soil. A summarizes of the physical and climatic features of the study area is given in Table 1.1.

Table 1.1: Physical and climatic features in Compartment 70 of Pasir Raja Selatan Forest Reserve, Dungun, Terengganu MALAYSIA

Physical Features	
Area (ha)	428
Elevation (m.a.s.l.): Highest	620
Lowest	530
Mean slope (%)	37
Soil (Major Series)	Beserah
Drainage Density (km/km^2)	3.2
Climatic Features	
Annual Rainfall (mm)	3030
Air Temperature (^{o}C)	
(i) Mean Maximum	23.8
(ii) Mean Minimum	23.1
Relative Humidity (%)	90
Air Pressure (kPa)	683

1.6 Research Problems

There are five major problems indicated in this study which needs to be investigated. Perhaps, this study will provide some indicator and contribution to the authorities and local people in this matter. The following are the problems need to be highlighted:

1. Logging, road construction and heavy machine usage in forest activities are challenges to minimize the impact on forest environment especially land degradation and soil erosion as well as minimizing contamination of water resources.
2. Actual measurement of soil loss using conventional method are time consuming and expensive.
3. Under the Environmental Quality Act, 1974 (Amendment) 1985, most development require Environmental Impact Assessment (EIA) to be conducted and have the results presented in the form of reports. Handling environmental data manually is almost impossible, what more if analysis is needed. Thus, in the erosion assessment and analysis there exists a few problems:
   (a) A demand for the generation of soil erosion risk maps for EIA in view of the rapid land development in Malaysia.
   (b) The need for the soil erosion risk maps to be produced in a very fast and yet economic manner especially in rapid assessment report such as macro EIA report for the proposed forest operations in each state in Peninsular Malaysia.

(c) Environmental data is manually analyzing and rapid assessment yet losing its information's quality for the generating of the erosion risk map is not feasible.

4. Detail information is needed on soil survey to determine soil erodibility, continuous rainfall data from automatic rainfall recorder and reduce grid size for in the topography map.

5. In many cases detached soil is deposited only a few meters away from the source. This is particularly a problem where the base of hillslopes is adjacent to riparian areas. Sediment entering riparian systems can be detrimental to riparian vegetation and degrade water quality. Another problem posed by soil erosion during wet season, flood occurred at the downstream at Kampung Pasir Raja and settle up the formation of sediment/bed load in the river which engaged with public concern.

Alternatively, the statistical analysis using STATGRAPHICS Plus and two other study sites are used to validate the model moreover in strengthening the model itself.

1.7 Research Objectives

The main objective in this study is to develop a tool for soil erosion risk mapping in Malaysian Forest Catchment in Pasir Raja Selatan Forest Reserve. To enhance the study, there are additional objectives as follows:

1. To identify the related parameters on soil erosion analysis;
2. To quantify the soil erosion risk through field measurement;

3. To produce the soil erosion risk map using GIS tool; and
4. To validate the soil erosion risk map with other site study.

1.8 Scope and Limitations

The study was conducted in a small catchment area which based in the forest management plan of Terengganu Forestry Department. The area was delineated by compartment which covered of less than 500 hectares per area. The boundary of compartment was divided by river. The Compartment 70 was selected for this study area since it began operated logging in 2007 and accomplished in late 2008. Since the landscape of the study was undulating and forested area, only downstream area had been involved for surface erosion measurement. Two months (November and December 2007) of Automatic Weather Station (AWS) climatic data not available due to big flood occurred at the access road to Pasir Raja Selatan Forest Reserve. Alternatively, we were able to get the secondary data from Department of Irrigation and Drainage of the Dungun District.

1.9 Structure of the Thesis

This study comprised into five chapters. Chapter 1 as an introduction of the study discussed about the general information of soil erosion approach and the parameterizations. In chapter 2, the segment consist of the literature review of erosion related models applied to soil erosion impacts research while chapter 3 covers the Methodology describing the information of study area and material that been used to obtain the erosion data using conventional and GIS. Chapter 4 includes

the results summaries from the analysis and discusses the result. Lastly, Chapter 5 consists of conclusions derived from the study and its summary.

REFERENCES

Anderson, M.G., (1983). Road-cut slope topography and stability relationships in St. Lucia, West Indies. *Appl. Geogr.* 3, Pg 104– 114

Anderson, M. G., and Burt, T. P. (1985). Hydrological Forecasting. *John Wiley & Sons Ltd.* Chichester, UK

Anon, (1996). Field measurements of soil erosion and run off. In http://www.fao.org/docrep/t0848e/t0848e-07.htm. Assessed on 22 March 2010

Anon (2007). Annual report 2006. Forestry Department Peninsular Malaysia. Kuala Lumpur. Malaysia

Baban and Kamaruzaman (2001) Modelling soil erosion in tropical environments using remote sensing and geographical information systems. *Hydrological Sciences-]'ournal-des Sciences Hydrologiques,* 46(2) April. Pg 191-198

Bagarello, V., Di Stefano, C., Ferro, V. and Pampalone, V. (2011). Using plot soil loss distribution for soil conservation design. Catena 86 (2011). Pg 172–177

Baharuddin, K., Zulkifli Yusop and Abdul Rahim Nik, (1999). A Guide For Estimating Surface Soil Loss Using Modified Soil Loss Equation (MSLE) on Forest Land. *FRIM Technical Information Handbook No. 23.* Pg 1-2

Beven, K. J. (1989). Changing ideas in hydrology – the case of physically-based models. *Journal of Hydrology*, 105: Pg 157 – 172

Beven K.J., and Moore I.D. (1994). Advances in Hydrological Processes. Terrain Analysis and Distributed Modelling in Hydrology. *John Wiley & Sons.* New York. USA

Beven K., Lamb R., Quinn P., Romanowicz R., and Freer J. (1995). TOPMODEL. In: Computer Models of Watershed Hydrology. *Water Resources Publications.*

Edited by Vijay P. Singh. Department of Civil and Environment Engineering Louisiana State University, Baton Rouge, LA 70803-64405, USA

Carr, W. W., W. R. Mitchell and W. J. Watt. (1991). Basic Soil Interpretations for Forest Development Planning: Surface Soil Erosion and Soil Compaction. *Land Management. Report No. 63.* Ministry of Forests, Research Branch, Victoria

C.A.J.M. de Bie, (2005). Assessment of soil erosion indicators for maize-based agro-ecosystems in Kenya. Catena 59 (2005). Pg 231–251

Dangermond, J. (1993). The Role of Software Vendors in Integrating GIS and Environmental Modelling, Environmental Modelling with GIS. *Oxford University press.* New York – Oxford, USA

Douglas (2003) Predicting road erosion rates in selectively logged tropical rain forests. Erosion Prediction in Ungauged Basins: Integrating Methods and Techniques. *Proceedings of symposium I-IS01 IUGG2003 Sapporo*. IAHS Ptibl. no. 279. 2003

Elena Amore, Carlo Modica, Mark A. Nearing, and Vincenza C. Santoro, (2004). Scale effect in USLE and WEPP application for soil erosion computation from three Sicilian basins. Journal of Hydrology 293 (2004). Pg 100–114

Elliot, W. J., and D. E. Hall. (1997). Water Erosion Prediction Project (WEPP) forest applications. *General Technical Report INT-GTR-365*. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station

Elliot,W.,J., and Robichaud,P.,R.,(2001). Comparing Erosion Risks from Forest Operations to Wildfire. Proceedings of the International Mountain Logging and 11th Pacific Northwest Skyline Symposium: 2001 - A Forest Engineering Odyssey. Seattle, WA: College of Forest Resources, University of Washington and International Union of Forestry Research Organizations. Pg 78-89.

Presented at *The International Mountain Logging and 11th Pacific Northwest Skyline Symposium 2001*, December 10--12, 2001, Seattle, WA

Fedra, Kurt. (1993). GIS and Environmental Modelling; Environmental Modelling with GIS. *Oxford University press*. New York – Oxford, USA

Flanagan, D.C and S.J. Livingston (1995). USDA-Water Erosion Prediction Project: User Summary. NSERL Report No. 11. West Lafayette, IN: USDA-ARS National Soil Erosion Research Laboratory

Garten,C.T. (2004). Predicted Effects of Prescribed Burning and Timber Management on Forest Recover. Environmental Sciences Divisions in http://www.ornl.gov/~webworks/

Goldman, S.J., Jackson,K. and Bursztynsky,T.A. (1995). Erosion and Sediment Control Handbook. McGraw Hill Book Company

Guillermo A. Baigorria & Consuelo C. Romero, (2007). Assessment of erosion hotspots in a watershed: Integrating the WEPP model and GIS in a case study in the Peruvian Andes. Environmental Modelling & Software 22 (2007) Pg 1175-1183

Igneous Rock, Geological Society Malaysia (2011). Assessed on 11 January 2012. http://www.gsm.org.my/geosciences/geoscience/rocks/rocks.htm

Jetten, V. G. (1994). Modelling the Effects of Logging on the Water Balance of a Tropical Rainforest. A Study in Guyana. *Tropenbos Series 6*. The Tropenbos foundation. Wageningen. Department of Physical Geography, Faculty of Geographical Sciences. Universiteit Utrecht

Jusoff, K., (1995). Estimation of Rate of Recovery of Disturbed Soils from Ground-based Logging in Peninsular Malaysia. *Faculty of Forestry, Universiti Pertanian Malaysia*

Keith Beven, Paul Quinn, Renata Romanowicz, Jim Freer, James Fisher and Rob Lamb (1995). TOPMODEL AND GRIDATB - A USERS GUIDE TO THE DISTRIBUTION VERSIONS (95.02). In: *CRES Technical Report TR110 (2nd Edition)*. Centre for Research on Environmental Systems and Statistics Institute of Environmental and Biological Sciences Lancaster University, Lancaster LA1 4YQ, UK

Kerem.H. (2000). Suspended Sediment Estimation for Rivers using Artificial Neural Networks and Sediment Rating Curves. *Turkish Journal Engineering Environmental Science*, Vol 26, Pg 27-36

Kirkby, M. J., Naden, P. S., Burt, T. P., and Butcher, D. P. (1993). Computer Simulation in Physical Geography. *John Wiley & Sons*. Chichester, U.K

Koning, H. H. J. de, Vekdkamo, A., Verbulrg, P. H., and Beergsma, A. R. (1998). CLUE: A Tool for Spatially Explicit and Scale Sensitive Exploration of Land Use Changes. *Wageningen Agricultural University*

Krause,J. and Diekkrüger,B. (1999). Modelling Soil Erosion at the Catchment Scale Derivation of Model Discretization and Parameters using Relief Data. *Geophysical Research Abstracts,* Vol. 5, 08581, 2003, European Geophysical Society 2003

Kumar,M. (2003). Evapotranspiration modeling using artificial neural networks. *PhD thesis*, Indian Institute of Technology

Lehigh Valley Planning Commission, (2008). Steep Slopes – Guide / Model Regulations published in http://www.lvpc.org/pdf/SteepSlopes.pdf

Licznar,P. and Nearing,M.A. (2001). Artificial neural networks of soil erosion and runoff prediction at the plot scale. *Journal of Hydrologic Engineering*, Vol. 51, Pg 89– 114

Luce, C.H., and Black,T.A., (1999). Sediment production from forest roads in western Oregon. *Water Resour. Res.* 35 (8), Pg 2561–2570

Luce, C.H., and Cundy, T.W., (1994). Parameter identification for a runoff model for forest roads. *Water Resour. Res*. 30 (4), Pg 1057–1069

MACRES. (2003). In http://www.remotesensing.gov.my/

Megahan,W.F., (1972). Subsurface flowinterception by a logging road in mountains of central Idaho. In: Scallany, S.C., McLaughlin, T.G., Striffler, W.D. (Eds.), *Proceedings of the Watersheds in Transition Symposium*. American Water Resources Association, Urbana, IL, Pg 350–356.

Meyer,L. D., and Wischmeier,W.H., (1969), Mathematical Simulation of Process of Soil Erosion by Water. *Transaction American Society Agriculture Engineering,* Vol 12, Pg 754–758

Montgomery, D.R., (1994). Road surface drainage, channel initiation, and slope instability. *Water Resour. Res.* 30 (6), Pg 1925–1932

Montgomery, D.R., Dietrich,W.E., (1994). A physically based model for the topographic control on shallow landsliding.*Water Resour. Res.* 30 (4), Pg 1153–1171

Morgan, R.P.C., (1986). Soil Erosion and Conservation. *2nd Ed. Longman*

Palco Syp HCP. (2006). Assessment of Watershed Disturbance and Recovery. *Public Review Draft, Vol II* published in http://resources.ca.gov. Assessed on 21 December 2010

P.R. Robichaud, C.H. Luce, and R.E. Brown (1993). "Variation among Different Surface Conditions in timber harvest sites in the Southern Appalachians." In *Proceedings from the Russia, U.S. and Ukraine International workshop on quantitative assessment of soil erosion. Moscow, Russia.* Sep. 20-24. West

Lafayette, IN: The Center of Technology Transfer and Pollution Prevention, Purdue University, Pg 231-241

R.Barthel (2006). Common problematic aspects of coupling hydrological models with groundwater flow models on the river catchment scale. *Advances in Geosciences*, 9, Pg 63–71

Raghuwanshi, N.S., Singh,R. and Reddy,L.S. (2006). Runoff and Sediment Yield Modeling Using Artificial Neural Networks: Upper Siwane River, India. *Journal of Hydrologic Engineering.* Vol 11, No 1, Pg 71-79

Reid, L.M., and Dunne, T., (1984). Sediment production from forest road surfaces. *Water Resour. Res.* 20, Pg 1753–1761

Reiners, W. A., Bouwman, A. F., Parsons, W. F. J., and Keller, M. (1994). Tropical rain forest conversion to pasture – Change in vegetation and soil properties. *Ecological Applications,* 4, 2: Pg 363-377

Renard, K.G., Foster, G.R., Weesies, G.A. and Porter, J.P. (1991). RUSLE: Revised Universal Soil Loss Equation. *Journal of Soil and Water Conservation,* United States Department of Agriculture, Volume 46 (1), Pg 30-33

Robin, P. Merot, Ph., Beven, K. (1995). Sensitivity to space and time resolution of a hydrological model using digital elevation data. *Hydrological Processes*, 9: Pg 69 - 85

Roslinah & Norizan (1997) Soil Erosion and Hydrological Study of the Bakun Dam Catchment Area, Sarawak Using Remote Sensing and Geographic Information System(GIS) in http://www.gisdevelopment.net/aars/acrs/1997/ts2/ts2005 Assessed on 12 September 2009

Rovey, E. W., Woolhider, D. A., and Smith, R. E. (1977). A Distributed Kinematic Model of Upland Watersheds. *Hydrology Paper No. 93*. Colorado State University

R.K. Singh, R.K. Panda, K.K. Satapathy and S.V. Ngachan, (2011). Simulation of runoff and sediment yield from a hilly watershed in the eastern Himalaya, India using the WEPP model. Journal of Hydrology 405 (2011). Pg 261–276

Sapari, Nasiman and Raja Azie, R.Z and Jusoh, Hisyam (2010). Groundwater in fractured granite for water supply of remote areas in Malaysia. Water Practice and Technology. In Geological Survey, Department of Malaysia (1987). *Groundwater Resource Study of Seri Gading Johor and Rembau-Tampin-Gemas, Negeri Sembilan: Fourth Malaysian Plan (1981-1985)* Project Report Department of Geological Survey, Kuala Lumpur

Shamsudin, S.A., Lion, M. and Iskandar, S., (2006). Monitoring the Changes in the Hydrological Attributes with the Establishment of Forest Plantation for Water Resource Management in a Catchment *Forest Hydrology Unit*, Forest Research Institute of Malaysia

Sadeghi, S.H.R., Azari, M. and Ghaderi Vangah, B. (2008). Field evaluation of the Hillslope Erosion Model (HEM) in Iran. Biosystem Engineering 99 (2008). Pg 304 – 311

Singh, V. P. (1995). Computer Models of Watershed Hydrology. Vijay P. Singh (ed.). *Water Resources Publications*. USA

Sinha, S. K. (1997). Global change scenario: Current and future with reference to land cover change and sustainable agriculture – South and South-East Asia context. *Current Science*, 72, 11: Pg 846 - 854

Shin-Cheng Yeh, Chao-An Wang, Hui-Ching Yu. (2007). Simulation of soil erosion and nutrient impact using an integrated system dynamics model in a watershed in Taiwan. Environmental Modelling & Software 21 (2006). Pg 937-948

Smith, R. E., Goodrich, D. C., Wollhiser, D. A., and Unkrich, C. L. (1995). KINEROS – A kinematic runoff and erosion model. In: Computer models of

watershed hydrology. Vijay P. Singh (ed.). *Water Resources Publications*. USA

Solorio, J.,D.,B., MacDonald, L.H., & Hughes, D.J. (2004). Recovery of runoff and erosion rates after forest fires: an assessment using rainfall simulations. *European Geosciences Union,* Volume 6

Troeh, F.R., Hobbs, J.A., and Donahue, R.,L. (1980). Soil and Water Conservation-For Productivity and Environmental Protection. *Prentice Hall*

Warren, S. D., Mitasova, H., Hohmann, M.G., Landsberger, S., Iskander, F.Y., Ruzycki, T.S. and Senseman, G.M. (2005). Validation of a 3-D enhancement of the Universal Soil Loss Equation for prediction of soil erosion and sediment deposition. Catena 64 (2005). Pg 281–296.

Warrington, G.E., Knapp, K.L., Klock, G.O., Foster, G.R., & Beasley, R.S., (1980). Surface erosion. In Mulkey, L.A., An approach to water resources evaluation of non-point silvicultural sources. *A Procedural Handbook. Forest Service Unites States* Department of Agriculture Washington D.C.USA

Wemple, B.C., Swanson, F.J., and Jones, J.A., (2001). Forest roads and geomorphic process interactions, Cascade Range, Oregon. *Earth Surf. Process. Landforms* 26, Pg 191–204

Wischemeier, W.H. and Smith, D.D., (1965). Predicting rainfall erosion losses from cropland east of the Rocky Mountains Guide for selecting and practices for soil and water conservation.*USDA Agricultural Handbook 282*. In Kasran,B., Nik,A.R., and Yusop,Z. (1999). A Guide for Estimating Surface Soil Loss using the Modified Soil Loss Equation (MSLE) on Forest Land. Forest Research Institute of Malaysia

Wischmeier (1977) Soil erosion: Prediction and control: in *The Proceedings of A National Conference on Soil Erosion*, May 24-26, 1976. Purdue University, Indiana. Soil Conservation Society of America: 77-74183

Woolhiser, D. A. (1996). Search for Physically-Based Runoff Models – A hydrologic El Dorado. *Journal of Hydrology*, 122, 3: Pg 122 - 129

Wu, J.S., ASCE, M., Han, J., Annambhotla, S. and Bryant, S. (2005). Artificial Neural Networks for Forecasting Watershed Runoff and Stream Flows. *Journal of Hydrologic Engineering,* Vol 10, Pg 216-222

Xian-Li Xu, Wen Liu, Ya-Ping Kong, Ke-Li Zhang, Bofu Yu, Ji-Ding Chen, (2009). Runoff and water erosion on road side-slopes: Effects of rainfall characteristics and slope length. Transportation Research Part D 14 (2009). Pg 497–501

Zaknich, A. (2003). Neural Networks for Intelligent Signal Processing. *World Scientific Publishing Co. Pte. Ltd*

Ziegler, A.D., and Giambelluca, T.W., (1997). Importance of rural roads as source areas for runoff in mountainous areas of northern Thailand. *Journal of Hydrology*. 196, Pg 204–229