QUANTIFICATION AND MODELLING OF SEDIMENT LOADING IN OIL PALM CATCHMENT

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Dedicated to individuals
I love with all my heart

Thanks for everything in every second of my life
World is nothing to me compared to both of you
(Ayah and Mak)
Mokhtar Bin Abdullah
Khalijah Binti Ali

Thanks for the support and motivation
Backbone and colours of my life
(Brothers and Sister)
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ABSTRACT

A small and matured oil palm catchment of 15.62 ha in Ladang Sedenak, Johor was monitored to study the Suspended Solids (SS) loading and factors influencing the sedimentation rate. This study is designed to establish comprehensive understanding on hillslope erosion processes in oil palm plantation catchment. Ten storm events with a total of 133 samples were analyzed for SS concentration and turbidity. Rainfall and streamflow were recorded continuously. Baseflow samples were also analysed. SS concentration ranged between 2 and 2710 mg/L during storms but only from 3 to 6 mg/L during baseflow. Turbidity values range between 20.5 NTU and 2875 NTU. The relationships between SS concentration and turbidity for individual storm events are not consistent with coefficient of determination, r^2 ranging from 0.37 to 0.96. The intercepts of the regression line range from -57.2 to 391.9 whereas the slopes from 0.44 to 1.66. Therefore, all event data are combined to minimise the variation. The new SS-turbidity relationship for the combined events is SS=0.813Tur+3.69 (r^2=0.86, p<0.0001). Sedimentation process was examined in terms of hysteresis loops which demonstrate five clockwise loops, three figure eight patterns and two single-valued lines. In general, there was a depletion of sediment supply before the discharge has peaked. The depletion of sediment delivery, relatively early in the storm event could be associated with a limited supply of sediment during long-lasting and intense storms. The EMC for SS concentration ranges between 36 and 2046 mg/L, with a mean of 940 mg/L. Based on the EMC values of individual storm, the resulted SS load range from negligible to 2.51 ton. SS loading was also predicted using MUSLE. The runoff factor in MUSLE was estimated using two different techniques; 1) by the established curve number technique (SCS TR-55) and 2) by rainfall-runoff relationship at the study site. A better prediction of SS loading was obtained when the peakflow in MUSLE was estimated from rainfall-runoff relationship. Analysis of soil erosion model showed that the annual SS loading predicted by MUSLE is 10.03 ton/ha/yr whereas the USLE is 12.31 ton/ha/yr. SS loading at the catchment outlet was corrected by multiplying value of soil loss on the hillslope with Sediment Delivery Ratio (SDR). By applying a SDR value of 0.87, the resulted SS loading is 10.71 ton/ha/yr which is close to the value derived by MUSLE (10.03 ton/ha/yr).

ABSTRAK

Kajian beban pepejal terampai (SS) dan faktor yang mempengaruhi kadar pengenapan di tadahan kecil (15.62 hektar) kelapa sawit yang matang telah dijalankan di Ladang Sedenak, Johor. Kajian ini di reka untuk mendapatkan lebih kefahaman mengenai proses hakisan cerun bukit di kawasan tadahan ladang kelapa sawit. Sepuluh peristiwa hujan dengan jumlah 133 sampel telah dianalisis untuk kepekatan SS dan kekeruhan. Curahan hujan dan aliran sungai direkod berterusan. Sampel aliran dasar juga dianalisis. Sampel air sungai ketika aliran ribut mempunyai julat kepekatan SS antara 2 hingga 2710 mg/L dan 3 hingga 6 mg/L ketika aliran dasar. Nilai kekeruhan pula adalah antara 20.5 NTU dan 2875 NTU. Hubungan antara kepekatan SS dan kekeruhan bagi hujan ribut yang berlainan adalah tidak seragam dengan r^2 antara 0.37 dan 0.96. Nilai pintasan garisan regresi yang berjulat antara -57.2 hingga 391.9 dengan kecerunan di antara 0.44 hingga 1.66. Oleh itu, kesemua data telah digabungkan untuk mengurangkan variasi. Hubungan baru antara kepekatan SS dan kekeruhan bagi semua hujan ribut adalah SS=0.813Tur+3.69 (r^2=0.86, $p<0.0001$). Kepekatan SS juga dianalisis dalam bentuk gelung histerisis. Gelung histerisis menunjukkan 5 pola melawan pusingan jam, 3 bentuk angka lapan dan 2 bentuk garisan. Secara umum bekalan atau punca SS telah berkurang sebelum berlakunya aliran puncak. Penurunan kepekatan SS yang lebih cepat berbanding luahan menunjukkan bekalan SS yang agak terbatas semasa hujan yang lama dan lebat. Nilai EMC bagi kepekatan SS adalah antara 36 dan 2046 mg/L, dengan purata 940 mg/L. Berdasarkan nilai EMC, julat beban SS bagi ribut yang berasingan adalah dari terlalu kecil (diabaikan) hingga 2.51 tan. Beban SS turut dianggar menggunakan MUSLE. Faktor air larian dalam MUSLE ditentukan menggunakan dua kaedah berbeza, 1) teknik CN (SCS TR-55) dan 2) hubungan curahan hujan-air larian di kawasan kajian. Ramalan beban SS yang lebih baik diperolehi apabila aliran puncak dalam MUSLE dianggar menggunakan hubungan curahan hujan-air larian. Jumlah beban SS tahunan yang diramal menggunakan MUSLE adalah 10.03 tan/ha/yr manakala USLE 12.31 tan/ha/yr. Beban SS yang diramal di titik limpah tadahan telah diselaraskan dengan mendarab nilai hakisan cerun dengan Nisbah Penghantaran Enapan (SDR). Dengan nilai SDR sebanyak 0.87, jumlah beban SS yang diperolehi ialah 10.71 ton/ha/yr iaitu hampir menyamai nilai yang diramalkan menggunakan MUSLE (10.03 ton/ha/yr).

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LIST OF ABBREVIATIONS

AnnAGNPS	-	Annualized Agriculutral Non-Poin Source
EMC	-	Event Mean Concentration
MASMA	-	Urban Drainage Design Standards and Procedures for
MPOB	-	Malaysian Palm Oil Board
MSLE	-	Modified Soil Loss Equation
MUSLE	-	Modified Universal Soil Loss Equation
NTU	-	Nephelometric Turbidity Units
RUSLE	-	Revised Universal Soil Loss Equation
SCS TR-55	-	U.S. Soil Conservation Service Technical Release 55
SDR	-	Sediment delivery ratio
SS	-	Suspended sediment
USLE	-	Universal Soil Loss Equation

LIST OF SYMBOLS

C	-	Cropping and management factor
CN	-	Curve Number
I_a	-	Initial abstraction
K	-	Soil erodibility factor
LS	-	Slope length and slope factor
P	-	Conservation practice factor
Q_P	-	Peak discharge
q_u	-	Unit peak discharge
R	-	Rainfall erosivity factor
S	-	Slope steepness factor
V_R	-	Runoff volume
Y	-	Sediment yield

METRIC EQUIVALENTS

1 hectare (ha) = 10 000 square meter (m^2)

1 hectare (ha) = 2.47 acres (ac)

1 cubic meter (m^3) = 1000 litre

1 tonne per hectare (ton/ha) = 0.45 ton per acre (ton/ac)

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Oil palm was introduced to Malaysia in 1870 as an ornamental plant, and in 1917, the first commercial planting was undertaken. Owing to the government encouragement to diversify the crops from rubber to oil palm, the planting was expanded rapidly. Since then oil palm plantations continue to expand throughout the country. Within relatively a short period, Malaysia became one of the world largest commercial producers and exporters of palm oil. In 2008, the total palm oil export earnings are RM 65.2 billion from RM 45.1 billon in 2007. Therefore, the palm oil industry contributes significantly towards the country's foreign exchange earnings and the increased standard of living among Malaysians (Wu *et al*., 2008).

Malaysia's plantation companies must produce crude palm oil using the best management and agriculture practices to guarantee the industry's sustainability and exports. The growth of palm oil industry has been phenomenal with the increasing demand for vegetable oil such as biodiesel, oleo-chemical products and biomass by-products. Oil palm plantation development initially involved opening up of land areas and associated activities such as land clearing, biomass management and disposal, earthworks, planting and replanting activities. The impact of palm oil plantation is significant and therefore good management and agriculture practices are necessary.

Non-point source pollution has been recognized as a significant source of surface water quality problems (Ignazi, 1993; Ongley 1996). Fine and coarse sediment transported by surface water can result in different types of problem. Fine sediment is a major pollutant of aquatic systems. For example, deposition of fines has been repeatedly shown to degrade the benthic habitat of fish and other organisms (Lowe and Bolger, 2000) and impair water quality (Reiser, 1998). A major concern on stream and catchment management is the ecological impact of increased fine sediment load following land use practices (Brown and Krygier, 1971; Beschta, 1978). In agricultural areas, streams draining cultivated areas can undergo significant bank erosion and instability (Wilkin and Hebel, 1982) as well as increased sediment yields and runoff volumes (Allan *et al*., 1997; Vache *et al*., 2002), resulting in both sedimentation and significant soil and nutrient losses. As such excess fine sediment in streams often leads to ecological problems (Salant *et al*., 2008).

1.2 Problem Statement

Malaysia alone accounted for more than 40% of the total world palm oil production. In fact, for the past five decades, Malaysia's oil palm plantation area and crude palm oil production have been increasing gradually. From a mere 0.054 million hectares in the early 1960s, it increased steadily to 4.48 million hectares in 2008 (MPOB, 2009). Being a tropical palm, oil palm can be cultivated easily in Malaysia. An improved management of oil palm plantation needs to be implemented in order to achieve sustainable growth. Soil erosion and river sedimentation are important issues in water and catchment management. High erosion rate often leads to river constriction, increases water treatment costs, threaten aquatic habitats, and increases in flood frequency.

Knowledge of rates of soil erosion and sedimentation losses is crucial for sustaining the health of plantation ecosystems. Malaysia is a developing country where agriculture plantation is an important component of land use. Beside forest, plantation ecosystems can play crucial role for the conservation of water and soil resources. According to Wurbs and James (2002), soil is protected from erosion by its vegetative cover. Human activities that disturb or remove vegetation, such as logging, mining, agriculture, and construction, may greatly increase soil erosion. Therefore, it is important to make sure that a large part of palm oil plantation is covered by vegetation to maximize and sustain the production.

Oil palm cultivation can accelerate erosion and sedimentation processes especially during clearing of land. This results in more sediment being washed away into water courses. Large amount of money is spent every year to clean up sediment and repairing eroded stream bank, washed out roads and other erosion damages. Moreover, high sediment load is also responsible for pollution of many lakes, stream and rivers. The only practical solution is to reduce the surface runoff thereby lowering erosion intensity. Accelerated erosion and sedimentation rates are best controlled by minimising ground disturbances and applying effective soil conservation measures.

Adequate soil erosion control requires a quantitative understanding of the mechanisms governing soil erosion, identifying those major factors that cause soil erosion, predicting the amount and distribution of soil loss in relation to possible causal factors, and making an erosion assessment for alternative best management practices that can be used to facilitate conservation policies (Gao *et al*., 2002; Wang *et al*., 2006). Hence, it is timely to carry out detailed studies on erosion and sediment yield from oil palm catchments which aimed at minimising erosion problems. Erosion and sedimentation measurement can be conducted using a small catchment approach to enable linkages between slope and stream processes to be established. Thus far very little work has been carried out on rate of erosion from oil palm plantation on a catchment basis. Such information is crucial for planning and management of catchment resources in particular the soil and water. The effect from overland flow during heavy storm in the study site which caused high sediment concentration in stream is shown in Figure 1.1.

Figure 1.1: Occurrence of Horton overland flow during heavy storms causing high suspended sediment concentration in stream

1.3 Objectives

The main aim of this study is to quantify and predict sediment loss from oil palm plantation. The specific objectives are:

i) To determine sediment load into the stream during storm events.
ii) To investigate the hydro-meteorological factors that influence erosion and sediment loading in an oil palm plantation.
iii) To calibrate and validate soil erosion models for application to local environment.

1.4 Significance of The Study

Upon completion this study is designed to establish comprehensive understanding on hillslope erosion processes in tropical plantation catchment. Specifically the following outcomes are expected:

i) Validated erosion model for local application.
ii) A method for a reliable estimation of sediment loading.
iii) Major parameters that influence erosion and sedimentation are identified.

1.5 Scope of Study

Based on the above objectives, this study covers the following scopes of work:

i) Setting up experimental catchment in Ladang Sedenak.
ii) Installation of equipment which include rain gauge, water level recorder, water sampler and automatic turbidity meter.
iii) Sampling of streamflow during baseflow and stormflow conditions.
iv) Carry out laboratory analysis for suspended solids concentration and turbidity.
v) Estimate event sediment loading using Modified Universal Soil Loss Equation (MUSLE).
vi) Estimate sediment loading based on observed data in the field.
vii) Predict sediment yield based on rainfall and peak discharge data.
viii) Compare the observed sediment loading estimates from MUSLE and USLE models.

1.6 Research Methodology

The general methodology used in this study is summarized in Figure 1.2 which basically involves setting up of equipment, field data collection, laboratory analysis, data analysis, prediction of soil loss and suspended solids loading, and validation of selected erosion models.

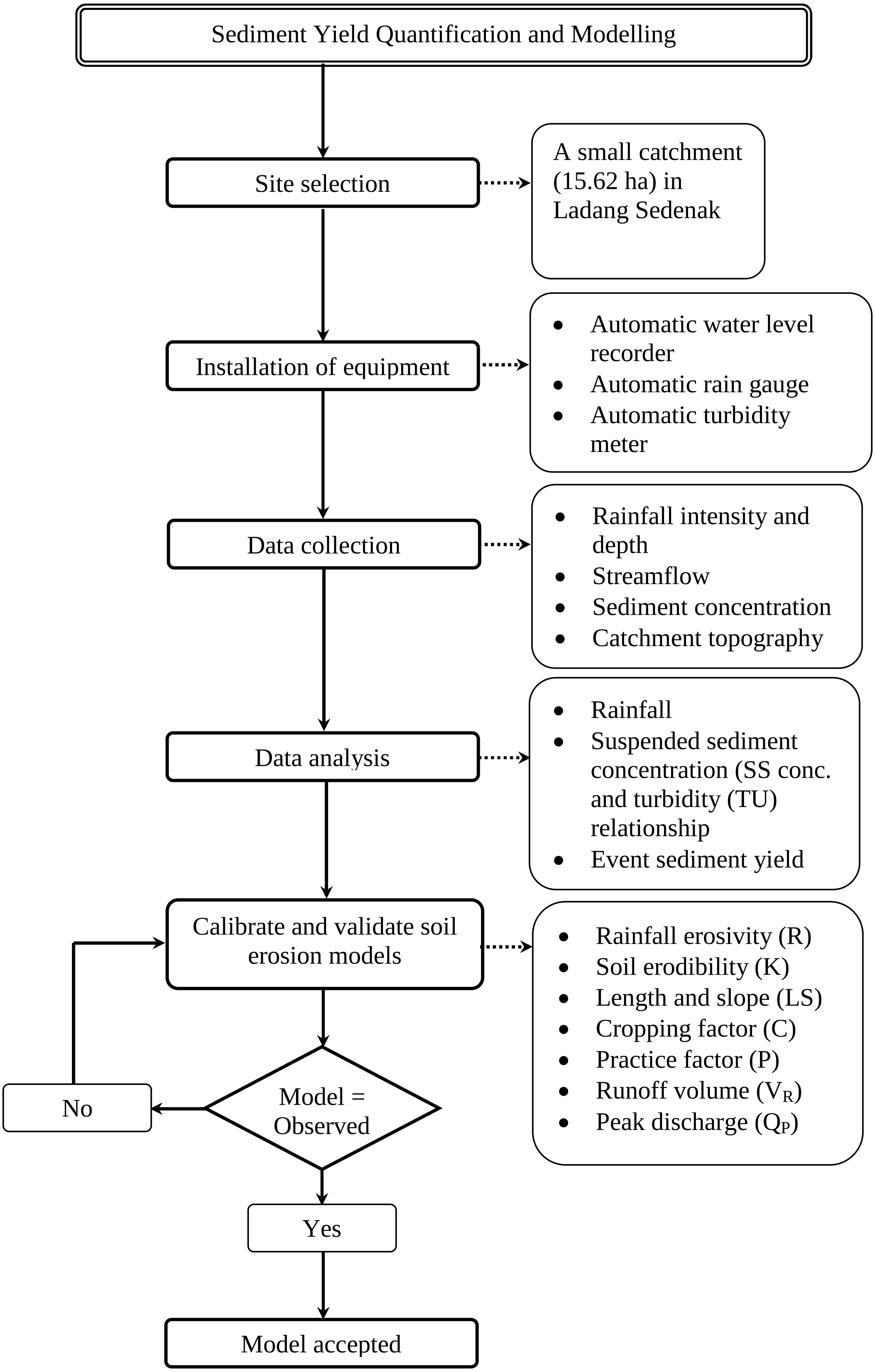

Figure 1.2: The research design and procedure

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