THE HYDROLOGY AND SUSPENDED SEDIMENT YIELD OF SG. TUARAN, SABAH

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DECLARATION

The materials in this thesis are original except for quotations, excerpts, summaries and references, which have been duly acknowledged.

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ABSTRAK

HIDROLOGI DAN HASIL BEBAN SEDIMEN TERAMPAI DI SG. TUARAN, SABAH

Objektif utama kajian penyelidikan ini adalah untuk mengenal pasti ciri-ciri hidrologi dan sedimen terampai di Sg.Tuaran. Kajian ini telah mendapati bahawa Sg. Tuaran mempunyai kofiesien air larian permukaan tahunan yang tinggi (62.2%) dan peratusan aliran dasar yang tinggi (86.2%) pada tahun 2002 dan 2003. Terdapat 100% luahan sungai melebihi 3 m^3s^{-1}. Nilai puncak curahan kadar alir hujan dan turbiditi adalah tinggi di antara masa 17:00-6:00 dalam sehari. Masa pulangan nilai turbiditi dengan nilai 1000 NTU ialah 1.1 bulan dan nilai luahan sungai pada nilai pulangan yang sama ialah 52 m^3s^{-1}. Hubungan di antara kepekatan sedimen terampai dan turbiditi adalah tinggi (r^2 = 0.963). Histerisis antara kepekatan sedimen terampai dan luahan sungai menunjukkan hubungan tersebut adalah bersifat dinamik. Justeru itu, ia sukar untuk ditentukan dengan menggunakan formula empirikal yang mudah. Purata min hasil beban sedimen terampai adalah 124.4 $tkm^{-2}yr^{-1}$. Hubungan di antara hasil beban sedimen terampai bulanan lebih bergantung kepada luahan sungai daripada hujan bulanan dengan nilai r^2 = 0.691, manakala hubungan di antara taburan hujan bulanan dengan luahan sungai adalah turut linear dengan nilai r^2 = 0.733. Akan tetapi, hubungan di antara ketiga-tiga sifat hidrologi ini mempunyai resolusi masa dan musim yang sangat kompleks. Corak taburan hujan yang berubah-ubah telah dikenalpasti di kawasan kajian. Melalui kajian ini, dapat dilihat bahawa Sg. Tuaran mempunyai taburan air bawah tanah yang tinggi, hasil beban sedimen yang rendah di bawah limit dan kualiti air sungai yang sesuai untuk projek bekalan air II.

ABSTRACT

THE HYDROLOGY AND SUSPENDED SEDIMENT YIELD OF SG. TUARAN, SABAH

The main objective of the study was to determine the general hydrological and suspended sediment transport pattern in Sg. Tuaran. Sg. Tuaran has high annual runoff coefficient (62.2%) and percentage of baseflow contribution (86.2%) from 2002 to 2003. The 100% of time discharge exceeded was 3 m^3s^{-1}. Most of the stormflow peak and high turbidity values occurred from 5 p.m. to 6 a.m. of the next day. High turbidity value of 1000 NTU has return period of 1.1 months, and the corresponding river discharge of the same return period was 52 m^3s^{-1}. The suspended sediment concentration-turbidity relationship of Sg. Tuaran was linearly related with high r^2 of 0.963. Hysteresis of suspended sediment concentration-discharge showed that the relationship was dynamic. Hence, it was difficult to determine the relationship by simple empirical formula. The average suspended sediment yield (2002-03) was 124.4 $tkm^{-2}yr^{-1}$. The relationship between monthly suspended sediment yield was dependant on monthly runoff with r^2 of 0.691. Relationship between monthly rainfall and runoff was linearly related with r^2 of 0.733. Nevertheless the relationship among all hydrological variables on individual storm events was complicated. High spatial variability of rainfall was observed in the study catchment. The study showed that Sg. Tuaran has high groundwater contribution, sediment yield of the catchment was below the range of tolerable limit, and the water quality of Sg. Tuaran is suitable for water supply II. Hence, the catchment is suitable selected for water supply project.

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CHAPTER 1

INTRODUCTION

1.1. Introduction

For many years, sediments had been studied on their nature and properties for water and catchment management purposes. Sediment yield is one of the best indicators to understand the denudation process in a catchment. The study of catchment hydrology and the impacts of land management often related with the transport rate of suspended sediment (Lewis, 1996). Suspended sediment has been denoted as one of the contaminants in rivers and it is the host for the transport of many contaminants including nutrients and heavy metals (Olive & Rieger, 1992). By studying the sediment transport of a river, the transportation of contaminants could also be understood well. The quantitative and qualitative study of suspended sediment yield is important both in water quality and catchment management.

Suspended sediment is a non-point source pollutant. Sediment yield in each catchment varies according to the catchment's climate, geology, topography, vegetation, and land use in the surrounding area. Intensive monitoring on the trend and characteristics of suspended sediment yield within a catchment is therefore important. In many studies, the suspended sediment concentration and water discharge is established to compute sediment yield. Nevertheless the sediment-discharge relationship is not direct (Eisma, 1992). Therefore long term intensive monitoring of river discharge and suspended sediment concentration is crucially important but very costly. Turbidity has been suggested as a cost effective way of studying suspended sediment (Walling, 1978; Lewis, 1996). Strong relationships between SSC and turbidity have been identified (e.g. Lewis *et al.*, 2002; Gippel, 1995; Thomas, 1988).

The Sg. Tuaran is a protected river under Eight Malaysia Plan (Sabah Town Planning, 2002). Although gazetted as a water catchment by Sabah Town Planning, there is no proper documentation available pertaining to the basin hydrological behaviour and suspended sediment yield. This study aimed at determining the hydrology and suspended sediment yield and the hydrological behaviour of Sg. Tuaran. The results obtained can be used for further investigation and reference to the local authorities when deciding on land use management matters of the catchment, particularly in achieving a balance between conversion to agricultural purposes and accelerated soil concerns.

1.2. Objectives of the Research

The main objective of the study was to determine the general hydrological and suspended sediment behaviour in the Sg. Tuaran. The specific objectives were as follow:

(i) To determine the hydrological, suspended sediment and turbidity behaviours of the river.

(ii) To establish the relationship between suspended sediment concentration and turbidity, and discharge.

(iii) To compute the suspended sediment yield of Sg. Tuaran.

(iv) To establish the relationship between suspended sediment yield and river discharge, and rainfall.

(v) To support the Sg. Tuaran as main source of water supply for the Tamparuli town.

CHAPTER 2

LITERATURE REVIEW

2.1. Status of Surface Water in Malaysia

Malaysia located in the humid tropics which experiences high annual rainfall and high humidity. Malaysia has abundant of water resources, the estimated annual water balance in Malaysia is 990 billion m^3, the annual surface runoff is estimated at 57.1%, and groundwater recharge, 6%, while the remainder is evaporated to the atmosphere (Nather Khan, 1992; Figure 2.1) More than 98% of water usage in Malaysia is derived from surface water and 2% from groundwater (Ministry of Science, Technology and the Environment, 2002).

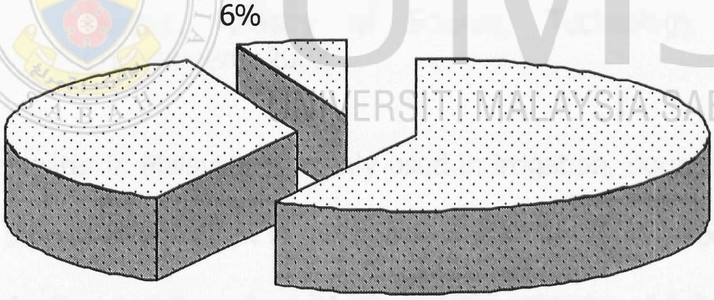

Figure 2.1: Water balance in Malaysia.

Source: Nather Khan, 1992.

2.2. Increasing Demand of Water Usage

In recent years, Malaysia experiences high growth in water demand due to rapid development and population increase. The demand of water increased from 8.9 billion m^3 to 11.9 billion m^3 to 1990, and it is estimated at 20.0 billion m^3 by the year 2020 (Ministry of Science, Technology and the Environment, 2002; Figure 2.2). The demand for water usage in domestic and industrial purposes is expected to increase in the future, due to the continuous population growth and government policies to boost economic growth in the agricultural and industrial sectors.

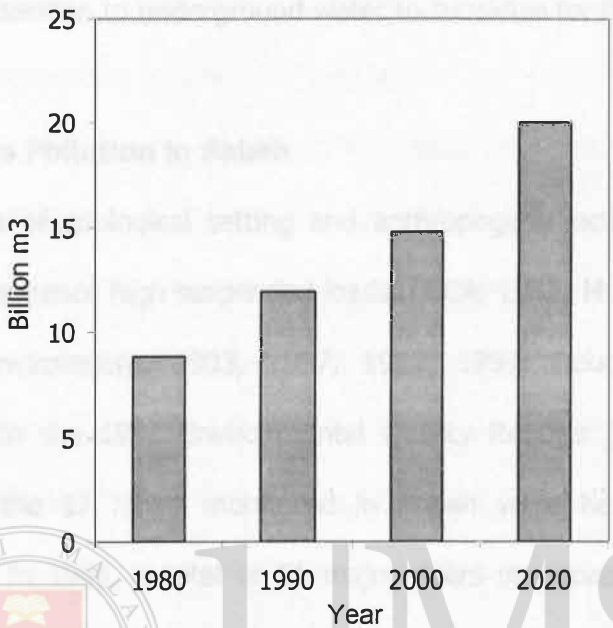

Figure 2.2: The Annual Water Demand Projection (in billion m^3).

Source: Ministry of Science, Technology and the Environment, 2002.

Surface water in Malaysia is mainly used in irrigation, domestic and industrial consumption, among all irrigation is the heaviest user. In 1990, about 83% of water was used in irrigation and it reached 94.3% in 1995 (Ministry of Science, Technology and the Environment, 2002). The number of water pipes had been increased from 1990 to 2000 showing the demand of water usage is increasing in future (JICA, 2002). However in recent years Malaysia has experienced water shortage in high demand water demand area (Ministry of Science, Technology and the Environment, 2002). Although the projected water demand in 2020 is less than 4% of the potential annual surface runoff, the temporal and spatial variation of rainfall give rise to uneven distribution of water in the country. Among of areas experiencing water shortage are the Klang Valley and Parts of Kelantan. In Kelantan, the high water demand is due to heavy usage for irrigation purposes. During dry period, various part of the state resorted groundwater for domestic water supply. Apart from that, some places in Sarawak, Pahang, Terengganu, the Federal Territory of Labuan, and Sabah are turning their attention to underground water to subsidize for the water shortage.

2.3. Suspended Solids Pollution in Sabah

Due to the nature of geological setting and anthropogenic activities, most of the rivers in Sabah experience high suspended loads, (JICA, 1982; Murtedza et al., 1987; Department of Environment, 1993, 1997, 1998, 1999; Douglas *et al.*, 1999).

According to the 1992 Environmental Quality Reports (DOE, 1993), there were 12 out of the 17 rivers monitored in Sabah were heavily polluted with suspended solids. In 1996, a total of 51 major rivers monitored in Malaysia were found to be polluted with suspended solids, and Sabah was ranked as the second highest (DOE, 1997). In 1998, there were 7 rivers polluted with suspended solid in (DOE, 1999). A study suggested that soil loss in the Sg. Kinabatangan was about at 7.8 million tones per year (Juin *et. al.*, 2000). Several river basins with forestry and agricultural activities experienced high frequency of floods for examples Sg. Padas, Sg. Kinabatangan, Sg. Segama, and Sg. Labuk (Juin *et. al.*, 2000). This was due to changes in hydrological regime as the result of land conversion and deforestation.

Extensive land conversion is one of the main reasons for the high sediment yield in Sabah (Juin *et. al.*, 2000; Mohamad, 1987). Logging, agricultural, plantation, mining and construction involving earth works and land clearing are the major activities related to soil erosion and sediment yield (DOE, 1993, 1997, 1998, 1999). The silt deposited in the lower reaches of rivers was found to be originated from the upland area which has been undergone logging and land clearing activities (UNEP, 2001). Sediment production in logged areas will recover in time when vegetation has re-grow but someway similar to forest re-grow for examples oil palm, rubber, roads, quarries could be sources of sediment indefinitely (Natural Resources Office Sabah, 1994).

2.4. Water Resource Planning Needed in Sabah

Sabah is currently facing the challenge of rapid economic development and population growth which increasing the demand of the state's water usage and land conversion. At present, adequate water supply is obviously not always available. During dry season, water shortage occurred in certain areas as the result of some perennial streams dry up (Natural Resources Office Sabah, 1994). A better water management is needed in Sabah in order to fulfil future demand. Under the Eight's Malaysia Plan, a total of 6 river catchments in Sabah have been selected under the River Pollution Prevention and Water Quality Improvement Program. The rivers selected are Sg. Tuaran, Sg. Petagas, Sg. Likas, Sg. Sembulan, Sg. Seguntur, and Sg. Tawau.

2.5. The Study of Suspended Sediment Yield

Suspended sediments are fine particles transported in suspension by the flowing water in streams and rivers (Singhal *et. al.*, 1981). Suspended load may consist of sand, silt and clay-sized particles that are supported by turbulent motion in the steam flow (Shen & Julien, 1995), it is predominantly wash load (Singhal *et al.*,1981). Most of sediments are transported by flowing water as suspended load (Singhal, Joshi & Verma, 1981), which can be accounted for 67% of total load (Manahan, 1997). Bedload is the larger solid particles rolled along the streambed.

There are numbers of reasons for studying river suspended sediment yield. First, the amount of suspended sediment transported by a river represents the amount of top soil and sediment eroded and transported by rivers (Olive & Rieger, 1992). Hence sediment yield is often use as the indicator of denudation process operating in a catchment. Second, most sediments are transported by streams as suspended load that accounts for 90% of the total load in a perennial stream (Singhal *et* al., 1981). Hence, suspended sediment is often used in catchment erosion studies. Third, suspended sediment is the host of contaminant. Suspended sediment less than 63 μm is a primary carrier of chemical pollutant such as phosphorus, chlorinated pesticides and heavy metals. Thus, the contaminant transport in a river will be understood if the sediment transport of the river is identified.

By conducting a detail study of suspended sediment yield in a catchment, we are able to understand the erosion process, the contaminant transport operating in a catchment, and the effect of land use toward sediment yield will be understand.

2.6. Erosion and Suspended Sediment Yield

Erosion is the main source of suspended sediment yield in rivers. It is characterized by the detachment, entrainment and transportation of soil particles from land surface or from bed and banks of streams. It is a complicated process, which relates to interaction between topography, geology, climate, soil, vegetation, land use and man-made development (Shen & Julien, 1995).

Soil erosion occurs either as (1) natural geological process such as weathering of rocks or; (2) anthropogenic process, which is the disturbance of natural vegetation by human activities. When the rate of erosion exceeds the normal erosion rate, this is known as accelerated soil erosion.

Erosion can occur in many forms. Water however is the main agent of soil erosion, and is the primary concern of this study. In general, it can be divided into sheet erosion, gullies erosion and channel erosion. When the vegetation is removed from land surface, any erosive agent could directly impact on land surface and causes the detachment and transportation of soil particles. When rainfall directly strikes onto unprotected land, soils are detached by raindrop splash as sheet erosion. The detached soils are then transport by surface runoff. The surface runoff causes the formation of rills and channel, as surface runoff is passing through the rills, they become larger and wider in the down slope direction. When the rills become larger gullies, this is called gullies erosion. Channel erosion is the removal and transport of soil by concentration flow, this will result bed and river bank erosion. After a complete cycle of erosion, transportation, and deposition, these particles often referred to as sediments.

2.7. Accelerated Soil Erosion and Human Activities

Accelerated soil erosion is the main reason for high sediment yield (Douglas, 1967; Meade, 1969; Walling, 1995; Douglas *et al.*, 1999). The geological erosion rate was 24.7 $tkm^{-2}yr^{-1}$ but accelerated soil erosion rates caused by human activities can be more than 100 times in excess of the geological erosion rate (Shen & Julien, 1995).

Human activities such as deforestation, intensive agriculture and urbanization increase annual sediment yield from less than 100 to several 100 $tkm^{-2}yr^{-1}$ (Gupta, 1996), but the tolerable limit of erosion ranged from 250 to 1250 $tkm^{-2}yr^{-1}$ (Lal, 1984). The effect of land-use changes on catchment sediment transport have been well documented in urbanizing catchments (Kithiia, 1997, Øverland & Kleeberg, 1991, Valero-Garcés, Navas & Machín, 1997). The impact of acceleration erosion is more significant in Southeast Asia as it is a potential high erosion region. Suspended yields in most of Southeast Asia range from 200 to 1000 $tkm^{-2}yr^{-2}$, with some regions exceeds 1000 $tkm^{-2}yr^{-2}$ (Figure 2.3). A study suggested that in many developing countries in South-East Asia, annual suspended sediment yields were increasing at a rate of 1.6 times the rate of population growth (Abernethy, 1990).

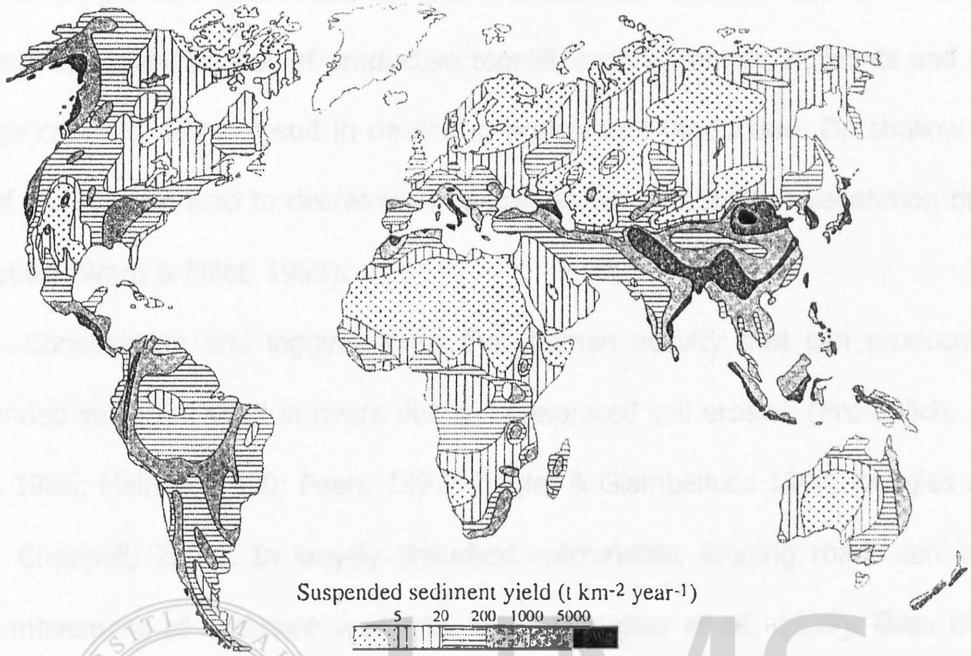

Figure 2.3: The Global Pattern of Suspended Sediment Yield.

Source: Lvovich *et al.*, 1991.

Accelerated soil erosion results in several physical environmental problems and causes economic loss due to its impact on the physical environment. Among that is the loss of top soil and degradation of soil quality. High intensity rainfall often makes the magnitude of erosion is more significant in humid tropics. Vegetation cover is one of the most important and effective factors reducing accelerated soil erosion. Roots and leaves are important structures that protect soil detached from high erodible raindrop and they reduce surface runoff velocity and surface erosion as well. A region with good vegetation cover often produces less sediment yield (Sharma, 1996). Catchments having more than 50% of forest cover produce less suspended sediment yields (Lai *et al.*, 1996).

Agricultural activities often bring about accelerated soil erosion, degradation, and increase in suspended sediment concentration in rivers and streams (Peart, 1997) when no proper soil conservation measure is adopted. Erosion reduces fertility and productivity of land by loss of productive topsoil, organic matter, nutrients and water storage capacity, which result in decline in agricultural production. On shallow soils, loss of top soil can lead to decrease in infiltration which results in vegetation growth restriction (Ward & Elliot, 1995).

Construction and logging is another human activity that can produce high suspended sediment yield in rivers due to accelerated soil erosion (Froechlich, 1991, 1995, 1986; Malmer, 1990; Peart, 1997; Ziegler & Giambelluca 1997; Douglas *et al.*, 1999; Chappell, 2004). In largely disturbed catchments, logging roads can induce mass movement of sediment load into rivers (Douglas *et al.*, 1999). Even though when vegetation has re-grown, sediment sources recovered from the impacts of logging and forest road construction, some impacts may still carry on, especially from failure of old roads and local logging path (Chappell *et al.*, 2004) and other disturbed areas reactivated by unusual extreme storm events at (Douglas *et al.*, 1999).

2.8. Sediment Yield Variation

Sediment yield varies with climate, space and time (Grant & Wolff, 1991; Gorden, *et al.*, 1992). Variation in sediment transport is significant during storms (Lewis, 1996; Sinun, 1995; Walling, 1974), year to year (Gordon *et al.*, 1992), either in the same or different catchments (Grant & Woff, 1991). Changes in land use, drainage basin size, stream flow regime can lead to variation in sediment yield from year to year (Gorden, McMahon & Finlayson, 1992). Huge amount of sediments are transported during a few, large storm events (Douglas, 1967, 1999; Grant & Wolff, 1991; Gellis, 1993; Olive & Rieger, 1991; Sarma, 1986; Thomas, 1988; Uhrich & Bragg, 2003). Hence, a single storm may yield huge amount of suspended sediments, sometimes it accounted for 90% of annual transport (Singhal, Joshi & Verma, 1981; Pye, 1994; Douglas *et al.*, 1999).

Suspended sediment discharge often displays a direct relationship with river flow discharge. Generally, suspended sediment concentrations are usually higher during the rising stage compared with the corresponding falling stage (Pye, 1994). Sediments are picked up during the rising stage and deposited during the falling stage. When the sediment supply is exhausted, suspended sediment concentrations fall quickly and *vice versa* (Eisma, 1992).

2.9. Problems in the Estimation of Suspended Sediment Yield

The rating curve equation of suspended sediment concentration and river discharge has been used in the calculation of suspended sediment yield in many studies. To calculate suspended sediment yield, suspended sediment concentration data and discharge data are required to establish the suspended sediment concentration-discharge relationship. Therefore the accuracy of the estimation depends on the adequate number of samples and representative distributions of suspended sediment concentrations and river discharge data.

Many studies have shown that the suspended sediment concentration-discharge relationship can be very complicated. The relationship is affected by seasonal (Walling, 1974) and land use changes (Sinun, 1995). The relationship is dynamic during storm events which during the hysteresis may differ one storm to another. Lack of sufficient suspended sediment concentration data to develop clear and identified suspended sediment concentration-discharge relationship in each storm event could result in serious inaccurate calculation of sediment yield as most of the sediment is transported during storm event (Singhal, Joshi & Verma, 1981; Pye, 1994; Douglas *et al.*, 1999).

Owing to the complicated suspended sediment concentration-discharge relationship, high frequency sampling for suspended sediment concentration data is important (Thomas, 1988). Sediment traps or automatic liquid samplers had been used in several studies to capture suspended sediment samples during storm events to increase the reliability of suspended sediment concentration data. However, the numbers of samples can be limited and frequent sampling of suspended sediment concentration is costly. Turbidity was then used to develop the suspended sediment concentration-turbidity relationship, it was found to be more cost effective compared with suspended sediment concentration (Lewis *et al.*, 2002). The relationship between turbidity and suspended sediment concentration can be determined empirically (Thomas, 1988) and the relationship comparatively stable (Lewis, 1996). In most cases suspended sediment concentration and turbidity was linear related with low variance (Lewis, 2002).

2.10. Catchment Management

A catchment is an area that contributes runoff to a given point in a stream or river. Sometimes, it is referred to as a watershed or drainage basin. Within a catchment, accelerated soil erosion is often related with soils, vegetation, topography, climate, and river flow. The amount of water flowing from upstream to down stream is dependent on land use in the upper catchment. When natural vegetation in upstream is disturbed, it reduces infiltration and percolation. Consequently this reduces groundwater flow. Large-scale vegetation removal upstream can bring about several impacts downstream. Some of the impacts are flooding and sedimentation.