IMPACT OF DAM AND LAND USE CHANGE ON THE FLOW CHARACTERISTICS OF SELANGOR RIVER BASIN

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DEDICATION

This thesis is dedicated to my father, Mohd Bahar bin Mohd Ariffin, who taught me that the best kind of knowledge to have been that which is learned for its own sake. It is also dedicated to my mother, Nor Meza binti Mat Lasim, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Rainfall-runoff response is the inter-play between rainfall, and the properties of a catchment. The aim of this study is to evaluate the influence of dam and land use change on the hydrological properties specifically on runoff, stormflow volume, time to peak and flow duration curve. This study chose Selangor River Basin (SRB) in view of its importance in providing about 40% of the water supply to Selangor and Klang Valley. There are two dams in the SRB, namely Sungai Selangor Dam and Sungai Tinggi Dam. In this study, SRB is divided into two catchments, namely CA (1529 km^2) and CB (220 km^2) of which CB is a sub-basin of the CA. Fifty two percent of the land area in CA is covered by forest, 11.7% is urban area and the rests are oil palm and agricultural. 94% of CB is covered by forest and forms the entire basin of the Sungai Selangor Dam. Prior to the dam construction in the year of 2007, the monthly runoff coefficient for CA ranges from 0.19 to 0.48 while for CB ranges from 0.59 to 0.79. This data was observed and collected in ten years period of time. The monthly runoff in CB shows a larger variation after the completion of dam with runoff coefficient between 0.28 and 0.89. The baseflow and stormflow before the dam construction made up about 51.5% and 48.5% of the total flow, respectively. The effect of dam operation was evident from the shift in the flow duration curve with reduction in the proportion of extreme high flow especially for CB and increased in the proportion of extreme low flow for CA. However, both low flow and stormflow in CA recorded a decrease of 70% and 58%, respectively. This must be due to heavy abstractions of river water for the treatment plants. The HEC-HMS model was calibrated and validated for three rainfall categories: light, medium and heavy. The findings showed that the future changes in land use are expected to increase the peak flow, and stormflow volume simultaneously shorten the time to peak. It is also found that the model parameters for years 2006 and 2016 were different and attributed to changes in the land use. The simulated peak flow in 2016 for 100-year ARI storm is three-fold higher than the base line condition in year 2006. In conclusion, the higher the imperviousness area the higher the peak flow and stormflow volume but lower the time to peak.

ABSTRAK

Tindak balas hujan dan air larian ialah interaksi di antara hujan dan ciri-ciri tadahan. Tujuan kajian ini adalah untuk menilai pengaruh empangan dan perubahan guna tanah terhadap ciri-ciri hidrologi khususnya terhadap air larian, isipadu aliran ribut, masa ke puncak dan lengkung tempoh aliran. Kajian ini memilih Lembangan Sungai Selangor (SRB) kerana kepentingannya dalam menyalurkan kira-kira 40% bekalan air ke Selangor dan Lembah Klang. Terdapat dua empangan di SRB iaitu empangan Sungai Selangor dan empangan Sungai Tinggi. Dalam kajian ini, SRB dibahagikan kepada dua tadahan iaitu CA (1529 km^2) dan CB (220 km^2) yang mana CB merupakan sub-lembangan kepada CA. Lima puluh dua peratus daripada kawasan tanah di CA adalah hutan, 11.7% adalah bandar dan selebihnya merupakan kelapa sawit dan pertanian. 94% dari kawasan di CB masih dilitupi hutan dan membentuk keseluruhan lembangan bagi empangan Sungai Selangor. Pada tahun 2007 sebelum pembinaan empangan, pekali air larian bulanan untuk CA adalah di antara 0.19 hingga 0.48 manakala untuk CB dari 0.59 hingga 0.79. Data ini dicerap dan dikumpul dalam tempoh sepuluh tahun pemerhtian. Air larian bulanan di CB menunjukkan variasi yang lebih besar selepas pembinaan empangan selesai dibina dengan pekali air larian di antara 0.28 dan 0.89. Bagi aliran dasar dan aliran rebut, masing-masing membentuk kira-kira 51.5% dan 48.5% daripada jumlah aliran sebelum pembinaan empangan. Kesan operasi empangan jelas menunjukkan anjakan dalam lengkung tempoh aliran dengan pengurangan peratusan aliran tinggi melampau terutamanya untuk CB dan peningkatan aliran rendah melampau untuk CA. Walau bagaimanapun, kedua-dua aliran rendah dan aliran ribut di CA mencatatkan penurunan sebanyak 70% dan 58%. Kemungkinan besar, ini disebabkan peningkatan pengambilan air sungai oleh loji rawatan air. Model HEC-HMS telah ditentukur dan disahkan untuk tiga kategori hujan: hujan ringan, sederhana dan lebat. Pada masa hadapan, perubahan guna tanah dijangka akan meningkatkan aliran puncak, dan isipadu aliran ribut tetapi memendekkan masa untuk capai ke puncak. Juga didapati bahawa parameter model bagi tahun 2006 dan 2016 adalah berbeza dan ini berkait dengan perubahan guna tanah. Aliran puncak simulasi pada tahun 2016 untuk ribut ARI 100 tahun adalah tiga kali ganda lebih tinggi daripada keadaan garis dasar pada tahun 2006. Kesimpulannya, semakin tinggi kawasan kelap air semakin tinggi aliran puncak, dan isipadu aliran ribut tetapi memendekkan masa ke puncak.

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LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
API	-	Graphic Antecedent Precipitation Index
ARI	-	Average Recurrence Interval
C	-	Runoff Coefficient
CA	-	Catchment A
CB	-	Catchment B
CN	-	Curve Number
DEM	-	Digital Elevation Model
DID	-	Department of Irrigation and Drainage
ET	-	Evapotranspiration
FDC	-	Flow Duration Curve
HEC-HMS	-	Hydrologic Engineering Center-Hydrologic Modelling System
IHA	-	Indicators of Hydrologic Alteration
LUAS	-	Lembaga Urus Air Selangor
MICE	-	Multivariate Imputation by Chained Equation
MIKE-SHE	-	Systeme Hydrologique European
NEM	-	Northeast Monsoon
NSE	-	Nash-Sutcliffe Efficiency
R^2	-	Coefficient of Determination
SCS-CN	-	Soil Conservation Service Curve Number
SRB	-	Selangor River Basin
SWAT	-	Soil and Water Assessment Tool
SWM	-	Southwest Monsoon
UH	-	Unit Hydrograph
UH	-	Unit Hydrograph
WTP	-	Water Treatment Plant

LIST OF SYMBOLS

A	-	Area
C	-	Runoff Coefficient
Cc	-	Compactness constant
Dd	-	Drainage density
Fs	-	Stream frequency
Lb	-	Basin Length
Lg	-	Length of overland flow
Lsm	-	Mean stream length
Lu	-	Stream length
m^3/s	-	Speed
Nu	-	Total number of streams
P	-	Perimeter
R^2	-	Square of Correlation Coefficient
Rc	-	Circulation ratio
Re	-	Elongation ratio
Rf	-	Form factor
Rt	-	Drainage texture
Sw	-	Shape index
t-lag	-	Lag time
Tp	-	Time of peak
u	-	Stream order

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Water availability and water demand have an impact on the socioeconomic development of a country. Malaysia is one of the developing countries that is undergoing a rapid increase in population along with significant growth in the urbanization and industrialization sectors to enhance standard of living. This has led to increases in water demand and water conflicts (Mohd Firdaus Hum & Abdul Talib, 2016). The conflicts arise when the water demand exceeds the available supply, and its water allocation fails to meet the demand. Therefore, in order to avoid a future conflict between competing demand, it is necessary to develop tools and techniques for improving water management. The main challenge to many water authorities is how to fulfil the increasing demand with limited water resources (Ali, Saadon, Faiza, & Rahman, 2014).

The Malaysia's climate is also affected by global climate change. In recent years, there is a growing concern about climate change risks in developed and developing countries such as it will affect water resources, public health, agriculture, energy infrastructure and other sectors in number of ways (Shahid et al., 2017). According to Shahid et al. (2017), climate change will increase daily temperature, change precipitation patterns, accelerate sea level rise, increase soil salinity, change soil moisture levels and land stability and increase the frequency of extreme hydrologic events. Increase in air temperature could accelerate the global hydrological cycle which are precipitation and evapotranspiration (Tan, Ficklin, Ibrahim, & Yusop, 2014). Climate and land use changes can significantly influence the hydrological characteristics of a watershed which directly affecting the water resources including altering the runoff volume (Narsimlu, Gosain, & Chahar, 2013).

Malaysia has undergone large-scale land use change to propel her economic development after gaining independence. Malaysian economic development in the 1960s and 1970s was mainly focussed on agricultural sector. As the result, most of the forested area had been converted into oil palm and rubber plantations (Abdullah & Nakagoshi, 2006). In the 1980s, Malaysian economic showed major transformation to focus on manufacturing sector and since then it became the fastest growing sector. The country's gross domestic product has grown to about 22.6%. As the result, the manufacturing sector has been catalysing other development activities such as urbanization and development of major infrastructures (Abdullah & Nakagoshi, 2006).

The state of Selangor is the most populated state in Malaysia. The demand for raw water in Selangor has reached to a stage where the demand exceeds the water availability and has difficulty to cater for the increasing demands in the near future (Ali, Saadon, et al., 2014). Selangor River Basin is the most important catchment which contributes over 60% of the water demand in the Klang Valley (Santhi & Mustafa, 2013). The rapid growth of population and economy development in Hulu Selangor and Kuala Selangor lead to changes in the land use in Selangor River Basin (SRB) which may consequently lead to changes in the hydrologic cycle. These changes could affect the hydrologic processes that affect the streamflow, water yields, low or high flows, erosion, surface runoff and evapotranspiration. Precipitation that falls in developed areas is expected to have a shorter time of concentration or in the other words may flow faster into streams and thus increasing the storm-water runoff response (Blume, Zehe, & Bronstert, 2007). This study aimed at assessing the effects of land use change on the hydrological characteristic of the Selangor River Basin (SRB).

1.2 Problem Statement

According to DID (2014), the number of flood event occurring along the Selangor River has increased from two events in 2000 (22 Dec and 7 Dec) to eight events in year 2014 and mostly flood event occur in Kuala Selangor especially during the monsoon and inter monsoon periods. As in other parts of Peninsular Malaysia, SRB receives two monsoons namely southeast monsoon (i.e., June to September) and northeast monsoon (i.e., December to March). Being the main source of raw water for Selangor and Klang Valley, it is extremely crucial to understand the long-term effect of land use on rainfall-runoff response.

About 57% of the land use in the SRB is still covered by natural forests which includes the forest reserve in the Selangor Dam's basin. This is followed by agricultural land which include rubber, oil palm plantations and some paddy fields that made up about 23% of the basin area (Othman, Chowdhury, Wan Jaafar, Faresh, & Shirazi, 2018). The land use changes might have modified the basin's hydrological behaviours. Besides assessment of historical data, the application of hydrological models could help demonstrate changes in the hydrological behaviour over a long term. It's also possible to predict the likely impact on streamflow behaviour based on land use change scenarios (Du et al., 2012). The information is useful for the state government and local authorities to plan appropriate land use and conservation strategies to ensure the sustainability of water resources in the basin.

The aim of this research is to study the rainfall characteristic and rainfall-runoff response (i.e., stormflow volume, baseflow, total runoff, runoff coefficient, *C*) to dam operation in the upstream and land use change. The land use will be assessed by comparing the impervious level to be determined from land use map from year 2006 and 2016. Then, future land use scenarios will be assessed to simulate the hydrograph properties such as stormflow volume and time to peak. In addition, the hydrograph properties resulted from an extreme rainfall (100-year ARI) was examined.

1.2.1 Research Objectives

The main goal of this studies is to assess the dam's influence on the hydrological attributes and the flood control effectiveness in the Selangor River Basin (SRB). The study's aim is to be achieved by addressing the specific objectives as follows:

(a) To examine rainfall characteristics of the basin.

(b) To assess the influence of dam on the streamflow characteristic in two catchments of different sizes

(c) To model the hydrograph properties of the catchment under changing land-use using the HEC-HMS hydrological model.

1.3 Scope of Study

Several software and methods such as ArcGIS, HEC-HMS, Google Earth Pro and R program were used in this study. Generally, this study involved collation of rainfall and rainfall data from Department of Irrigation and Drainage, data handling, hydrological analysis and simulation of hydrograph. The scope of this study is listed as follows

1. Filling the missing data originally obtained from the Department of Irrigation and Drainage (DID) using R program (MICE) for rainfall data.
2. Create the Selangor River Basin (SRB) map from DEM data (15m resolution from Alos Palsar) using ArcGIS. The SRB was divided into two sub-basins according to the location of their water level station, namely Catchment A (at Rantau Panjang station) and Catchment B (at Ampang Pecah station).
3. Preparing land use map by downloading the data from the USGS Earth Explorer (https://earthexplorer.usgs.gov/) with 30 m resolution then imported it into ArcGIS to be processed as a layer.

4. Preparing Theisen Polygon for determining the areal rainfall of the basin by using ArcGIS.

5. Characterising the long-term rainfall behaviour which include the annual rainfall, temporal rainfall (heat map), rainfall intensity, monthly and annually rainfall trends and spatial pattern using R program. This analysis used 11 years daily rainfall data (2007-2017) for Catchment A and 10 years rainfall (2009-2018) for Catchment B.

6. Developing regression models on the relationship between runoff and rainfall to see the impact of dam on the yearly and monthly rainfall-runoff pattern.

7. The land use change was derived from google earth pro for year 1996, 2006 and 2016. After the polygon of impervious areas (road, building, degradation land) for each year, the files were imported into ArcGIS to map the pervious and impervious area. Then, the rainfall runoff response for each year was analysed to calculate the stormflow volume, total baseflow, time to peak, t-lag, raising and falling limb in order to study the effect land use change on hydrograph characteristics.

8. Performing hydrological modelling using HEC-HMS to examine the hydrograph properties under three future land use conditions with different storm intensities (light, medium and heavy rainfall). Then, the models were calibrated and validated using different sets of rainfall data.

9. The design rainfall using 100-year ARI was assessed to calculate the stormflow volume and time to peak.

1.4 Important of Study

The significance of this study is to understand how changing land-use and water abstraction activities affect the hydrological behaviour of SRB over past of 20 years. The result also can be used to estimate the future stormflow and baseflow volume including t-lag of hydrograph. This can help water authority to estimate and improving water supply management and water conservation. Besides that, the research findings are useful for land use planning in order to minimize flood risk.

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LIST OF PUBLICATION

Bahar, A. F., Yusop, Z., Alias, N. E., & Ramli, M. W. A. (2021). Influence of Dam to Rainfall-Runoff Response in a Tropical Climate – A Case Study of Selangor River Basin, Malaysia. IOP Conference Series: Materials Science and Engineering, 1153(1), 012004.