RAINFALL RUNOFF MODELLING USING GEOGRAPHIC INFORMATION SYSTEM

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Specially dedicated to *my dad*,

thank you for your never ending support,

And also to the special man, my husband Ahmad Fithi

that always be together,

your love is my inpirations.

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ABSTRACT

In Peninsular Malaysia, states located at the east such as Kelantan, Terengganu, Pahang and southeast part of Johor face flood problem especially during Northeast monsoon. In the state of Johor, the town of Kota Tinggi has the most flood occurrence. This is due to high rainfall intensity, its location at low lying area and urbanisation activities, which increase impervious areas and created higher surface runoff. The purpose of this study was mainly to investigate and develop the relationship of rainfall and runoff using Geographic Information System (GIS). Sungai Johor river basin where Kota Tinggi is located was selected as the study area. The river basin was modelled by using Hydrology Engineering Centre – Hydrological Modelling System (HEC-HMS). The simulated hydrograph was calibrated against the observed hydrograph at Rantau Panjang station (19 January 2003 to 26 January 2003). Then, the model was validated against the data on 9 July 2006 to 13 July 2006. The result of calibration and validation showed that simulated hydrograph was in good agreement with the observed hydrograph. The calibration and validation were evaluated by using Nush and Sutcliffe (N-S) model efficiency index and the scores are 0.91 and 0.72, respectively. These scores considered as excellent and very good. A model simulation was also conducted for flood event in January 2007. However, the simulated hydrograph is higher than observed hydrograph. This can be due to the telemetric station located at Rantau Panjang station was inundated by the extreme streamflow. For future development scenario, 25% increment of impervious area at selected subbasin is modelled. The results showed an increment of the flow discharge at Kota Tinggi for about 4.2% (subbasin 7 and 8), 6.5% (subbasin 1 and 2) and 23% (whole area). Besides that, simulation by using IDF curve for 5 minutes storm duration of 100 years return period (ARI) using S.M. Bukit Besar station showed that the runoff is still lower than the runoff during flood event in January 2007. This result showed that the rainfall intensity in January 2007 is much higher. As a conclusion, the SCS-CN method in the HEC-HMS model with GIS application is suitable for Sungai Johor river basin.

ABSTRAK

Di Semenanjung Malaysia, negeri di bahagian Timur seperti Kelantan, Terengganu, Pahang dan bahagian tenggara Johor berhadapan masalah banjir terutamanya ketika Monsun Timur Laut. Di negeri Johor, Kota Tinggi adalah bandar yang kerap dilanda banjir. Hal ini berlaku kerana lebatnya hujan, lokasinya di kawasan tanah rendah dan aktiviti pembangunan yang meningkatkan kawasan tidak telap air dan meningkatkan air larian. Tujuan utama kajian ini adalah untuk menyiasat dan menghasilkan hubungan antara hujan dan air larian menggunakan Sistem Maklumat Geografi (GIS). Lembangan Sungai Johor di mana terletaknya Kota Tinggi telah dipilih sebagai kawasan kajian. Lembangan ini dimodelkan dengan menggunakan *Hydrology Engineering Centre – Hydrological Modelling System* (HEC-HMS). Hidrograf simulasi telah dikalibrasi dengan hidrograf cerapan di stesen Rantau Panjang (19 Januari 2003 hingga 26 Januari 2003). Kemudian, model ini divalidasi dengan data pada 9 Julai 2006 hingga 26 Julai 2006. Hasil proses kalibrasi dan validasi menunjukkan hidrograf simulasi berhubung baik dengan hidrograf cerapan. Kalibrasi dan validasi ini telah dianalisis menggunakan model indeks efisien Nush dan Sutcliffe (N-S) dan nilainya adalah 0.91 dan 0.72. Nilai ini dikategorikan sebagai cemerlang dan sangat baik. Simulasi telah juga dilakukan untuk kejadian banjir pada Januari 2007. Namun, hidrograf daripada simulasi lebih tinggi daripada hidrograf cerapan. Hal ini mungkin disebabkan stesen telemetri di Rantau Panjang ditelenggami oleh aliran sungai yang luar biasa. Bagi senario pembangunan masa hadapan, 25% peningkatan kawasan tidak telap di kawasan lembangan yang terpilih telah dimodelkan. Hasilnya menunjukkan peningkatan kadar alir di Kota Tinggi sebanyak 4.2% (lembangan kecil 7 dan 8), 6.5% (lembangan kecil 1 dan 2) dan 23% (seluruh kawasan). Selain itu, simulasi menggunakan lengkung IDF tempoh 5 minit untuk kala kembali (ARI) 100 tahun di stesen S.M. Bukit Besar menunjukkan kadar alir masih rendah berbanding ketika banjir pada Januari 2007. Hasil ini menunjukkan lebatnya hujan pada Januari 2007 adalah sangat tinggi. Kesimpulannya, kaedah SCS-CN dalam model HEC-HMS dan GIS adalah sesuai untuk digunakan di lembangan Sungai Johor.

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LIST OF ABBREVIATION

ARI	-	Annual Recurrence Interval
ASTER	-	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	-	Digital Elevation Model
DID	-	Department of Irrigation and Drainage
DOA	-	Department of Agriculture
DOE	-	Department of Environment
GIS	-	Geographic Information System
GIUH	-	Geomorphologic Instantaneous Unit Hydrograph
GUI	-	Graphical User Interface
HEC-HMS	-	Hydrology Engineering Centre – Hydrological Modelling System
IDW	-	Inverse Distance weighted
InSAR	-	Interferometric Synthetic Aperture Radar
KeTTHA	-	Ministry of Energy, Green Technology and Water
LiDAR	-	Light Detection and Ranging
MMD	-	Malaysia Meteorological Department
NWRC	-	National Water Resource Council

PWD	-	Public Work Department
RSO	-	Rectified Skew Orthomorphic
SCS-CN	-	Soil Conservation Service-Curve Number
SMA	-	Soil moisture accounting
SRTM	-	Shuttle Radar Topography Mission
TMPA	-	TRMM Multi-Satellites Precipitation Analysis
TRMM	-	Tropical Rainfall Measuring Mission
UH		Unit Hydrograph
WGS	-	World Geodetic System
WSD	-	Water Supply Department

LIST OF SYMBOLS

F	-	Actual retention
I	-	Initial abstraction
Q	-	Actual direct runoff
S	-	Watershed storage
P	-	Total rainfall
C	-	Runoff coefficient
i	-	Average rainfall intensity
A	-	Drainage area
$Z(si)$	-	Measured value at the ith location
λi	-	Unknown weight for the measured value at the ith location
s_0	-	prediction location
N	-	Number of measured values
f_t	-	Loss during period t
k	-	Saturated hydraulic conductivity
$\phi - \theta_i$	-	Volume moisture deficit
S_f	-	Wetting front suction
F_t	-	Cumulative loss at time t

c	-	Conversion constant
T_p	-	Time to UH peak
Δt	-	Duration of excess precipitation
$T\ lag$	-	Basin lag time
t_r	-	Rainfall duration
U_p	-	Standard peak of UH
C_p	-	Peak coefficient of UH
X	-	Dimensionless weight
K	-	Travel time of the flood wave through routing reach
L	-	Length of farthest path
Y	-	Percent of slope
E	-	Efficiency index
Q_o	-	Mean of observed discharges
Q_m^t	-	Simulated dischrages at time t
Q_o^t	-	Observed discharges at time t

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Water is a valuable component of human life. It supports life system globally and acts as a major controlling element of earth's climate. In order to sustain this valuable resource, effective water management is needed to maintain this resource for drinking water, agriculture, industry, urbanisation, hydropower, fishery, transport and other activities. For successful and optimum management of water resources, knowledge on hydrology including hydrological cycle is greatly required. Figure 1.1 shows the water cycle which also knows as hydrological cycle. There are many elements involved in this never-ending cycle and runoff is one of its critical elements. Surface runoff takes place when water on earth surface neither infiltrates nor suffers evapotranspiration (Thompson, 1999).

Generally, average annual rainfall in Malaysia is about 3000mm per year (Chan, 2004). High amount of excessive runoff quantities on ground surface will cause all reservoirs such as river, lakes and many more meet the maximum storage capacity hence leads flood to occur.

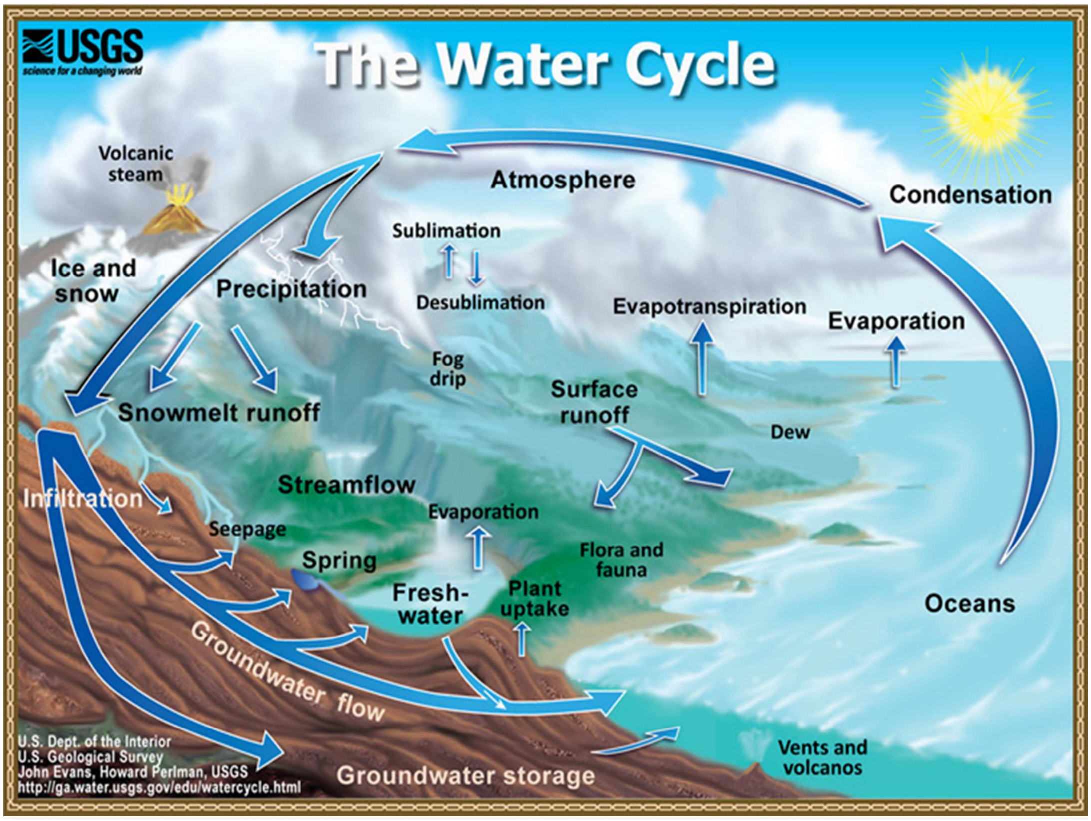

Figure 1.1: The hydrological cycle (Source: USGS, 2014)

To continue, surface runoff is influenced by several factors. One of them is land use such as forest, urban area, open area and agriculture area (e.g. oil palm or rubber tree plantation). The influence of land use in runoff generation is very complicated. Land use and soil cover seize huge control on interception, surface retention, evapotranspiration, and resistance to overland flow (Olivera and Maidment, 1999). Every land use has different surface runoff as each possesses different soil type which causes differences in infiltration rates. Land use change from forest to agriculture activities reduces infiltration and increase runoff (Santillan *et al*,, 2011).

Excessive runoff can also cause flood. This can be due to high intensity of rainfall and urbanization. In Malaysia, flood event usually occurs during Northeast monsoon which usually starts around November to March. There are many states affected by flood in Malaysia especially in the east coast of Peninsular Malaysia, i.e Kelantan, Terengganu and Pahang, and south Peninsular Malaysia; Johor. Kota

Tinggi area possesses the highest flood occurrence in Johor. The worst flood occurrence in Johor in recent year was recorded in December 2006. The flood occurred in two separate phases in late December 2006 and early January 2007. The disaster had caused more than 100,000 people evacuated from the residents due to flood. Subsequently, in January 2011, Kota Tinggi was hit once again. Hence, Kota Tinggi an administrative town with a large population has been chosen for the study. Soil Conservation Service (SCS) is used because it suits Kota Tinggi soil condition as an agricultural town. SCS uses curve number in order to get accurate forecast. SCS method is also suitable to be used because it is able to take into account antecedent of soil moisture in its data collecting procedure which is a crucial process in identifying curve number.

1.2 Problem Statement

The negative effects of changes in land cover especially on watershed ecosystems have been widely recognized throughout the world. Changes such as forest cover reduction through deforestation and conversion for agricultural purposes can affect watershed response to rainfall which will result to the increasing of surface runoff volumes. Rise of runoff will contribute to the increasing chances of flooding and sedimentation from receiving water bodies (Santillan *et al.*, 2011).

Flood and sedimentation can affect country's economy as flood can cause a great damage. Most of irrigated lands have thin surface soil horizon which are prone to erosion and decrease of productivity if not properly managed (Carter, 1993).

Hence, it is very important for planners to formulate strategies beforehand in order to avoid or minimize the undesirable effects of future land-use changes especially after they understand on how land use changes have negative influence on stream flow pattern. Urbanization may have a huge impact whether directly or indirectly on hydrological processes such as changes in total runoff or stream flow, alteration of peak flow characteristics, and changes in river's amenities (Alansi *et al.*, 2009). This study will also provide useful information for several other agencies which involved in water management in Malaysia as shown in Table 1.1.

Table 1.1: Agencies involved with water management in Malaysia (Chan, 2004)

Agency	Responsibility
Department of Irrigation and Drainage (DID)	Responsible towards operation of water resources development projects that involve river, drainage, irrigation, flood mitigation and also operation of national hydrological network.
Ministry of Energy, Green Technology and Water (KeTTHA)	Responsible towards formulating policy directions and strategies on the whole water services industry including water supply and sewerage.
Water Supply Department (WSD)	Responsible towards planning and water supply for domestic and industrial sector.
Department of Environment (DOE)	Responsible towards coordinating all activities related to the discharge of wastes, and prevention and preservation of point source pollution.
National Water Resource Council (NWRC)	Responsible towards formulating the National Water Policy, Water Resources Master Plans, determining priority of water use, and facilitating more effective water management including the implementation of inter-state water transfer.
Malaysia Meteorological Department (MMD)	Responsible towards weather forecast, hydro-meteorology, and climatologic studies.
Forest Department	Responsible towards technical directions and advices on forestry management and development, conservation of forests, assessment utilization, and also in development of forest resources.

Therefore, as runoff is a dynamic process which dependants on factors that varies in both spatially and temporally, a much more reliable data is needed in order to calculate the effectiveness of water management (Solomon, 2005). Conventional hydrograph methods that been used previously for this application are difficult to apply, time consuming, and expensive. Thus, an alternative method which is a combination of ground measurement with remote sensing and GIS technique was chosen to be applied for this study.

1.3 Objectives of the Study

Mainly, this study will investigate and generate the relationship of rainfall and runoff using Geographic Information System (GIS). The detail objectives to be achieved in this study are as follow:

1. To model Sungai Johor catchment by using Hydrology Engineering Centre – Hydrological Modelling System (HEC-HMS).
2. To calibrate and validate hydrological parameters.
3. To forecast and evaluate hydrograph/discharge at Sungai Johor river basin based on certain scenarios.

1.4 Scope of Study

The scopes of this study are as follow:

- This study used hydrological data that gathered from many departments such as rainfall data and stream flow discharge from Department of Irrigation and Drainage (DID), land use type and hydrological soil type obtained from

Department of Agriculture (DOA), and also Digital Elevation Model (DEM) data from satellite Shuttle Radar Topography Mission (SRTM).

- The rainfall data used in this study are within year 2003 to 2010
- Curve number was determined based on land use and soil types by referring to its curve number classes available in Guideline for Erosion and Sediment Control in Malaysia by DID
- Rantau Panjang station was selected for the purpose of calibration and validation as this is the only station that DID had a continuous data of flow discharge.
- Certain scenarios will be modelled; different land use and different Annual Recurrence Interval (ARI)
- Sungai Johor basin has a telemetric station at Rantau Panjang managed by DID. Rantau Panjang station is located at the upper stream of Kota Tinggi. Figure 1.2 shows the study area. Some basic information about Sungai Johor area can be found in Table 1.2.

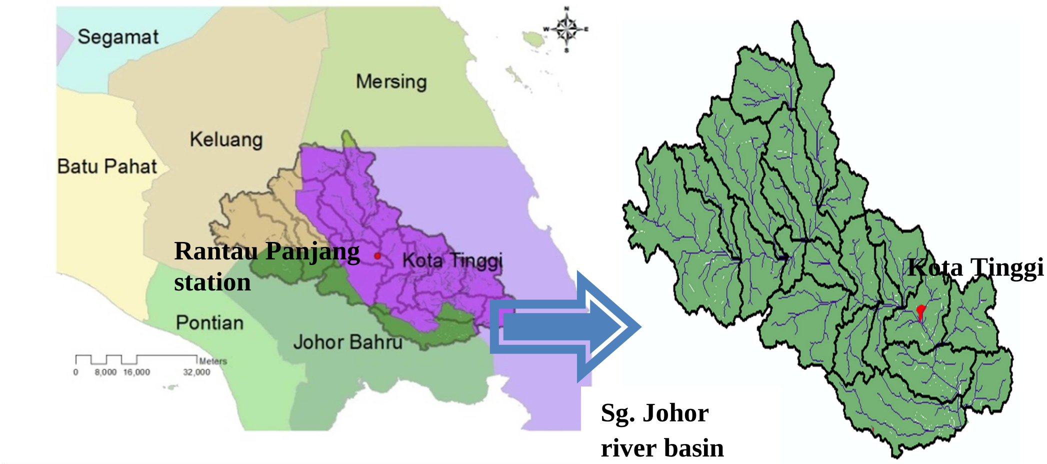

Figure 1.2: Sg Johor river basin for study area

Table 1.2: Basic Information of Sungai Johor river basin (Chikamori *et al.*, 2012)

Name: Sg Johor		
Location: central part of south Johor	N 1°27’ - 1°49’	E 103°42’ - 104°01’
Area: 2.636 km^2	Length of main stream: 122.7 km	
Origin: Mt Gemuruh (109 m)	Highest point: Mt. Belumut (1010 m)	
Outlet: Straits of Johor	Lowest point: River mouth (0 m)	
Main tributaries: Sayong River, Linggui River, Semangor River, Tiram River, Lebam River		
Main reservoirs: Linggui Dam (impounded in 1993)		
Mean annual precipitation: 2470 mm (basin average)		
Population: 220000	Main cities: Kota Tinggi	
Land use: Urban, Forest, Oil Palm, Other Crops, Water Body, Swamps		

1.5 Significance of the Study

This research can provide contribution and a better solution for water management especially when it is able to identify and gather details about runoff distribution. Nevertheless, this study will provide better solution that can help water related authorities such as DID, DOE, DOA and WSD such as SAJ, SYABAS etc., to manage water resources effectively. Therefore, we can sustain our water resource for future demands.

Other than that, utilizing the GIS and Remote Sensing technologies will give more benefit to water authorities. As we know, it is very difficult to get all the information needed such as DEM in using ground-based measurement especially in rural or remote area due to several limitations. Therefore these technologies will save our cost of operational as GIS will make the analyses of geospatial data quickly and easier.

In addition, this research is also very important for planners to formulate their strategies. This will help to ensure undesirable effects on changes of land-use can be minimized as it is highly influenced by runoff. Thus, this research will be very valuable for flood simulation.

1.6 Organization of the Thesis

The thesis is divided into two major parts: the objectives/ study area/ literature review (Chapter 1 and 2) and methodology/ results/ discussions (Chapter 3 and 4). Chapter 5 describes the major conclusions and recommendations for future works.

For Chapter 2, the detail review about i) water issues, ii) limitation of data, iii) GIS approach, iv) determination of runoff, v) rainfall characteristic, vi) rainfall interpolation, vii) DEM selection, viii) rainfall runoff model, ix) selected computer model for calibration and validation will be explained.

The detail of methodology will be explained in Chapter 3 on which methods will be used, what tool to be used for data processing and modelling work and how to calibrate and validate the obtained results.

Chapter 4 discussed the results obtained from the modelling work. This chapter is divided into: (1) Rainfall analysis; (2) processes of hydrological input parameters; (3) model calibration and validation; (4) evaluation of model efficiency; (5) simulation of surface runoff based on various scenarios of urbanization and Annual Recurrence Interval (ARI). Finally, Chapter 5 concludes the outcome of this study.

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