STUDY OF RAINFALL-RUNOFF RELATIONSHIP BY USING HYDROLOGIC MODELING SYSTEM (HEC-HMS) FOR KUANTAN RIVER BASIN, PAHANG

NABILAH BINTI MAMAT

A thesis submitted in fulfillment of the requirements
for the award of the degree of
B.Eng (Hons.) in Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JULY 2015

ABSTRACT

River is important in human life. River is very useful and has various functions in human life such as for domestics, economics, connection for one place to other places and many more. The main function is the river is to flow the water to the water storage or sea. Landuse changes and urbanization has always been blamed as among the major causes of the increase in the magnitude and frequency flooding. Flash flood had occured in Kuantan River due to low lying of the draining area which the drainage capacity cannot cater the quantity of water when the capacity of runoff increases. When the quantity of the runoff is increasing and filled all the drainage and river, the flood will then occur. Therefore, this research aim is to carry out rainfall-runoff relationship for Kuantan River basin by using HEC-HMS, to apply the rainfall-runoff analysis by using Clark method in HEC-HMS and to determine discharge based on rainfall data. Relationship between rainfall and runoff will then be determined by the producing hydrograph from this software. In this software, hydrology parameter such as rainfall data and stream flow data are important to simulate rainfall-runoff data. In this study, HEC-HMS were used to develop hydrologic model for Sungai Kuantan basin based on the available data. The performance of determination correlation coefficient is used to measure the performance of the hydrologic modelling. From the simulated results, the maximum discharge was 286.3 m^3/s during December 2011 at Bukit Kenau discharge station. The correlation coefficient for November 2011 was 0.9382 for Bukit Kenau discharge station. Approximately correlation coefficient to 1.0000 is better.

ABSTRAK

Sungai sangat penting di dalam kehidupan manusia. Sungai sangat berguna dan mempunyai banyak fungsi dalam kehidupan manusia seperti domestik, ekonomi, hubungan antara satu tempat ke satu tempat yang lain. Fungsi utama sungai adalah untuk mengalirkan air ke simpanan air di laut. Perubahan guna tanah dan pembandaran sentiasa dipersalahkan sebagai antara punca utama peningkatan dalam magnitud dan kekerapan banjir. Banjir kilat telah berlaku di Sungai Kuantan kerana kawasan penyaliran rendah yang kapasiti saliran tidak boleh manampung kuantiti air apabila kapasiti peningkatan air meningkat. Apabila kuantiti air larian semakin meningkat dan memenuhi semua perparitan dan sungai, banjir akan berlaku. Oleh itu, tujuan kajian ini adalah untuk menjalankan hubungan hujan-air bagi lembangan Sungai Kuantan dengan HEC-HM, untuk mengaplikasi analisis hujan-air dengan menggunakan cara Clark dalam HEC-HMS dan untuk menentukan pelepasan berdasarkan data hujan. Hubungan antara hujan dan air larian akan ditentukan oleh hidrograf daripada perisian ini. Dalam perisian ini, parameter hidrologi seperti data hujan dan data aliran sungai adalah penting untuk mensimulasikan data hujan-air larian. Dalam kajian ini, HEC-HM telah digunakan untuk membangunkan model hidrologi untuk lembangan Sungai Kuantan berdasarkan data yang ada. Prestasi pekali korelasi penentuan digunakan untuk mengukur prestasi pemodelan hidrologi. Daripada keputusan yang telah disimulasi, pelepasan palaing maksimum adalah 286.3 m^3/s di stetsen pelepasan Bukit Kenau. Pekali kolerasi untuk November 2011 ialah 0.9382 untuk pelepasan stesen Bukit Kenau. Nilai yang terdekat dengan 1.0000 adalah lebih baik.

TABLE OF CONTENTS

LIST OF TABLES

x

6.16 Station No 3930401 for 2011 61

LIST OF FIGURES

LIST OF SYMBOLS

A	Catchment area in km^2
CN	Curve Number
I_a	Initial Abstraction
l_i	Incremental stream length
n	Manning value
R	Baseflow
R^2	Correlation coefficient
S	Weighted slope of main stream in m/km
S	Potential maximum retention after runoff begins
S_i	Incremental slope
Q_B	Baseflow in m^3/s
T_c	Time of concentration
t_{lag}	Lag time
$X_{model,i}$	Simulated value at time or place
$X_{obs,i}$	Observed value
%	Percentage
$\sum$	Summation

LIST OF ABBREVIATIONS

DID	Department of Irrigation and Drainage
HEC-HMS	Hydrologic Engineering Centre-Hydrologic Modelling System
JPS	Jabatan Pengairan dan Saliran
JUPEM	Jabatan Ukur dan Pemetaan Malaysia
RMSE	Root Mean Square Error
SCS	Soil Conservation Services
UH	Unit Hydrograph

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

River is important in human life. River is very useful and has various functions in human life such as for domestics, economics, connection for one place to others place and many more. The main function of the river is to flow the water to the water storage or sea (Ahmad Abdul Ghani et al., 2013).

Hydrology deals with surface water and groundwater, their independence, and their interaction with earth materials. The study of hydrology includes all aspects of the hydrologic cycle, including atmospheric phenomena such as precipitation and evapotranspiration. The engineering hydrology includes flooding, flood analysis, flood control and seepage through earth dams. Large-scale field tests, rather than tests conducted in a laboratory, should form the basis of design, and computer assisted mathematical models to analyze data and predict hydrologic trends, although essential, should be used with discretion (Ian & D.B., 1995).

Most of the Earth's water, 97%, resides in the ocean system, with about 2.5% on land. The atmosphere holds less than 0.01%, in spite of the fact that atmospheric water is so important to weather and climate. The annual precipitation for the earth is more than 30 times the atmosphere's total capacity to hold water. This fact indicates the rapid recycling of water that must occur between the earth's surface and the atmosphere. Distribution of earth's water shown in Figure 1.1.

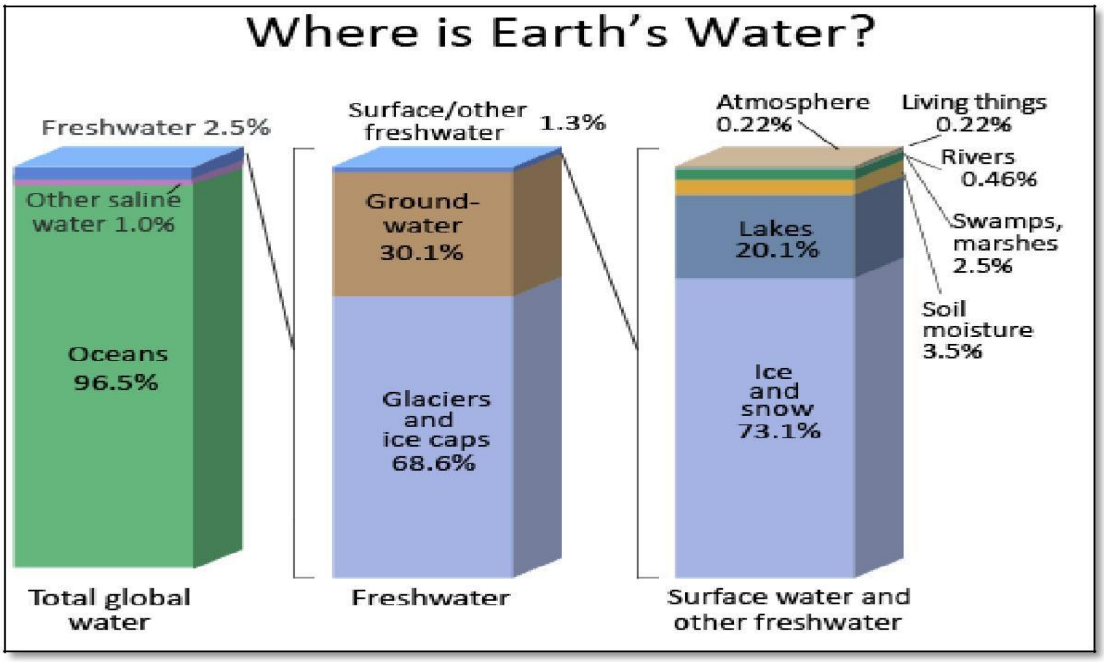

Figure 1.1: Distribution of earth's water

Source: H. Gleick (editor), 1993

Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS) had been used as a tool for the hydrologic modelling of Sungai Kuantan basin. HEC-HMS is used as hydrological model which was widely applied in many water resources studies (He et al.2007, García et al. 2008). In this study, HEC-HMS was used to determine the rainfall-runoff relationship and analyze rainfall-runoff data.

HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic drainage basins. Also, the function of HEC-HMS is can be used for solving the possible problems in a wide range of geographic areas. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Relationship between rainfall and runoff will then be determined by the producing hydrograph from this (HEC-HMS) computer software (U.S Army Corps of Engineers, 2008).

1.2 OBJECTIVES OF STUDY

The objectives of this study are:

1. To carry out rainfall-runoff relationship of Kuantan River basin by using HEC-HMS.
2. To apply the rainfall-runoff analysis by using Clark method in HEC-HMS.
3. To determine discharge based on rainfall data.

1.3 SCOPES OF STUDY

Kuantan River Basin is in the district of Kuantan at the north eastern end of Pahang State in Peninsular Malaysia. It is one of the important river basins in Pahang and covers an area of 1677 km^2 catchment area which started from forest reserved area in Mukim Ulu Kuantan through agricultural areas, Kuantan town (state capital of Pahang) towards the South China Sea. Kuantan River Basin consists of several important tributaries and these rivers drain the major rural, agricultural, urban and industrial areas of Kuantan District and discharge into South China Sea. Figure 1.2 below shows Kuantan River basin.

Figure 1.2: Kuantan River basin

Source: Department of Irrigation and Drainage, 2015

According to F HEC-HMS model were used to determine the rainfall-runoff relationship and analyze rainfall-runoff based on available data of Kuantan River basin. HEC-HMS is equipped to model a network of channels and helps to simplify the data that obtain from rainfall and runoff value. Relationship between rainfall and runoff will then be determined by the producing hydrograph from this software.

1.4 PROBLEMS STATEMENT

Nowadays, flood is one of natural disaster in Malaysia that give impact and effect to the social tragedies, economic and human. A lecturer of Universiti Malaysia Pahang (UMP), Ali, (2013) said that the movement or hydrological processes in the basin is also the cause of the flooding in Kuantan than construction of new roads reclaimed higher than the original level. Heavy rainfall can cause the excess of runoff rise to the high water levels and causing the low-lying areas to be flooded. Flash flood had occured in Kuantan River due to low lying of the draining area which the drainage capacity cannot cater the quantity of water when the capacity of runoff increases. When the quantity of the runoff is increasing and filled all the drainage and river, the flood will then occur. Moreover, a large part of this river basin area is well developed urban area with different land-use activities and also high population density were also the major causes of the flood problem. Usually, land-use changes within a river basin give impacts to the hydrologic behavior of the basin. Figure 1.3 shows that the flood occurred in Kuantan.

Figure 1.3: Flood occurred in Kuantan

Source: Astro Awani, 2014

Kuantan River basin located in Kuantan District area has six administrative mukims (small district). In terms of land use, the main types of land use in this district are forest and agriculture that cover approximately 56% and 32% respectively, from the whole area of Kuantan District. Majority of the forested areas are at the west of Kuantan District or in upstream of the basin. Besides that, there is an ex-tin mining land in Sungai Lembing or at upstream or low sub basin area. The mining activities was started in 1906 and stopped in 1986 due to economic recession in our country.

In order to prevent the disaster happen, this research was carried out to analyze the relationship between rainfall and runoff. Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS) is one of the computer programs that can be used to simplify the data and assist to understand the hydrological characteristics. HEC-HMS was used to develop rainfall-runoff from a design rainfall or historic rainfall event for Kuantan River basin. In this software, hydrology parameter such as rainfall data and stream flow data are important to simulate rainfall-runoff data. By analyzed the data using HEC-HMS, it can assist to recognized the rainfall-runoff relationship in a certain period.

CHAPTER 2

LITERATURE REVIEW

2.1 IINTRODUCTION

For this chapter, the topic covered hydrology, hydrologic characteristics, physical characteristics of the basin, flood, rainfall-runoff relationship, hydrograph, software for analyzing rainfall and runoff relationship and advantages of HEC-HMS.

2.2 HYDROLOGY

Hydrology is the study of water on the Earth (Meinzer, 1923). A knowledge of hydrology is one of the key ingredients in decision-making processes where water is involved. According to Gupta, (1979), the knowledge of hydrology is not only useful in the field of engineering, but also in agriculture, forest, and other branches of natural science.

2.2.1 Hydrologic Cycle

Hydrologic cycle is the continuous, unsteady circulation of water from the atmosphere to and under, the land surface and back to the atmosphere by various processes (Walesh, 1989). The Hydrologic Cycle, also known as the water cycle is the most important natural phenomenon on Earth. Hydrologic cycle is defined as the pathway of water as it moves in its various phases through the atmosphere, to the earth, over and through the land, to the ocean and back to atmosphere (National Research Council, 1999). It describes the constant movement and endless recycling of water between the atmosphere, land surface, and under the ground. Also, the hydrologic cycle supplies the force needed for most natural processes, thus supporting life itself. Figure 2.1 define the components and illustrate the pathway of water in hydrologic cycle.

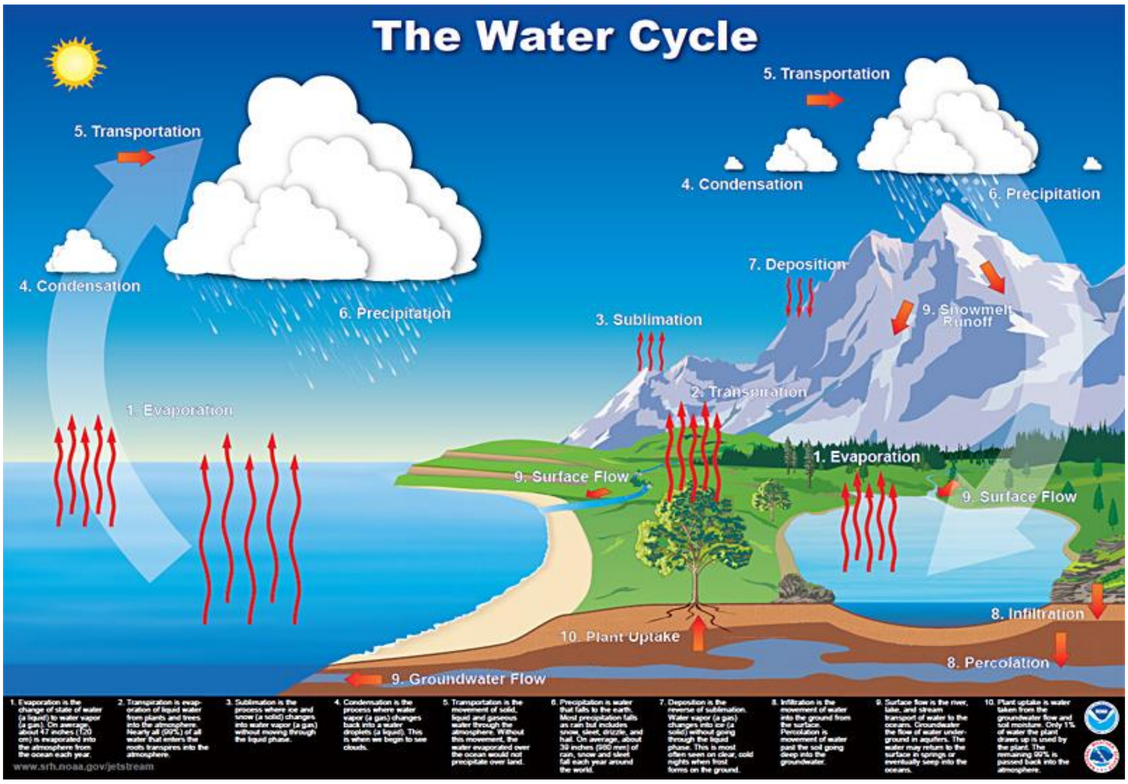

Figure 2.1: Hydrologic cycle

Source: National Oceanic and Atmospheric Administration Education Resources, 2015

Within the hydrologic cycle, water may appear in all three of its states; solid, liquid, and gas. Wards, (2002) has explained the hydrological processes involved in the cycle. In this cycle, water is transferred from the surface to the atmosphere through evaporation which a substance changes from liquid to the gas phase. The sun's heat provides energy to evaporate water from the earth's surface. As air containing water vapour rises up and condenses into clouds, water droplets grow into larger and will not be able to stay suspended in the cloud. When this occurs, precipitation will occur. Precipitation can occur primarily as rain. Annual amounts of precipitation are unpredictable and variable ranging from approximately 2000 mm to 4000 mm for various locations in Malaysia. When precipitation falls to the ground surface, it will either be absorbed into the ground (groundwater) or flow into streams, rivers, lakes or end up back in the oceans. After that, some of runoff will be evaporated and some of the groundwater will be taken by plants and then transpired (Hubbart, J, 2011).

H. Gleick, (1993) has explained the approximately 97% of the Earth's water is salty and is stored in oceans. The remaining 3% is fresh water and, if uncontaminated, is considered to be potable and drinkable by animals and utilized by non-salt tolerant plants. Fresh water is stored primarily as ice in glaciers and icecaps, but also in groundwater, lakes, streams, and rivers. Water retained as soil moisture is small fraction of the total, but is extremely important for the production of food and fiber. The amount of water existing in the gaseous state is relatively constant and is estimated to be 12900 km^3. Table 2.1 shows that the estimate of global water distribution.

Table 2.1 Estimate of global water distribution

Source	Volume × 1000 km^3	Total water (%)	Fresh water (%)
Oceans	1338000	96.5	-
Ice, glaciers, snow	24064	1.74	68.7
Groundwater			
Fresh	10530	0.76	30.1
Saline	12870	0.94	-
Soil moisture	16.5	0.001	0.05
Ground ice and permafrost	300	0.022	0.86
Lakes			
Fresh	91.0	0.007	0.26
Saline	85.4	0.006	-
Atmosphere	12.9	0.001	0.04
Swamps	11.47	0.0008	0.03
Rivers	2.12	0.0002	0.006
Biological water	1.12	0.0001	0.003
Total fresh and saline	1385984	100.0	100.0

Source: Gleick, (1993)

The definition of a model may be made in several different contexts. Here, an environmental model is defined as the process of applying preconceived ideas on data to make a prediction in which an informed decision may be made (J.Gourley et al., 2004).

2.3 HYDROLOGICAL CHARACTERISTICS

When study about hydrology, it is important to know the hydrological characteristics before go further. Hydrological characteristics include rainfall distribution and runoff distribution and specific peak discharge. According to Ministry of Economic Affairs of Taiwan 2004, hydrological characteristics are rainfall, runoff and specific peak discharge.

2.3.1 Rainfall

Rain is form of droplets that have condensed from atmospheric water vapour. Eventually, the water droplets grow into larger droplets by colliding and coalescing with each other. Rain develops when growing cloud droplets become too heavy and not be able to remain suspended in the cloud and as a result, fall out of the cloud toward the surface as rain. Rain can also begin as ice crystals that collect each other to form large snowflakes. As the falling snow passes through the freezing level into warmer air, the flakes melt and collapse into rain drops. Precipitation in the form of water drops of sizes larger than 0.5 mm. The maximum size of the raindrop is about 6 mm (Kanhu, 2001). On the basis of its intensity, rainfall is classified as shown in Table 2.2.

Table 2.2: Intensity of rainfall

Type	Intensity
Light rain	< 2.5 mm/h
Moderate rain	2.5 mm/h to 7.5 mm/h
Heavy rain	>7.5 mm/h

Source: Kanhu, (2001)

2.3.2 Runoff

Precipitation is the primary source of all waters. When rain starts falling on a more or less pervious area, it is consumed in many ways such as the rainfall is intercepted by buildings, trees, grasses and other objects. Thus, preventing it from reaching the ground, some part of infiltrates into the ground, some part of it finds its way to innumerable small and large depression, if rain continues, the soil surface becomes covered with a film of water and is known as surface detention and flow begins to start to words an established surface channel. Runoff may be defined as that part of precipitation as well as of any other flow contribution which appear in surface streams (Gupta, 1979). Runoff, sometimes referred to as overland flow, is the process whereby water moves from the ground surface to a waterway or water body. Normally applies to flow over a surface. Rain falling in a watershed in quantities exceeding the soil or vegetation uptake becomes runoff. Runoff will be used to collectively describe the precipitation that is not directly infiltrated into the groundwater system. Runoff producing events are usually thought of as those that saturate the soil column or occur during a period when the soil is already saturated. Thus infiltration is halted or limited and excess precipitation occurs. This may also occur when the intensity rate of the precipitation is greater than the infiltration capacity.

2.3.2.1 Factor Affecting Runoff

There are many factors affecting runoff such as the intensity of rainfall, duration of rainfall, distribution of rainfall, direction of storm movement, soil moisture and other climate conditions. The intensity of rainfall has a great influence on runoff. Rainfall with higher intensity will generate more runoff than low intensity rainfall. If rainfall continue over an extended period, the water table may rise and sometimes even may touch the ground surface in low lying areas, reducing the infiltration capacity to zero of that area and there may be chances of serious flood hazard. The runoff from a drainage basin depends on distribution of rainfall. For a given total rainfall all other conditions being the same, greater the coefficient, greater will be the peak runoff. However, for the same distribution coefficient, the higher the peak runoff would result for the storm falling on the lower part of the basin.

2.3.3 Specific Peak Discharge

Peak discharge is the peak rate of surface runoff from a drainage area for a given rainfall. The peak discharge from a small rural watershed is usually caused by intense rainfall. The intensity of rainfall affects the peak discharge more than it does the volume of runoff. Intense rainfall that produces high peak discharge in small watersheds usually does not extend over large area.

2.4 PHYSICAL CHARACTERISTICS OF THE BASIN

Physical characteristics of the basin include the land use, slope of the drainage, elevation of the basin.

2.4.1 Land Use

The land use or land management has a great effect on the resulting surface runoff. Consider a virgin forest area, in which a thick mulch of leaves and grass have accumulated. In such areas even the heaviest down pours or rains would be unable to generate surface runoff that would reach the streams. On the other hand, if the forest is removed and the land is cultivated after removing the mulch, the ground will become compacted. As a result of which even a mild rainfall will result in appreciable surface runoff.

2.4.2 Slope

Investigations on experimental runoff plots have shown that steep slope yield more runoff than those with gentle slope (Sharma, 1993). In addition, it was observed that quantity of runoff decreased with increasing slope length. In case of steeper basins the velocity of flow will be more and runoff will take lesser time to reach the stream, resulting in higher runoff.