RAINFALL - RUNOFF MODELLING FOR THE BATU KURAU RIVER BASIN USING HEC-HMS MODEL

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by

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Perubahan Pengkalan tanah dan pembandaran selalu disalahkan sebagai antara penyebab peningkatan besar dalam skala dan kekerapan banjir. Banjir kilat telah berlaku di Sungai Kurau disebabkan oleh kawasan saliran yang rendah di mana kapasiti saliran tidak dapat menampung kuantiti air ketika kapasiti limpasan meningkat. Amabile kuantiti aliran langsung meningkat dan memenuhi semua longkang dan sungai, banjir akan berlaku. Oleh itu, tujuan kajian ini adalah untuk melakukan projek pemodelan larian hujan dengan menggunakan Model HEC-HMS, menentukan hubungan larian hujan di lembangan Sungai Kurau, Perak, dan mendapatkan model yang sesuai untuk meramalkan hidrograf aliran langsung setelah penentukuran dan proses pengesahan. HEC- HMS adalah salah satu model larian hujan yang dikeluarkan oleh US Army Corps. Hubungan antara hujan dan air-larian akan ditentukan oleh hidrograf dari perisian. Adalah perlu untuk memahami hubungan antara penggunaan tanah dan tindak balas tadahan. Model larian hujan digunakan secara meluas dalam meramalkan perubahan dalam proses hidrologi. Analisis perubahan penggunaan tanah pada aliran langsung pada tadahan menunjukkan bahawa penukaran dari hutan ke kawasan pertanian meningkat menunjukkan peningkatan tertinggi dalam aliran puncak dan isipadu aliran langsung. Data hidrologi seperti curah hujan dan aliran sungai penting untuk mensimulasikan proses hujan dan larian dalam perisian ini. Dalam kajian ini, Nash Sutcliffe Efficiency digunakan untuk mengesahkan penentukuran dan pengesahan model. Kecekapan model, untuk model yang dikalibrasi dan disahkan adalah 0.954 dan 0.922 yang merupakan korelasi yang dapat diterima antara data yang diperhatikan dan simulasi.

ABSTRACT

Changes in land use and urbanization have always been blamed as among the causes of a major increase in magnitude and frequency of flooding. Flash floods occurred in Batu Kurau basin due to drainage capacity is not possible to accommodate the quantity of water as the capacity of the runoff increases. When the quantity of runoff is increased and filling all drains and rivers, floods will occur. Therefore, the purpose of this study is to conduct rainfall-runoff modelling exercises using the HEC-HMS Model, determining the relationship of rainfall-runoff relationship at Batu Kurau basin, Perak, and to get a suitable model to simulate the streamflow hydrograph after calibration and validation process. HEC- HMS is one of the common rainfall-runoff models released by the US Army Corps. The hydrograph generated from the software will determine the rainfall and runoff. It is necessary to understand the relationship between land use and catchment response. Rainfall-runoff models are widely used in predicting changes in hydrologic processes. Analysis of the land use changes on the catchment runoff showed that conversion from forest to agricultural land area increases show the highest increased in peak discharge and runoff volume. Hydrological data such as rainfall and streamflow are important to simulate the rainfall and runoff process in this software. In this study, Nash Sutcliffe Efficiency was used to verify the model calibration and validation. The model efficiency, for calibrated and validated model is 0.954 and 0.922 respectively, which is acceptable correlation between the observed and simulated data.

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LIST OF SYMBOLS

%	Percentage
T_{lag}	Lag time
t_c	Time of concentration
A	Watershed drainage area
s	Slope
CN	Curve Number
tr	Rainfall duration
C	Conversion constant
t	Basin lag
∑	Summation

LIST OF ABBREVIATIONS

CN	Curve Number
DID	Department of Irrigation and Drainage
HEC HMS	Hydrologic Modelling System
NSE	Nash-Sutcliffe Efficiency
OBS	Observed Value
PRF	Peak Rate Factor
RMSE	Root Mean Square Error
SCS-CN	Soil Conservation Service Curve Number
RRM	Rainfall Runoff Modelling
SCS	Soil Conservation Service
EDC	Euclidean Distance to Centroids
IPS	Institut Pengajian Siswazah
USM	Universiti Sains Malaysia
GIS	Geographic Information System
SWAT	Soil & Water Assessment Tool

CHAPTER 1

INTRODUCTION

1.1 Research Background

Runoff is one of the parts used in watershed management of hydrological components. Appropriate hydraulic structure planning and reduction of natural hazards in this area require surface runoff evaluations primarily dependent on meteorological, topographical, geological, soil, and soil usage patterns. Many methods for determining runoff based on the above elements are available (Tirkey, Pandey and Nathawat, 2014). The outflow estimation is currently based on geographic information (GIS) systems and hydrological models (Skhakhfa and Ouerdachi, 2016). Some of the models that determine the runoff are HEC -HMS (Hydrological Engineering Center - System Hydrological Modeling), SWAT (Soil & Water Assessment Tool), and TOPMODEL. This integration enables the assessments and forecasts of the impact of river flow areas management practices (Abdulkareem *et al.*, 2018).

Based on the project, this model has been used for annual runoff forecasting based on rainfall data in the Kurau River catchment for 2015-2019. Hydrology is about learning the process flow of water (Abdulkareem *et al.*, 2018). The study of the water cycle, or the water movement through it, is known as hydrology. As a tool for hydrological modelling of the Kurau region, the Hydrologic Engineering Centre-Hydrological System (HEC-HMS) has been used. HEC-HMS is used in many water resources studies as a hydrological model (Rohith *et al.*, 2021). HEC-HMS was used to ensuring the rainfall-runoff relationship and to analyzing rainfall-runoff data during this study.

The ocean system is the most significant part of the Earth's water of 97%, with a pair of 0.5%. Even though the atmosphere is essential for weather and climate, the atmosphere holds only 0.01% (Rohith *et al.*, 2021). The planet's annual precipitation adds up to 30 times the total water capacity of the atmosphere. This reality shows the rapid recycling of water between the surface and the atmosphere. Earth's water distribution in Figure 1.1 (Peslier *et al.*, 2017).

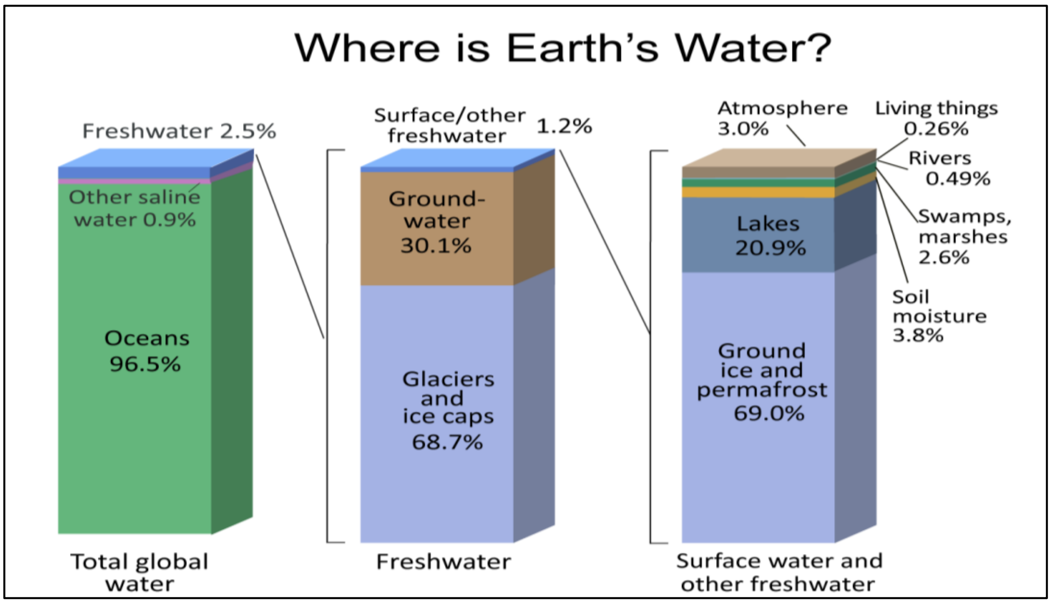

Figure 1.1 Distribution of earth's water (Peslier *et al.*, 2017)

HEC-HMS is designed to simulate dendritic drainage basin precipitation-runoff mechanisms. In addition, to determine the possible problems in an extremely wide selection of geographic areas, the performance of HEC-HMS will be used. This includes mass water and flood geophysics from the geography and small urban or natural river basins. A manufacturing hydrograph of this (HEC-HMS) computer code can then determine the relationship between rain and runoff (USACE, 2000).

1.2 Study Area

In this study, the catchment area of Batu Kurau basin in Perak Malaysia (Figure 1.2) was selected. Kurau Valley was chosen because this research case study is located in Perak, Malaysia (Pls, 2009). The Kurau River is the main drainage artery of the basin, which drains an area of about 68 $km^{2,}$ which is usually a lowland area and drained by the Kurau and Ara Rivers.

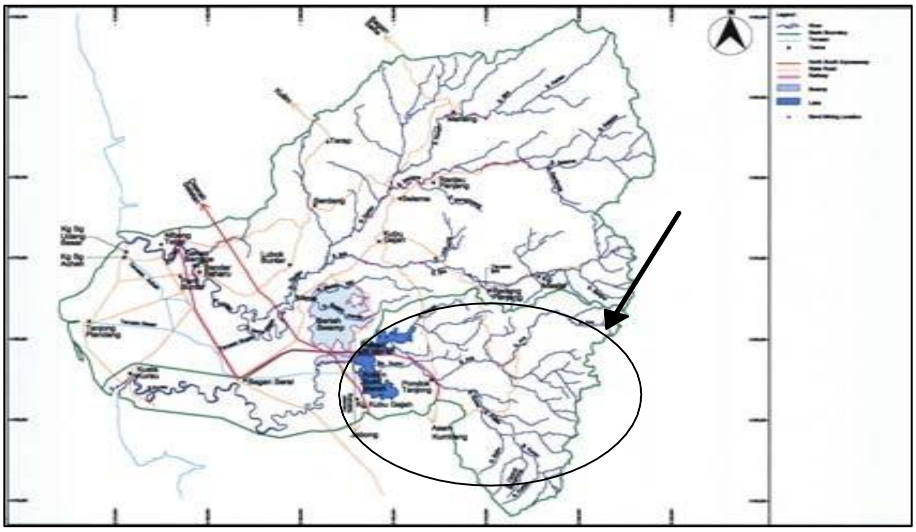

Figure 1.2 Catchment Area of Sungai Kurau in Perak (Peslier *et al.*, 2017)

Two river subsystem's upper part are the subsystems of the Kurau River and the Merah River. Drain to the steep ground by undulating. For tree-growing, areas within the former subsystem are extensively developed, with the latter subsystems being the most landed in the Pondok Tanjong Forest Reserve. Larut, Matang and Selama are situated in the upper section of the Kurau valley, while Kerian is located downstream. The state of Perak is both districts. The Kurau basin is mainly rural in nature, with many villages located along the riverbanks, from mid to lower reaches (Pls, 2009).

The basin of Kurau is one of the appropriate basins for this study for land use and development changes. However, the area's most land use is forestry (46.29%) and agriculture (42.80%), with about 50% being owned privately, making it very difficult to implement good land management policies. Figure 1.3 shows that the location distance between rainfall station and streamflow station is 14.2 km. The flow rate of the catchment channel was calculated at Pondok Tanjung station (5007421) at Sungai Kurau, while the rainfall station (5007420) is located at Sungai Kurau Bt.14.

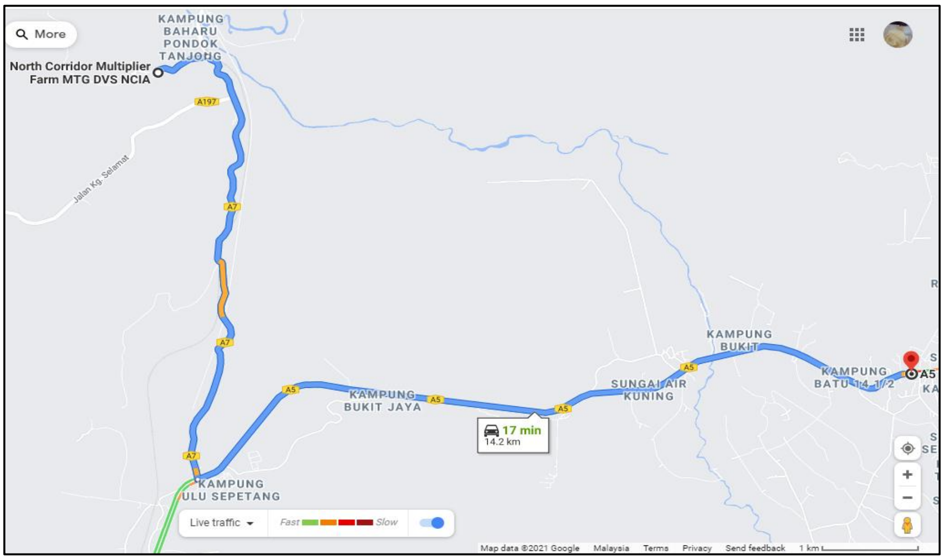

Figure 1.3 Location Distance between Rainfall Station and Streamflow Station (*Kuala Kurau Map | Malaysia Google Satellite Maps*, no date)

On 10th September (Utusan, 2007), 578 individuals in the district of Hassan had to be exhausted once two-meter-high floods refused to recede for a week, and from 141 families in 3 villages (Kampung Batu 40, Kampung Balik Bukit, Kampung Abu Hasan Bah). The incidence of floods in the Bukit Merah Waters reservoir caused event water in severe rain for 4-5 hours a day for three days, Dewan Undangan Negeri Alor Pongsu's fellow, Sham Mat Sahat, said. As the Bukit Merah reservoir cannot store the excess water from upstream, the statements mentioned above suggest heavy rainfall from the upstream watercourse system causes flooding into downstream areas (Buslima *et al.*, 2018).

1.3 Problem Statement

Currently, floods are the most significant disaster in Malaysia's social and economic population. Sungai Kurau is a drainage area in general lowland areas classified as the rivers that contribute to the flood problem. Heavy rains will make the overflow become higher and can cause a flood. Flash floods have occurred in the Sungai Kurau catchment because of the lower location in the drainage. When the quantity of overflow increases and fills all drains and rivers, flooding will occur (Pls, 2009). Moreover, most of these river basin areas developed in urban areas land use activities, and more people at one place without enough space are also a major cause of flood problems. Typically, changes in land use in river basins influence the behaviour of hydrological basins.

To prevent disasters, this research is conducted to determine the relationship between rainfall and runoff. This software is an effective tool that can simplify data and help make accessible hydrological features. Based on this model, hydrological parameters such as volume of precipitation and volume of discharge are common components to determine rainfall overflow. Analyzing the model could help identify the duration of a particular rainfall relationship.

1.4 Objectives of Study

The objectives of this research are:

- To calibrate and validate HEC - HMS model for Batu Kurau catchment.
- To evaluate flood Magnitude for different ARI - 25, 50 and 100 years.
- To evaluate Batu Kurau basin flow due to deforestation.

1.5 Scope of Study

The collected data of Sungai Kurau will be used for HEC-HMS modelling. The result of the simulation should be the design runoff hydrograph within the model of Batu Kurau basin. The hydrological model is calibrated by considering the peak discharge, runoff volume and shape of hydrograph. The simulation performance of the model is evaluated using statistical methods which is the Nash-Sutcliffe Efficiency (NSE). The data of streamflow were obtained from the Department of Irrigation and Drainage Malaysia (DID). The data obtained included the rainfall data collected from the rainfall stations within Ldg. Pondokland at Pondok Tanjung and the streamflow data collected from the Pondok Tanjung. Catchment response connected to any future development would then be analyzed and evaluated.

1.6 Dissertation Outline

Chapter 1 highlights the research background, problem statement, research objectives and scope of work. Chapter 2 explains the literature review relevant to the research study, mainly on hydrological modelling. Chapter 3 describes the research methodology that covered the data processing, the hydrological model development in the HEC-HMS software, and the rainfall-runoff analysis on various land use scenarios. Chapter 4 presents the analysis of results and the discussions on the findings. Finally, chapter 5 concludes the outcome of this study and makes some recommendations for future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In Malaysia, particularly on the west coast of the Malaysian peninsula, rapid development is occurring. Mostly because of the active trade and growing towns on the west coast. Rapid development has long been overlooked in Malaysia, and the hydrological effects are in this case. Deforestation and development change the distribution across a river season and year considerably (Schreider *et al.*, 1996).

The term catchment reactivity measures that catchment reacts to various factors. These factors include climatic influences such as temperature, rainfall, evaporation, wind speed and cloud direction (Schreider *et al.*, 1996). Non-climatic factors, particularly urban development, have a significant impact on predictions of rainfall runoffs. The HEC-1 kinematic wave model would have components that represent the previous unprecedented mix of urban land use (Scharffenberg, 2016).

2.2 Flood Overview

Flood is the most prevalent natural disaster in many people worldwide. According to the 'Human Cost of Weather-related Disaster 1995-2015,' floods have affected 2.3 billion people and have affected 47% of all weather-related disasters since 1995. The flood showed an increase of an average of 171 from the last decades in the period 2005-2014 (average 127 cases). In the last few decades, the frequency and severity of floods have increased (Jackson, 2013). It shows that floods affect human well-being significantly. This leads to huge financial losses that disrupt the values of the environment, history and culture (UNISDR, 2015).

A flood can be described as a sudden increase in water levels that lead to overflows of water from its natural or artificial boundaries into dry land. Overflow drain will cause floods because of storm or other tidal events. The most popular is the overflow of the river or stream. This spreads across the surrounding floodplain (Zakaria *et al.*, 2018). Most of the floods take hours or days, which allows the residents to prepare or evacuate. However, quickly and with little warning, flash flooding is generated. Over the year, the number and severity of flood events are increasing. It is most probably due to the rapid change in urban land use (M. Szwagrzyk *et al.*, 2018).

2.3 Effect of Land Use Change on Catchment Response

2.3.1 Urbanization

Urbanization can change hydrograph peaks in many ways. Deforestation would be one of the main effects of development. Hydrologist has long discussed the role of forests in controlling water production and hydrograph peaks (Geremew, 2013). One of the major sources of increase in basin runoff was deforestation. Forest litter has always contributed to the catchment's storage effects. Deforestation is an unavoidable event in project development and will significantly increase the volume release (Gwenzi and Nyamadzawo, 2014).

Moreover, the urbanization of the ground with its created surface will increase. Usually, these surfaces are paved roads of concrete or asphalt and can influence the volume of runoff. Surface runoff theoretically moves into the flow or stream flow faster. The roughness of the surface decreases. The HEC-HMS was adopted by (Geremew, 2013) to boost urbanization by raising the sub-catchment curve number. The chart shows that urbanization increases basin flow and greatly accelerates the time of flow concentration (Xu and Zhao, 2016a).

2.3.2 Other Previous Research

Computer models are now widely used in private and civil organizations in computing rainfall and runoff relationships for catchment areas. Usually, models are performed for a single storm event to allow us to predict future flood events. Mitigation projects will then be performed on junctions with possible flooding patterns in a model. Listed are few proofs regarding land use effect on catchment response simulation works by numerous research:

a. The Xitiaoxi watershed was selected for the analysis of hydrological responses to different levels of urbanization. Preliminary results suggest that urbanization will increase flood peaks and a shortening of flood duration in urban areas (Xu and Zhao, 2016a).
b. S. Yu Schreider examined the impact of land use in the Murray Darling Basin in Australia on potentially current flow responses. The intensive development of the river flow catchment has been influenced by land use and losses caused by evaporation and sedimentation (Schreider, Jakeman and Pittock, 1996).
c. A case study in the Bernam watershed concluded that land use changes alter the rainfall-runoff relationship and runoff sediment. The decline in flow curves for annual and monthly rainfall mass curves and runoff mass curves in the 1980s were slightly smaller than in the 1990s. This means that the amount of overflow and sediment loss in the 1990s was higher than in the 1980s due to urbanization (Dlamini *et al.*, 2017).

2.4 Hydrologic Cycle

The hydrological cycle is the ongoing and unsteady circulation by different water processes from the atmosphere down to the earth's surface and back to the atmosphere (Walesh, 1989). The water cycle is the most important natural phenomenon globally and is also known as the water cycle. The hydraulic cycle is defined as the passage of water, as it passes through the atmosphere, the earth, the oceans and the atmosphere in different phases (Gat, 1996). It describes the continuous circulation and recycling of endless water from the ground to the ground between the atmosphere and soil. In addition, the hydrological cycle gives life itself the strength needed for most natural processes. The components are determined, and water transit through the hydrological cycle is described in Figure 2.1.

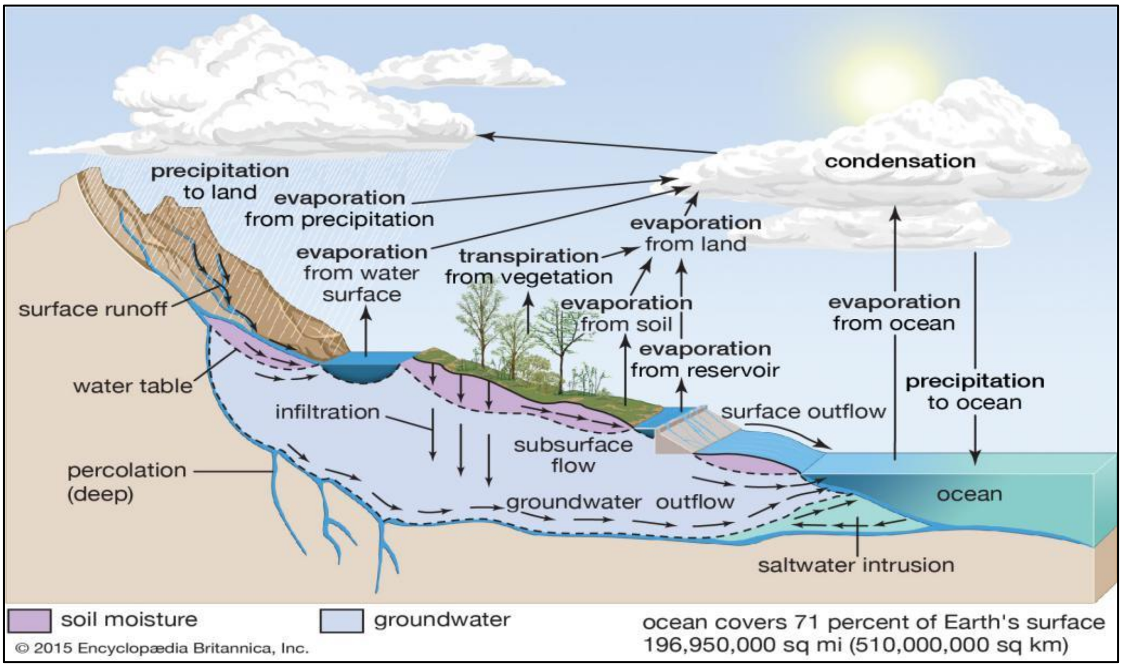

Figure 2.1 Hydrologic Cycle (Gat, 1996)

2.4.1 Rainfall

Rain might have been a kind of droplet condensed from atmospheric vapour. The water droplets eventually collide and coalesce into bigger droplets. Rain develops when growing cloud droplets become too severe and are not ready to remain suspended within the cloud and therefore fall like rain from the cloud to the surface (Shaw *et al.*, 2017). Rain can even start as giant snowflakes as ice crystals collect each other. Since falling snow flows into hotter air through the freezing level, the flakes smooth out and collapse into raindrops. Precipitation in the type of water drops greater than 0.5 mm in size. About half-dozen millimetres, the size of the drop is the largest. Precipitation is assessed based on intensity, as illustrated in Table 2.1.

Table 2.1 Intensity of Rainfall (Kleinman et al., 2006)

Type	Intensity
Light Rain	<2.5 mm/hr
Moderate Rain	2.5 mm/hr to 7.5 mm/hr
Heavy Rain	>7.5 mm/hr

2.4.2 Runoff

Overland flow can act as the portion of precipitation and the contribution of other flows that appear in the surface flow (Wagener, Wheater and Gupta, 2004). This overland flow will be used to describe along with the groundwater system of indirect precipitation occurrences producing overland flows, usually considered soil saturation columns occurring at the time of soil saturation. Therefore, infiltration is stopped or restricted, and there is excess rainfall. This can also occur when the precipitation rate is greater than the infiltration capacity (Hallema *et al.*, 2016).

2.4.2(a) Factor affecting Runoff

Much that affects running, like the intensity of rainfall, duration of precipitation, precipitation, the direction of storm movement, soil moisture, and other weather. The intensity of the rain has an important influence on the flow of water. Raining at a higher intensity will lead to more runoff than rainfall with low intensity (Mohamadi and Kavian, 2015). The water surface can grow and sometimes even touch the soil surface in low-lying areas, which reduces the infiltration capacity to zero, and can lead to a danger of flooding when it rains for a long period. Waterway disposal in the basin depends on the rainfall distribution (Ran *et al.*, 2012). The bigger the coefficient, the larger the peak run. For a certain rain, all other conditions are the same. However, the higher the peak run will lead to storms falling to the bottom of the basin for the same distribution coefficient (MSMA 2nd Edition, 2012).

2.4.3 Specific Peak Discharge

The peak release is the peak speed of the drainage area surface runoff for certain precipitation. Typically, the events of small river flows are due to heavy rainfall. The intensity of the precipitation is more important than overall. Heavy rains which generate high peak emissions are not widely spread in large areas in small river flow zones (MSMA 2nd Edition, 2012).

2.5 Effect of Land Use Change on Flood Characteristics

The rapid growth in human population and development has led to significant changes in the world's land use. Change in land cover is converting open areas to impervious areas, and changes in land use and urban covers affect flooding (M. Szwagrzyk *et al.*, 2018). The storage capacity of the newly constructed area is reduced, and therefore, the rapid runoff increases (Walsh, Fletcher and Burns, 2012). Development along the river affects the water supply ability of the river channels and thus increases the flow levels. Furthermore, frequent floods cause channel and bank erosion in urban streams (O'Driscoll *et al.,* 2010). Many investigators have examined the effects of floods of land use change. This study examines the impact of land use on flood damage.

Based on a study by (Ligtenberg, 2017), the duration and magnitude of the storm and the development of land use affected the volume of fluxes and peak releases from flood hydraulics. The study shows that precipitation events with longer storms have less runoff and a higher volume of runoff. The study also reported an increase in peak release and runoff volumes associated with an increase in the magnitude of the storm. In addition, the study found that the increase in the imperishable area within the river basins leads to a higher rate of runoff in terms of the impact of changing land use (Xu and Zhao, 2016b). In short, the study showed, however, that the peak runoff discharge is more sensitive to storm majors due to changes in land use.

The frequency and consequences of flooding are affected by land cover and land use (Szwagrzyk *et al.*, 2018). The coverage of the river canals determines the hydraulic flow conditions. The study predicted, with hydrological modeling, the impact of land use change on the peak release in the Polish Carpathian Basin. The findings showed that changes in land usage would increase flux and peak flux in urban basins and increase areas prone to flooding (M. Szwagrzyk *et al.*, 2018). The study highlighted the importance of the study, particularly in urban areas, on the impact of land use changes on flood risks.

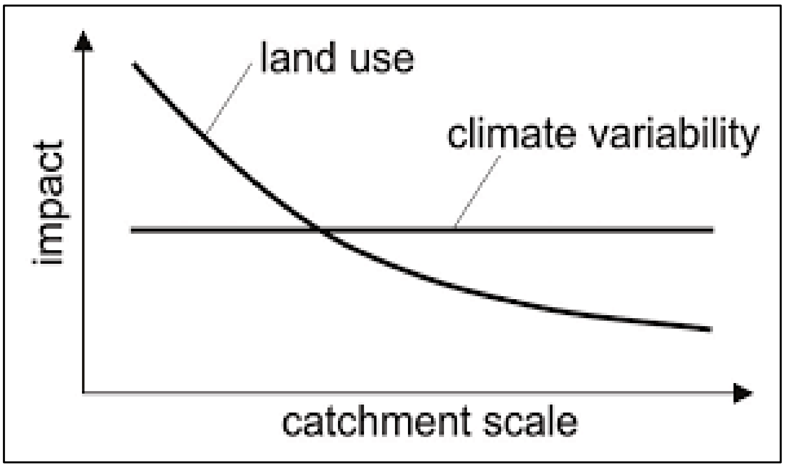

Figure 2.2 Hypothesized impact of land use changes and climate variability on hydrological response (Blöschl *et al.*, 2006)

2.6 The HEC-HMS Model

HEC-HMS model is used for the determination of complete hydrological catchment processes. It can be used to address hydrological analyses such as infiltration, hydrological routing, and unit hydrograph generation. As input for hydraulic modelling, the simulation result can be used. HEC-HMS software offers many good hydrological approaches to modelling precipitation-runoff in a tank (Hamdan, Almuktar and Scholz, 2021). The catchment area is informed for selecting the model, the hydrological study and engineering judgment are necessary.

The Sub-basins, Reaches, Junctions or other components can be the catchment area. These hydrological components are connected to a dendritic network. The Subbasin element handles the loss caused by the infiltration and converts the precipitation into surface runoff. The connecting element handles the data for observation (Laouacheria and Mansouri, 2015).

2.6.1 Rainfall Runoff Modelling

Rainfall runoff models (RRMs) are routinely used for hydraulic engineering and environmental studies today as standard tools. It is used in space and time to assess management strategies and catchment response to climate and land use variability in external streamflow series (Wagener, Wheater and Gupta, 2004). Rainfall is known to play a key role in surface dumping production. Thus, rainfall and surface ruin have a unique and significant relationship. When it rains, the leaves and stems of plants intercept the first drop of water.

These are commonly called bypasses when the soil surfaces are reached and water infiltrates into the ground to the point that the rainfall intensity rates exceed the soil's ability to infiltrate. The capacity of the soil to infiltrate depends on its texture and soil structure (Varvani and Khaleghi, 2018). Dry initial high ground capacity, but with the tempest going on, soil capacity is reduced to a constant value as the final infiltration rate (Viessman Jr. and Lewis, 2003).

Computer models and computer equipment for water control and water resources management are becoming increasingly important (Unesco, 2005). Since the early 1960s, many models have been developed and integrated into the software, usually with a combination of linear and non-linear functions (Wagener, Wheater and Gupta, 2004).

2.6.2 Calibration

The model type can be defined as a concept in HEC-HMS. Conceptual models are not confined to parametric modes, as opposed to parametric models. The conceptual classification covers two criteria: before modelling is carried out, the structure of these models is determined. The second is that specific parameters are not directly physically interpreted, in which they can be independently measured and calibrated using the observed data (Gupta, Beven and Wagener, 2005).

Calibration is a key process in identifying the model's best parameters. To simulate runoff hydrographs, HEC-HMS requires input parameters. Certain parameters in HEC-HMS cannot be correctly measured or estimated, which is part of the conceptual model problem (Beven and Freer, 2001).

2.7 HEC-HMS Parameters

HEC-HMS has its program language as a special programme. HEC-HMS can model a single event and a continuous hydrological event. The limits of a permanent hydrological event can last months, and a single event can also be modelled for one hour. In constructing the hydrological model, it seems that the analysis of various modelling methods and the selection of the ones that may represent the most real hydrological processes (USACE, 2000).

Several factors are used to select methods for the rainfall-runoff modelling that must be observed. In this case, the preferred methods can only be based on the limited measured data, unlike metric models (Scharffenberg, 2016),

- It must be given allowance and freedom of calibration as meteorological and runoff data can be collected but it may be different in terms of the time of the event.
- It must allow a good understanding of the changes of land use effect and produce results for the difference in perviousness only.
- The methods used should also be more precisely based on the features of the terrain in the sub-catchment of Sg for various parameters.

2.7.1 Unit Hydrograph Method

Unit hydrographs are popular and commonly used empirical models of direct flow relationships with excess precipitation (Gottschalk and Weingartner, 1998). In the absence of precipitation, the hydrographs unit can be described, and the data required to get the hydrograph unit can be processed (Kar, Yang and Lee, 2015). However, the model equations and parameters have limited physical importance. Instead, they were selected through the optimization of several performance criteria. Synthetic hydrographs are also a commonly used method for analyzing precipitation. Based on (Varadharajan and Bailey, 2013), synthetic unit hydrographs belong to three categories: Synder unit hydrograph, Land Conservation Service unit hydrograph, and Clark unit hydrograph. All hydrograph models of this synthetic unit are included in the HEC-HMS (USACE, 2000).

2.7.2 Rainfall Hyetograph

A time-series data showing rainfall in the catchment area are a hyetograph. The chart usually shows the rainfall collection over an area or a measurement area in an interval. Data of rainfall are collected in Malaysia by some departments and bodies, including the weather services and DID. Data may also be collected for its purpose by other agencies like water and wastewater agencies (MSMA 2nd Edition, 2012).

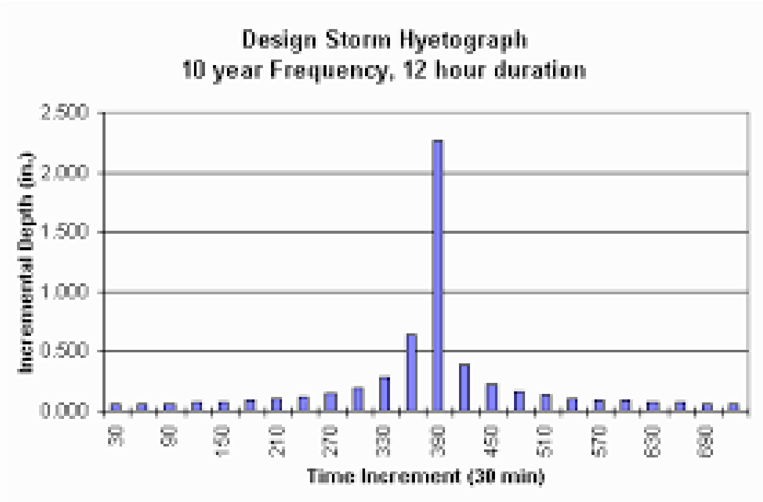

Figure 2.3 Example of Rainfall Hyetograph (Kharagpur, 2011)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology used to complete this project. The main objective of this report is to illustrate calibration and validation of the Centre for Hydrological Engineering Hydrological Modelling System (HEC-HMS) on data from the Batu Kurau River basin study area. HEC-HMS is a popular modelling tool with various computational methods to provide inflow and outflow. Since the methods in the HEC-HMS varies thus, it is crucial to plan and decide on the method of the model components. The modelling is carried out in three important steps. First, we must collect the required data for building the model of the basin and its elements. Then, the design rainfall must be calculated using MSMA 2nd Edition or other sources.

After the input is completed, compared the simulated and observed hydrograph by determining the coefficient of determination, R^2. If the R^2 is more than 0.7, then the model can be accepted. The parameters of the HEC-HMS model include the time of concentration of the catchment, the storage coefficient, and the curve number of the catchment. After that, the results will be computed, and a conclusion will be drawn from the results.

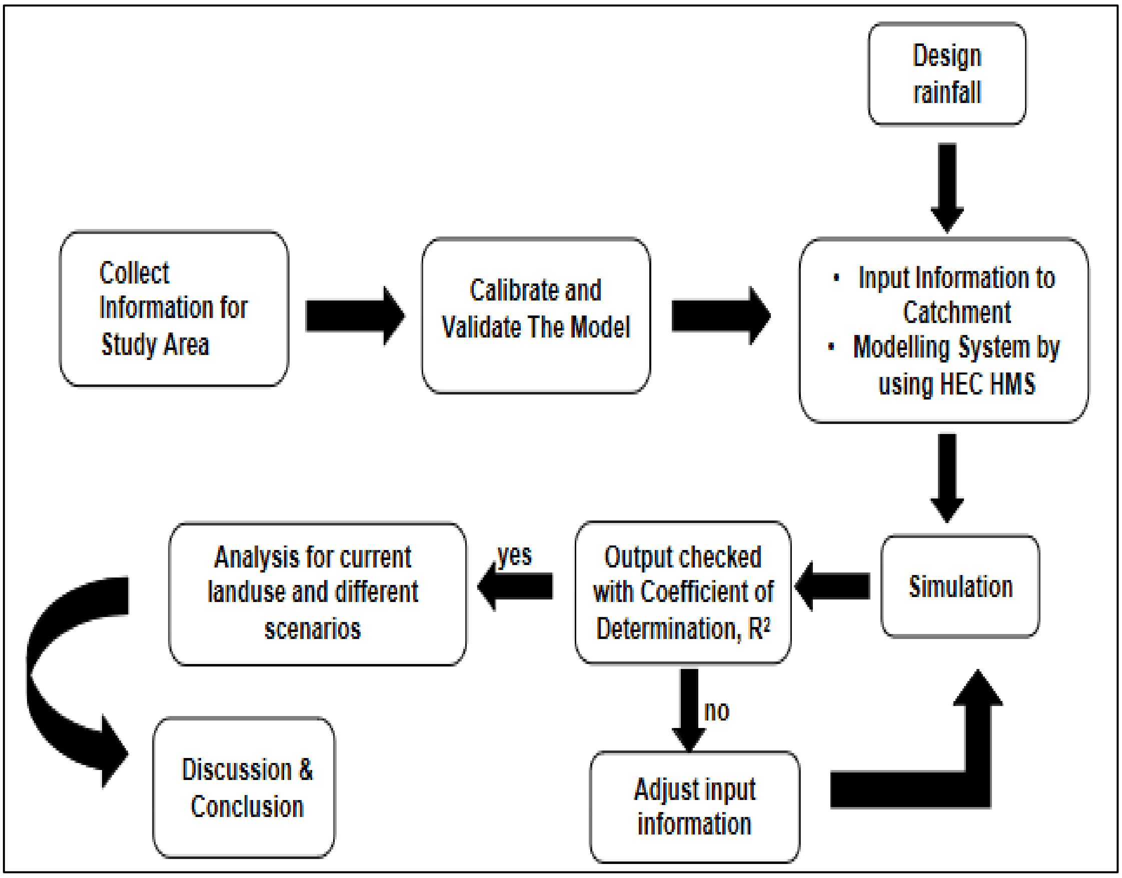

Figure 3.1 Flow Chart for HEC -HMS Modelling

3.2 Hydrologic Modelling System (HEC-HMS)

3.2.1 History

The hydrologic modelling system (HEC-HMS), like most hydrologic models, is used to formulate the relationship of precipitation (input) and runoff (output). It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, from small urban to natural watershed runoff (Hamdan et al., 2021). Hydrograph produced by the program is used directly or in conjunction with other software to study water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, flood plain regulation and system operation (Scharffenberg, 2016).

The modelling engine has drawn 30 years of experience in hydrologic simulation software. The initial program release was called version 1.0 and included most of the event simulation capabilities of the HEC-1 program. The tools for parameter estimation with optimization were much more flexible than in previous programs. Then a second major release known as Version 2.0 focused more on continuous simulation. Enhancement of the program is ongoing and HEC would continue its research in engineering needs for hydrologic simulation both in terms of simulation techniques and physical representation processes (USACE, 2000).

3.2.2 Control Specification

Control Specifications are one of the main components of a project. However, even they do not contain much parameter data. Their principal purpose is to control when simulations start and stop and what time interval is used in the simulation (Scharffenberg, 2016).

3.2.3 Watershed Physical Description

The basin model is responsible for describing the physical properties of the watershed and the topology of the stream network. It will contain the modelling components that describe infiltration, surface runoff, baseflow, channel routing, and lakes. It may additionally contain components for representing engineered structures such as diversion, reservoirs, and pump stations. It will generally be the focus of attention in performing simulations and viewing results. Thus, different development scenarios or management alternatives can be evaluated (Scharffenberg, 2016).

3.2.4 Meteorological Description

The meteorological model is responsible for resolving the boundary conditions acting in the river flow district during the simulation. Therefore, meteorological models are prepared for use with one or more basin models. If the basin model contains seabed elements, then the meteorological model must determine how precipitation will be generated for each basin. Evapotranspiration should be included in basin models configured for continuous simulation using one of the following loss methods: deficit constant, grid deficit constant, soil moisture accounting, grid soil moisture accounting (Scharffenberg, 2016).

3.2.5 Simulations Runs

Run a simulation is the main mode for running a simulation. Run a simulation is one of three components that can compute results: path simulation, optimization experiment, and analysis. Each run consists of one meteorological model, one basin model, and one control specification. Results can be viewed as graphs, summary tables, and time series tables via basin maps (Scharffenberg, 2016)

3.3 Data Collection

Data collection is the information collection and measurement process in a research field that enables the research project's results to be answered and evaluated. Information on the actual and future use of land, the hydrological groups of soil, hydrological records, the topography map, land use maps, and data deemed relevant for the study are required for the simulation process (Singh, 2018). Therefore, it is very important for the accuracy of data collection to obtain precise results and reduce the risk of an error (Jayawardena, 2020).

3.3.1 Satellite Images from Google Earth.

Figure 3.2 shows Batu Kurau's satellite images, and it is very important to get Kerian images from Google Earth before running simulations using HEC-HMS software. This is because the HEC-HMS software digitizes and utilizes satellite pictures of Sungai Kurau as well as the most common feats:

- Points
- Lines

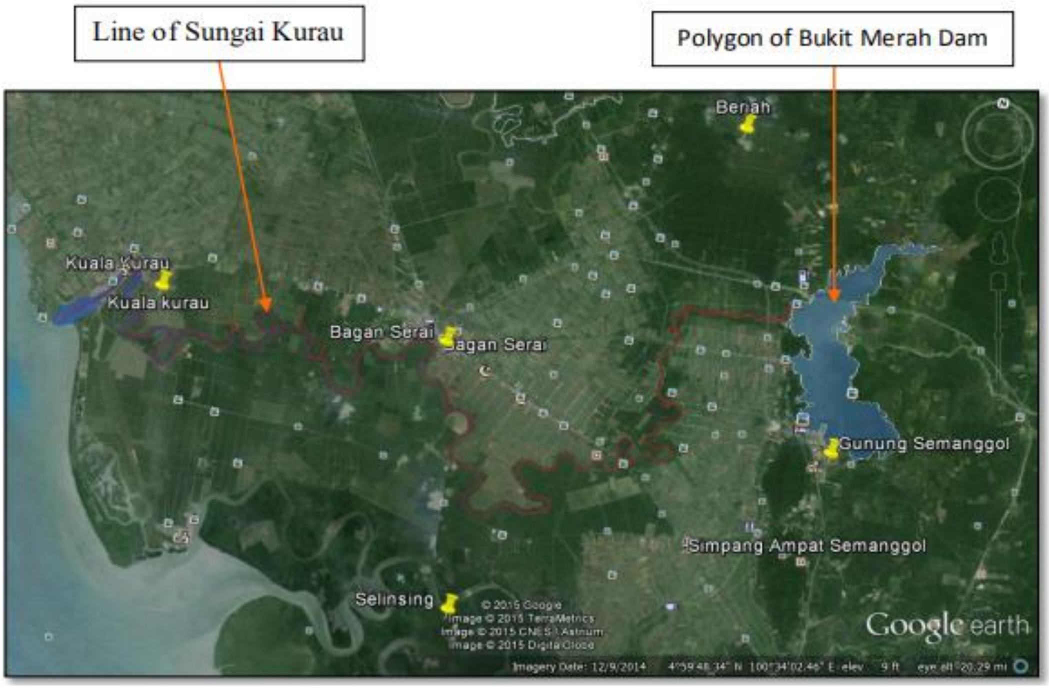

Figure 3.2 Satellite Image of Sungai Kurau by Google Earth (Kuala Kurau Map | Malaysia Google Satellite Maps, no date)

3.3.2 Collection of Rainfall data and Streamflow data

Kurau River rainfall and flow data for 2015 to 2019 were collected from Drainage and Department of Irrigation, DID. Table 3.1 and Table 3.2 shows the list of Perak Inventory Stations for rainfall data and streamflow data.

Table 3.1 Rainfall station for Sungai Kurau

Station Id	Station
5007020	Ldg. Pondokland at Pondok Tanjung

Table 3.2 Streamflow Station use in HEC-HMS model

Station Id	Station
5007421	Sg. Kurau at Pondok Tanjung

Digitalization is one of the tasks to be performed before hydrological modelling. The Kurau River satellite images from Google Earth are taken and digitalized along the river for 7.81 km in the hydrological modelling. Lines and polygons are the features used to digitize these rivers. Google Earth states that a line consists of two dots, which connect a straight line, and measures according to their length are carried out (Grossner, 2006). During the polygon tool, the perimeter and study area can be calculated by two or three points. Figure 3.3 shows where the flow and precipitation stations and sub-catchment deviation are located.