SIMULATION OF FLOOD INUNDATION MAP ASSOCIATED WITH SEDIMENT TRANSPORT FOR SUNGAI PAHANG

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SIMULATION OF FLOOD INUNDATION MAP ASSOCIATED WITH SEDIMENT TRANSPORT FOR SUNGAI PAHANG

by

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LIST OF ABBREVIATION

ADCP	Acoustic doppler current profiler
ARl	Annual recurrence interval
BRT	Buishand range test
DEM	Digital Elevation Model
DID	Department of Irrigation and Drainage
DMRC	Disaster Management and Relief Committee
DTM	Digital Terrain Model
ENSO	El Nino–Southern Oscillation
GIS	Geographic information system
IFRCRS	International Federation of Red Croos Red Cresent Societies
IFSAR	Interferometric Synthetic Aperture Radar
JICA	Japan International Cooperation Agency
JUPEM	Department of Survey and Mapping Malaysia
MK	Mann-Kendall
MRSA	Malaysia Remote Sensing Agency
NADMA	National Disaster Management Agency
NASA	National Aeronautics and Space Administration
NSC	National Security Council
NSE	Nash-Sutcliffe Efficiency
NWRS	National Water Resource Study
PDM	Probability Distributed Moisture
PTO	Fixed Operating Regulation
RBMU	River Basin Management Unit

RMSE	Root Mean Squared Error
SCP	Statistical change point
SNHT	Standard normal homogeneity test
SOPs	Standard Operating Procedures
SRTM	Shuttle Radar Topography Mission
SWE	Shallow water equations
TVD	Total Variation Diminishing
UNISDR	United Nations Office for Disaster Risk Reduction
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
VNR	Von Neumann ratio
WMO	World Meteorological Organization

LIST OF SYMBOLS

a	Intercept of the regression line
A	Flow area (m^2)
A_{gr}	Initial motion parameter
b	Exponent of store capacity (Pareto) distribution
b_e	Exponent in actual to potential evaporation rate function
b_g	Exponent of recharge function
c	The storage capacity of a point in the basin (mm)
C	Coefficient in the sediment transport formula
C_c	Coefficient of curvature
C_d	Coefficient of discharge / Spill Coefficient
C_k	Coefficient of kurtosis
C_s	Coefficient of skewness
C_u	Uniformity coefficient
C_v	Coefficient of variation
c_{min}	Minimum moisture store capacity (mm)
c_{max}	Maximum moisture store capacity (mm)
d	Average depth of flow (m)
d_i	rate of drainage from soil store (mm h^{-1})
d_{10}	Diameter for which 10 percent of material by weight passes (mm)
d_{16}	Diameter for which 16 percent of material by weight passes (mm)
d_{25}	Diameter for which 25 percent of material by weight passes (mm)

d_{30}	Diameter for which 20 percent of material by weight passes (mm)
d_{35}	Diameter for which 35 percent of material by weight passes (mm)
d_{50}	Mean sediment size / Diameter for which 50 percent of material by weight passes (mm)
d_{60}	Diameter for which 60 percent of material by weight passes (mm)
d_{65}	Diameter for which 65 percent of material by weight passes (mm)
d_{75}	Diameter for which 75 percent of material by weight passes (mm)
d_{84}	Diameter for which 84 percent of material by weight passes (mm)
d_{90}	Diameter for which 90 percent of material by weight passes (mm)
D	Sediment particle diameter (mm)
DX	Distance between spill source and sink (m)
D_{gr}	Dimensionless sediment diameter
E_i	Calculated potential evaporation (mm)
E'_i	PDM estimate of actual evaporation (mm)
f_c	Rainfall factor
$F(\ )$	The probability distribution function
F_{gr}	Sediment particle mobility
$f(c)$	Density function
g	gravitational acceleration (m/s^2)
G	Volumetric sediment transport rate (m^3/s)
Gr	Gradation coefficient

G_{gr}	Dimensionless sediment transport rate
h	Water depth (m)
$\mathrm{h_o}$	Null hypothesis
$\mathrm{h_a}$	Alternative hypothesis
k	Storage rate coefficient
k_b	Base flow time constant, controls length of recession (h mm^{2})
k_g	Groundwater recharge time constant (h $\mathrm{mm}^{\mathrm{bg-1}}$)
k_1	Time constant of surface flow storage for first (or only) linear reservoir (h)
k_2	Time constant of surface flow storage for second (if used) linear reservoir (h)
K	Conveyance
K_*	Calibration coefficient
L	Weir crest breadth (m)
m	Slope of the regression line
m_s	Sen's Slope Estimator
m_*	User defined modular limit
M	Exponent in the sediment transport formula
n	Manning's roughness coefficient
n_*	A transition parameter
N	Sample size
N_R	von Neumann ratio
N_*	Number of slope estimates m_i
NSE	Nash-Sutcliffe efficiency
P	Length of the wetted perimeter (m)

P_*	Number of tied groups
q	Lateral flow into the channel per unit length of channel (m^3/s m)
q_b	Baseflow (m^3/s)
q_c	Constant flow representing returns/abstractions, a losing or gaining system (m^3/s)
q_s	Surface runoff (m^3/s)
q_i	Observed flow (m^3/s)
q_{1D}	Source discharge per unit area (m/s)
Q	Discharge (m^3/s)
Q_i	Simulated flow (m^3/s)
Q_t	Observed flow at time t (m^3/s)
$\bar{Q}$	Mean of the observed flows over the T values of the summation (the total time steps in the monitoring period)
R	Hydraulic radius (m)
R_o	Range statistics
R^2	Correlation coefficient
R_m	Mean annual rainfall (mm)
R_{max}	Maximum annual rainfall (mm)
R_{min}	Minimum annual rainfall (mm)
$R/\sqrt{n}$	Buishand range test
RX1DAY	Monthly maximum 1-day rainfall (mm)
RX2DAY	Monthly maximum consecutive 2-day rainfall (mm)
RX5DAY	Monthly maximum consecutive 5-day rainfall (mm)
RX8DAY	Monthly maximum consecutive 8-day rainfall (mm)
RX10DAY	Monthly maximum consecutive 10-day rainfall (mm)
s_s	Specific gravity of sediment

S	Water surface slope (m/m)
S_{MK}	Man-Kendall test statistic
SD	Standard deviation
S_o	Channel slope (m/m)
$S_{o,x}$	Channel slope in the x direction (m/m)
$S_{o,y}$	Channel slope in the y direction (m/m)
S_f	Friction slope (m/m)
$S_{f,x}$	Friction slope in the x direction (m/m)
$S_{f,y}$	Friction slope in the y direction (m/m)
S_i	Given value of soil water storage across basin (mm)
S_{max}	The total possible soil moisture storage (mm)
S_t	Soil tension storage capacity (mm)
S_*	Partial sum
t	Time (h)
Δt	Time step (s)
T_o	Standard normal homogeneity test statistic
τ_d	Time delay (h)
u	Depth averaged velocity in the x direction (m/s)
u_{1d}	Velocity components of the source discharge q_{1D} in the x directions (m/s)
v	Depth averaged velocity in the y direction (m/s)
v_{1d}	Velocity components of the source discharge q_{1D} in the y directions (m/s)
V	Average flow velocity (m/s)

V_*	Shear velocity (m/s)
V_s	Settling velocity of the sediment particles
$V(t)$	Volume of direct runoff
Var	Variance
ϖ	Kinematic viscosity of water (m^2/s)
W	Water surface width (m)
x	Distance in flow direction (m)
X_k	Pettitt' test statistic
y'	Independent variable
$\bar{Y}$	Mean of the sample
z	Bed elevation (m)
λ	Bed porosity

SIMULASI PETA KEJADIAN BANJIR BERHUBUNG KAIT DENGAN PENGANGKUTAN ENDAPAN UNTUK SUNGAI PAHANG

ABSTRAK

Bencana banjir merupakan faktor utama yang mengakibatkan kematian dan kerugian ekonomi. Beberapa kajian menunjukkan risiko banjir secara global kini semakin meningkat. Kesan pembangunan yang mendadak telah meningkatkan impak hidrologi dan geomorfologi sesuatu kawasan tadahan. Peningkatan dramatik dalam permukaan air larian dan hasil enapan yang tinggi adalah dijangkakan apabila guna tanah dan perubahan permukaan tanah akibat pembangunan atau aktiviti manusia seperti pembalakan yang berlaku di kawasan lembangan sungai. Kajian ini boleh dibahagikan kepada empat (4) bahagian utama. Bahagian pertama adalah untuk menjalankan analisis trend data siri masa hujan tahunan dengan menggunakan ujian Mann-Kendall. Hasil kajian tersebut menunjukkan trend telah dikesan dari sebelas stesen hujan manakala empat (4) stesen hujan menunjukkan penurunan trend di lembangan Sungai Pahang. Bahagian kedua adalah untuk memberi gambaran keseluruhan perubahan saluran dan fenomena pengangkutan endapan di Sungai Pahang termasuk pengangkutan bahan dasar dari hulu ke muara sungai di Pekan. Perubahan profil dasar sungai adalah disebabkan oleh hakisan atau pemendapan di sepanjang Sungai Pahang telah disahkan melalui pengukuran geometri sungai yang berkait dengan perubahan spatial dalam pengangkutan endapan. Selepas banjir pada Disember 2014, taburan saiz endapan bahan dasar di Sungai Pahang adalah terdiri daripada kelikir dan pasir yang sangat kasar. Penilaian prestasi model InfoWorks PDM yang hampir berjaya menghasilkan semula hidrograf 2003 dan 2012 hingga

2014 meliputi aliran rendah dan tinggi akan ditekankan dalam bahagian ketiga penyelidikan ini. Bahagian keempat bertujuan untuk mengendalikan simulasi banjir menggunakan InfoWorks RS dengan mengambilkira pengangkutan endapan. Kawasan kejadian banjir telah dianggarkan berdasarkan reka bentuk input hydrograf bagi tempoh kala ulangan 100 tahun dan hujan ribut selama 8 hari. Perubahan permukaan air tertinggi dan dasar saluran untuk Sungai Pahang menunjukkan bahawa paras maksimum banjir dengan pemodelan pengangkutan endapan dan tanpa pemodelan pengangkutan endapan mempunyai perbezaan sekurang-kurangnya 0.30m. Perubahan yang berlaku pada paras dasar boleh menjejaskan paras banjir, seterusnya melimpahi tebing dan memberi impak kepada kawasan yang ditenggelami banjir. Kawasan banjir telah dikenalpasti meningkat sebanyak 306.84km^2 (30.21%) daripada hasil simulasi tanpa pengangkutan endapan berbanding dengan simulasi yang termasuk pengangkutan endapan. Oleh itu, hasil kajian ini menunjukkan bahawa adalah penting untuk mengambil kira pengangkutan endapan di sepanjang saluran sungai dalam ramalan kawasan kejadian banjir supaya peta banjir digital dapat dihasilkan.

SIMULATION OF FLOOD INUNDATION MAP ASSOCIATED WITH SEDIMENT TRANSPORT FOR SUNGAI PAHANG

ABSTRACT

Flood disasters are a major cause of fatalities and economic losses. Several studies indicate that global flood risk is currently increasing. Rapid urbanisation has accelerated impact on the catchment hydrology and geomorphology. When landuse and land cover change as a result of development or human activities, such as logging which takes place in river catchment areas, a dramatic increase in the surface runoff and higher sediment yield are expected. The present study can be divided into four (4) main parts. The first part is to carry out trend analysis using Mann-Kendall test for the annual rainfall time series data. The results demonstrate that increasing trends were detected for eleven (11) rainfall stations while four (4) stations showing decreasing trends in Sungai Pahang river basin. The second part attempts to give an overview of the channel changes and sediment transport phenomena in Sungai Pahang including bed material movement from the upstream of Sungai Pahang to the river mouth at Pekan. River geometry survey associated with the spatial variation in sediment transport has confirmed that changes in river bed profile occurred due to erosion or deposition along Sungai Pahang. The sediment distribution size for Sungai Pahang was found to be made up of very coarse sand and gravel after December 2014 flood. A rainfall-runoff model is developed and implemented for Sungai Pahang river basin. Performance evaluation of the InfoWorks PDM model was moderately successful in reproducing 2003 and 2012 to 2014 hydrographs covering both low and high flow, which have been the emphasis of the third part of this research. The fourth part is intended to deal with flood simulation using InfoWorks RS with the consideration of sediment transport modeling. The flood inundated area has been estimated based on the input design hydrograph of the 100-year annual recurrent interval and storm duration of 8 days. Peak water surface and channel bed changes for Sungai Pahang indicated that the maximum flood level with and without sediment transport modeling has a difference of at least 0.30m. The flooded area was identified to increase by 306.84km^2 (30.21%) from the simulations results without sediment transport compared to flood simulations with sediment transport. As a result, the current study shows that it is essential to take into account the sediment movement along the river channel for the prediction of flood inundation areas in order to produce digital flood maps.

CHAPTER ONE
INTRODUCTION

1.1 Background

Malaysia is fortunate in that historically it has not experienced natural disasters in the form of volcanoes and typhoons. The most common natural disaster frequently experienced in Malaysia is flooding. There are two catagories of flood occur in Malaysia, including monsoon floods and flash floods. Statistically, streams will equal or exceed the mean annual flood once every 2.33 years (Leopold et al., 1964). Flooding is a result of heavy or continuous rainfall exceeding the absorptive capacity of soil and the flow capacity of rivers, streams, and coastal areas. This causes a watercourse to overflow its banks onto adjacent lands. The Department of Irrigation and Drainage (DID) in Malaysia has estimated area vulnerable to flood disaster is approximately 33,298 km^2, or 10.1%, of the total land area and is affecting more than 5.677 million people which is around 21% total population of the country annually.

Several major floods have been experienced in Malaysia for the last few decades. The flood of 1926, supposedly the worst in living memory in Malaysia, affected most of Peninsular Malaysia, resulting in extensive damages to property, road systems and agricultural land and crops. In 1967 disastrous floods surged across the Kelantan, Terengganu and Perak river basins and few years later, in 1971, a catastrophic flood swept across many parts of the country, which Pahang was severely affected.

The objective of river basin studies is to draw up appropriate flood maps and also feasible projects for the respective basin areas so that their development is properly managed and that water resources management, including flood control measures, is effective and well-controlled. These studies recommend the optional flood control planning and design criteria for the respective basins. Generally, socio-economic considerations for the basin will dominate the design criteria (Chia, 2004).

Realising the need for a long-term water resources development strategy and master plan, the Malaysia Government has carried out a National Water Resources Study to develop a comprehensive and coordinated water resources development programme for the country in 1982. The study has formulated a long-term plan for flood mitigation works in various flood-prone areas of the country. In recent years, DID is more conscious of the need to carry out flood mitigation projects on a river basin basis rather than on a piecemeal basis. This kind of approach will involve a shift from the traditional thinking in terms of controlling flooding through expensive engineering structures to the more comprehensive approach of viewing the solution in terms of managing flooding by incorporating structural as well as non-structural measures.

Several major floods occurred in the last few decades in Sungai Pahang river basin, causing extensive damage and inconvenience to the community. According to records of past floods, 1926 flood was the worst flood affecting most of Peninsular Malaysia. However, official records are too insufficient to describe the condition of that flood in detail. The scale of January 1971 flood is over the 100-year annual recurrence interval (ARI) based on the hydrological probability analysis using the mean 8-day rainfall records followed by November 1988, December 1993, December 2007 and the most recent one December 2014. The sediment transport of Sungai Pahang should be well understood especially during northeast monsoon season which floods are governed by heavy and long durations of rainfall will result in the increase of discharge, bed erosion and deposition and it will cause river channel instability. Last December 2014 flood was expected to carry further sediment load from the upstream of the Sungai Pahang river basin.

1.2 Problem Statement

Two common approaches adopted in reducing the impact of flood problems have been increasingly adopted in Malaysia and these include structural and non-structural measures. The traditional approach to flood mitigation has primarily involved a structural approach to modifying flood characteristics. Whilst structural mitigation measures include river widening, deepening and straightening, with the aim being to reduce flood levels and extents, however, without adequate floodplain planning the benefit from the structural works is lost due to increased flooding from unplanned development. This approach often transfers the flooding problem further downstream. For non-structural measures, tools such as computer models can be used to quantify the effects of human interference to the river system. Such tools are widely available and are used in many countries worldwide, as well as in Malaysia (Chang et al., 2008; Leow, et al., 2009; Ab. Ghani, et al., 2010). However, the application of such tools were still limited in Malaysia because of the tools often fail to properly model the more extreme flood events, where the river flows are often supercritical. In Malaysia it is regarded as increasingly important to carry out a thorough analysis of flood events with the help of available river models to understand the flooding behavior before any structural measures are undertaken. Therefore, before any amendments are implemented within a river basin, river engineers or researchers must evaluate the potential extent and impact of flood events and advise the implementing agencies as to what steps shall to be undertaken to provide further preventative measures to avoid the anticipated flood problems that might occur (Ab. Ghani et al., 2009).

Currently, there is still no particular attempt yet in Malaysia to provide digital flood inundation maps taking into account sediment movement along the river channel. Alluvial rivers are self-regulating in the sense that they adjust their characteristics in response to any change in the environment. These environmental changes may occur naturally, such as climatic variation, human activities including damming, diversion, sand and gravel mining, channelization, bank protection and bridge construction. These changes to the river hydrology and sedimentation will in turn alter the channel morphology, which can include changes to channel cross-section, stability and capacity. Such changes will distort the natural quasi-equilibrium of a river. Ab. Ghani et. al (1998) attempts to quantify the effects of sediment movement and corresponding cross-sectional changes in producing the flood levels. Successful applications of several sediment transport models such as HEC-6 (Sinnakaudan et al., 2003), ISIS (MRC, 2005), HEC-RAS (USACE, 2015), InfoWorks (Walingford, 2012) indicate the possibility of extending the obtained results in mapping the flood prone areas by incorporating sediment transport bearing in mind the physical aspects of river ability to change its boundary (Ab. Ghani et al., 2000).

1.3 Significance of Study

Floods resulted from extreme weather events like heavy rain can have great social and economic impacts to the affected areas. Although Malaysia is experiencing tropical climate with high rainfall variability considered to be less prone to natural disasters, however Malaysia remains vulnerable to climate change and natural disasters, such as flood and land slide due to the increase in climate-related extremes events (Suhaila et al., 2010a). According to Syafrina et al. (2015), rainfall distribution within Peninsular Malaysia is highly variable temporally and spatially. Hence, it is essential to determine and investigate the rainfall trend variation for Sungai Pahang river basin as it becomes concomitant increase in our understanding in order to provide reliable climatic series for the future climate analyses and also identify the area that is hit by heavy rainfall that leads to flood and further reduce the flood impacts.

Flood propagations can be better understood by simulating the flow and water level using hydrodynamic modeling. The hydrodynamic flood routing can be recognised by the spatial complexity of the schematisation such as 1D model and 2D model. It was found that most of the available hydrological models for flood modeling are more focus on short duration (Azad, et al., 2017). As the hydrological model is event-based, calibration datasets often consist of fewer than a dozen events, each lasting a couple of days. However, the entire record of data for those stations is necessary for continuous simulation. Commonly, it is difficult to acquire lengthy and serially complete records datasets. Despite the availability of detailed topographic data, there is a lack of long-term observational data, eg. river streamflow data and complete rainfall data in many parts of the river basin especially in rural area. Therefore, it is essential to develop a rainfall-runoff model in order to produce time series of rainfall-runoff discharges, which can be used as upstream boundary conditions for the continuous long-term river modeling especially for large scale of river basin.

Due to effect of rapid urbanisation has accelerated the impact on the catchment hydrology and geomorphology, such rapid development which takes place in river basin areas will result in higher sediment yield and it will not only affects river morphology but also river channel stability, causing serious damages to hydraulic structures along the river and also becoming the main cause for serious flooding in urban areas. Due to it is very few studies dealing with the interaction of river overbank flow, sediment transport, and bed morphology exist, therefore, it is necessary to predict and evaluate the river channel stability due to the existing and future developments (Chang et al. 2008; Ab. Ghani et al. 2012).

1.4 Objectives of the Study

Sungai Pahang is the longest river in Peninsular Malaysia and flood is almost an annual event in Sungai Pahang river basin. The main objective of this study is to digitally map the flood inundation areas along Sungai Pahang using hydrodynamic model, InfoWorks RS, by taking into account of sediment movement along the river channel and flood extend in a floodplain. The specific objectives are listed as follows:

a) To determine and investigate trend variation in climatic elements of precipitation over the last 44 years since 1971 in Sungai Pahang river basin.

b) To assess characteristics and movement of sediments in the Sungai Pahang

c) To establish hydrologic and hydrodynamic modeling for continuous streamflow modeling covering low and high flow for large-scale river basin using rainfall-runoff model.

1.5 Scope of the Study

The scopes and limitations of the present study are as follows:

a) The extraction of hydraulic, sediment data and the modeling reach was limited from Kuala Tembeling to the river mouth of Sungai Pahang.

b) A semi-distributed model (Infoworks PDM) was used to determine the total catchment rainfall runoff for Sungai Pahang river basin.

c) 1D and 1D-2D coupled hydrodynamic model (Infoworks RS) was used to simulate the sediment transport and flow condition in Sungai Pahang.

d) River hydraulic data used for sediment transport modeling was limited to the availability of information and data obtained.

e) Flood events used in the study are up to 2014 based on the existing landuse of 2012 in the Sungai Pahang river basin shown in DID (2013) study report.

1.6 Organisation of the Thesis

This thesis is divided into six chapters. Chapter One provides a brief introduction and discussion on the flood in Malaysia, the objectives and scope of the study. This chapter also discusses the necessity and validity of this research. Chapter Two succinctly reviews on the various approaches of hydrological analysis, rainfall-runoff modeling in gauged and ungauged river basin and also hydrodynamic modeling incorporated with sediment transport. The chapter in this thesis addresses and provide a description of the methods used in hydrological modeling. Chapter Two also outlines a literature review of the previous works and recent developments pertaining to river flood modeling by adopting a mixed 1D-2D approach. Various research that have been conducted over a large number of sub-disciplines associated with the rainfall-runoff model and hydrodynamic model. There are several criteria in selecting a proper hydrological model, as well as hydrodynamic model.

Chapter Three gives an overview of the study area - Sungai Pahang, follow by the general research methodology adopted to achieve the ultimate objectives of this study. Details on methods, techniques and procedure of data collection, data management and data processing in the study are elaborated. Developing of the semi-distributed hydrologic model and hydrodynamic modeling incorporating sediment transport are discussed in this chapter.

Chapter Four presents the research finding throughout the study. These include results of the hydrological data analysis, followed by rainfall-runoff modeling. The impact of sediment transport modeling result is quantified and compared with the results of flood extend without any sediment transport consideration. The outcome is directed to support the decision making process regarding current and future flood management practices.

Chapter Five provides a conclusion of the research finding throughout the study and provides practical recommendations for future work. Six appendices are also provided to show the details of any relevant discussions.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The frequency of natural disasters has tripled over the last four decades (Munich Re, 2000). According to Glickman et al. (1992), floods accounted for over 30% of all disasters between 1945 and 1986. It is more than 18% of all natural disasters occur in developing countries and flooding is ranked as one of the most frequent, damaging, destructive and devastating natural disasters (IFRCRS, 1998; UNISDR, 2002).

A flood is defined as any high flow, overflow, or inundation by water that causes or threatens damage. Flooding is a natural phenomenon occurring from time to time for a river or stream, result of heavy or continuous rainfall exceeding the absorptive capacity of soil and the normal carrying capacity of rivers or streams affecting many regions around the world. This causes a watercourse to overflow its banks onto adjacent lands. According to Chia (2004), there are two types of rainfall causing flooding, i.e. moderate intensity, long duration rainfall covering a wide area and high intensity, short duration localised rainfall.

Rivers modelling study for flood analysis is considered very important technique to understand nature of river with environmental changes (Merwade et al., 2008; Gichamo et al., 2012; Md Ali et al., 2015). Sediments erode from upstream and are then transported and finally deposited at downstream thereby lowering the depth of river channel. Rivers, as a result, overflows during flooding which affects the surrounding areas. Anthropogenic interruption near river such as increasing settlements and deforestation also affects the river channel. High rainfall is one of the important factors in creating a flood which, combined with anthropogenic activities, contributes to the main channel and tributaries of the river basin causing strong downstream flood.

Flood studies and flood mapping forms the basis for better understanding of flood behavior and risk, also provides the foundation for flood risk management decisions. Development and implementation of flood studies and flood mapping impact a wide-range of key users in areas as diverse as land use planning, emergency management, and community awareness. This chapter describes the common structure in flood studies, which leads to the need of hydrology analysis, rainfall-runoff modeling and sediment transport modeling to improve our understanding of flood behavior (Figure 2.1).

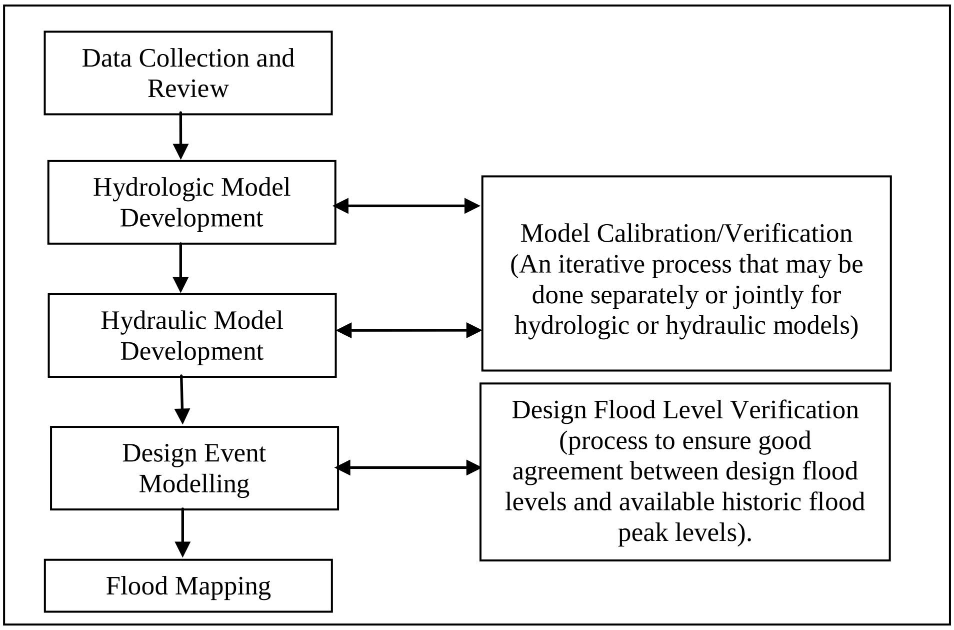

Figure 2.1: Flood study process

2.2 Extreme Events

2.2.1 World Scenario

The concern about extreme events continues to increase in the world. The main extreme events are temperature and precipitation, and these patterns are the change of frequency and intensity as a result of climate change due to human influences. Figure 2.2 summarizes the assessment of natural disasters over the world based on the reinsurance company, Munich Re’s NatCatSERVICE (Munich Re, 2017). NatCatSERVICE is an interactive online tool offers information, analyses and statistics on the development of natural disaster losses over recent decades. The trend of an increasing number of registered hydrological events worldwide has continued and this increase has been more significant since the early 1990s (Figure 2.3). In 2016, NatCatSERVICE recorded there are 750 loss events, where 130 (17%) events were very severe and severe disasters. The remaining 83% were moderate and minor loss events. By contrast, the number of hydrological events has been increased from 39% (2015) to 50% (2016), where river flooding, flash floods, and mass movement accounted for half of all disaster events worldwide in 2016.

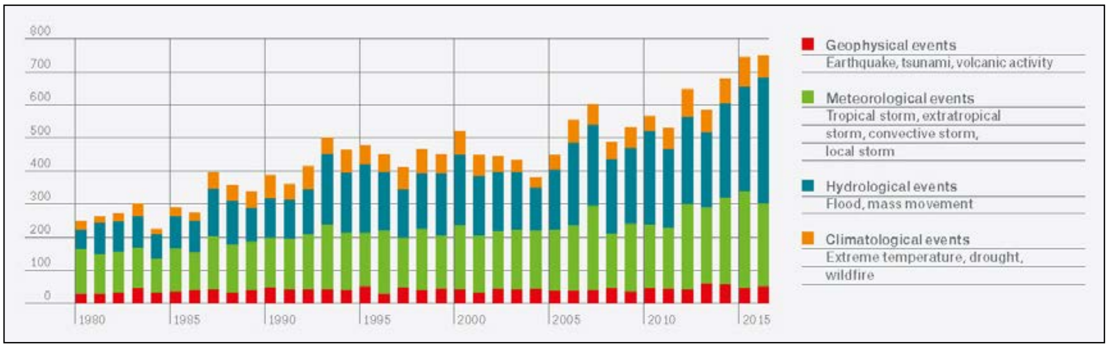

Figure 2.2: Number of loss event worldwide
(Source: Munich Re NatCatSERVICE, 2017)

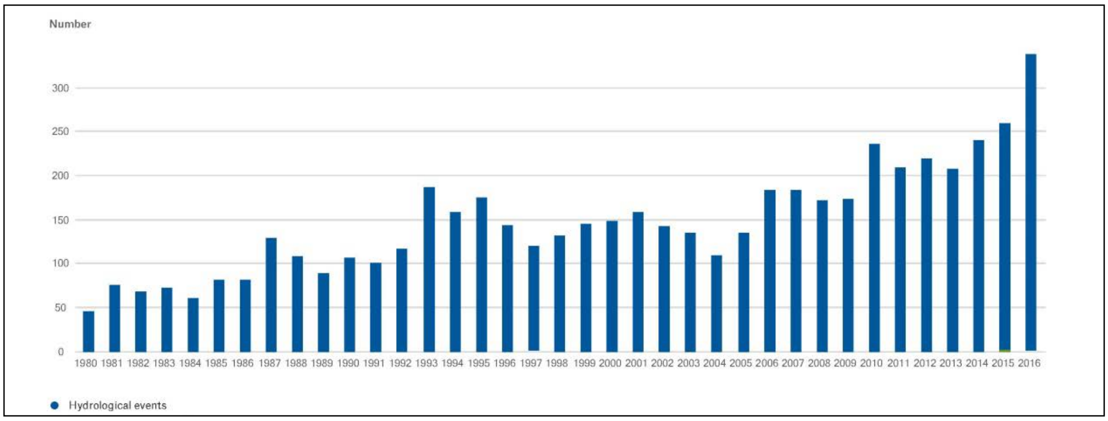

Figure 2.3: Number of flood / flash flood events worldwide
(Source: Munich Re NatCatSERVICE, 2017)

Rainfall is an important climatological variable that ensures the availability of water on earth through the hydrologic cycle and it is therefore knowledge in its changing patterns is deemed essential in the midst of ensuring water security in a changing climate. Rainfall also is the most important factor in creating a flood. In order to understand the dynamics of climate change and trends of rainfall pattern more holistically, many research and studies have been the focus the rainfall variable, such as Karmeshu (2012), Santosh & Ramesh (2013), Kiros et al. (2017), Li et al. (2017).

Global climate change is arguably changing rainfall patterns in different regions of the world. Many studies all over the world have been conducted to detect changing pattern and amounts of rainfall. In addition, global climate predictions indicated that these trends are likely to continue for several decades with obvious implications for the frequency with which river and urban flooding could occur. Novel research efforts have pushed forward the understanding and the mapping of global flood hazard (Sampson et al., 2015; Dottori et al., 2016) and finally enabling process-based modeling of river flood risk at global scale under present and future climate conditions.

2.2.2 Malaysia Scenario

Flood is one of the natural disasters most aware of in Malaysia. National Security Council (NSC) Malaysia defines a disaster under NSC Directive No. 20 as "an incident that occurs in a sudden manner, complex in nature, resulting in the loss of lives, damages to property or the environment as well as affecting the daily activities of local community". Major floods frequently isolate towns, create major disruptions to road and rail links, and result in economic loss and human suffering. Wide spread damage to houses and business premises as well as losses in agriculture are common. The main causes of flooding in Malaysia are as follows:

i. increased runoff rates due to the urbanisation;
ii. loss of flood storage as a result of development extending into and taking over flood plains and drainage corridors;
iii. inadequate drainage systems or failure of localised drainage improvement works extended insufficiently downstream;
iv. constriction at bridges and culverts that are either undersized or partially blocked by debris buildup or from other causes;
v. siltation in river and natural drainage system from indiscriminate land clearing operations;
vi. localised continuous heavy rainfall;
vii. inadequate river capacity;

viii. tidal backwater effect;

ix. phenomenon wave setup;

Disaster management in Malaysia is traditionally based almost entirely on a government-centric top-down approach (Chan, 2015). After several dramatic flooding events struck the country since the 1960s, causing substantial lives and property losses, the government had taken several positive steps and seriously planning to envisage flood mitigation projects in its national plans. The Permanent Flood Control Commission was established by a Cabinet decision on 21 December 1971 to study short-term measures to prevent the occurrence of floods and long-term measures for flood mitigation. National Security Council (NSC) Directive No. 20, which is about the policy and mechanism related to the national disaster management and relief activities promulgated in 1997 translated substantially by the establishment of the Disaster Management and Relief Committee (DMRC). DMRC to carrying out its responsibilities of NSC at the national, state and district level depending on the magnitude of disaster occurred with the combined objectives to preventing loss of human life and to reducing flood damage. In year 2015, the National Disaster Management Agency (NADMA) has been set up to coordinate government agencies in tackling disasters. NADMA is the key agency and Fixed Operating Regulation (PTO) for flood disaster management. All agencies under NADMA has their own responsibility to convey flood relief delivery system for victims when flooding occurs based on Standard Operating Procedures (SOPs).

Dates as far back as 1886, Malaysia had experienced several major flood events at the east-coast of Peninsular Malaysia and the flood in 1926 and 1967 where disastrous floods surged at the east-coast (Chia, 2004; Alias et al., 2016). A few years later in 1971, another flooding event was swept across many parts of the country. In the year 2006, 2007 and 2008, heavy monsoons rainfall again have triggered major floods along the east-coast, and most recent one is December 2014 extreme flood. Floods in Malaysia have been reported more frequently in recent years. It is therefore important to relate flood events to rainfall records to provide information on the rarity and the extreme level of the rainfall causing the floods. Based on studied done by Endo et al. (2009), Suhaila et al. (2010a), Syafrina et al. (2015) and Alang Othman et al. (2016) records on heavy rainfall amount and events were reported to have an increasing trend. Most of the major historical flood events occurred were related to the north-east monsoon season which carries abundant of rainfall to the east-coast (D/iya et al., 2014; Khan et al., 2014; Alias et al., 2016). The total amount of rainfall, frequency and average precipitation of wet days have shown increasing trend for several stations during the north-east monsoon.

2.3 Studies of Trend in Historical Rainfall Data

Statistical tools are commonly used to detect the significant of trends in climate and hydrological field. Many studies have investigated the existence of trends in observed rainfall records in different regions in the world. Findings from these studies appear to give contradictory conclusions by showing increases at some locations but also decrease at others, while some studies find no evidence for any change at all. However, it is important to gain an improved understanding if these changes have been translated into a corresponding change in river flows, by examining the presence of trend in historical rainfall records.

2.3.1 Record Length

In general, there is no clear indication on the record length that is required to perform an appropriate hydrological analysis associated with meaningful results. Table 2.1 summarised some findings/suggestions from past studies based on the quality control of hydrological dataset.

Table 2.1: Findings/suggestions from past studies based on the quality control of hydrological dataset

No	Research/Study	Findings/Suggestions
1	WMO (1989)	A climate normal is the mean of the climatological variable over a 30-year period.
2	Kundzewicz and Robson (2000)	Data series should be as long as possible. Short data series can be strongly affected by climate variability which can give misleading results. For investigation of climate change, a minimum of 50 years of record is suggested - even this may not be sufficient.
3	Manton et al. (2001)	Trends in extreme daily rainfall over the period from 1961 until 1998 were investigated using rain gauge data from 91 stations in 15 countries in Southeast Asia.
4	Robson (2002)	Proposed that typical gauged records length of 40 years or so are insufficiently long to differentiate between the impacts of climate change and climate variability.
5	Burn and Hag Elnur (2002)	Minimum record length of 25 years based on the 1960 to 1997 study period to ensure the validity of the trend results statically.
6	Kundzewicz et al. (2005)	Recommends the use of minimum record length of 50 years when examining the trend in observed data. In studying very large catchments in the US.
7	Ziegler et al. (2005)	Concluded that the record length required to detect trend due to climate change is anywhere between 60-120 years.
8	Costa and Soares (2009a)	All stations with at least at least 30 years with less than 5% of observations missing used for the homogenisation analysis.
9	Endo et al. (2009)	More than 200 stations data across Southeast Asia countries used to examine the trend in extreme precipitation indices over the period from 1950 until 2000. The analysis shows that the number of wet days tends to decrease, while average wet-day precipitation intensity shows an increasing trend in these countries.
10	Caloiero et al. (2011)	Statistical analysis has been performed over 109 cumulated rainfall series with more than 50 years of data observed in a region of Southern Italy (Calabria). The higher percentages of rainfall series show possible year changes during decade 1960 – 1970 for almost all of the temporal aggregation rainfall.
11	Jagadeesh and Anupama (2014)	Daily rainfall data of four rain gauge stations of Bharathapuzha basin, India for the period of 33 years (1976–2008) has been collected to determine trends based on the non-parametric Mann–Kendall test for the trend and the non-parametric Sen's method for the magnitude of the trend.
12	Li et al. (2017)	Long-term daily rainfall time series spanning 34 years (1980–2013) at 22 rainfall stations in Singapore are used in the study to investigate the variability and trends in precipitation extremes in a tropical urban city-state.

2.3.2 Parametric Versus Non-Parametric Methods

Analysis and modeling of time series of hydrologic data under climate variability and change can be used for evaluation of impacts and risk and commonly required in hydrologic and hydraulic engineering design. In the parametric modeling framework, this analysis involves selecting an appropriate statistical distribution before estimating the parameters of the specified distribution and quantiles. Although parametric methods (i.e. normality, linearity, and independence) achieve efficient estimation in terms of errors and biases, however the disadvantage of the methods is that the distribution of the observations must be known. Unfortunately, past studies have to rely on approximate distributions when a truly exact mathematical representation of the distribution either does not exist or is impossible to obtain using a limited set of observations. It can be hypothesised that the substitution of an approximate distribution for the exact distribution could lead to large errors in quantile estimates (He and Valeo, 2009). Furthermore, the assumption of the parametric is mostly not satisfied by hydro-climatologic data (Huth and Pokorna, 2004).

In statistical analysis, non-parametric test is considered better and it displays much insensitivity to outlier unlike parametric test (Mann, 1945). Non-parametric methods commonly were found to be suitable for skewed data and the sample size is large (Hirsch et al., 1982). This methods not only tend to be more resistant to a misbehavior of the data (e.g. outliers) but also give results close to their parametric counterparts and lay well within the confidence limits even the distributions are normal (Huth and Pokorna, 2004).

The Mann-Kendal (MK) test, also called Kendall's tau test is a statistical test widely used to assess the trend in hydrological time series. This test is a non-parametric test first proposed by Mann (1945) and was further studied by Kendall (1975) and improved by Hirsch et al. (1982, 1984). MK test used to detect monotonic trends in series of climate data or hydrological data (Bose et al., 2015) even if there is a seasonal component in the series. Therefore, the important strength of the test is that it is less prone to the effect of outliers and also can apply for a dataset that suffers from missing values, uneven sampling and non-linear trends (Birsan et al., 2005). Due to its applicability irrespective of the data distribution function present in the time series data, the assumption of normality for the random variables is not needed in using the MK test (Smith, 2000). As this method can test trends in a time series without requiring normality or linearity, MK test is highly recommended by the World Meteorological Organisation (WMO) for trend detection analysis (Mourato et al., 2010).

Many research and studies used non-parametric method around the world and the results were satisfactory (Zhang et al., 2000; Xu, 2003; Huth and Pokorna, 2004; Bani-Domi, 2005; Partal and Kalya, 2006). For instance, Karmeshu (2012) studied trends in annual precipitation for nine states in the Northeastern United States using MK test. The MK test demonstrated that there is an increasing trend in precipitation in only six states. The trend lines in general identify a trend towards decreased number of rainy days throughout the basin, which is associated with decrease in the duration of the wet season. Al-Houri (2014) carried out trend detection using time series plots and also MK test, while Kiros (2017) used linear trend and MK test for Amman-Zarqa Basin in Jordan based on daily rainfall data available for 15 rainfall gauge stations. Both analyses showed trend towards decreased duration of the wet season associated with decreased number of rainy days for most of the stations. Furthermore, there is an increasing trend in the maximum and average daily rainfall for most of the stations. MK test, on the other hand, demonstrated that none of the parameters under the study showed statistically significant trends.

Besides that, many researchers in Malaysia used statistical approach to their study related to investigating changes in intensity and frequency and analysed for trends in extreme rainfall events (Wong, et al., 2009; Suhaila et al., 2010a; Syafrina et al., 2015; Lin et al., 2015; Mayowa, et al., 2015; Che Ros et al., 2016). For instance, Syafrina et al. (2015) used non-parametric test to analyse rainfall trends and found that hourly extreme rainfall events in Peninsular Malaysia showed an increasing trend with notable increasing trends in short temporal rainfall. Mayowa, et al. (2015) used MK test and the Sen’s slope method to examine trends in rainfall based on the 40 years (1971–2010) rainfall data from 54 rainfall stations distributed over the east coast of Peninsular Malaysia. The results generated from the analysis showed that it was a substantial increase in the annual and North East monsoon rainfall.

A study by Che Ros et al. (2016) for Sungai Kelantan river basin firstly investigated the homogeneity (using four absolute homogeneity tests: the Pettitt test, standard normal homogeneity test (SNHT), Buishand range (BR) test, and von Neumann ratio (VNR) test). Time series data were verified by homogeneity test for the purpose of constructing a reliable database for various hydrologic analyses. Then a trend analysis of annual rainfall variability was conducted by using MK test based on the 30-year sampling of homogenous time-series rainfall data. In general, the homogeneity or inhomogeneity nature of the data should be verified in using measured climatological data, (i.e. rainfall data). A climatic series is said to be homogenous when variations recorded in the time series are truly due to climatic variations (Lazaro et al., 2001) but not due to measurement errors or conditions around observation sites (Kang and Yusof, 2012). The trend analysis results showed a decreasing trend in 1957–1987 and increasing trends in 1981–2011 for Sungai Kelantan river basin.

2.4 Hydrological Modeling

Rainfall is the main sources of water input to the river basin where it is influenced by the water storage and discharge of a river, especially during the rainfall event. On the other hand, study of rainfall distribution during the flood event is crucial because it can provide numerous influence to a better understanding of rainfall in the river basin and leads to better decision making in order to mitigate the factors of flooding events. In general, hydrological models are often referred to as ‘Rainfall-Runoff’ models, since they use rainfall data to estimate runoff or river discharge. In other words, the hydrological model uses input parameters (basin parameters and rainfall characteristics) and as the output gives runoff characteristics for this particular basin. One of the outputs of hydrological calculation is a discharge hydrograph. The discharge hydrograph presents stormwater flow as a function of flow rate over the time at a given location. A hydrograph is a graphical representation of the river discharge or streamflow reaction to precipitations (Figure 2.4).

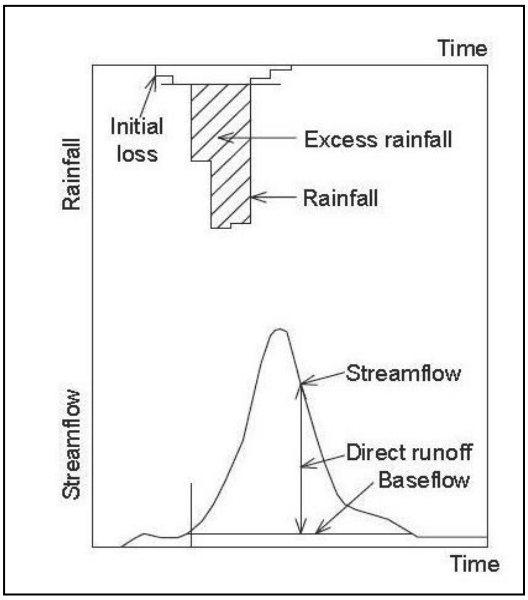

Figure 2.4: Discharge hydrograph form rain event
(Modified from Chow et al., 1988)

There are two categories of hydrological model: the simple "empirical" or "black box" models, those that seek to verify observations using historical data, for instant the rational method, are based on mathematical equations that relate input variables with output variables on an empirical basis without much concern to the processes within the model; and the more complex "conceptual" or "physically-based" models which represent individual hydrological processes based on the fundamental physics and governing equations to compatible physical processes in the hydrological cycle. Hydrologic modeling has been classified in various ways and one such classification distinguishes the hydrologic simulation modeling systems as lumped parameter, semi-distributed parameter, or distributed parameter models. Majority of the lumped parameter models are based on empirical methods whereas more recent distributed models are physically based. The three model categories are presented graphically in Figure 2.5.

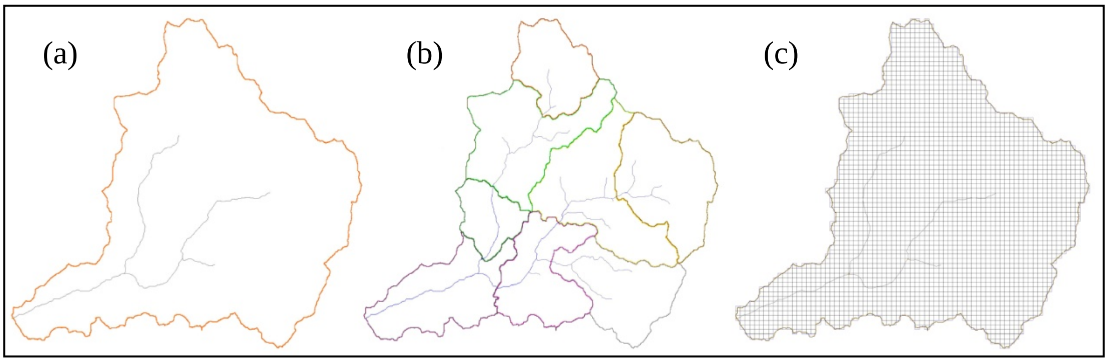

Figure 2.5: Graphic representation of (a) Lumped, (b) Semi-distributed and (c) Distributed models

2.4.1 Lumped Hydrologic Models

A numerical formulation that represents a river basin as a single homogeneous unit and develops a single outflow hydrograph is referred to as a lumped model (Jones, 1997). Lumped models were developed since the 1960s (e.g. the Stanford catchment model (Crawford and Lindsey, 1966)). According to Abbot and Refsgaard (1996), a lumped model is a model where the river basin is regarded as one unit and variables and parameters in the model represent a model average or effective values for the entire drainage area. Many researchers have proven to be successful in simulating an observed flow hydrograph using are simple lumped parameter models, due to these models require fewer parameters or data to be defined and calibrated for their operation.

The applicability lumped model is limited to gauged river basin as the expected conditions are within the historical data used for calibration and no significant change in river basin conditions has occurred (Reed et al., 2004). Lumped models make the assumptions that rainfall is uniformly distributed over a river basin including uniform soil types, vegetation types and land use practices. Blackie and Eeles (1985) defined a list of the cases where the lumped models are more suitable:

- Quality control and filling in of missing data;
- Extensions of historic flow records;
- Generation of synthetic data runs for civil engineering design work and other applications;
- Water resources assessment;
- Water resources management including real-time forecasting.

2.4.2 Semi-Distributed Hydrologic Models

The semi-distributed models discretise the river basin into homogeneous sub-basins based on the topography or drainage area. The infiltration or rainfall parameters are treated as homogeneous within each sub-basin and the runoff is determined (Biftu and Gan, 2001). Whether a model is defined as lumped or distributed depends upon whether the modeling domain is sub-divided. They were initially developed to combine the advantages of both lumped and distributed models. If the river basin being modeled is divided into smaller computational elements (sub-basins), then the lumped sub-basin models that represent spatially variable parameters and conditions as a series of sub-basins with average characteristics are formed. This model configuration is called a semi-distributed model (Hunter et al., 2002). Semi-distributed models are commonly used in the operative hydrologic forecast services because of their well-balanced ratio between the model spatial accuracy and duration of simulation and calibration effort.