NUMERICAL SIMULATION OF MUDFLOW INTERACTION WITH SABO-DAM BY USING TWO-DIMENSIONAL DEPTH-AVERAGED 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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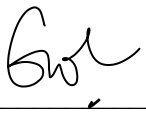

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ABSTRAK

Aliran lumpur adalah fenomena geologi yang dicirikan oleh tanah runtuh yang bergerak pantas yang mengancam nyawa dan harta benda dengan memusnahkan segala-galanya di laluan mereka tanpa sebarang amaran. Aliran lumpur mempunyai kepekatan yang lebih tinggi bagi sedimen zarah halus dalam cecair terdiri daripada sebahagian besar zarah halus, kelodak, pasir dan tanah liat. Sabo-dam merupakan salah satu kaedah mitigasi yang dipilih untuk mengatasi aliran lumpur di Malaysia. Kajian ini bermotivasi oleh keperluan untuk mengurangkan kesan bencana aliran lumpur yang lazimnya dicetuskan akibat paras hujan yang lebat, penebangan hutan yang tidak terkawal dan penggunaan tanah di tanah tinggi. Model purata kedalaman dua dimensi (DA-CIP-2D) dengan skema Profil Interpolasi Terkandas (CIP) telah dibangunkan untuk mensimulasikan aliran lumpur menggunakan data topografi Batu Hampar, Gunung Jerai, Kedah. Model DA-CIP-2D telah disahkan dengan model empangan-pecah-sebahagian terhadap penyelesaian analisis dan kemudian model rheologi telah disahkan terhadap data eksperimen daripada kajian literatur. DA-CIP-2D yang disahkan telah digunakan untuk mensimulasikan aliran lumpur dan interaksinya dengan empangan Sabo. Keputusan menunjukkan keupayaan model untuk mensimulasikan aliran lumpur dengan kehadiran empangan Sabo. Kesan ketinggian empangan Sabo dalam mengurangkan halaju puncak, puncak kedalaman aliran, dan masa ketibaan dapat ditunjukkan dengan baik melalui model DA-CIP-2D. Dengan struktur Sabo 6.0 m, halaju puncak, kedalaman aliran puncak dan panjang alir akhir boleh dikurangkan sebanyak 21.2%, 6.5% dan 5.5% masing-masing. Peningkatan ketinggian struktur Sabo boleh mengurangkan lagi halaju puncak dan kedalaman aliran puncak, tetapi dengan mengorbankan peningkatan risiko banjir di bahagian hulu struktur Sabo.

ABSTRACT

Mudflow is a geological phenomenon characterized by fast-moving landslides that are threatening to life and property by destroying everything on their path without any warning. Mudflow has a higher concentration of fine particle sediments in fluid, in which, the sediment grains consist of significant portion of fine particles, silts, sands and clay. Sabo-dam is one of the selected mitigation methods to overcome mudflow in Malaysia. This research is motivated by the need to mitigate the effects of mudflow disasters which are normally triggered due to intense rainfall level, uncontrolled deforestation and land use of highland. A two-dimensional depth-averaged model (DA-CIP-2D) with Constrained Interpolation Profile (CIP) scheme was developed to simulate mudflow using the topography data of Batu Hampar, Gunung Jerai, Kedah. The DA-CIP-2D model was verified with partial dam-break problem against analytical solution and then the rheological model was validated against experimental data from literature study. The validated DA-CIP-2D was used to simulate mudflow and its interaction with Sabo-dam. Results demonstrated the ability of the model to simulate mudflow with the presence of Sabo-dam. The effect of Sabo-dam height in mitigating the peak velocity and peak flow depth, and their arrival time was well demonstrated by using the DA-CIP-2D model. With a 6.0 m Sabo structure, the peak velocity, peak flow depth and final runout length can be reduced by as much as 21.2%, 6.5% and 5.5% respectively. Increasing the height Sabo structure could further mitigate the peak velocity and peak flow depth, but at the expense of increasing the chances of flooding at the upstream part of the Sabo structure.

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LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamics
CIP	Constrained Interpolation Profile
DEM	Digital Elevation Model
FDM	Finite Difference Method
NAHRIM	National Water Research Institute of Malaysia
SOR	Successive Over Relaxation

NOMENCLATURES

μ	Dynamic viscosity
η	Plastic viscosity
ν	Kinematic viscosity
τ	Shear stress
τ_y	Yield stress
ρ	Fluid density
P	Flow pressure
t	Time
g_x	Gravitational acceleration in x-direction
g_y	Gravitational acceleration in y-direction
$\boldsymbol{V}$	Velocity vector
$\boldsymbol{g}$	Gravitational acceleration vector
$\boldsymbol{\sigma}$	Stress tensor

CHAPTER 1

INTRODUCTION

1.1. Background

Computational Fluid Dynamics (CFD) is the process of mathematically modeling a physical phenomenon involving fluid flow and solving it numerically by utilizing computational skills. Application of computational fluid dynamics has revolutionized many different fields such as geotechnical, hydraulic and fire engineering and other industries since the late 20th century.

Mudflow is a geological phenomenon characterized by fast-moving landslides, which is driven by the force of gravity. Mudflow has a higher concentration of fine particle sediments in fluid, in which, the sediment grains consist of significant portion of fine particles, silts, sands and clay. For hyper-concentrated fluid, the flow is termed mudflow if the content of clay particle ($\leqslant 40\mu m$) is high, and the term debris flow is used when the content is low. (Coussot and Laigle, cited in Puay et al., 2016).

Sabo-dam is one of the selected mitigation methods to overcome mudflow in Malaysia. Sabo-dam is one type of check dam which is an erosion control structure that can be constructed by rocks, logs, reinforce concrete, or other suitable product that is placed across a natural or man-made channel or swale. The Sabo-dam can reduce the flow velocity and prevent sediment or debris from passing through it and allow those sediment to accumulate and trap behind the dam which decreases the steepness of the stream. For steep topography, the downstream channel may be stepped to contribute to further energy dissipation.

This research can achieve Goal 6 – *Clean Water and Sanitation* and Goal 13 – *Climate Action* of the Sustainable Development Goals (SDGs) stated by UNESCO.

Goal 6 which is ensure availability and sustainable management of water and sanitation for all. By constructing the Sabo-dam can overcome the infiltration of slurries problem and pollution of downstream water supplies occurred by mudflow and debris flow. Whereas Goal 13 which is take urgent action to combat climate change and its impacts. Climate change also one of the causes for the mudflow event, while the construction of Sabo-dam can overcome the problems of infiltration of slurries and pollution of downstream water supplies occurred by mudflow and debris flow. This research can significantly reduce the cost of water treatment of the water supplies.

In this research, a hydrodynamic numerical model (two-dimensional depth-averaged model) based on depth-averaged equations were developed and used to simulate mudflow interaction with Sabo-dam. First, the model is verified with partial dam-break problem against analytical solution and then the model is validated against experimental data from literature study. Finally, the numerical model is used to study the efficiency of Sabo-dam in reducing the mudflow speed, run-out distance, arrival time and flow depth.

1.2. Problem Statement

Mudflow is usually triggered by intense rainfall, dam-break or glacial outburst floods, or by land sliding that may or may not be associated with intense rain or earthquakes. These phenomena usually occur at the highland region of Malaysia, such as at Cameron Highlands, Ulu Klang, Baling, and Gunung Jerai. (Figure 1.1 to 1.4)

Recently, serious flooding incidents were reported at several areas in Northern Region of Peninsular Malaysia with unusual rainfall intensity which 281 mm in 6 hours exceeding 70-years Average Recurrence Interval (ARI) on 18th August 2021. From the perspective of geological, old dormant landslide is one of the main contributing factor

for this mudflow occurrence. Mudflow was triggered at Gunung Jerai, Yan, Kedah on 18th August 2021 at 09:30 UTC (18th August 2021 at 17:30 Malaysia Standard Time). The heavy downpour caused water surges and landslides on Gunung Jerai that later hit Yan, Kuala Muda, and Bandar Baharu district in Kedah with mudflow.

The surrounding location of Gunung Jerai Resort was severely damaged. Difficulty in road access from the affected mudflow sites hampered the search and rescue of the casualties believed to have drowned and been swept away by the strong current. This incident has affected approximately 879 families (4,395 people) in the affected area of Yan district and 86 families (430 people) in Kubang Pasu district. The data collected is based on the district office in Yan and Kuala Muda as of 22nd August 2021. (Mohd. Husni, 2021)

In order to mitigate the effects of mudflow phenomenon, two-dimensional depth-averaged model were developed and used to simulate and study the mudflow interaction with Sabo-dam. A comprehensive CFD model capable of simulating the flow of mudflow under different combination of rheological properties and boundary conditions is defined. Various of useful parameters such as mudflow speed, run-out distance, arrival time and flow depth can be used to evaluate the efficiency of Sabo-dam. Besides, supervisory control and data acquisition (SCADA) system can be implemented on site with network of intelligent devices with the first system through smart sensors and control outputs which can used to measure and control specific elements of the first system in the future.

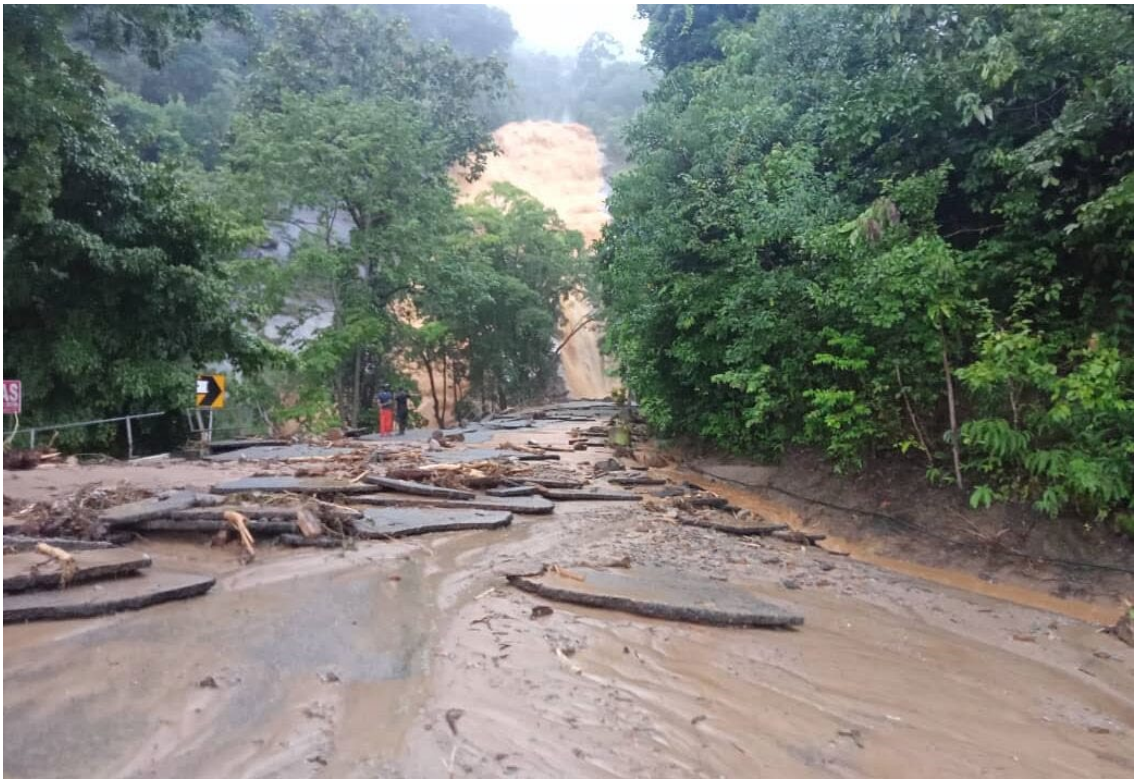

Figure 1.1: Mudflow Struck Seri Perigi, Gunung Jerai on 18th August 2021 (Mohd. Husni, 2021)

Figure 1.2: Mud and Debris Left on Site Near Titi Hayun, Gunung Jerai (Captured on 17th March 2022)

Figure 1.3: Size of Transport Material with Palm for Scaling Purposes (Captured on 17th March 2022)

Figure 1.4: Mudflow Struck Kampung Iboi, Baling (Captured on 7th July 2022)

1.3. Objectives

The following objectives are set in this study in accordance with the main concern as stated in the problem statement.

- To develop a two-dimensional depth-averaged model (DA-CIP) to simulate mudflow with suitable rheological model for mudflow.
- To evaluate the efficiency of Sabo-dam in mudflow mitigation.

1.4. Scope of Study

This study focuses on the numerical simulation of mudflow with high concentration of mud and its interaction with a simplified Sabo-dam. A two-dimensional depth-averaged model is selected to simulate mudflow. Topography data at Batu Hampar, Gunung Jerai, Kedah (5° 46' 33.79" N, 100° 23' 56.7" E) is used in the simulation of mudflow scenario. Batu Hampar is one of the locations where mudflow occur at Gunung Jerai, Yan, Kedah on 18th August 2021. The topography data is obtained in the form of DEM from National Water Research Institute of Malaysia (NAHRIM), and it is shown in Figure 1.5. The location of Batu Hampar is shown on Google Map in Figure 1.6. The satellite view of Batu Hampar area is shown in Figure 1.7.

Due to the lack of data on the type of mudflow that occurred in Gunung Jerai, this study assumed that the mudflow is highly concentrated with fine material. In addition, the model could not be calibrated because there is lack of data from the mudflow incident, i.e., peak discharge, arrival time and flow extend of the mudflow. In this study, only a simple Sabo-dam design is proposed to study the efficiency of the Sabo-dam in mitigating the mudflow phenomenon.

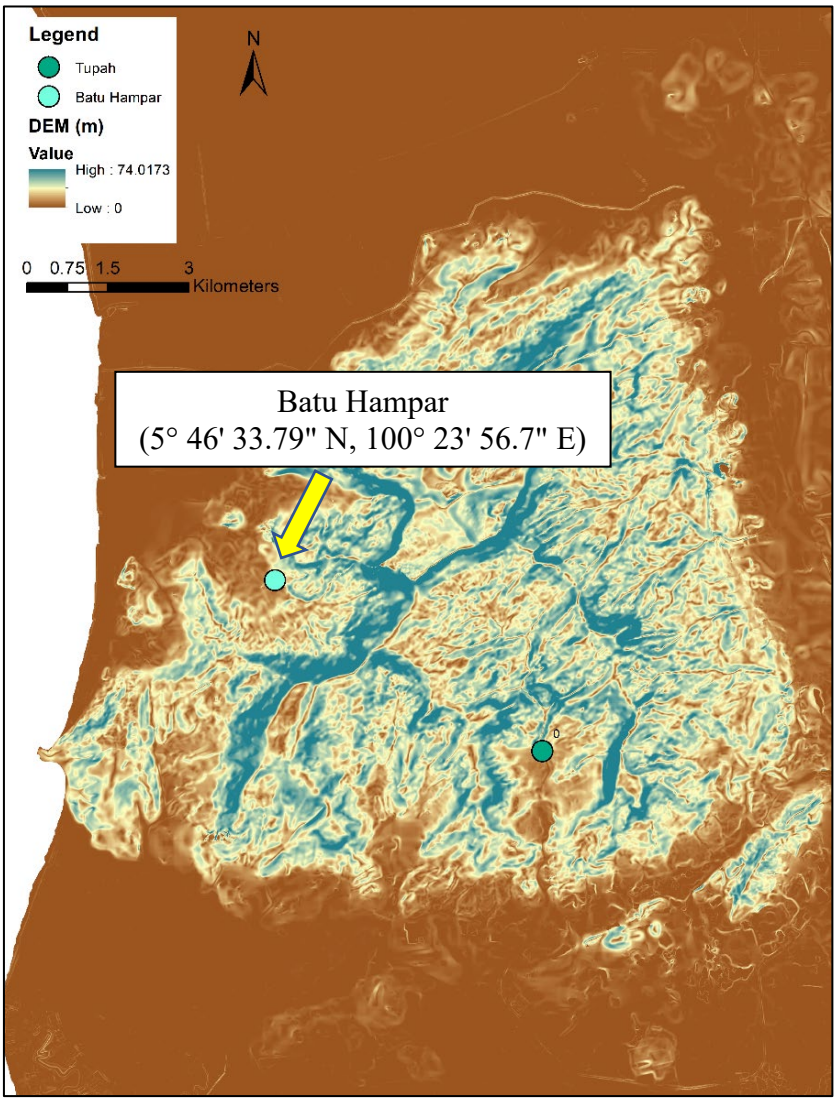

Figure 1.5: DEM Data Obtained from NAHRIM Showing the Location of Batu Hampar and Tupah.

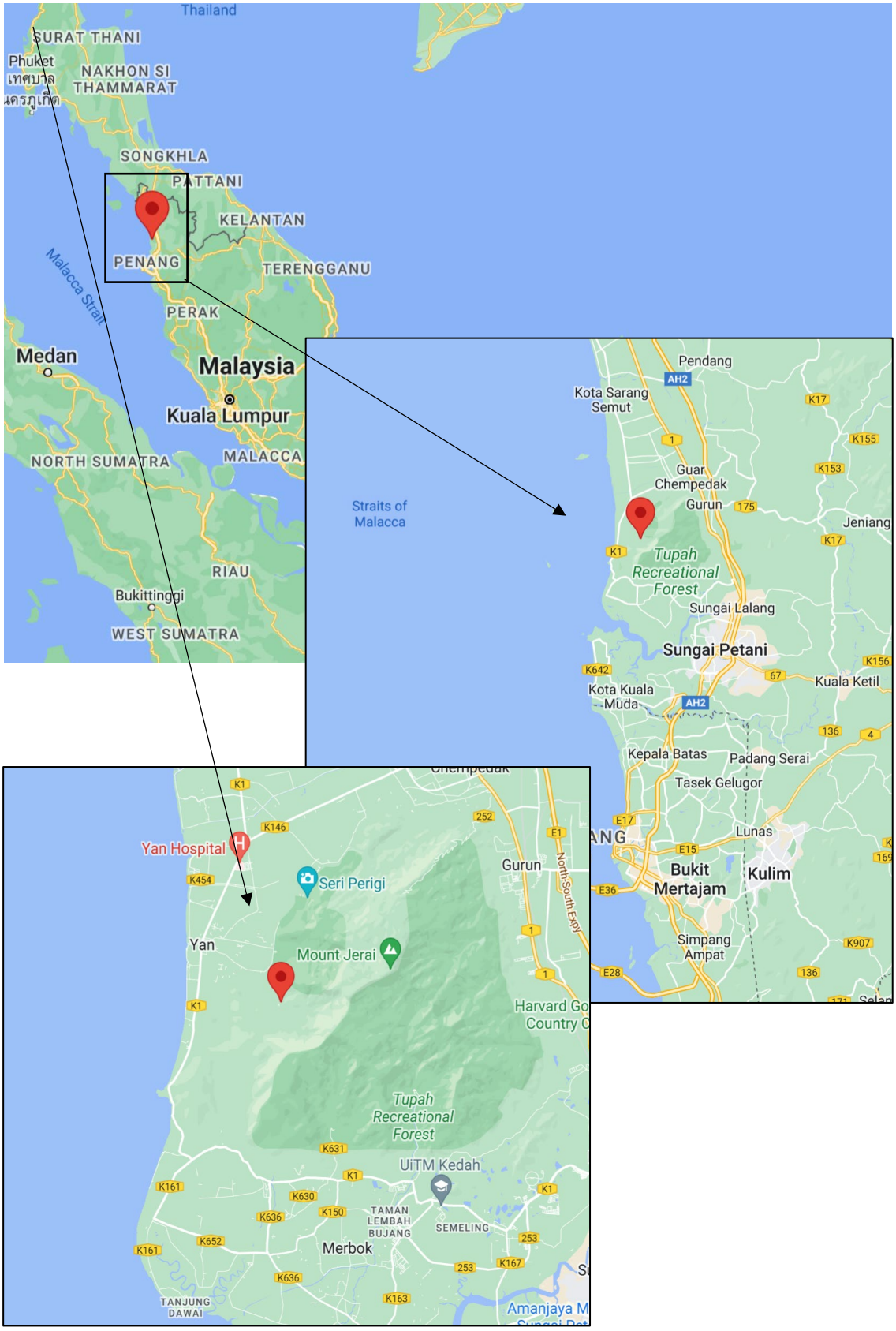

Figure 1.6: Location of Batu Hampar

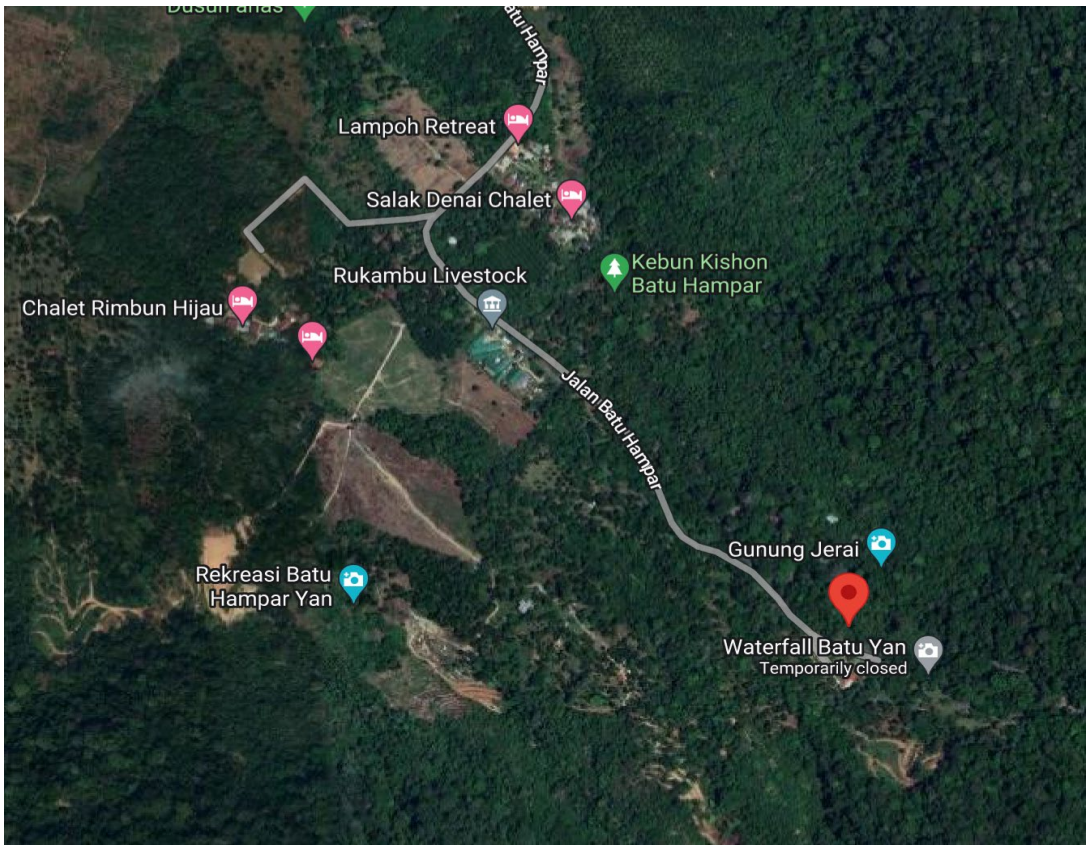

Figure 1.7: Satellite View of Batu Hampar Area

1.5. Dissertation Outline

The thesis has been organized in five chapters. A brief outline of the chapters is as follows:

Chapter 1 contains the introduction of the thesis. It gives foreword about the computational fluid dynamics and phenomena of mudflow. The chapter gives an overview of the thesis including four important elements: background of the research, problem statement, objective of the study and scope of study.

Chapter 2 is enriched with throughout and extensive literature reviews of the study. The chapters provide important theoretical and methodological understanding of related topics based on various research.