



# **GEOLOGY AND FLOOD HAZARD ANALYSIS IN KUALA KRAI, KELANTAN**

by

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## DECLARATION

I declare that this thesis entitled “GEOLOGY AND FLOOD HAZARD ANALYSIS IN KUALA KRAI, KELANTAN” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

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# **Geology And Flood Hazard Analysis in Sungai Sok, Kuala Krai,**

## **Kelantan**

### **ABSTRACT**

Over the years, floods have emerged as one of world's most devastating events. Kelantan is one of the impacted states in Malaysia where the Northeast Monsoon produce flooding in several district from October to March as a result of severe rainfall. The research was conducted at Sungai Sok, Kuala Krai, Kelantan and the study area covers about 25km<sup>2</sup> which aligned along latitude 5°23'30.00"N to 5°20'48.00"N and longitude 102°16'00"E to 102°18'48.00"E. The objectives of the research are to produce the geological map of Sungai Sok, Kuala Krai, Kelantan with scale 1:25000 and to generate flood hazard map using different parameter. Due to the limited information about the geological features, geological mapping has been conducted and structural data such as strike and dip, lithology, joint and the other geological features were collected. Flood hazard map was constructed by collecting and evaluating data on all flood-related factor, such as flow length (rainfall and water level), elevation, slope, land use and river distance. The parameter that triggered floods in Sungai Sok area were analysed. In order to achieve objectives, Weighted Overlay Method (WOM) and Geographic Information System (GIS) were used as tools. From the weighted technique tools, the data were processed in ArcGIS software which enables the production of a flood hazard map by superimposing one map image over another as well as displays low, medium, and high-level flood zonation map. The results show the potential flood area in near future were determined accurately and this research can give essential information containing strategy development and planning adaptation which can be provided by a reasonable flood risk analysis.

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**Geologi dan Analisis Bahaya Banjir di Sungai Sok, Kuala Krai,  
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**ABSTRAK**

Selama bertahun-tahun, banjir telah muncul sebagai salah satu peristiwa paling dahsyat di dunia. Kelantan merupakan antara negeri yang terjejas di Malaysia di mana Monsun Timur Laut mengakibatkan banjir di beberapa daerah dari Oktober hingga Mac akibat hujan lebat. Penyelidikan dijalankan di Sungai Sok, Kuala Krai, Kelantan dan kawasan kajian meliputi kira-kira 25km<sup>2</sup> yang sejajar sepanjang latitud 5°23'30.00"N hingga 5°20'48.00"N dan longitud 102°16'00"E hingga 102° 18'48.00"E. Objektif kajian adalah untuk menghasilkan peta geologi Sungai Sok, Kuala Krai, Kelantan dengan skala 1:25000 dan menjana peta bahaya banjir berdasarkan faktor banjir yang berbeza. Oleh kerana maklumat yang terhad tentang ciri geologi, pemetaan geologi telah dijalankan dan data struktur seperti mogok dan celup, litologi, sendi dan ciri geologi yang lain telah dikumpulkan. Peta bahaya banjir telah dibina dengan mengumpul dan menilai data mengenai semua faktor berkaitan banjir, seperti panjang aliran (curahan hujan dan paras air), ketinggian, cerun, guna tanah dan jarak sungai. Parameter yang mencetuskan banjir di kawasan Sungai Sok telah dianalisis. Bagi mencapai objektif, Weighted Overlay Method (WOM) dan Geographic Information System (GIS) telah digunakan sebagai alat. Daripada alat teknik berwajaran, data telah diproses dalam perisian ArcGIS yang membolehkan penghasilan peta bahaya banjir dengan menindih satu imej peta di atas imej peta yang lain serta memaparkan peta zon banjir peringkat rendah, sederhana dan tinggi. Keputusan menunjukkan potensi kawasan banjir dalam masa terdekat telah ditentukan dengan tepat dan penyelidikan ini boleh memberi maklumat penting yang mengandungi pembangunan strategi dan penyesuaian perancangan yang boleh disediakan oleh analisis risiko banjir yang munasabah.

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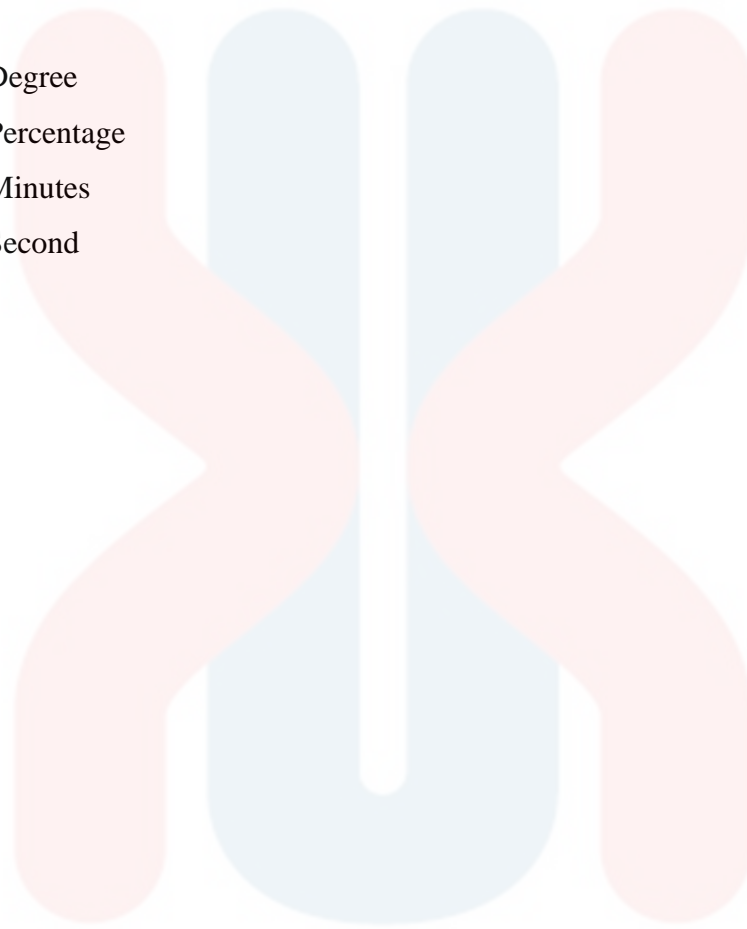
## LIST OF ABBREVIATIONS

<b>DEM</b>	Digital Elevation Model
<b>GIS</b>	Geographical Information System
<b>GPS</b>	Global Positioning System
<b>USGS</b>	US Geological Survey Earth Resources and Science Centre
<b>WOM</b>	Weighted Overlay Methods

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## LIST OF SYMBOLS

°	Degree
%	Percentage
'	Minutes
”	Second



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## CHAPTER 1

### INTRODUCTION

#### 1.1 General Background

This research entitled “Geology and Flood Hazard Analysis in Kuala Krai, Kelantan”. Sungai Sok, Kuala Krai, Kelantan is located in the east zone of Kuala Krai district. This study emphasizes on two aspects which is geology and flood hazard analysis.

The geology component encompasses a wide range of subfields, including lithology, geomorphology, structural geology, topography, and others. Geology has the potential to shed light on the long and eventful history of Earth and the state of the planet in the past. Malaysia is on the Sunda tectonic block, which encompasses most of Southeast Asia (Simons et. al, 2007). Previously, Malaysia was regarded to be located on a continent that was generally free of catastrophic plate tectonic events like as earthquakes and volcanic eruptions (Vigny et. al., 2005).

Throughout the fieldwork, geological phenomena such as folding, and faulting were recorded by traversing and sampling. Besides, additional information such as site of the outcrop, the strike and dip, the lithology and sedimentary structure, and other geological features was also identified. During geological mapping, fresh samples were gathered for petrographic investigation and thin section evaluation.

Geological map of the study area in a 1:25,000-scale was created as the result of the general geology investigation.

Floods are the most common water-related disaster worldwide. Ibrahim (2007) defines a flood as a considerable rise in a river, lake, basin, or beach. Malaysia experience flash and monsoon flood that caused by rain, wind, and human activities (logging, settlement, and agriculture) (Musa G, 2014). Monsoon floods is most common natural disaster in Peninsular Malaysia's especially in Kelantan, Terengganu, Pahang, and Johor due to heavy rain from November to March. Monsoon floods, except flash floods, may be predicted. Repercussions include property damage and loss, death, pollution, social disruption, and health difficulties. Long-term flooding damages property (Bari, 2021).

At the end of 2014, several districts in Kelantan have been hit by floods following heavy rain over the past few days. According to (The Star Online, 2022), Kuala Krai was among the district badly affected by floods which caused residents suffered losses due to damaged properties such as houses, vehicles, and furniture. Besides heavy rainfall, other unexplained causes of flooding caused panic and confusion among the public. Therefore, the causal factors of the flood must be investigated. There is a need of flood analysis study especially in densely populated areas as an alternative for early preparation or prevention for society during monsoon season.

Geographic Information System (GIS) is an effective tool to complete the research, hence it plays an important role in flood mapping investigations. In addition

to giving information on land use planning, GIS can combine data from several sources. GIS may provide several advantages in urban planning. Enhanced mapping and analysis, faster and more intense access, higher information acquisition efficiency, and improved service quality are a few examples (Infotech,2020). ArcGIS software can generate detailed maps with an abundance of information that make it easy to spot potential dangers.

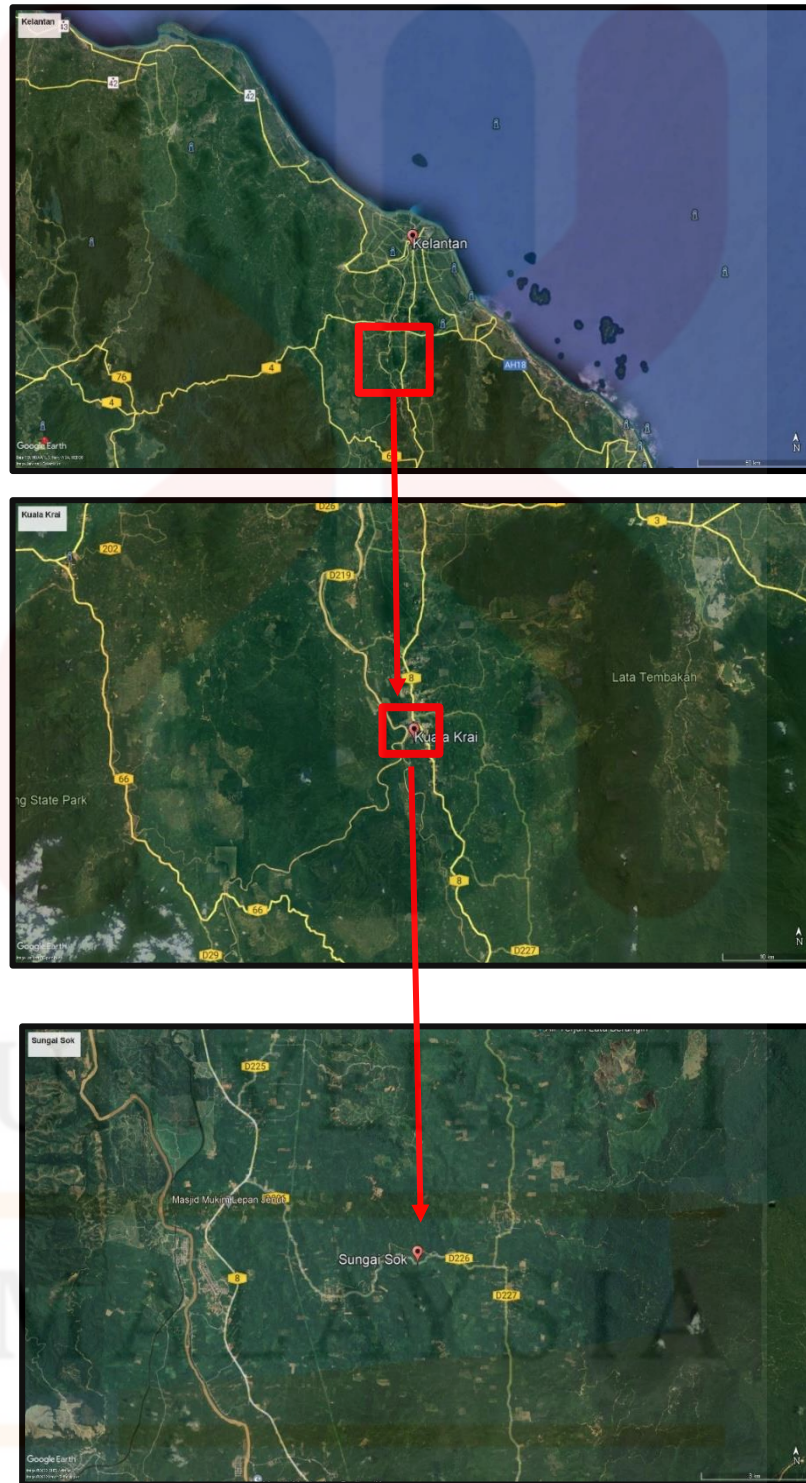
## **1.2 Study Area**

### **1.2.1 Location**

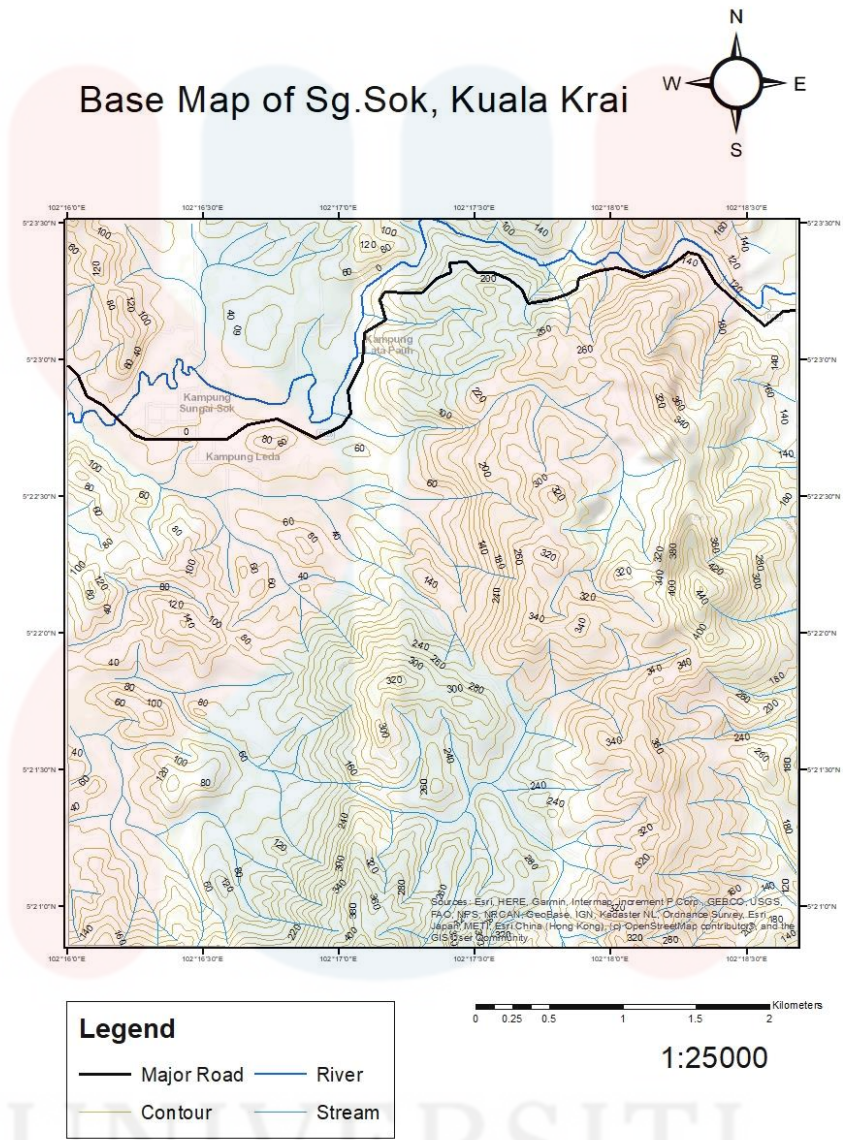
Sungai Sok is located in Kuala Krai, the second biggest district in Kelantan. Kuala Krai has a boundary with Gua Musang in the south, and it shares an eastward border with Terengganu, while its western border is with the state of Jeli. Kuala Krai was once known as Kuala Lebir in historical records. Sungai Sok is aligned within coordinate  $5^{\circ}22'55.1''\text{N}$  to  $102^{\circ}16'29.3''\text{E}$  and encompass about 25 km<sup>2</sup> of the total areas.

In this study region, which includes geological mapping as well as flood hazard mapping, it is appropriate to undertake this research since the area has a high likelihood of experiencing flooding, particularly in the village area that is mainly close to the Sungai Sok. There are several villages in the vicinity of the Kuala Krai district, and human activity is also one of the primary elements contributing to floods in the region. Consequently, the significance of this research was that it would assist in updating the data geology of Kuala Krai, Kelantan which in Sungai Sok area, and would help to prevent flood hazards. Figure 1.1 shows the location of the study area and base map

of the study area is indicated in Figure 1.2. It aligned from latitude  $5^{\circ}23'31.01''\text{N}$  to  $5^{\circ}23'31.74''\text{N}$  and longitude  $102^{\circ}16'0.33''\text{E}$  to  $102^{\circ}18'40.96''\text{E}$ .



**Figure 1. 1:** Location of Sungai Sok, Kuala Krai, Kelantan

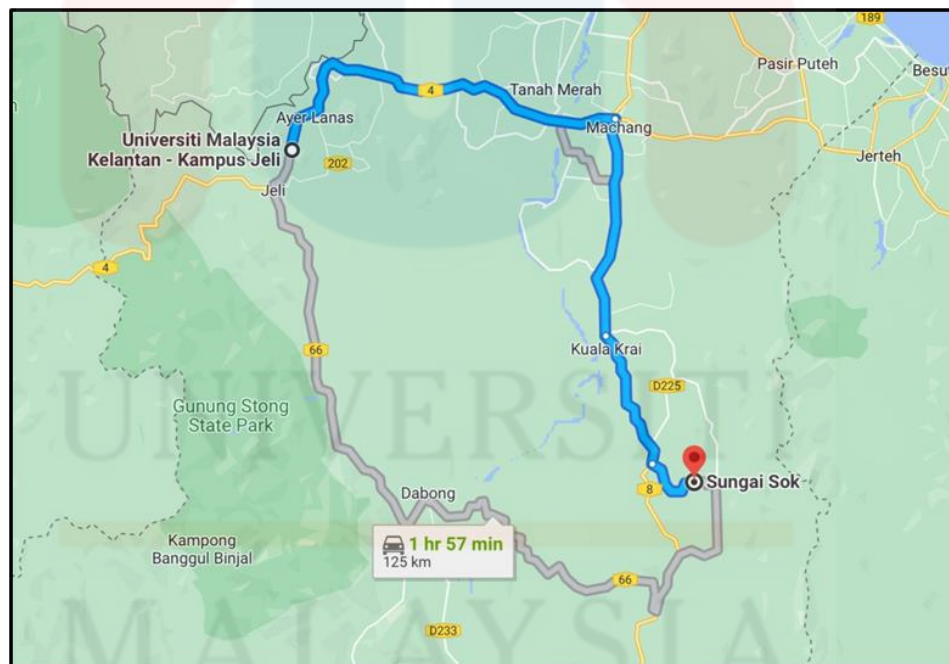


**Figure 1. 2:** Base Map of study area.

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### 1.2.2 Road Accessibility

Sungai Sok is a villages or rural area in the Kuala Krai district in southern-central Kelantan. The location of the study area is very accessible due to the area's extensive and diverse road network. Using local roads, collector streets, and other roads, some remote areas are accessible by motorcycles. The road link inside the research region facilitated geological mapping operations and the river which plays important part to get flooded with heavy rainfall. From Universiti Malaysia Kelantan, Jeli to Sungai Sok, Kuala Krai Kelantan, it takes roughly 1 hour and 57 minutes to reach the destination through Lebuhraya Timur Barat Route 4 (Figure 1.3).



**Figure 1. 3:** Route from UMK Jeli to study area via driving.

### 1.2.3 Demography

Kuala Krai is the second largest province in Kelantan. The bordering provinces of Kuala Krai are Machang to the north and Gua Musang to the south. The total land area of Kuala Krai Province is 2,329, square kilometres, or 910 square miles. By the year 2020, the population of Kuala Krai had reach 105,007 as stated by Kuala Krai Background (2015).

Moreover, Kuala Krai also divided into three sub district area that is Olak Jeram, Batu Mengkebang and Dabong. Olak Jeram (757.6 km<sup>2</sup>) consist of 67 villages, while Batu Mengkebang (726.9 km<sup>2</sup>) and Dabong (844.5 km<sup>2</sup>) consist 122 villages and 27 villages respectively.

### 1.2.4 Land Use

Most of the land in Kuala Krai is committed to use for rural and urban developments. This is because the location is near town and settlement area. Currently, in Kuala Krai, clear indicators of improvement can be seen in the infrastructure of hospitals, public libraries, schools, and commercial districts, in contrast to the expansion in other locations. In addition to that, the land in Kuala Krai is used for a variety of agricultural pursuits. The bulk of the land area in the studied region is comprised of plantation regions, such as those devoted to the production of palm oil and rubber trees.

### **1.2.5 Sosial Economic**

In the study area, the most significant sources of income come from agricultural operations, followed by services provided to the government and self-employment. The government sector is extensive and consists of multiple entities, such as state or local government as well as all central units, which enables it to provide a wide variety of services to the public. As a result of the study area's proximity to rubber tree and palm oil plantations, many people in the surrounding area are employed as independent contractors or labourers.

### **1.3 Problem Statement**

The use of geological mapping is one of the primary methods to ascertain the geological features at the study area in details. Works by Arham et al, (2020) have shown several elements that lead to the flooding issue such as terrain, geomorphology, drainage, engineering constructions, and climate. Due to the limited information about the geological features, which is important for flood studies, so there is a need of updating geological map of Sg. Sok, Kuala Krai.

Flooding is one of the most well-known hazards because it may occur everywhere, whether naturally or unnaturally, and it can occur at any time. In this research area, since flooding is brought by an excessive amount of rain during the monsoon seasons as well as convective showers that fall throughout the hot and humid months, geological factors are among the most significant elements to consider. Even though flooding happens in the Kelantan area on a yearly basis, the consequences of

flooding cannot be avoided or minimised. This study was conducted to determine the elements that contribute to the effect of catastrophe on the community and the surrounding environment. The floods that happened in the region may be better understood if a geological map is created and examined.

#### **1.4 Objective**

The objectives of the research are as followings:

1. To produce the geological map of Sungai Sok, Kuala Krai, Kelantan with scale 1: 25 000.
2. To generate flood hazard map using different parameter of flood occurrence.

#### **1.5 Scope of Study**

This research is focusing on producing the geological map in 25 km<sup>2</sup> of Kuala Krai area, Sg Sok. The geological mapping aspect of the current project was mainly based on fieldwork inputs including collection of samples from fresh outcrops, recording structural trends in rocks, and other field observations such as geomorphological features, drainage pattern etc. All these field related data was then processed in GIS based platform including the petrographic studies to generate geological and other thematic maps.

The flood risk area map which consists of different levels was produced based on a few parameters such as flow length (rainfall and water level), elevation, slope, land use, and river distance using Weighted Overlay Method (WOM). Each parameter is scored by assigning a weight and valued to each categorization, and then been overlaid used ArcGIS 10.3 software. This GIS technique that can digitally describe and display flood hazard area. The secondary data of rainfall distribution and water level data of Kuala Krai were gathered from Department of Irrigation and Drainage Malaysia (DID), Malaysian Meteorological Department and United States Geological Survey (USGS) website.

#### **1.6 Significance of Study**

Geological mapping is one of the most effective methods for determining the geological characteristics of a research area because the geological features are map-able with more accurate information. Other than that, the structural geology exposed in Sungai Sok area can revealed the history of tectonic movement which the future flood and geohazard can be predicted.

Utilizing a flood hazard map is one of the most efficient ways to determine the frequency of floods in a certain area. This is because a flood hazard map is built based on the accuracy of weighted overlay method, water level and amounts of rainfall collected. According to Merz et al. (2010), it is essential to first carry out a flood hazard assessment. Because of this, the implementation of flood hazard management based on flood hazard analysis may help to contribute to a reduction in the monetary value of the loss.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

This chapter describes the literature review of prior research conducted in the study area or analogous studies used by the previous researcher. The purpose of the literature review is to justify the methodology and process used in this study. This chapter addresses the regional geology of Sungai Sok, Kuala Krai, including stratigraphy, structural geology, historical geology, and a study of flood analysis

#### 2.2 Regional Setting

The western half of Peninsular Malaysia is referred to as Sibumasu, while the eastern part is either referred to as Indochina or East Malaya. The peninsula is split into two cantons (Pour and Hashim, 2015). These two continents are split along the middle by the Bentong-Raub Suture zone. Because of stratigraphy and mineralization, it was segmented into three longitudinal bands: a western tin belt, a centre gold belt, and an eastern tin belt. Each of these bands included a different kind of mineralization.

Western Belt, Central Belt, and Eastern Belt are the three proposed subdivisions, according to Khoo and Tan (1983). After that, Khoo and Tan cut the island in half, creating two distinct portions known as the Kinta-Malacca sector and

the northwest sector. As stated by Tija et al., (1972), four structural domains on the Peninsula were identified: northwest, west, central, and eastern. These four regions are as follows: The Lebir Fault zone divides the eastern and central belts, while the Bentong-Raub line divides the central and western bands (Figure 2.1). The eastern and central belts are isolated from one another (Hutchison, 1975).



**Figure 2. 1:** Map of Peninsular Malaysia which divided into Sibumasu and Indochina, divided by Bentong-Raub suture zone and Semanggol Formation of northwest Peninsular Malaysia.

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### 2.3 Stratigraphy

Stratigraphy is the part of geology that looks at how layers of rock are put together and how they fit into the geological time scale. According to Heng (2006), the Main Range Granite in the southern part of Kelantan includes the Dabong region, which is near intrusive igneous rocks, sedimentary rocks, and metamorphic rocks. This region is divided into three groups based on the types of rocks present: lower Paleozoic rocks in the west, Permian-Triassic rocks in the middle, and Jurassic-Carbonaceous rocks in the east. The Stong Complex, located to the north of Dabong, is composed of three plutonic components, Berangkat Tonalite, Kenerong Micro-granite, and Noring Granite, in deteriorating age sequence. The Berangkat Tonalite and Kenerong Micro-granite components are highly deformed and strongly foliated. However still, the geology of the westernmost part of Kuala Krai is dominated by the Gua Musang and Taku Schist rock formations and the granite Strong Complex (Khoo and Tan, 1983).

### 2.4 Structural Geology

The Taku Schists seem to have gone through a recumbent folding phase at the same time as metamorphism, which was followed by an open folding phase. Due to folding that happened later, the complex has a plunging antiformal structure with a north-south fold axis. This is what happened because of folding. It is possible that this late folding phase will happen while the Tekai Group folds. During its formation, the Tekai Group was folded into large, gently sloping folds. Like the Taku Schist antiform, the fold axes go from north to south.

The Central Belt rocks that surround the Main Range Granite are metamorphic, in addition to polytropic schist, phyllites, and amphibole schist. The Taku Schist in north Kelantan contains the most regional metamorphic rocks in the Central Belt. The terrain expands significantly when the low-grade phyllites that surround the Taku Schist are included. Serpentinite has also been found in the Late Triassic era, according to McDonald (1967). The Taku Schists must be an older rock formation since they were metamorphosed in the Late Triassic.

In the Kelantan area, there are four types of rocks: granitic rock, sedimentary or metasedimentary rock, extrusive rock (volcanic rock), and unconsolidated sediment. Joints and faults are common in granitic rocks, but sedimentary rocks often have folding, faulting, and joints in addition to joints and faults (Figure 2.2). Both the Main Range granite in the west of the state of Kelantan and the Boundary Range granite in the east are made up of granite rocks (Department of Minerals and Geoscience Malaysia, 2003).

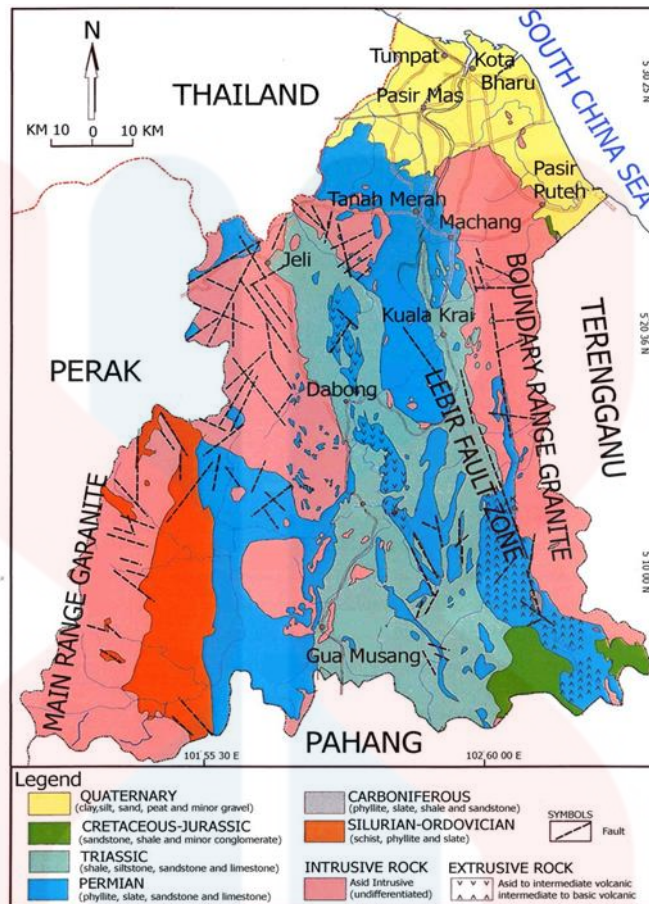


Figure 2. 2: Geological Map of the Kelantan state.

## 2.5 Historical Geology

At the beginning of the Mesozoic Era, a big part of the Peninsula's newly formed land mass was lifted and left above water. Naval sedimentation shows that there are two areas: the northwestern depocenter Kodiang-Semanggol and the central depocenter Gua Musang-Semantan (Gobbett, 1973). The first one was built on the continent of Upper Paleozoic Sibumasu. It was the only thing left from what was once a huge area of marine deposits in the Late Paleozoic.

On the Upper Paleozoic shelf of East Malaya, the Gua Musang-Semantan depocenter grew and moved. During the Triassic, there was a lot of tuff and related

lava, tuffaceous siliciclastic, and conglomerate in the Gua Musang-Semantan depocenter. This shows that there was a lot of volcanic activity and instability in the basin. Geologists call the rocks in the deeper parts of the Gua Musang-Semantan depocentre "flysch" because they are made up of a lot of turbidites (Gobbett & Hutchison, 1973).

As Kelantan is in the north-eastern corner of Peninsular Malaysia, the Kelantan River is the largest river in the area. It starts where the Galas River and the Lebir River encounter. The site is close to the district of Kuala Krai and winds through the coastal plain until it reaches the South China Sea. However, Kuala Krai was called Kuala Lebir once before. The Kelantan River basin covers 923 km<sup>2</sup>, which is about 85% of the area of the state. In the northern part of the river basin, the land is flat or has a gentle slope and the southern part, there are sharp scrapes and steep slopes. In the state of Kelantan, different kinds of igneous, sedimentary, and metamorphic rocks are spread out from north to south. Kuala Krai is the second biggest district in Kelantan, coming in second place after Gua Musang. Machang lies to the north of Kuala Krai, Gua Musang to the south, Terengganu to the east, and Jeli to the west. Kuala Krai has boundaries with all these states.

## **2.6 Research Specification**

### **2.6.1 Floods**

The scenario of the huge flood occurrence in Bandar Kuala Krai in 2014 clearly demonstrates that it encompasses the concepts of hazard, risk, and tragedy. This is because the floods happened when the water level of Sungai Kelantan and its tributaries, Sungai Galas and Sungai Lebir, rose over their normal levels owing to

heavy rains that continued for many days, resulting in river overflows. Since the river was unable to take in the large quantity of water that was released, water began to overflow into the Bandar Kuala Krai population area, posing a threat to people's health and the physical environment. Sungai Kelantan's highest recorded water level was 34.17 metres, which surpassed the 25-meter danger barrier in Tangga Krai, Kuala Krai (eBanjir Negeri Kelantan, 2015).

Besides, as the rainfall, the annual precipitation on the east coast of Peninsular Malaysia, which varies from 2500 to 3000 millimetres, may be attributed, in part, to the effect of the northeast monsoon (98 to 118 inches). The monthly precipitation totals were more than 500 millimetres in both November and December (20 inches). In most years, the rainy season starts in December and continues throughout January, notably in the central and southern areas, and even in the northern regions in certain years. In general, the rainy season begins in December (Che Ros & Tosaka, 2018).

Moreover, for the first time since 1967, Kelantan has seen a flood of this magnitude. The worst affected region is Kuala Krai. Rainfall in Kelantan of 850 mm over ten days exceeds the average rate of 100 mm when irrigation and drainage systems cross the river at Kuala Krai's junction. Precipitation was above normal due to a cloudy forecast for Johor (<http://www.met.gov.my>). There is also the problem of deforestation in addition to the rain. Even in the watershed region or river, deforestation happened. Deforestation-related logging caused the demolition of various infrastructures (Wardah, 2015).

Other than that, floods caused by heavy rain that started on December 17, 2014, forced 3,390 people in Kuala Krai, Kelantan, to leave their homes, (Sapa-dpa Midrand, 2015). From December 21 to December 23, 2014, it started raining hard for three days in a row in Gua Musang. This rainfall set a new record with 1,295 millimetres, which is about how much rain falls on average in 64 days. Because of this, the water levels in three major rivers, the Galas River at Dabong, the Lebir River at Tualang, and the Kelantan River, rose well above the danger level (Murty, 2015). At Dabong, Gua Musang, the Galas River reached 46.47 metres (danger level: 38 metres). At Tualang, Kuala Krai, the Lebir River reached 42.17 metres (danger level: 35 metres), and the Kelantan River reached 34.17 metres.

### **2.6.2 Causative Factors of Flood**

Kelantan suffered the most losses because of the destruction of products and premises in Kuala Krai because of the 2014 flood catastrophe (Nasir Nayan et al, 2017). There are a lot of communities at the affected area could not have the food supply or drink because all the food stores were covered with mud. Besides, floods in Malaysia are produced by a mix of natural and human forces (Arham et al, 2020). As human forces, there are an irresponsible people that had done the illegal logging at some area which triggered to the flood when the heavy rain in the monsoon season. Muqtada et al., (2014) stated that from November to March, the Northeast monsoon brings strong rains to Kota Bahru, Kelantan, annually causing flooding. In Peninsular Malaysia, surface factors such as low-lying terrain, inadequate drainage system and design, coastal regions situated below high tide level, and the loss of natural retention space all contribute to flooding (Sathimurthy et al, 2019).

Uncontrolled land development caused significant soil erosion in the upstream areas, which resulted in siltation of riverbank sediments with muddy and sandy materials, some of which included heavy metals (Nurul Akma et al., 2015). Soil erosion was thought to be 100 times greater than normal in the upper basin of the Kelantan River before the flood since the bulk of land uses in the upper basin had been turned to agriculture. More than half of the changes were due to oil palm (152%) and mixed agriculture (158%), but the remainder of changes were due to deforestation (Adnan and Atkinson, 2011). Over a 12-year period, from 1988 to 2000, agricultural land conversion rose by approximately 400%. (9.3 percent). Damage to homes and farmland was incalculable due to the flood plain silting, which occurred at the height of the storm when trees were uprooted, and abandoned logs were transported.

### **2.6.3 Flood Hazard Analysis Using GIS**

GIS is a computer system used for mapping and analysing objects and occurrences on the surface of the planet. The geographical denotes the coordinate-based locations of the data components. The term information refers to the data's characteristic or information. Data such as soil type, slope, rainfall data from the imaging satellite Himawari 8, Landsat 8 OLI, and catastrophic event observation data are collected using GIS and remote sensing techniques (Berkat & Fitriana, 2021). Besides, Elsheikh et al., (2015) also employed the GIS-based analysis of prospective flood risk regions using Multicriteria Decision Analysis (MCDA). The terrain value was taken from the topographic map for each soil type and shown in a GIS layer.

## CHAPTER 3

### MATERIALS AND METHODS

#### 3.1 Introduction

This section discussed about several materials and methodologies that were used to conduct this research. Every information and data collection obtained from the geological mapping and field survey was recorded with all the picture of the outcrop was taken as a reference.

#### 3.2 Materials

This section divided materials into two types which is for geological mapping and for flood hazard map.

##### 3.2.1 Materials for Geological Mapping

The equipment that was used in the process of geological mapping included a Brunton compass, hammer, measuring tape, HCL, hand-lens, and GPS.

- a. Compass - Compass was used to determine the direction of degree measurement (azimuth) via the Earth's magnetic field. Additionally, the strike and dip angles and directions may be measured.

- b. Hammer - A hammer was utilised to shatter the exposed outcrop rock sample in the research region
- c. Measuring tape - To measure the length of the outcrop in the research region, the measuring portion of the rock formation was measured using a measuring tape.
- d. Hydrochloric Acid (HCL) - The testing of limestone rock using hydrochloric acid. The presence of gas bubbles and a fizzy effect on the rock indicates if the rock is carbonate.
- e. Hand lens - Hand lens was used to observe the properties of the mineral that is contain.
- f. GPS - A Global Positioning System was utilised to determine the longitudinal and latitude in order to trace the daily journey along the research region

### **3.2.2 Materials for Flood Hazard Analysis**

Secondary data on rainfall distribution and water level as well as Digital Elevation Model (DEM) of Kuala Krai were required to create the flood hazard map.

Maps of causative factors such as slope, flow length, river distance, land use or land cover and elevation were derived from secondary data gathered by agencies and geological mapping. Secondary data sources include the Department of Irrigation

and Drainage Malaysia (DID), the Malaysian Meteorological Department, and the United States Geological Survey (USGS).

a. Lithology Map.

During the geological mapping, the lithologies of the research region were gathered. The lithology was established by studying rocks and their boundaries. During the observation, the data collected in the field are plotted to create a lithology map.

b. Slope Map.

The slope degree was determined by estimating the slope during geological mapping or by extracting it from satellite-imaginary data. It displays the slope distributions dependent on the angle. The slope is categorised according to the Zuidam classification of 1985.

c. River Distance

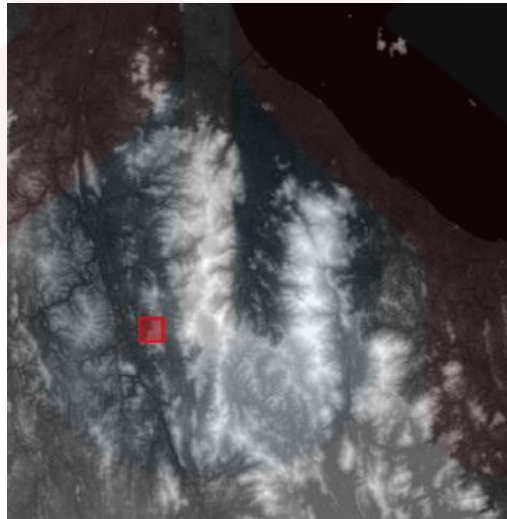
The drainage map or river distance map was created using DEM obtained from the USGS websites. It is important that drainage map related to flood hazard map by showing high and low hazard sub-basin zone.

d. Land use map.

Using geological mapping and the Digital Elevation Model, the land use of the study region was mapped.

e. Digital Elevation Model (DEM)

Digital Elevation Model (DEM) is used to investigate the geomorphologic characteristic of terrain in relation to the underlying influence of geology. All elevation data was used to create elevation map and slope map. Shuttle Radar Topography Mission's (SRTM) was acquired by the website of earth explorer of U.S Department of the Interior U.S. Geological Survey which shown in Figure 3.1. It is a high-quality product with a horizontal ground resolution of 30 meters from year 2014. The SRTM data was used to compare with the created DEM for the flood plain in the study area.



**Figure 3. 1:** SRTM with red box of study area.

### **3.3 Methodology**

Geological mapping inputs included the gathering of samples from fresh outcrops, the recording of structural trends in rocks, and other field observations including geomorphological characteristics, drainage pattern, and slope variation.

For flood hazard analysis, the changes in water level and rainfall were identified. By doing that, the potential flood area in near future can be determined by weighted the parameter and causative factor in the study area.

The flood hazard map and geological map were generated using ArcGIS software to determine the parameter's distribution. Public, private, and third sector need flood maps for a wide range of activities, including the establishment and enforcement of zoning regulations, land use standards, construction code standards, planning and construction of transportation networks, flood warnings, evacuations, and emergency planning. With the weighted overlay technique tool, all parameter data were processed in ArGIS software. The use of the weighted overlay method is crucial in GIS as it allows for the creation of a map illustrating potential flood risks by layering different map elements. This method ensures that various factors are considered and combined to produce a map that divides the area into regions of varying flood vulnerability, such as low, medium, and high-risk zones. Figure 3.2 shows the overall flowchart of research methodology.

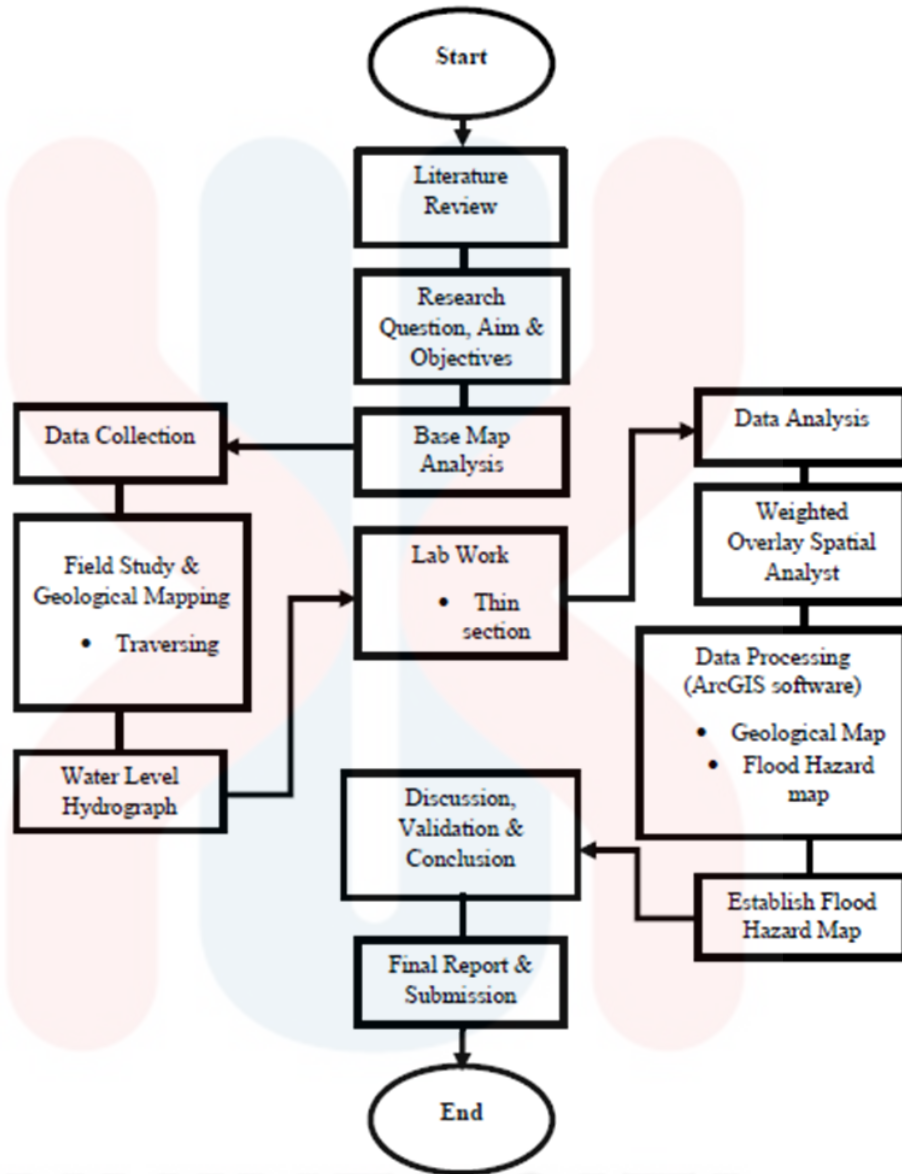


Figure 3. 2: Research Flow Chart.

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### 3.3.1 Preliminary Studies

Research methods were thoroughly analysed and mapped out in advance of getting started, so that all necessary information could be gathered. An article evaluation of prior research in the subject region or related to flood hazard analysis was conducted in order to acquire further information for the investigation. It is significant and critical since it requires brainstorming and a general understanding of what must be done. Because of this, the research area's geology, history, lithology, and formation are understood.

### 3.3.2 Field Studies

#### a. Sampling

During the process of geological mapping, a representative sample of the rocks was gathered for use in further research. The lithology and formation of the sites are entirely dependent on the rocks. In order to ensure accurate results from petrologic research, fresh rock samples were collected from exposed outcrops. Weathered samples were avoided if possible.

#### b. Traversing

Traversing is a technique used in the survey area for network control. The mode of traversal may influence the observations obtained at an outcrop. By crossing the research region, data such as joint, fracture, faulting, structure, and measuring section of the outcrop were collected and observed.

### 3.3.3 Laboratory Work

The minerals in rocks are recognised by their texture, clasts, matrices, twinning, and crystals in petrological research. Laboratory analysis was performed on field-collected material. It began with the fragmenting of the rock into smaller bits. After that, grinding and polishing were performed. After many grindings, the material was reduced to a thin slice. The tiny part of the rock sample is sliced thinly for microscopic examination. Using a polarised microscope, the texture of the rock was examined.

Under a polarised microscope, the thin section technique is used to examine rocks. A fresh sample might result in a more accurate observation, since the thin slice provides a clearer glimpse of the minerals. The presence of a weathered rock may influence the results of the thin section examination.

### 3.3.4 Data Processing

#### a. Methods for flood hazard analysis area.

During the geological mapping process, data pertaining to the recent flood that occurred in the study region were incorporated to DEM data. In relation to their sub classes, the more exact weighted score of each triggered parameter and factor was generated.

#### b. Evaluation of causative factors that triggered flood to occur.

Five parameters which is flow length, elevation, slope, land use and river distance were considered in the evaluation of causative factor that cause flood to occur.

The occurrence of flood usually happens from these factors also from heavy rainfall, thus, during the geological mapping, all sort of data in the study region such as water level and rainfall distribution were collected.

c. Flood hazard map.

For the flood hazard map production, the Weighted Overlay Method was used. Weighting gives each topic map emphasis (parameter). The weight of each thematic map is defined by the degree to which each GIS analysis-relevant geographical parameter influences the probability of floods (Suhardiman, 2012). Moreover, scoring gives each class a score for each criterion. Class effect on occurrences determines scoring. More event impact, higher score (Adlyansah et al, 2019). To obtain a total score / value, a value and weight must be given so the balance between the two may yield a score. Giving values for each parameter is the same, 1-5, although weighting relies on its effect on flood risk (Matondang, 2013).

As mentioned by Guntara (2013), overlays are created by mixing many layers on a computer screen or plot. One digital map's properties were added to another which create both maps' properties.

### 3.3.5 Data Analysis and Interpretation

Geological mapping, which involves traversing and sampling, is a significant undertaking in which all geological properties and components are studied and documented. A comparison was made between the satellite-imaginary data and the geological survey and mapping data. During the observation of the research region, data were analysed to construct the geological map. The ArcGIS 10.2 software was

used to create a geological map of the Sungai Sok region at a scale of 5 x 5 km. Geological mapping data, such as inclination, lithology, rock border, and deformation of rocks, were updated and exhibited on a geological map of the research region.

GIS was also used to create a flood hazard map in order to extract facts which the lineament was interpreted by analysing the positive and negative lineament on the topographical map and Google Maps. The flood hazard map was constructed by collecting and evaluating data on all flood-related factors, such as flow length, elevation, slope and land use. The data from the hyetograph and hydrograph were then used to assess the water level of the flood that occurred in the study area.

As for flow length factor, it divided into two that is water level and rainfall. In part of water level, it will divide into four parts: normal, caution, warning and danger. Each level has its own level inside river, as example, the danger level will be causing flooding. The rainfall also categorized into three level risk that is light rain, moderate rain and heavy rain.

## CHAPTER 4

### GENERAL GEOLOGY

#### 4.1 Introduction

General geology is the chapter that focuses on research and discussion findings about geomorphology, stratigraphy, structural geology, and the history geology of the study area. The recent research study, an analysis of data gathered from remote sensing surveys, and the implementation of geographic information systems are all included in the material that is addressed in this chapter.

##### 4.1.1 Brief Content

Geomorphology is described as the study of the Earth's characteristics and the factors that impact them, including the description, categorization, and evolution of the Earth's surface. It encompasses the investigation of changes in the landform's topography, drainage pattern, and drainage pattern, as well as the weathering process.

The study of the history, composition, relative age, and distribution of rock strata is known as stratigraphy. Stratigraphy also refers to the interpretation of rock layers to explain the history of the Earth. Studies of lithology (also known as lithostratigraphy), fossil content (also known as biostratigraphy), and the relative and

absolute age of the layers (also known as chrono stratigraphy) are possible to be further improved based on the findings of correlations between various strata.

The geological structure provides information on the architecture of the Earth's crust as well as the geological events that are responsible for the rocks deforming and changing shape. In most cases, it encompasses the different structures that make up a tectonic unit, including as anticlines, thrusts, faults, lineament, and other similar features. Additionally, main and secondary structures are included in the field of structural geology. The geological formation allows for the identification of historical geology as well as the lithology that is present in the region of research.

#### **4.1.2 Accessibility**

The major road in the study area is located near the centre of the region. The Kuala Krai town and the Sg. Sok region are both connected by the main road. It is beneficial for the researchers to investigate every component during fieldwork. In addition to this, the mapping procedure is facilitated by the presence of unpaved roads within the scope of the investigation.

#### **4.1.3 Settlement**

The area for study is situated in the middle of two different communities. Both Kampung Chucuh Puteri and Kampung Sg. Sok are the names of the respective villages. With a total population of 30, 150 persons (in 2020), the local Malay community makes up the majority. The majority of them make their living by tapping rubber for a living and having their own businesses. It provides an explanation for the

reason why the majority of their land is occupied by oil palm trees and rubber plantations.

#### **4.1.4 Forestry (Vegetation)**

The forest in the research region is classified as dense. This is due to the very thick vegetation that has a wide variety of plant species. Plantations of oil palm trees and rubber trees make up the majority of the study area, which is mostly regarded to be a planted region. Moreover, some of the villagers also work for logging at the nearby factory in the study area.

## **4.2 Geomorphology**

Peninsular Malaysia's geomorphological evolution has been impacted by the regional events, and its current landforms arise in part from its protracted subaerial exposure throughout the Tertiary era, with weathering and erosion predominating. However, the Peninsula has also been affected by the global climatic and sea-level variations during the Quaternary period, when deposition processes were predominant, particularly in the coastal regions. Figure 4.1 (a) and (b) shows the geomorphology of study area.



**Figure 4. 1 (a) and (b):** Geomorphology of study area.

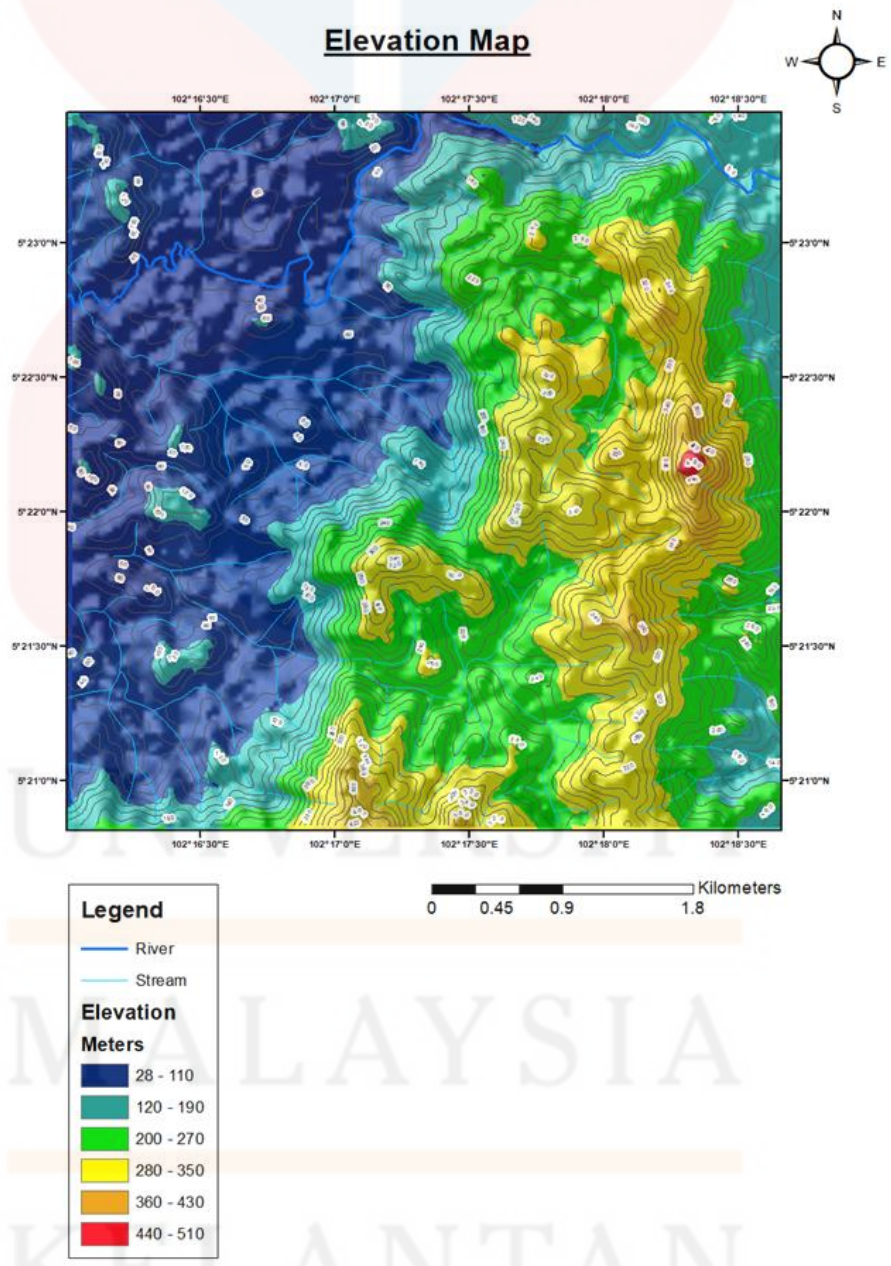
#### **4.2.1 Landform**

A topography map is crucial for understanding the area's natural and artificial geological characteristics. The topographic map comprises both the contour lines, which operate as a form of the Earth's surfaces, and the unique features, which include roadways, lakes, houses, and many other types of structures. Elevation information might alternatively be shown using contours. Based on the height of the contour, a digital topographic map of the research region was produced in a digital geographic model using the Triangular Irregular Network (TIN) tool included in the ArcGIS software. The topographic unit can be identified based on the differences in elevation of the study area. Table 4.1 describes the landform classification by elevation range in meters above sea level while Figure 4.2 shows the elevation map of study area.

**Table 4. 1:** The landform classification

Relief/Landform	Elevation (m)
Low hill	40-100
Hill	100-240
High Hill	240-460

(Sources: Van Zuidam, 1985)



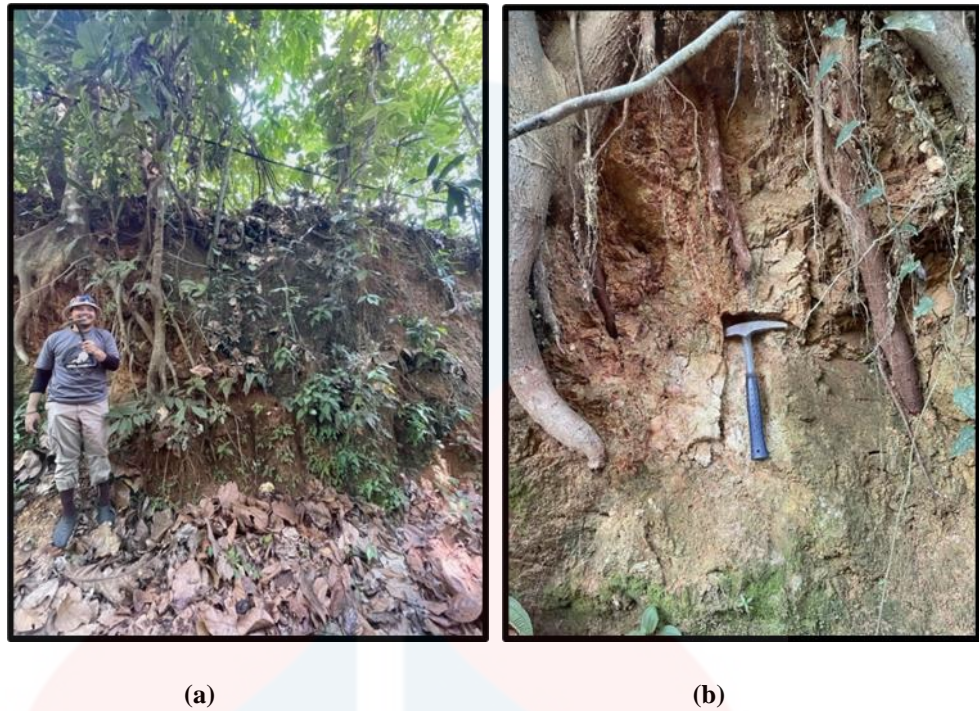
**Figure 4. 2:** Elevation map of study area.

#### 4.2.2 Weathering

Weathering is the process in which the rocks and minerals have been broken down physically and transformed chemically at or near Earth's surface. Weathering and erosion primarily affect landforms on the earth's surface. Weathering occurs because of physical, chemical, and biological impact on the rock. The rate of weathering is affected by a variety of factors, including lithology, climate, terrain, and groundwater.

Physical weathering is caused by physical forces that break rocks into smaller pieces without altering the mineral makeup of the rocks. Physical weathering is caused by physical pressures originating from water, air movements, and changes in internal tension. The primary causes of physical weathering include thermal expansion and contraction of rock, alternating freezing and thawing of water between cracks and fissures inside rocks, pressure release from overlaying materials, crystal development within rock, and the growth of plants and living creatures in rocks.

On the other hand, evidence of chemical weathering can be found in the transformation of rock into one or more new compounds through its chemical processes. This is because of the chemicals in the atmosphere that act directly on the surfaces of the rocks. This form of weathering is most likely to occur in climates that are hot, humid, and tropical. The outcrop in Figure 4.3 (a) and (b) is the example of chemical weathering that had transform the original condition of the rock to new compound and shows the outcrop grade was completely weathered to residual soil. As the color and appearance , the rocks had been oxidizing or staining minerals, causing discoloration or changing the overall appearance of the rock.

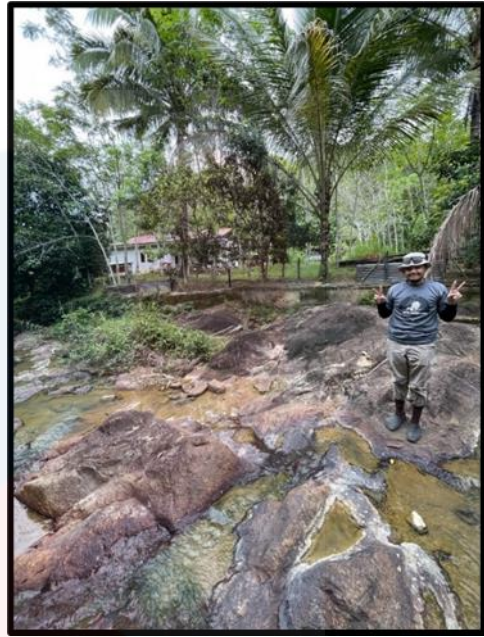


**Figure 4. 3 (a) and (b):** The outcrop which identified as weathered by chemical weathering.

Moreover, as the biological weathering process, it takes place when a force or pressure is applied to the rocks to break them apart or degradation the minerals that are contained inside them. Increasing the amount of rock surface that is exposed makes it feasible for other physical forces to accelerate the process of the rock's degradation. If there is water, plants can thrive in almost any environment. Growing into the fissures and cracks in rocks and soil, the roots of trees and other plants can organically break down rocks by growing into them. As a direct consequence of this, they grow increasingly brittle and finally fall apart completely. Figure 4.4 (a) and (b) show the example of landform that had been affected from biological weathering process. The root wedging had resulted the rocks break apart then exerting pressure as they expand.



(a)



(b)

**Figure 4.4 (a) and (b):** The outcrop which identified as weathered by biological weathering.

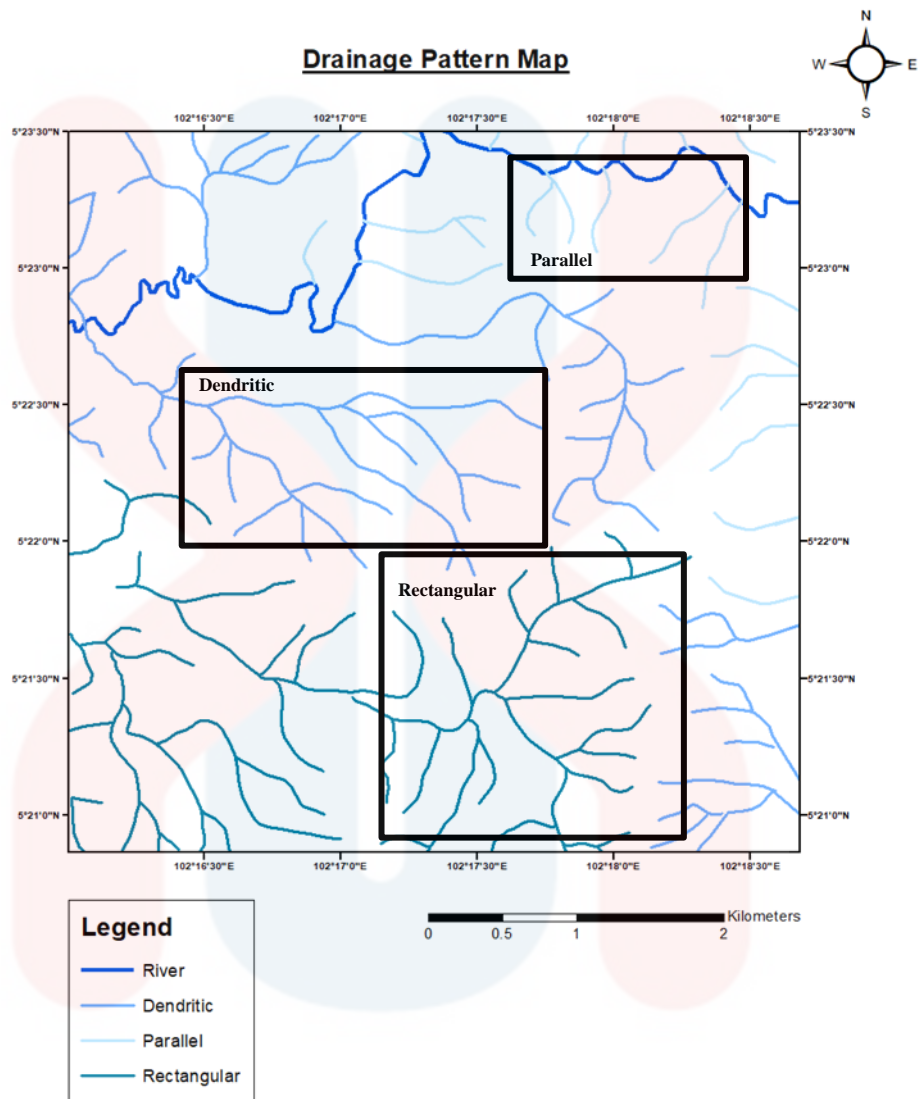
### 4.2.3 Drainage Pattern

The drainage pattern is the arrangement of streams on the surface of the globe because of the drainage system. It was created by streams, rivers, and a lake that served as a drainage basin. The drainage pattern was determined by the underlying geology. Examples of drainage pattern include dendritic, parallel, trellis, rectangular, radial, centripetal, and deranged patterns.

There are three types of drainage pattern that can be observed in the study area, which is dendritic, rectangular, and parallel. Dendritic pattern is the most prevalent drainage pattern, which resembles tree branches. It was created when the river channel followed the terrain's slope. The lithology underneath this pattern is composed of homogenous material. The lithology that found at the dendritic pattern is hornfels which is a non-foliated structure.

Next, rectangular patterns gather at the rock that are nearly homogeneous resistance to erosion. In this pattern, several geological formations may be recognised resulted from the erosion that happened. The weathering and erosion along the joint were produced by runoff water in long and narrow crevices. The lithologies that were found at the rectangular pattern is quartzite.

Lastly, a parallel drainage system is a pattern of rivers caused by steep slopes with some relief. Because the hills are steep, the streams are fast and straight, and they all flow in the same direction and the lithologies that found in this drainage pattern is granodiorite. A watershed is an area or ridge of land that divides the water into different basins, rivers, or seas. It also includes rivers, dams, ponds, wetlands, and all the groundwater around them. Figure 4.5 shows the drainage pattern maps of the study area.



**Figure 4. 5:** Drainage map of the study area showing dendritic, parallel, and rectangular

### 4.3 Lithostratigraphy

The study of geological strata and the stacking of those strata is called stratigraphy. The properties of layered rocks, as well as the connection between the age of creation and the layered rocks themselves, were investigated and discovered. Lithostratigraphy is one of the sub-disciplines that fall under stratigraphy subtopic.

The topic focuses on the investigation of rock layers and attempts to explain the connection between the creation of igneous, sedimentary, and metamorphic rocks.

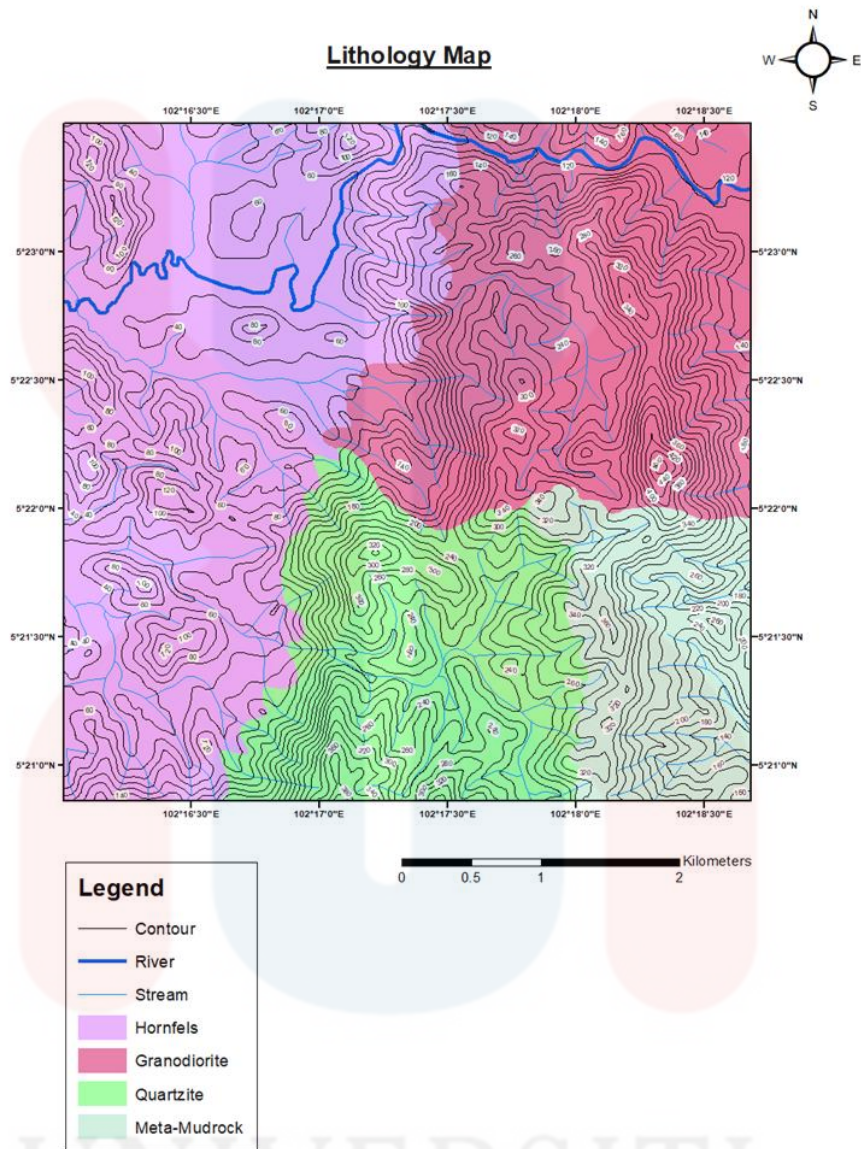
Lithology is the study and description of the physical features of rocks, especially hand specimens and outcrops (Bates and Jackson, 1980). The lithology characteristics include colour, grain size, rock type, and mineral content. There are four main lithologies in the study area which are quartzite, hornfels, granodiorite and meta-mudrock. The lithologies does divided into period time which are Permian and Triassic. Table 4.2 shows the stratigraphic unit of the study area. The rock found are assumed to be in Gua Musang Formation, Aring Formation and Taku Schist.

**Table 4. 2:** Stratigraphic unit.

Era	Period	Formation	Lithology	Description
Mesozoic	Triassic	Aring Formation		Meta-Mudrock
Paleozoic		Permian	Gua Musang Formation	
	Taku Schist			Hornfels

#### 4.3.1 Stratigraphy Position

Stratigraphy, also known as lithostratigraphy, is the process of defining the layers of rocks based on their lithology and how they relate to the age of the strata. Lithostratigraphy was required to ascertain the history of the region as well as its age. The stratigraphy of the region was used to categorise the lithology of the rocks that found and observed in study area. Figure 4.6 shows the lithology map of study area.



**Figure 4. 6:** Lithology map of study area.

### 4.3.2 Unit Explanation

Based on the Figure 4.6, the maps illustrate the lithology unit of the study area which consist of granodiorite, hornfels, quartzite and meta-mudrock.

### a. Granodiorite

Granodiorite is an intrusive rock that is composed of elements that are intermediate between those of diorite and granite. Although it resembles diorite or granite in appearance, it contains more quartz than diorite and more mafic minerals than granite. Besides, the rocks that cool slowly deep underground in places called plutons that are filled with magma. This slow cooling lets crystals form that are easy to see. Both rocks were made when continental rocks melted near places where plates move under each other and forming granodiorite (Golden Gate, 2015). As the granodiorite at the study area, it can be observed that the texture of the hand specimen was coarse grained, and the colour is reddish. Figure 4.7 (a) and (b) shows the outcrop and hand specimen of granodiorite in study area.



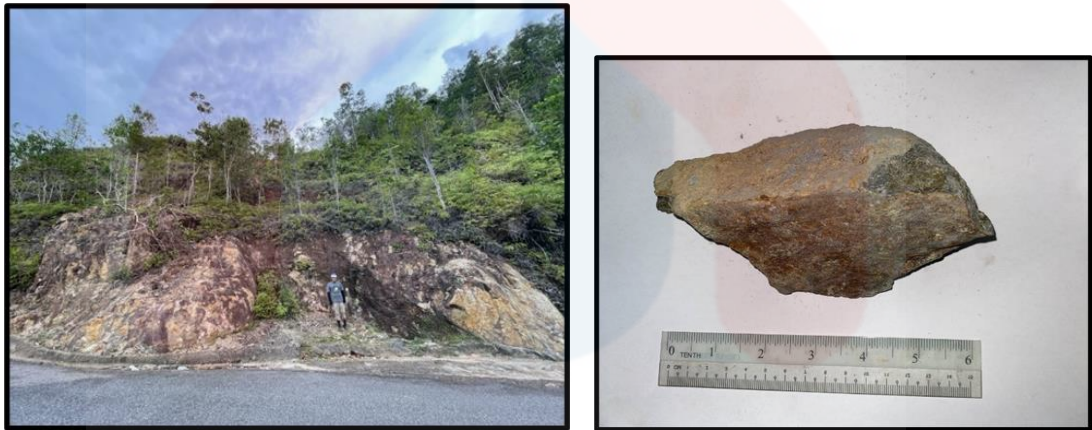
(a)

(b)

**Figure 4. 7 (a) and (b):** The outcrop and hand specimen of granodiorite.

## b. Hornfels

Hornfels is a fine-grained metamorphic rock that belongs to a group of contact metamorphic rocks that have been burned at high temperatures by the heat of igneous intrusions and have become massive, splintery, very hard, and in some cases very tough and durable. According to fresh sample that been collected at the study area, the hornfels texture consist of talk and fine-grained. The sample also are non-foliated structure. Figure 4.8 (a) and (b) shows the outcrop of hornfels and hand specimen that been collected.



(a)

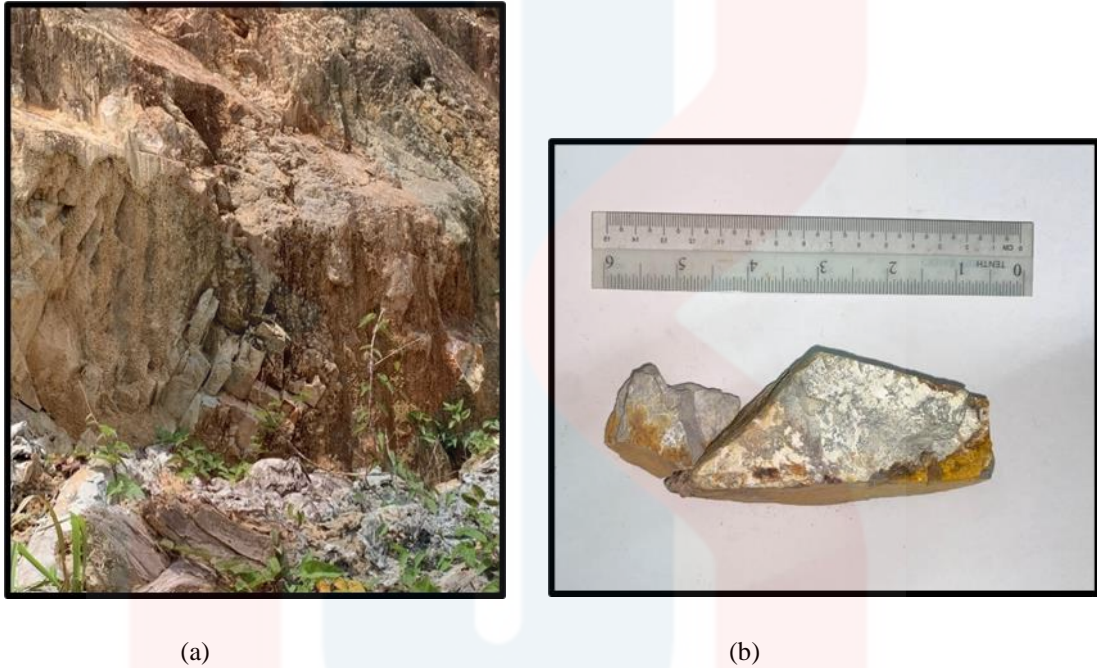
(b)

**Figure 4. 8 (a) and (b):** The outcrop and hand specimen of hornfels.

## c. Quartzite

According to (Science, 2019), quartzite is a non-foliated metamorphic rock made almost entirely of quartz. It shows what happens when a quartz-rich sandstone is changed by heat, pressure, and chemical changes. When these things happen, the sand grains and the silica cement that holds them together change shape. Besides, when sandstone is glued to quartzite, the quartz grains in the sandstone re-crystallize along

with the old glue, making a mosaic of quartz crystals that fit together. Through metamorphism, most or all the sandstone's unique texture and sedimentary structures are lost. Figure 4.9 (a) and (b) below shows the outcrop of quartzite in the study area. The outcrop can be observed as the colour is greyish and crystalloblastic texture.

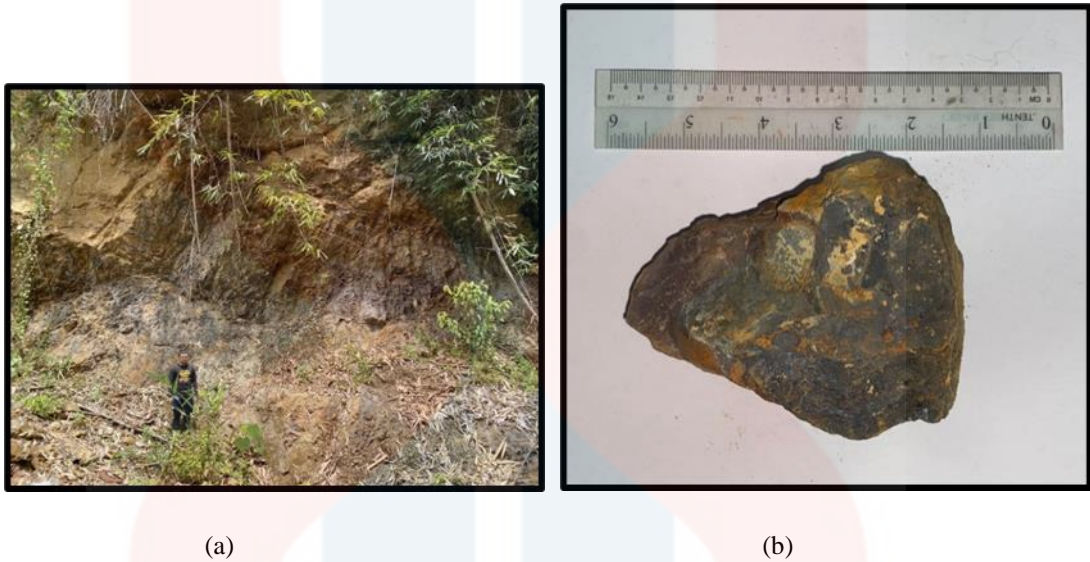


**Figure 4.9 (a) and (b):** The outcrop and hand specimen of quartzite.

#### d. Meta-mudrock

Meta-mudrocks are sedimentary rocks that have a fine grain size and are mostly composed of silt and clay-sized pieces. They are also known as argillites in certain circles. Even with the petrographic microscope, it is difficult to observe them since their grains are so small. However, they are significant rocks due to the fact that they are the sedimentary rocks that are found in the greatest abundance, making up more than 65 percent of all sedimentary rocks, and are thought to be the source rocks for petroleum and natural gas, in addition to sometimes being valuable ore deposits.

As the observation in the field, the meta-mudrock are consist of silica clay after been process in petrographic analysis. The quartz mineral within the hand specimen were low relief with anhedral crystal shape. Figure 4.10 (a) and (b) shows the meta-mudrock outcrop at the field of study area.



**Figure 4. 10 (a) and (b):** The outcrop and hand specimen of meta-mudrock.

### 4.3.3 Analysis of Petrography

Petrographic analysis is a method for examining the optical properties and microstructural aspects of the thin layer of rocks gathered during geological mapping. Under the microscope, the mineral composition and minerals were identified using two methods: cross polarised and plane polarised. Petrography analysis described mineral compositions that were difficult to discern with the naked eye.

A total of four petrographic analyses were carried out on each of the primary lithology units present in the research site. Petrographic research was performed on hand specimens of granodiorite, hornfels, quartzite, and meta-mudrock. The research included cutting thin sections and analysing the rocks.

The petrographic study allowed for the identification of the percentages of the mineral composition. From that point on, the name of the genesis rock was identified using the categorization from Pettijohn (1975), or Gillen (1982), and Streckeisen (1976). The names of the rocks derived from the geological mapping were assigned based on their physical characteristics; however, the names of the rocks themselves will be derived from the petrographic examination of their mineral make-up.





b. Hornfels

**Table 4. 4:** Petrographic analysis of Hornfels.

SAMPLE CODE: K 02	
PPL (Plane Polarized Light)	XPL (Cross Polarized Light)
<p><b>Microscopic Observation:</b></p> <p>The observations were carried out at 10x ocular magnification and 5x objective magnification and on the observation of non-foliated structures (hornfelsic), crystal oblastic textures (nematoblastic) including grain sizes &lt;math&gt;&lt; 1/256 - 1/32 \text{ mm}&lt;/math&gt;, good sorting.</p> <p><b>Mineral Composition:</b></p> <p><b>Quartz (A4) – 10%</b> In PPL color absorption is colorless, relief is low, pleochroism is absent, anhedral crystalline forms, hemispheres are absent. In XPL the color of the gray – white interference of the 1st order, the dark corners are wavy, twins are absent.</p> <p><b>Talk (G1) – 74%</b> In PPL color absorption is colorless, low relief, weak pleochroism, anhedral crystalline form, hemispheres are absent. In XPL the interference color is blue – yellow of the 3rd order, the dark angle is oblique, the twin is absent.</p> <p><b>Silica Clay (G10) – 15%</b> In PPL, the absorption color is not brown – brown. In XPL the interference color is dark gray – black. Consists of micron-sized silicate material.</p> <p><b>Opal Mineral (D1) – 1%</b> In PPL black absorption color, low relief, pleochroism is absent, euhedral crystalline form – anhedral. In XPL the color of black interference of the 1st order, twins are absent.</p>	<pre> graph TD     Q1{foliated or banded?} -- NO --&gt; Q2{grain size}     Q1 -- YES --&gt; Q3{grain size}     Q2 -- medium --&gt; Q4{splintery?}     Q2 -- coarse --&gt; Q5{main minerals?}     Q3 -- very fine --&gt; Q6{colour?}     Q3 -- fine --&gt; Q6     Q3 -- medium --&gt; Q7{banding}     Q3 -- coarse --&gt; Q7     Q4 -- YES --&gt; R1[basalt]     Q4 -- NO --&gt; R2[marble]     Q5 -- calcite --&gt; R2     Q5 -- quartz --&gt; R3[quartzite]     Q5 -- pyroxene + feldspar --&gt; R4[granulite]     Q6 -- green --&gt; R5[slate]     Q6 -- pale --&gt; R6[phyllite]     Q6 --&gt; R7[mylonite]     Q7 -- distinct --&gt; R8[schist]     Q7 -- streaky --&gt; R9[gneiss]     Q7 --&gt; R10[mylonite]     </pre>
ROCK NAME: HORNFELS (GILLEN, 1982)	

c. Quartzite

**Table 4. 5:** Petrographic analysis of Quartzite

SAMPLE CODE: K 01	
<p><b>PPL (Plane Polarized Light)</b></p>	<p><b>XPL (Cross Polarized Light)</b></p>
<p><b>Microscopic Observation:</b></p> <p>The observations were carried out at 10x ocular magnification and 5x objective magnification and on the observation of non-foliated structures (granulose), the crystalloblastic texture (nematoblastic) includes grain sizes &lt;math&gt;&lt; 1/64 - 1/5 \text{ mm}&lt;/math&gt;, good sorting.</p> <p><b>Mineral Composition:</b></p> <p><b>Quartz (A1) – 100%</b></p> <p>In PPL color absorption is colorless, relief is low, pleochroism is absent, anhedral crystalline forms, hemispheres are absent. In XPL the color of the gray – white interference of the 1st order, the dark corners are wavy, twins are absent.</p>	
<p><b>ROCK NAME: QUARTZITE (GILLEN, 1982)</b></p>	

d. Meta-mudrock

**Table 4. 6:** Petrographic analysis of Meta-mudrock

SAMPLE CODE: K 04	
PPL (Plane Polarized Light)	XPL (Cross Polarized Light)
<p><b>Microscopic Observation:</b></p> <p>The observations were made at 10x ocular magnification and 5x objective magnification and on observations it was known massive – weak foliation structure, texture includes grain size &lt;math&gt;&lt;1/256 - 1/6\text{ mm}&lt;/math&gt;, sorting well, packaging open. It is a meta-sedimentary rock, characterized by the apparent arrangement of the mineral parallel which has not formed a foliation structure and has not yet appeared to be mineral fragmentation.</p> <p><b>Mineral Composition:</b></p> <p><b>Quartz (C9) – 2%</b>            In PPL color absorption is colorless, relief is low, pleochroism is absent, anhedral crystalline forms, hemispheres are absent. In XPL the color of the gray – white interference of the 1st order, the dark corners are wavy, twins are absent.</p> <p><b>Silica Clay (J1) – 96%</b>            In PPL, the absorption color is not brown – brown. In XPL the interference color is dark gray – black. Consists of micron-sized silicate material.</p> <p><b>Opal Mineral (A3) – 2%</b>            In PPL black absorption color, low relief, pleochroism is absent, euhedral crystalline form – anhedral. In XPL the color of black interference of the 1st order, twins are absent.</p>	
<p><b>Fig. 2.11</b> The Pettijohn classification of sandstones, often referred to as a "Toblerone plot" (Pettijohn 1975).</p>	
<p><b>ROCK NAME: META-MUDROCK (MODIFIED FROM PETTIJOHN, 1975)</b></p>	

## **4.4 Structural Geology**

Structural geology is concerned with the geological characteristics generated because of tectonic movement, which causes deformation. It is critical to analyse geometries and explore Earth tectonic activity, as well as rock stress and strain. The history of the Earth was understood through understanding structural geology. Deformation results in faults and folds. Geological mapping and lineament analysis utilising a terrain map was discovered the Earth deformation.

### **4.4.1 Fault**

A fracture or crack that runs through the rocks is called a fault. Faults are generated between the tectonic plates of the earth. The movement of a section of the Earth's crust along an active fault throughout the course of time happens in active faults, while the movement of the Earth's crust along non-active faults has ceased. Earthquakes are caused whenever the fault shifts in its position. Normal faults, reverse faults, and transform faults are the three primary categories of defects that may occur in a system. Faulting could further subdivide into the categories of strike slip fault, oblique fault, and dip-strike slip fault.

Normal faults occur when the hanging wall slides downward in relation to the footwall. It happens when a force pulls a rock apart. Reverse faults occur when compression forces squeeze rock together, forcing the hanging wall to slide upward at an angle of 45 degrees or greater. Thrust faults, on the other hand, have an angle smaller than 45 degrees. The third kind of fault is the transform fault, which includes strike-slip faults. There are two kinds of strike-slip faults: dextral strike-slip faults and

sinistral strike-slip faults. Dextral strike-slip faults occur when the opposing side travels to the right, while sinistral strike-slip faults occur when the opposite side moves to the left.

The fieldwork study revealed that the research region has faults. The existence of the fault plane and an assumed hanging footwall that faces the observation of the outcrop makes it simple to identify the fault structure in the field. This allows for easy recognition of the fault structure. It is speculated that the fault is an oblique-slip fault, which can be seen in Figure 4.11 with coordinate ( $5^{\circ}23'17.53''\text{N}$ ,  $102^{\circ}17'21.58''\text{E}$ ). Oblique-slip fault is the fault which made up of two separate fault components, which are referred to as the dip-slip component and the strike-slip component. As a result of the movement of the fault taking place at an angle across the fault surface, the magnitudes of the component displacements are extremely close to one another. In addition, because of the existence of faults, it is very difficult to quantify the beddings of the rocks. Because of the strong compressional strength and stress that is exerted between the rocks, the fault has caused the structures of the rocks to shift.



**Figure 4.11:** Oblique Slip-fault in the study area with coordinate ( $5^{\circ}23'17.53''\text{N}$ ,  $102^{\circ}17'21.58''\text{E}$ )

#### 4.4.2 Fold

Fold is a structure that was characterised according to the orientation of its axes and its appearance. It created because of pressures exerted on the region, which result in deformation. As a direct consequence of the above, a surface that was previously resting flat or otherwise undeformed becomes distorted. Anticline, syncline, monocline, chevron, plunging, harmonic, and recumbent are the types of folds. A fold that is convex upwards is called an anticline, while a fold that is concave upwards is called a syncline. Sometimes the folding is quite subtle, to the point where it is difficult to observe or perceive the inclination of the strata.

As shown in Figure 4.12 with coordinate ( $5^{\circ}23'14.39''\text{N}$ ,  $102^{\circ}17'10.79''\text{E}$ ), there was a recumbent fold which almost constantly have an axial plane that is horizontal. The linear, fold axial plane was orientated at a low angle, which caused the strata in one leg of the fold to be inverted. Moreover, it also can be called as isoclinal folds that have been reversed to the point that their limbs are virtually horizontal.



**Figure 4.12:** Recumbent fold of the study area with coordinate ( $5^{\circ}23'14.39''\text{N}$ ,  $102^{\circ}17'10.79''\text{E}$ ).

#### 4.4.3 Mechanism of Structure

##### a. Lineament Analysis

The geological structure of the Earth was interpreted from the information provided by lineaments, which are presented in a linear or straight-line style. When a satellite picture or an aerial shot was used, the surface of the land might represent the faulting and other structures at a big scale.

Furthermore, positive and negative lineament are the two categories which lineament were placed when they were categorised. Ridge and range were used to convey the positive lineament, whilst streams, faults, and valleys were used to provide the negative lineament. Before conducting geological mapping, a lineament analysis was carried out in order to detect the various geological structures, such as strike slip faults, faulting, folding, and joints. Figure 4.13 shows the lineament maps of the study area and Figure 4.14 are the rose diagram analysis from the lineament direction

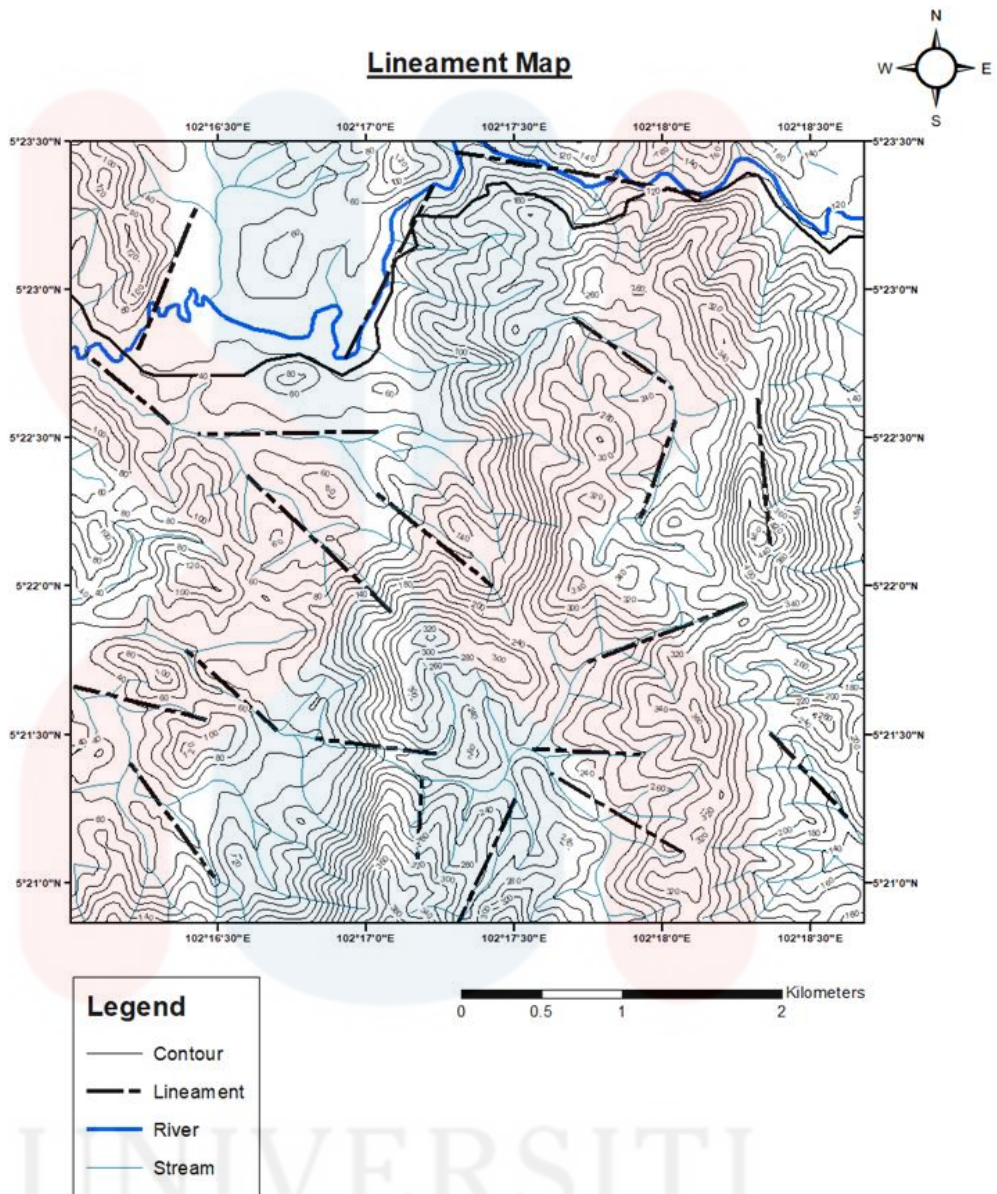
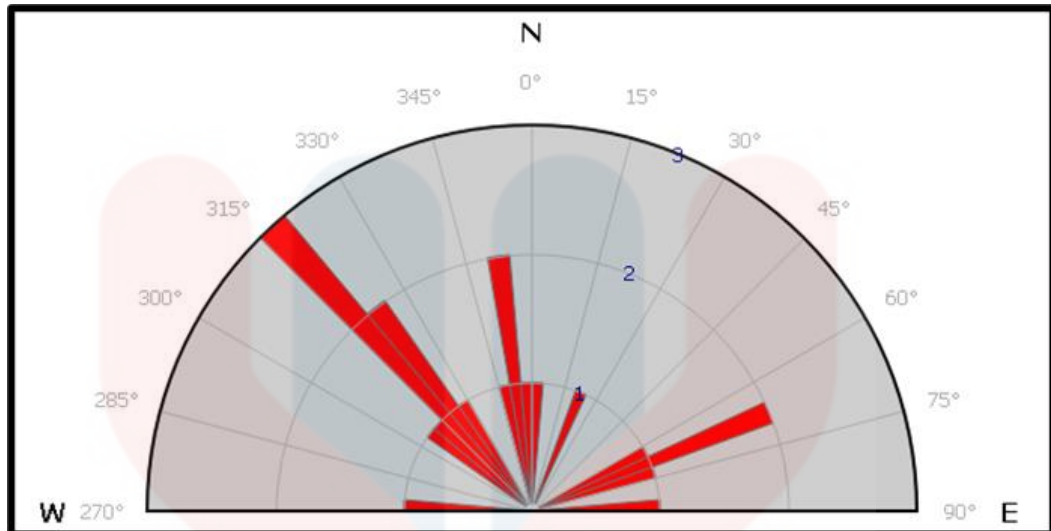


Figure 4.13: Lineament map of study area.

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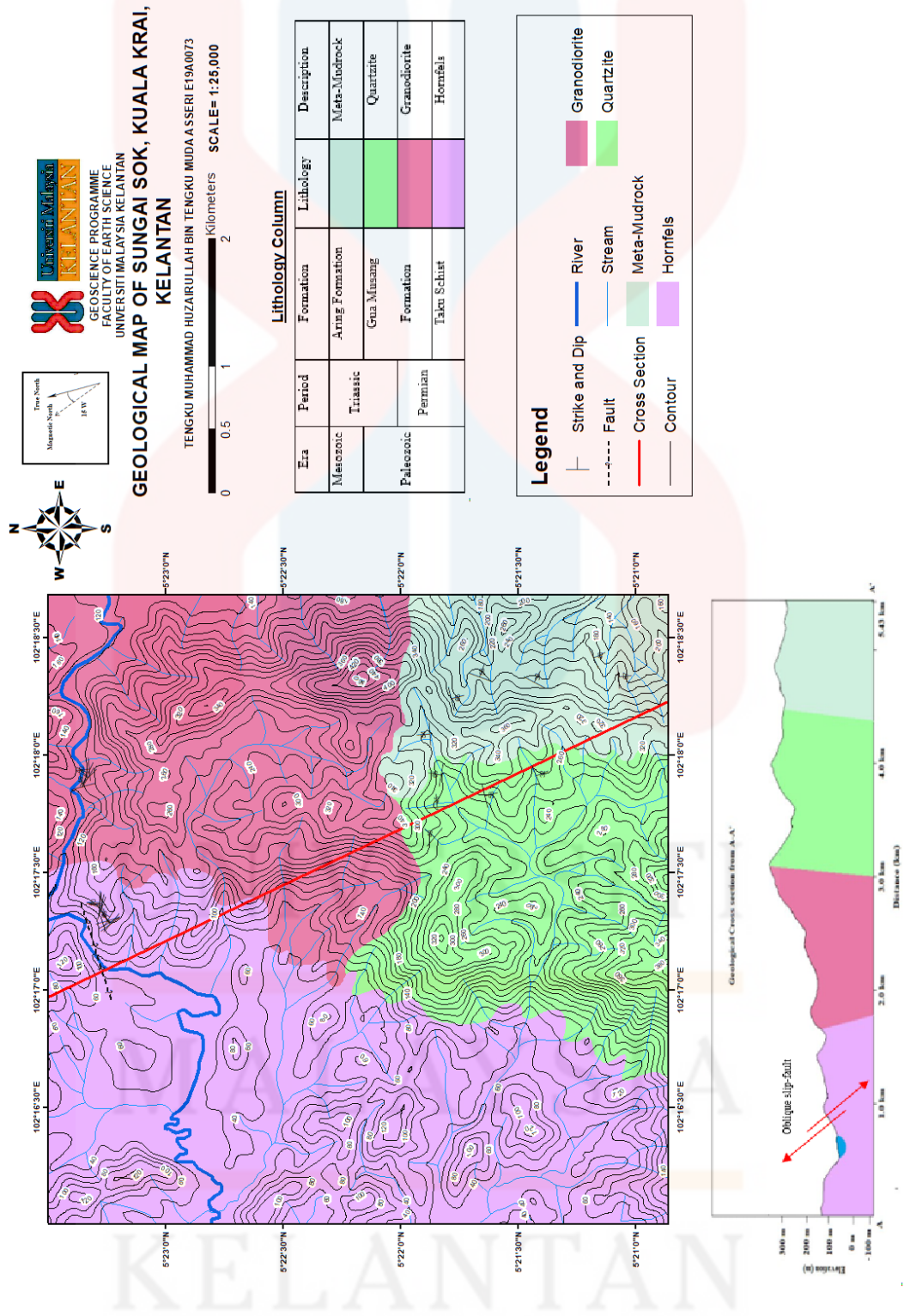


**Figure 4.14:** Rose diagram of the lineament analysis.

By referring the Figure 4.14, the biggest forces and stresses are from the north-west which indicate the red longest petal of the rose diagram.

#### **4.5 Historical Geology**

From the study area, it can be concluded that the historical geology of Sungai Sok, Kuala Krai, Kelantan is in the age of Permian and Triassic. This can be seen clearly from the stratigraphy column that stated in this study. However, the rock age in Kuala Krai area were stated as Permian, Triassic, Jurassic, and Quaternary as previous researcher observation. The locality of Sungai Sok is said as lower area or lower altitude which the major lithology that been observed was granodiorite, hornfels, quartzite and meta-mudrock which located near to the resident's area such as Kampung Sungai Sok and Kampung Chuchuh Puteri.



**Figure 4. 15:** Geological Map of study area.

## CHAPTER 5

### FLOOD HAZARD ANALYSIS

#### 5.1 Introduction

One of the natural calamities that takes place on a yearly basis in Peninsular Malaysia, particularly during the monsoon season, is flooding. It is because of the large quantity of rain that is consistently received each year. The average annual rainfall for Peninsular Malaysia was around 2, 400 millimetres, whereas Sarawak got 3, 800 millimetres, and Sabah received 2, 600 millimetres.

Kelantan is a state on Peninsular Malaysia's east coast and Kelantan is a nation that suffers the most from floods. When coping with floods in Kelantan, two major difficulties arise each year. There are several tributaries in the river system. These tributaries of the major rivers constitute the primary supply of water during floods. Kelantan's major source of water is the 248 kilometres in length which is Kelantan River. The primary tributaries of the Kelantan River are the Galas River that is 178 kilometres in length from the west and the Lebir River with 91 kilometres in length from the south. These rivers join the Kelantan River in Tangga Krai and flow into the South China Sea.

The second reason is the yearly monsoon season. It is regularly impacted by the northeast winds of northeast monsoon. The northeast winds continue to blow over

the South China Sea, striking the east coast of Peninsular Malaysia. Due to this season, the states on Peninsular Malaysia's east coast are prone to receiving continuous heavy rainfall for many days, perhaps up to nine days during the flood catastrophe of 2014. The flood of 2014 was one of Malaysia's biggest natural catastrophes, particularly in Kelantan.

As a result, Kelantan has been struck every year towards the end of the year. However, the most significant floods encountered by inhabitants in Kelantan are in year 1926, 1967 and 2004. This flood disaster was known as 'Bah Merah' through the time. The name 'Bah Merah' refers to the crimson tint of the floodwater. The hue arises from the erosion of the hills and slopes as the water poured through. The flood also comprised substantial silting materials, resulting in catastrophic red floods in cities and villages.

### **5.1.1 Causes of Flood**

Every year, Malaysia is subjected to intense precipitation, with the annual average being between 2,000 and 2,500 millimetres. During the monsoon seasons, which typically last from April to September (in the southwest) and from October to March (in the northeast), these rain showers grow much stronger (Northeast). The additional precipitation is often more than the rivers and other current drainage systems can handle (causing the rivers to break their banks and overflow), as well as the amount of water that the land can absorb (resulting in the rainwater becoming surface run-off). Hence, the heavy rainfall is the main factor that causing floods in Malaysia, (Bari, 2021).

Moreover, Malaysia was formerly densely forested, but it has been losing forests at an alarming pace in recent years. According to Google's global forest map, Malaysia experienced the world's greatest deforestation rate of 14.4% between 2000 and 2012. Though the rates have decreased in recent years, researchers believe that the loss of forest cover is still contributing to the increasing floods. Though deforestation cannot be blamed for every recent flood, it is well known that forests may act as a buffer against excessive rainfall; a tropical rainforest can intercept around 30% of rainfall in its canopy, with the remainder being absorbed into the soil or taken up by tree roots (Team, 2022). Thus, it is sure that deforestation also plays its roles by causing floods in Malaysia, especially in Kelantan.

## 5.2 Parameter of Causative Factor

The weightage of the parameter selected in determining the flood hazard area is shown in Table 5.1.

**Table 5.1:** Weightage of parameter of flood causative factor.

No	Parameter	Weightage (Wi)
1	Slope	4
2	Flow Length (Rainfall & Water Level)	5
3	River Distance	5
4	Land use / Landcover	5
5	Elevation	30

### 5.2.1 Slope

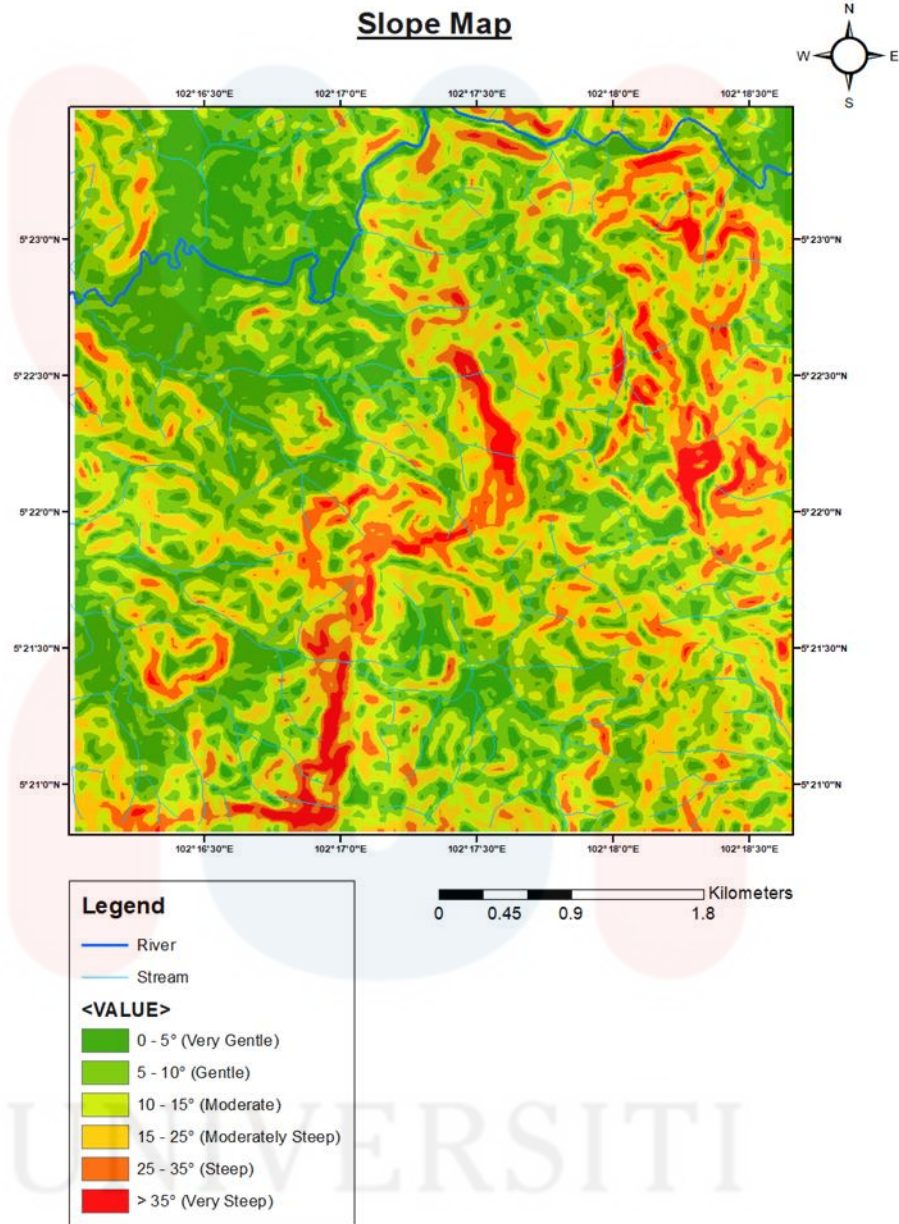
A flood occurs when water rushes downhill from higher elevations to lower points on the earth's surface. The rains had an effect on the direction that the water was flowing. The influence of forces acting in a downward direction adds to a low or reduced level of strength. When assessing the potential for flooding in the region under investigation, slope is an essential factor to take into consideration. According to the Malaysia Slope Classification developed by the Geological Society of Malaysia, the slope was divided into six distinct groups as shown in Table 5.2.

**Table 5. 2:** Slope Classification

No	Class	Description
1.	0 - 5°	Very Gentle
2.	5 - 10°	Gentle
3.	10 - 15°	Moderate
4.	15 - 25°	Moderately Steep
5.	25 - 35°	Steep
6.	> 35°	Very Steep

**Source 1:** Geology Society Malaysia, 2004

During geological mapping, a field observation was conducted at one place in the study area which at (a) N 5° 23' 21", E 102° 18' 15". Figure 5.1 shows the slope map that was generated from Digital Elevation Model (DEM).



**Figure 5.1:** Slope map of the study area.

Using the slope categorization developed by the Geology Society of Malaysia (GSM), the weightage and score for the slope are each split into six separate categories, and there are 4 weightage scores. This is because the slope factor has an impact on the incidence of floods. The degrees of slope influence the ratings, and a gentle slope results in higher points.

**Table 5. 3:** Weightage and score for slope.

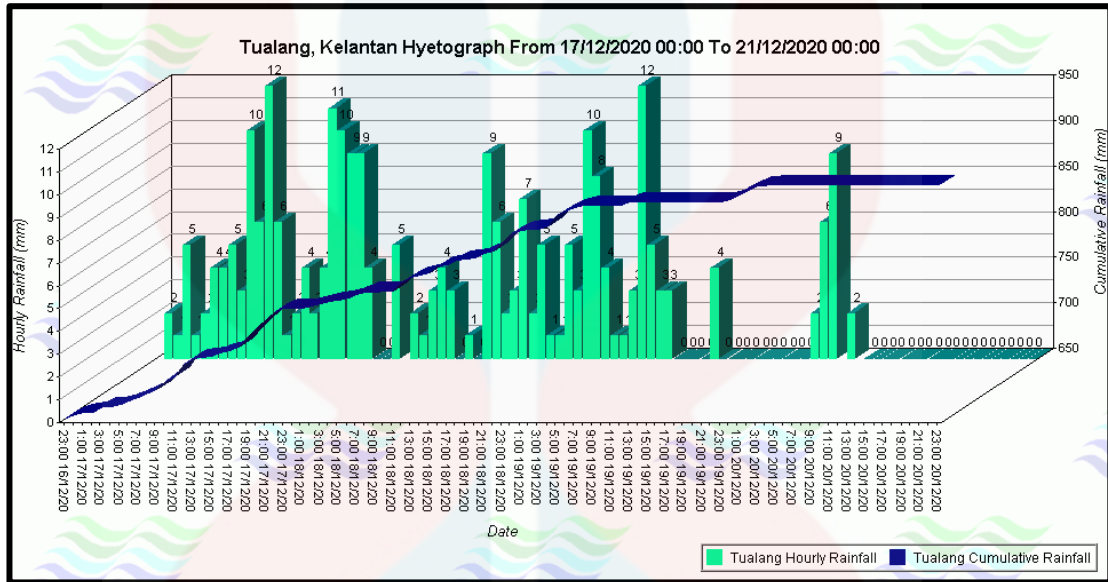
No	Class	Weightage (Wi)	Score (Sij)	Weightage X Score (Wi x Sij)
1	0 - 5°	4	1	4
2	5 - 10°	4	2	8
3	10 - 15°	4	3	12
4	15 - 25°	4	4	16
5	25 - 35°	4	5	20
6	> 35°	4	6	24

### 5.2.2 Flow Length

#### a. Rainfall

Flooding is frequently caused by heavy rain that continues for many days. Malaysia's meteorological agency has shown a rainfall pattern in parts of Malaysia's Peninsular states. Most Peninsular Malaysian states, including Kelantan, Terengganu, Pahang, Malacca, and Negeri Sembilan, had fewer than 200 millimetres of rain in September 2020. Peninsular Malaysia is anticipated to experience rainfall ranging

from 100 millimetres to 300 millimetres in November 2020. The quantity of rainfall in December 2020 is between 200 and 700 millimetres.



Source 2: Department Drainage and Irrigation (DID) Kelantan.

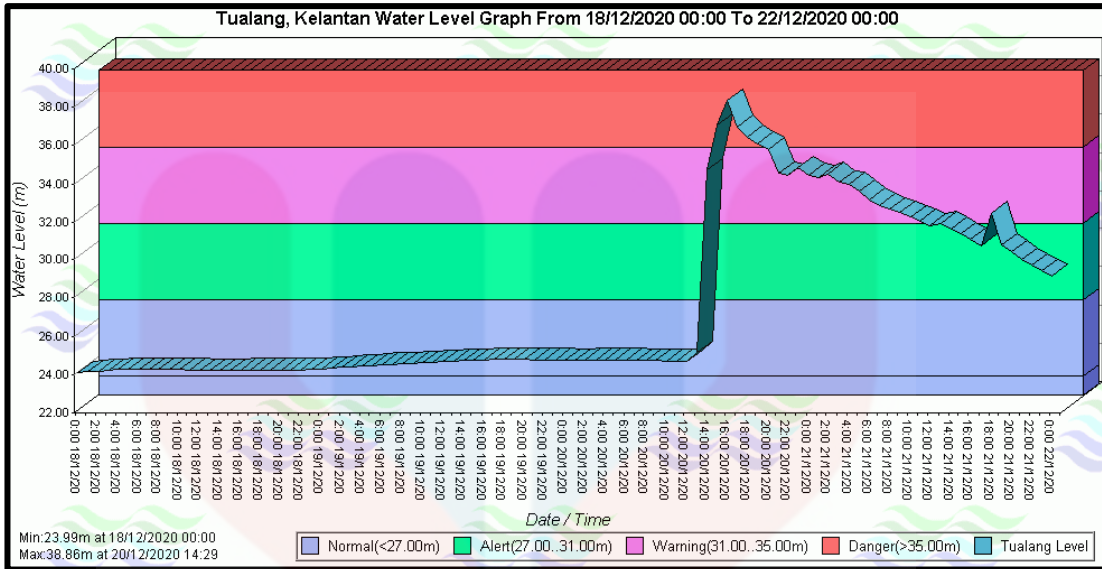
Figure 5. 2: The hyetograph of Tualang.

The rainfall data which was recorded at 11 rain measurement stations in Kelantan, revealed that significant quantities of rain fell for four days in a row, beginning on December 17 and ending on December 20. These four days occurred between December 17 and December 20 and according to the record, the quantity of rainfall that occurred on various days was found to be much higher than the typical amount. The only day in December in which the quantity of rainfall was consistent with normal was on the 16th. The overall quantities of rainfall that have been recorded throughout all stations add up to 3,780 millimetres, with the greatest record being set at the rain measurement station in Kg. Jeli, which recorded a total of 536 millimetres of rainfall.

Next, on December 20, the total amount of rainfall that was measured at all stations was 1533 millimetres, with the maximum quantity of rainfall being recorded at Gunung Gagau in Gua Musang. This station received 116 millimetres of precipitation. The measurements that were taken in Gua Musang also took into account the neighbouring areas of Kg Aring and Kg Laloh. In the Kuala Krai district, which encompasses both Dabong and Tualang, it was found that the total quantity of rainfall in each of these areas was higher than 200 millimetres.

The highest amount of rainfall ever recorded in Gua Musang was 1150 millimetres, and it was caused by a series of intense downpours that took place over the course of four days in a row. From the 17th to the 20th of December, there was rainfall that was measured at 402 millimetres, 708 millimetres, 533 millimetres, and 240 millimetres respectively. The entire quantity of precipitation that was recorded over the course of these four consecutive days is equivalent to the amount that would be received over the course of 64 days of normal rainfall, which would be 29.42 millimetres per day.

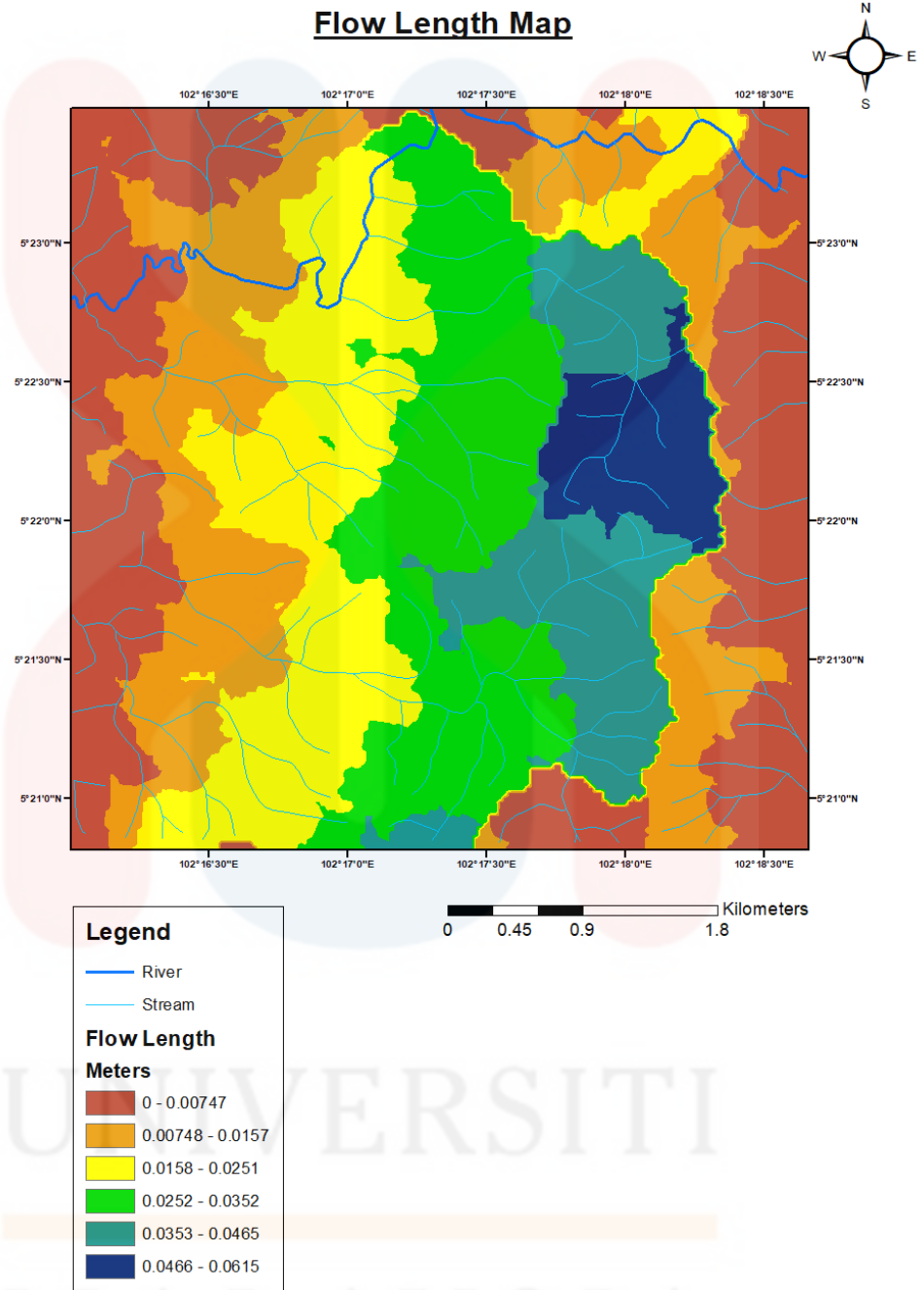
Besides, the rapid rise in river level in the Lebir River that was caused by the heavy rainfall in the Gunung Gagau region then influenced for the increasement of river level in the Tangga Krai. In addition to this, the location of Gunung Gagau, which is at a height of more than 1,400 metres above mean sea level, is also one of the elements that contribute to the occurrence of floods. The water that comes from Gunung Gagau tends to travel quickly down the mountain, generating a descent wave that has the potential to ultimately pierce the valley as well as the cliff of the river.



**Source 3:** Department of Drainage and Irrigation (DID) Kelantan.

**Figure 5. 3:** Water level graph of Tualang.

According to recorded data of rainfall and water level in four station, Tualang, Laloh, Dabong and Kuala Krai (Department of Irrigation and Drainage Kelantan, 2020), the trend of heavy rainfall was similar in 2020 and 2021. Recently, in 2022, the heavy rainfall which caused flooding in Northeast had occur at the same date which is 17 December 2022 to 21 December 2022. Figure 5.2 and Figure 5.3 shows the rainfall chart and water level graph from one of the stations, Tualang in 2020 while Figure 5.4 shows the flow length map of the study area.



**Figure 5. 4:** Flow length map of study area.

In flood hazard analysis, it is crucial to determine the movement of water over the terrain and the potential speed at which it can reach various locations in the event of a flood. The flow length maps were the parameter that depict the distance from

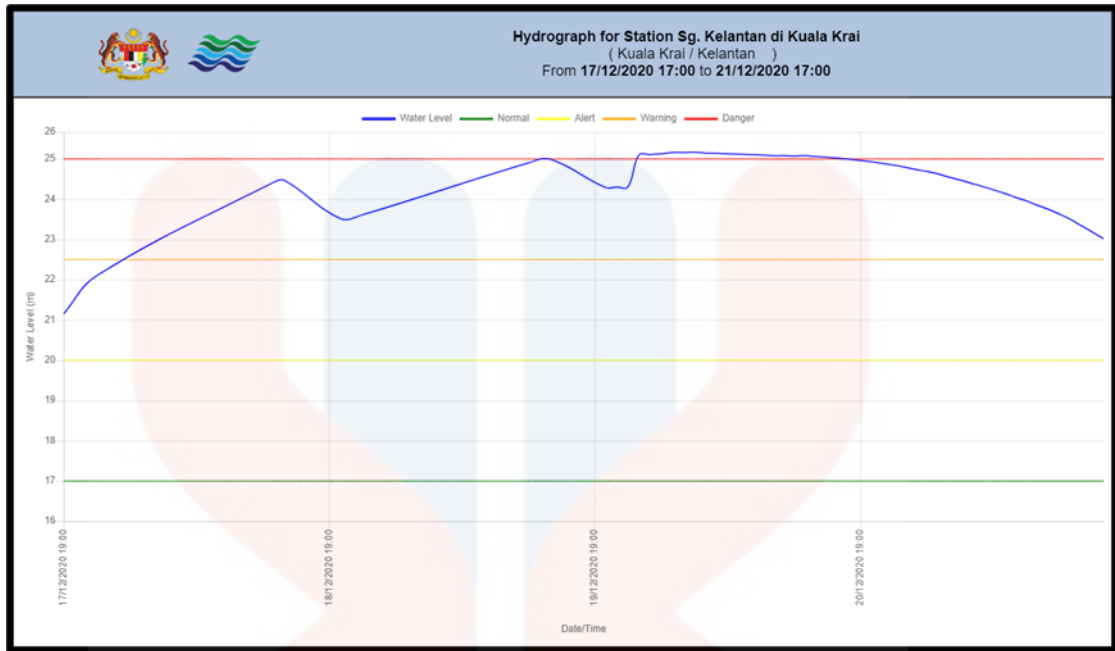
every point on the terrain to the nearest water source, such as a stream or body of water. The areas that are closest to these water sources will have the shortest flow lengths, making them more susceptible to flooding, while those areas furthest from these sources will have the longest flow lengths and thus be at the lowest risk for flooding.

a. Water Level

The hydrograph depicts the fluctuating water depth at a given period. According to the graph, there are three levels of water: danger, alert, and normal, with 25, 22, and 20 metres, respectively. During periods of drought, smaller streams are often dry, but when significant rainfall strikes the area, as it will in December 2020, all the streams become turbulent, carrying a massive number of sediments and overflowing their banks.

According to the analysis, length is the most significant component in establishing the flood hazard analysis for Kuala Krai Town, Kuala Krai, Kelantan, followed by depth. Duration was defined as the time it took for flood conditions to return to normal, whilst depth was defined as the depth of the water during the flood event.

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Source 5: Department of Drainage and Irrigation (DID) Kelantan.

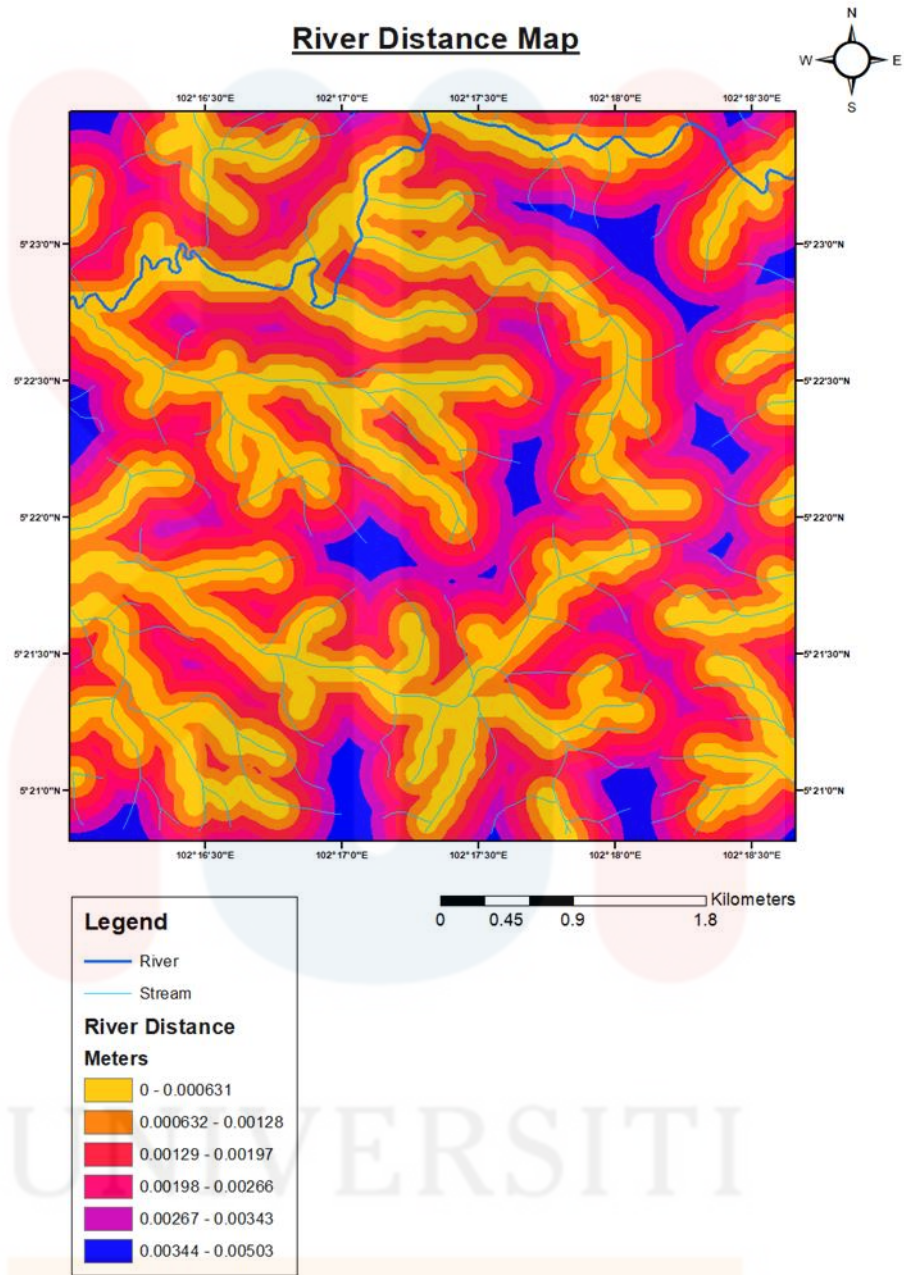
Figure 5. 5: Hydrograph of Sungai Kelantan in Kuala Krai which exceed danger zone.

The area of high flood zone is referred to as the danger water level when it began to rise above 25 metres. Based on the above flood risk map, the Kelantan River and Kuala Krai Town region was designated as a high-risk flood zone because of its low elevation. When the water level in a medium flood zone climbs to or above 22.5 metres, an alert is issued. According to hydrograph data, the water level began to steadily rise on 19 December 2020 and reached a dangerous level on 20 December 2020. At 20 m of water level and below 22.5 m, it was referred to as low water level, whereas below 20 m of water level, it was referred to as very low water level. This region focuses on low flood zone locations.

### 5.2.3 River Distance

The distance to rivers is the hydrological state of the region or the saturation degree of the soil on slopes has been characterised as a stability contributing parameter in the flood danger area in Kampung Sungai Sok. Both of these factors contribute to

the stability of the slopes. Infiltration of water into the soil, runoff, and movement of groundwater were all events that occurred as a result of the hydrological conditions (Thanh & De Smedt, 2011). There is a possibility that the slopes' vicinity to river lines may impact their stability. This is because the proximity to rivers will speed up the process of erosion that occurs along the slope and causing flood (Mancini et al., 2010). As the study area, most of the area were close to the river which led to flood when the water level from the river exceeds the danger zone. Figure 5.6 shows the distance to river map of the study area.



**Figure 5. 6:** River distance map of the study area.

A river distance map is a representation of the proximity of a certain location to a river or other water source. It can be a valuable tool in managing flood risks as it can pinpoint areas that are most susceptible to flooding. For instance, a location that is situated near a river would be more prone to flood damage than one that is farther

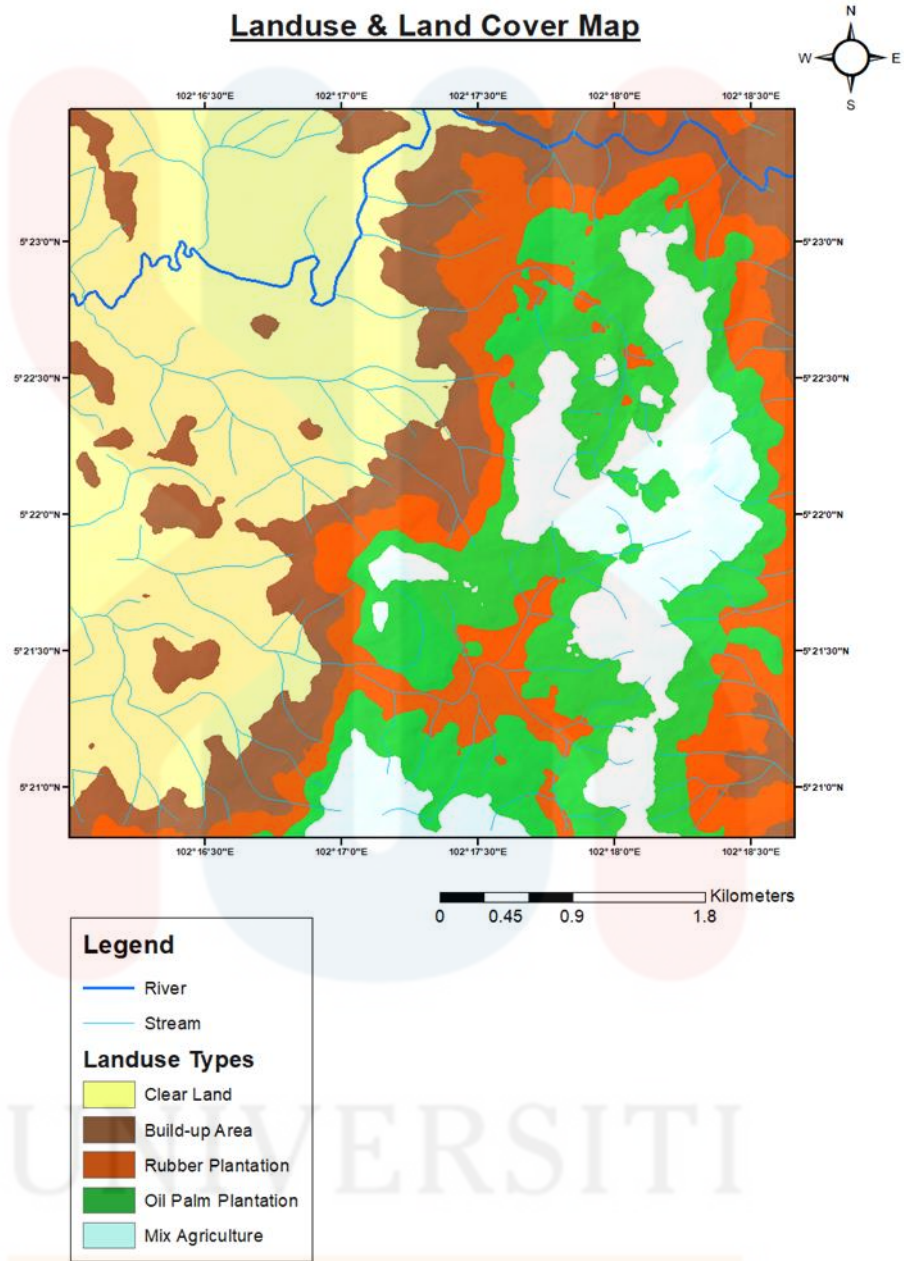
away. This information can be used to take proactive measures to reduce the risk of flooding, such as the construction of flood walls or levees. Additionally, during a flood event, having a river distance map on hand can aid emergency responders in identifying the areas that are most likely to be affected, allowing them to focus their efforts on the areas that need it most.

#### 5.2.4 Land use and Land cover

A land use map was created using secondary data received from DEM. Most of the area was used for agricultural purposes, such as the cultivation of oil palms and rubber plants, while the remaining portions were forested. In addition, areas of clear land that have a medium population density have been allotted in the Kampung Sungai Sok neighbourhood. The type of land cover was used to predict the degree of slope stability. The effects of human activity can hasten the onset of flooding and have a significant bearing on its severity. Table 5.4 shows the weightage and score for land use and land cover while Figure 5.7 shows the land use map of the study area.

**Table 5. 4:** Weightage and score for land use.

No	Class	Weightage (Wi)	Score (Sij)	Weightage X Score (Wi x Sij)
1	Clear Land	5	3	15
2	Build-up Area	5	2	10
3	Rubber Plantation	5	3	15
4	Oil Palm Plantation	5	4	20
5	Mix Agriculture	5	2	10



**Figure 5. 7:** Land use map of study area.

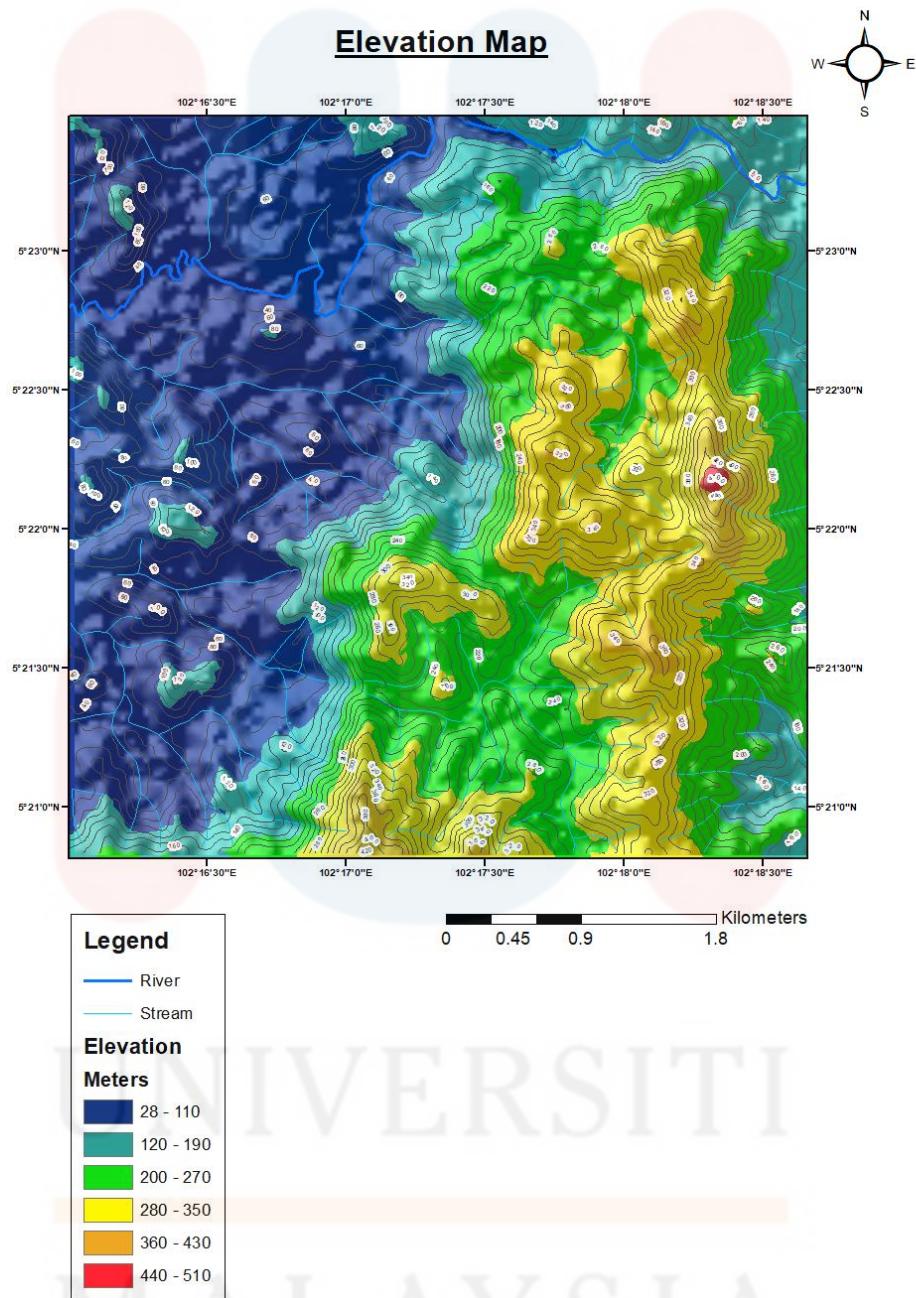
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### 5.2.5 Elevation

Elevation is a critical factor in determining flood hazard (Sarkar and Mondal, 2020). In general, the link between elevation and flood risk is inversely proportionate, implying that areas that are higher elevated are less likely to be impacted by floods. Low-lying areas, on the other hand, are very vulnerable to floods. For the flood hazard analysis study, an elevation map with a resolution of 30 metres was constructed using data from the Shuttle Radar Topography Mission's (SRTM) Digital Elevation Model (DEM). Figure 5.9 shows the flood hazard map of Kampung Sungai Sok, Kelantan. The red colour area indicates as flood hazard area which likely the elevation was below 50m above sea level. These events been observed when rain falls, the surface runoff may travel extremely fast from mountainous or hilly regions to low lying areas, making low lying areas more susceptible to floods. This is because mountainous or hilly places get more precipitation overall. The frequency and severity of floods has been linked to human activities that harm the environment. Table 5.5 shows the weightage and score of the elevation and Figure 5.9 shows the elevation map of study area.

**Table 5. 5:** Weightage and score for elevation.

No	Class	Weightage (Wi)	Score (Sij)	Weightage X Score (Wi x Sij)
1	Low Land	30	4	120
2	Low Hill	30	6	180
3	Hill	30	8	240



**Figure 5. 8:** Elevation map of study area.

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### 5.3 Flood Hazard Analysis

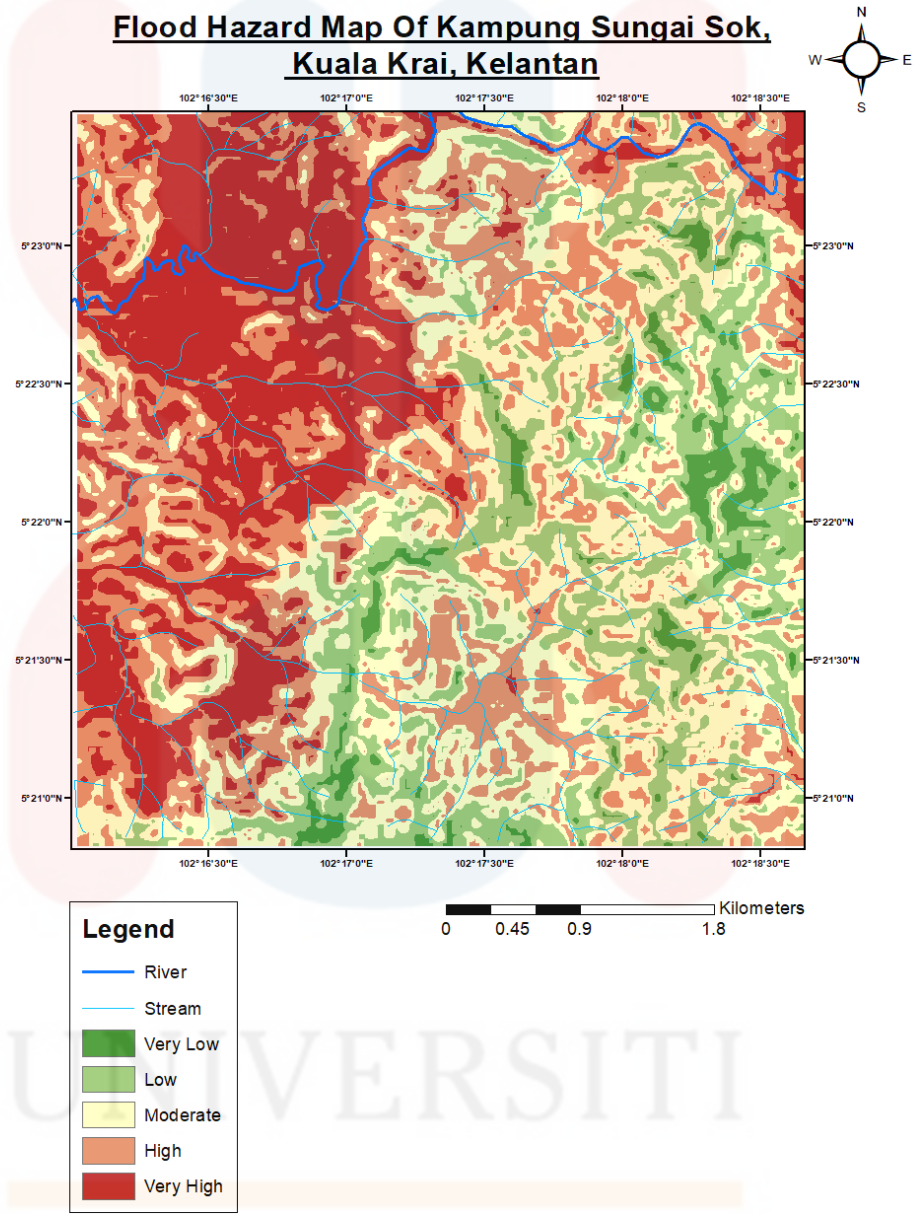
The preparation of the flood hazard map required the transformation of all chosen parameters into a raster data collection. After that, these raster data were classed according to their weightage. The map displaying the risk of flooding was created using the weightage overlay technique and the use of GIS. The slope, flow length, river distance, land use or land cover, and elevation are the flood causative factors that were selected as the criteria for this study. The parameters were each given a corresponding weight, and the overall contribution of all the factors was equal to 100%. It is necessary to reclassify the data in order to build the flood hazard map using the weightage overlay approach. The reclassified data sets are shown in Table 5.6.

**Table 5. 6:** The reclassify data with influence.

No	Raster Datasets	Influence
1	<b>Slope</b> 0 - 5 ° 5 - 10 ° 10 - 15 ° 15 - 25 ° 25 - 35 ° > 35 °	10
2	<b>Flow Length (Rainfall &amp; Water Level)</b> 0 – 0.00747 0.00748 – 0.0157 0.0158 – 0.0251 0.0252 – 0.0352 0.0353 – 0.0465 0.0466 – 0.0615	25
3	<b>River Distance</b> 0 – 0.000631 0.000632 – 0.00128	25

	0.00129 – 0.00197 0.00198 – 0.00266 0.00267 – 0.00343 0.00344 – 0.00503	
4	<b>Land use / Landcover</b> Clear Land Build-up Area Rubber Plantation Oil Palm Plantation Mix Agriculture	15
5	<b>Elevation</b> Low land Land Hill	25
	<b>TOTAL</b>	100

The flood hazard maps of the Sungai Sok region and the areas around it were seen in Figure 5.9. According to the maps, there is a moderate flooding region over the bulk of the research area, which accounts for 35% of the study area. 55% of the region under consideration is considered to have a low risk of flooding, while 10% of it is considered to have a high risk of flooding.



**Figure 5. 8:** Flood Hazard Map of Sungai Sok, Kuala Krai, Kelantan.

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In flood hazard analysis, slope, flow length, and river distance all play a vital role and are becoming the elements that have the most significant effect. A moderate slope has a greater risk of flooding than one with a steeper gradient. Flooding also be caused by excessive rainfall, which leads to a massive concentration of runoff that is much higher than the carrying capabilities of streams and rivers. River distance is another factor that contributes to flooding. Because of this occurrence, the water level will rise to a point where it will overtop the riverbanks and begin to flow into the floodplain region, a process that is referred to as overbank flow and will result in flooding. Table 5.7 shows the percentage of area that have risk to flood.

**Table 5. 7:** Flood risk area.

<b>Risk</b>	<b>Area Percentage (%)</b>
Low (0-50%)	55
Moderate (50-75%)	35
High (>75%)	10

The resulting flood risk map clearly depicts the spatial distribution of the flooded area, which is located in relatively low-relief regions. The results demonstrated that plantation acreage decreased significantly in high- and medium-risk zones, while urbanisation altered land use in low-risk zones

### CONCLUSION AND SUGGESTION

#### 6.1 Conclusion

This chapter summarize the findings from chapter 4, general geology and chapter 5 landslide hazard zonation and evaluation using GIS and remote sensing. It can be concluded that the objectives of this research are well achieved.

The first objective is to generate a 1:25,000-scale geological map of Sungai Sok, Kuala Krai, Kelantan. The objective was accomplished by the geological mapping conducted in the study area. In chapter 4, every aspect of geology, including geomorphology, stratigraphy, structural geology, petrography, and historical geology, was discussed in detail. The study area was generally divided into four lithologies: granodiorite, hornfels, quartzite, and meta-mudrock. There are numerous geological structures, such as major faults, folds, and joints.

The second objective is to evaluate the causative factors of flood to occur. The main causative factor for the occurrence of flood is the hydrological factors. The study area received high amount of rainfall intensity especially during the North-East monsoon due to the climate that raining throughout the year.

The flood hazard map was generated using five parameters, including slope, river distance, landuse, flow length, elevation. Using the Weighted Overlay Method

(WOM) in GIS software, these parameters were reclassified and overlaid. The flood hazard map was generated and divided into zones of very low, low, moderate, and high and very high flood risk. In general, 50% of the study areas' flood hazard potential is high, 30 % is moderate, and 20% is low. The parameters for flood hazard analysis were discussed, as well as the factors for flood hazard.

## 6.2 Suggestion

In order to improve the quality of geological mapping in future research, it is recommended that a thorough review of the geological history of the study area is conducted before beginning any field work. Additionally, expanding knowledge in structural geology and the different types of rock present in the area could also help in collecting more accurate data within a given time frame.

Moreover, in order to produce a more accurate flood hazard analysis map, it is recommended to choose appropriate parameters for the study area, as different parameters may produce different results. Therefore, this method must be thoroughly comprehended in order to set appropriate parameters. Different method for producing flood hazard maps can be explored such as Analytic Hierarchy Process (AHP) in order to obtain more reliable data and comparison between methods.

Finally, flood mitigation aids in reducing flood occurrences through the management and regulation of flood water flow. At least several measures must be taken to prevent flooding in Kelantan from worsening in the coming years. First, land clearing and logging should be halted or at least brought under control. If not, it should be executed in an appropriate manner. Next, construct an upstream water-retention structure, such as a dam, to hold water during heavy rainfall and monsoon season. Last but not least, flooding can be mitigated by aggressively silting and deepening rivers downriver. This action required upstream and downstream Kelantan River basin-level efforts.

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