DEVELOPMENT OF FLOOD RISK VULNERABILITY INDEX (FVI) FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA

FOREWORD

A research contract on the study and development of "Development of flood risk assessment (FRA) and flood vulnerability index (FVI) for critical infrastructure (CI) in Malaysia : A case study in Sungai Pinang, Pulau Pinang" was initiated and funded by Malaysian Construction Industry Development Board (CIDB) via its subsidiary Construction Research Institute of Malaysia (CREAM). The purpose is to improve the resilience of the built environment through – understanding risk of natural hazards to buildings and infrastructure; understanding issues and countermeasures against building and infrastructure with respect to Disaster Risk Reduction (DRR); mainstream DRR into planning, design, construction and maintenance of building and infrastructure; and adopting good pratices and lessons on building resilience for building and infrastructure from other countries.

This cross-disciplinary research was assigned to a team of professionals from hydrologist, hydraulic engineer, hydrodynamic modeller, socio economic expert and academicians. Through more than one-year duration, the product of the study has successfully produced five documents, i.e a inception report, a interim report, a final report and a guideline.

The final report explains and elaborate with case study on the methodology of assessing and developing the parameters-indicators of flood vulnerability index and flood risk classification of critical infrastructures. The semi-quantitative approach is divided into 4 main stages namely data acquisition and pre-processing of geospatial data, improvements of flood vulnerability cluster, indicators, sub-indicators and weight values, flood vulnerability and risk mapping case study and finally the evaluation of the flood vulnerability and risk assessment method. The key approach towards development of a reliable and practical landslide vulnerability assessment is to use the easily identified, measurable and most significant indicators. These were proven scientifically from the analysis of sensitivity of indicators and sub-indicators for the particular critical infrastructure.

To assess and develop the parameters-indicators of flood vulnerability assessment and risk index of critical infrastructures and assigning level for each parameter begins with the proposed flood vulnerability and risk assessment methods, initial flood vulnerability clusters, indicators, sub-indicators, weight values, vulnerability class and risk class as per literature. This information is improved based on series of focus group discussion (FGD) with different stakeholders and internal experts of the consultant team members. The final flood vulnerability clusters, indicators, sub-indicators, weight values, vulnerability class and risk class were produced based on the improvements made by the internal experts based on the initial weights assigned by the stakeholders and literature review.

ACKNOWLEDGEMENT

Construction Research Institute of Malaysia (CREAM), through the cooperation and support of various government department and agencies, and private sector in Malaysia, produced a series of documents on inception report, interim reports, draft final report, final report and a manual which are related to flood vulnerability assessment and flood risk analysis for critical infrastructure in Malaysia. The aim of such publication is to develop the capacity and capability of construction industry players related to high flood disaster risk reduction agenda by emphasis on professionalism, innovation and knowledge in the endeavour to improve the quality of life. This cross-disciplinary research was assigned to a team of professionals from hydraulic engineer, hydrodynamic modeller, socio economic expert and academicians

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DEVELOPMENT OF FLOOD RISK ASSESMENT AND FLOOD VULNERABILITY INDEX (FVI) FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA

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INTRODUCTION

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INTRODUCTION

1.1 BACKGROUND

Latest catastrophic events that occurred in Malaysia have witnessed numbers of massive devastation, economic change and loss of human life. The country has experienced unprecedented events, including the worst flood event in 50 years and strong earthquake in 39 years since 1976. Even though Malaysia geographically considered less vulnerable, the exposure to a range of climate-related disasters has intensified in part, due to climatic and topographical conditions.

New risks and vulnerabilities have emerged as the features of climate change in term of the scale, frequency, severity and unpredictability of extreme weather. Human activities including immense population growth, sprawling development and megacities is another factor that cause threats to the environment thus lead to disasters. In time of uncertainties,

the risk and vulnerabilities exposed by natural hazards and disasters rise at accelerating pace add sense of urgency to the challenge of being resilience.

Moving forward, resilience features need to be enhanced in multi-disciplinary actions. Enhanced resilience enables better anticipation of disaster and planning to minimise the impact and losses. The critical question is, how resilience is we, and are we ready to face various challenges and uncertainties in the future?

Conceptually, resilience needs to have the ability to maintain acceptable levels of functionality during and after disruptive events with recover full functionality within a specific period. The strategy in developing resilience involve short and long-term planning, investments of time and resources prior to an event. Resilience is a process that needs to take into account the economic, social, psychological, physical and environment factors that will ensure continuity to survive (Dodman, Ayers, & Huq, 2009)

The Sendai Framework for Disaster Risk Reduction 2015 to 2030 (SFDRR) adopted in 2015 echoes global commitment to address Disaster Risk Reduction (DRR) and the building of resilience to disasters with renewed sense of urgency (United Nations, 2015). Align with the global agenda, Malaysia government under the Eleventh Malaysia Plan aims to strengthening resilience against climate change and natural disaster. Building the culture and practice of disaster resilience will require focused action within and across multi sectors.

1.2 STUDY OBJECTIVES

The aim of this study is to develop flood risk assessment and vulnerability index for critical infrastructure in Sungai Pinang, Pulau Pinang. This is to be achieved through the following specific objectives as highlighted in the Terms of Reference: -

- To identify indicators that will be selected to construct an index for critical infrastructure in respected area.
- To develop a multi-criteria assessment of the critical infrastructure.
- To identify the parameters for developing flood vulnerability index (FVI) of critical infrastructure and assigning score for each parameter.

1.3 SCOPE OF WORKS

The scope of work as stipulated in the Terms of Reference are outlined as follows: -

- To identify indicators/ parameters for flood risk assessment and FVI for critical infrastructures.
- Review existing flood hazard/risk map of the study area.
- Prepare and verify methodology to develop FVI for critical infrastructures.
- Prepare and verify methodology to review existing flood hazard/risk map.
- Based on the reviewed, further identify the critical infrastructure.
- Collect, collate, and analyses data (primary and secondary) to support the development of FVI for critical infrastructures in the selected areas.
- Develop FVI for critical infrastructure.
- Propose flood and development zoning with respect to FVI

1.4 DELIVERABLES

The expected deliverables as stipulated in the Terms of Reference are outlined as follows:

- New flood risk map.
- FVI for Critical Infrastructures.
- Flood and development zoning.
- Presentation materials must be handed to CREAM.
- Provide training for CREAM personnel and others.

1.5 OUTLINE OF THE REPORT

This report discuss diligently the process and development of the flood vulnerability index for critical infrastructure in Sungai Pinang right from the initial stage in appreciating the study area in Sungai Pinang which is described in Chapter 2, analyzing and deriving the various hydrological parameters for the input in the hydrodynamic modelling is discussed in Chapter 3, hydrodynamic model development and simulation of flood hazard map for various scenarios are described in Chapter 4, generation of flood hazard maps, flood damage maps and flood risk maps are discussed and described in Chapter 5, Output from the Focus Group Discussion particularly in analyzing the definition of Critical Infrastructure in Sungai Pinang that is regards to flooding phenomenon was deliberately spell and discussed in Chapter 6 and derivation of Flood Vulnerability Index for the Critical Infrastructure in Sungai Pinang were explained in Chapter 7.

The following are the chapters contained in this report.

Chapter 1– Introduction

Chapter 2 – Description of Study Area

Chapter 3 – Hydrology Analysis

Chapter 4 – Hydrodynamic Analysis

Chapter 5 – Flood Hazard, Flood Damage & Flood Risk Analysis

Chapter 6 – Focus Group Discussion

Chapter 7 – Flood Vulnerability Index

CHAPTER 2

DESCRIPTION OF STUDY AREA

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DESCRIPTION OF STUDY AREA

2.1 THE SUNGAI PINANG RIVER BASIN

The Sungai Pinang river basin lies within the Latitude of *5^o 21′ 32″ N* to *6^o 26′ 48″ N* and Longitude of *100^o 14′ 26″ E* to *100^o 10′ 42″ E*. It is located on the north-eastern coast of Penang Island, which mainly comprises the urban areas of Georgetown, Air Itam and Paya Terubong towns and their vicinity as shown in **Figure 2.1**.

Sungai Pinang river basin area is approximately 46km square and it is the largest, most built-up river system on the island. Sungai Pinang flows originate from the central hilly to undulating part of the catchment. Others than the tributaries, Sungai Pinang itself is only about 3.6km. These tributaries are Sungai Jelutong (5.94km), Sungai Air Itam (12.88km), Sungai Air Terjun (9.30km), Sungai Dondang (6.97km), Sungai Air Putih (3.89km), Sungai Kecil (Parit Lumba Kuda) (2.64km) and Sungai Mati (0.6km).

Among these tributaries, Sungai Air Itam is the largest tributary and Sungai Mati is the shortest tributary. Sungai Air Itam is regulated by a water supply dam located at the upstream part. Most of Sungai Pinang and its tributaries have been channelized and lined during the development of the surrounding area.

The topography of the project area as shown in **Figure 2.2** can mainly be divided into two geomorphic zones namely the **Lowland Coastal Flood Plains** and the **Interior Hills**. The hill terrains, which are mainly located in the central and northern part of the island, are generally rugged and steep terrain with and average slope of more than 30 percent. In general, the elevation ranges from 300 m to 800 m, while the highest peak is Bukit Western (830 m) located at Penang Hill. On the other hand, the low or flat alluvial lands basically occupy the coastal side of the island. The elevations of these floodplains merely exceed the elevation of more than few meters while many areas near the estuary of Sungai Pinang are just 1 meter above the sea level.

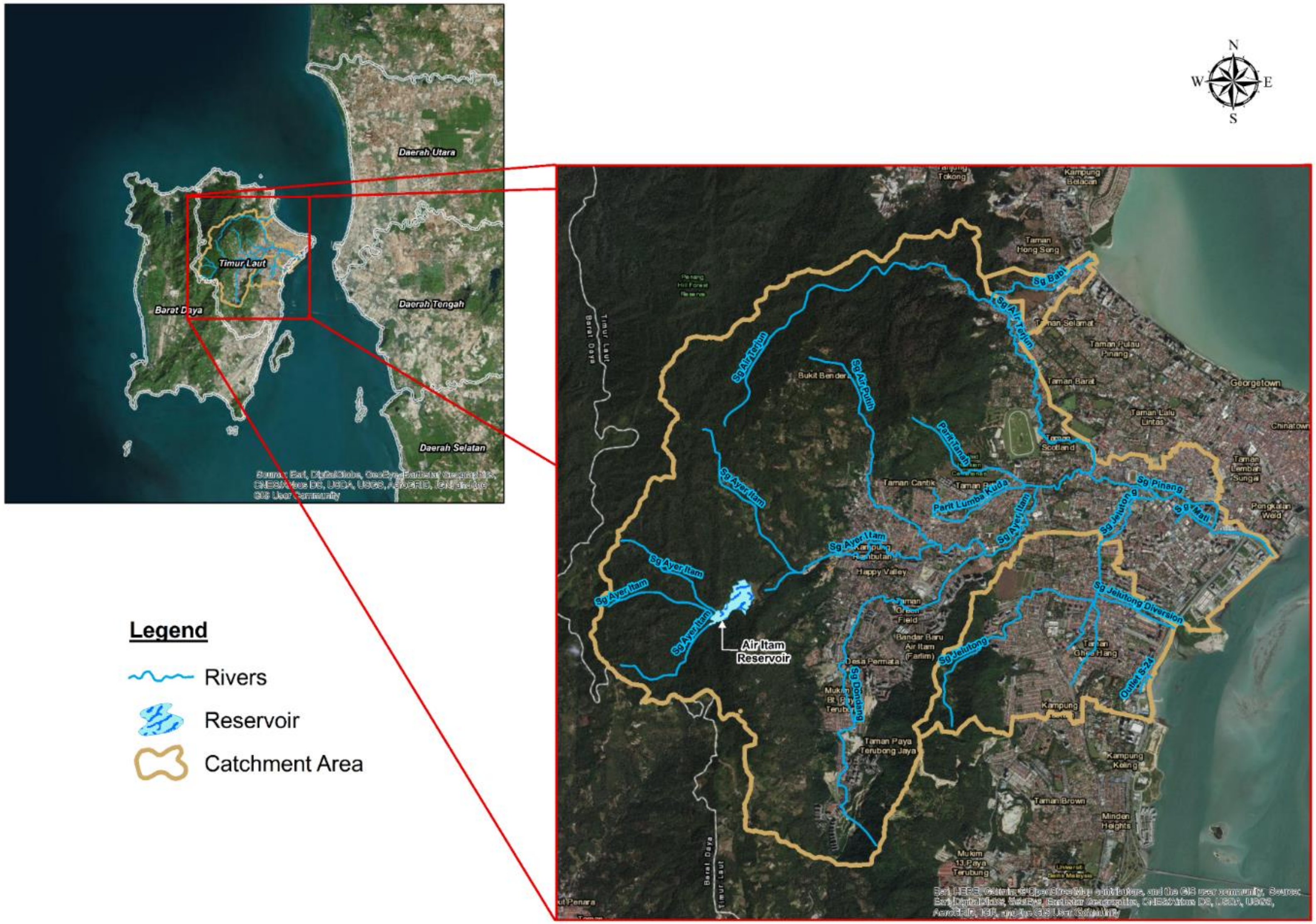


Figure 2.1: The Sungai Pinang Basin

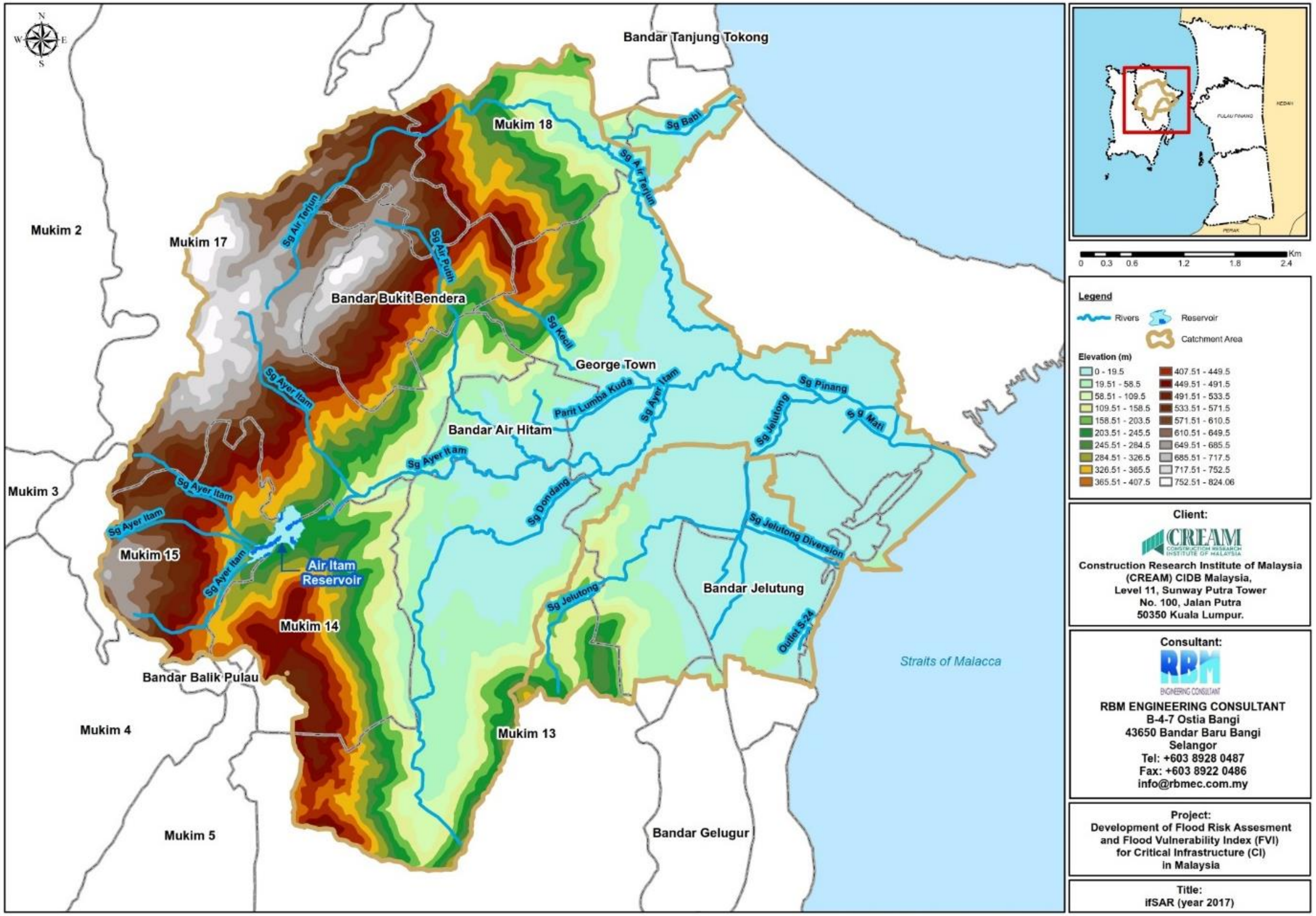


Figure 2.2: Topography of the Sungai Pinang Basin

2.2 ADMINISTRATIVE JURISDICTION

The project area is wholly located in the District of Timur Laut and comprise 8 mukims or sub-district, 12 Dewan Undangan Negeri and 5 Parliament as shown in **Figure 2.3**, **Figure 2.4** and **Figure 2.5**. The respective areas of those administrative boundaries within the project area are shown in **Table 2.1** to **Table 2.3**.

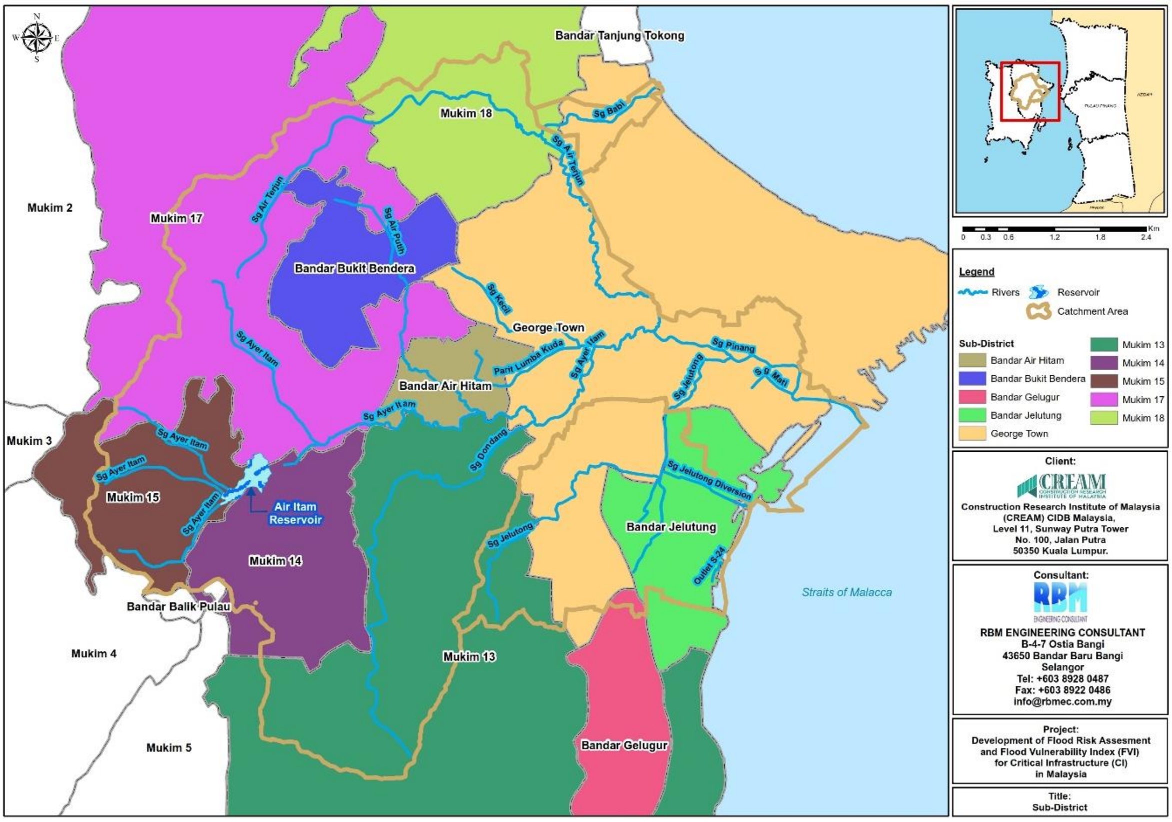


Figure 2.3: Mukim within the Project Area

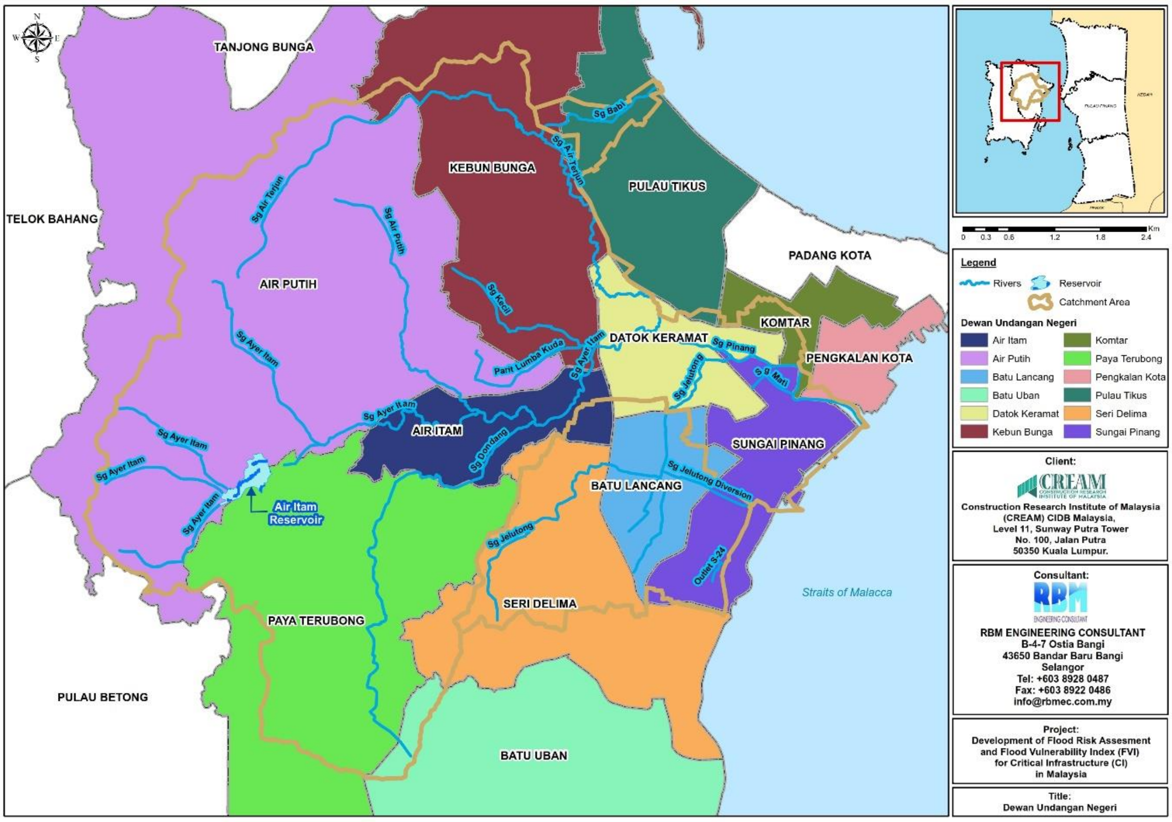


Figure 2.4: DUN within the Project Area

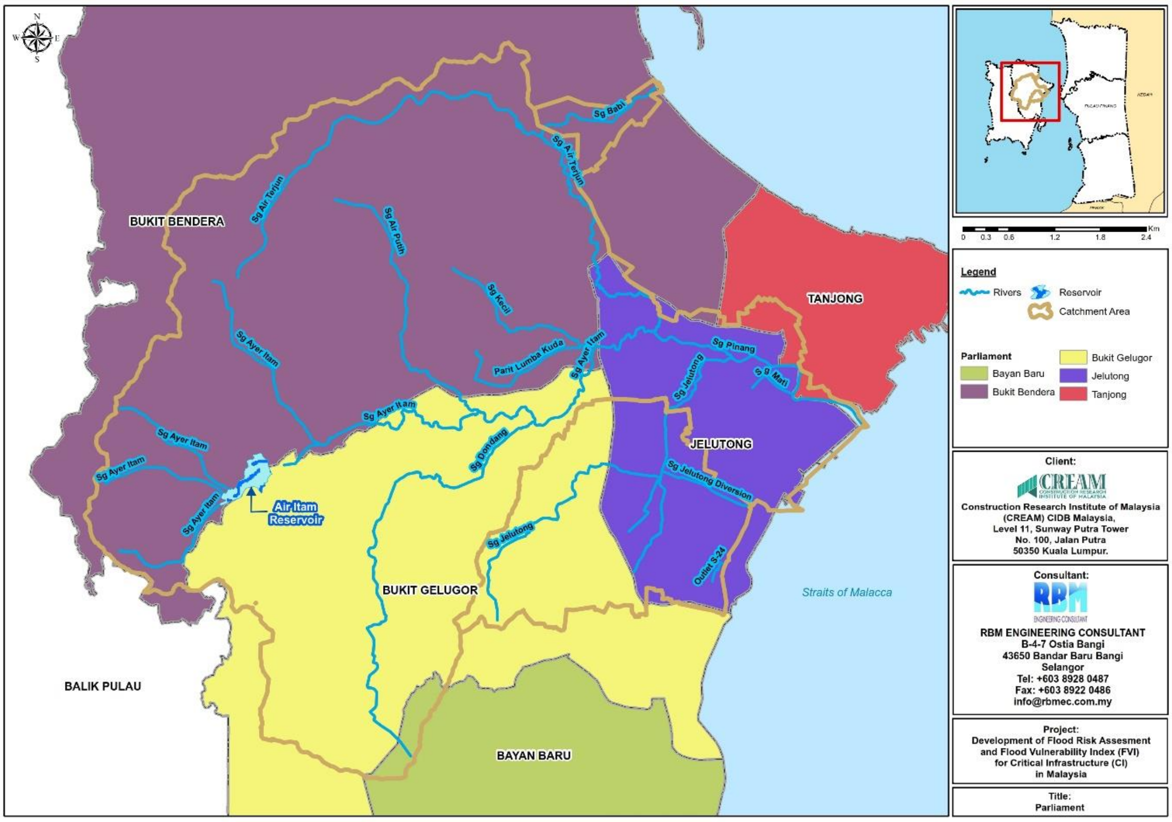


Figure 2.5: Parliament within the Project Area

Table 2.1: Mukim of the Sungai Pinang River Basin

Mukim	Area (m^2)
Bandar Air Hitam	1,750,822.60
Bandar Bukit Bendera	3,475,368.77
Bandar Gelugur	99,895.73
Bandar Jelutung	3,594,321.76
George Town	13,270,014.15
Mukim 13	9,569,681.96
Mukim 14	4,590,980.11
Mukim 15	3,535,538.43
Mukim 17	9,499,702.17
Mukim 18	3,882,340.99

Table 2.2: DUN of the Sungai Pinang River Basin

DUN	Area (m^2)
Air Itam	3,127,027.36
Air Putih	18,472,677.82
Batu Lancang	2,514,122.65
Batu Uban	461,520.53
Datok Keramat	2,893,298.95
Kebun Bunga	7,284,370.47
Komtar	437,401.33
Paya Terubong	10,230,606.04
Pengkalan Kota	57,241.72
Pulau Tikus	842,949.97
Seri Delima	4,434,591.86
Sungai Pinang	3,264,721.15

Table 2.3: Parliament of the Sungai Pinang River Basin

Parliament	Area (m^2)
Bayan Baru	461,520.53
Bukit Bendera	26,599,998.27
Bukit Gelugor	17,792,225.26
Jelutong	8,672,142.75
Tanjong	494,643.05

2.3 CLIMATE

Like other part in the west coast of Peninsular Malaysia, the study area experience uniform temperature, high humidity and heavy rainfall with two major monsoon seasons i.e., southeast and northeast monsoon. However, there are some uniform periodic changes in climates and based on these changes two inter-monsoon seasons can be observed between these major monsoons. These can be defined as follows in **Table 2.4**.

Table 2.4: Seasons in the Study Area

Seasons	Month
Northeast Monsoon	November – March
Inter-monsoon	March – May
Southwest Monsoon	May – September
Inter-monsoon	September - November

However, relatively less rain is received during the southwest monsoon season from May to September, due to the sheltering effect of Sumatra. The average rainfall in the area is around 2000 mm per year, with the lowest monthly average around 60 mm for January and the highest monthly averages around 210 mm for September and October.

2.4 GEOLOGICAL CHARACTERISTICS

The site is generally located on the granite and recent alluvium area as shown in Geological Map for the Project Area in **Figure 2.6**. This river traverses through granitic rock in the upstream area and cross recent alluvium area near the downstream. The granite occupies the major part of the main island and can be divided into two bodies: The North Pinang pluton and the South Pinang pluton. The granite in the northern part is believed to be of epizonal zone and was emplace during early Jurassic age of about 180 million years ago. The Sungai Pinang area is located in North Pinang pluton area and can be classified into Tanjung Bunga Granite.

The Tanjung Bunga granites are fine to coarse-grained and categorized as biotic granite due to the mica content in the rock. The granites can be divided into two phases which cut by quartz dykes, veins, numerous fault and shear zones. Some parts of the faults and shear zones are occupied by quartz veins. Medium to coarse grained biotite granite represents the first stage of magmatic activity. Some quartz veins existed around the island and may form as aplite dykes and vein. The residual soils derived from the granite varies from 6 to 15 meters thick are generally sandy in nature.

The alluvium covers the downstream area at eastern part of Sungai Pinang along valleys. This alluvium was deposited around 7 million years ago and only a few meters thick. The topsoil is usually consisting of yellowish brown clay and underlain by a thicker layer of brownish grey soft clay with abundant plant remains of fine to medium-grained sand. The base of the alluvium layer consists of coarse sand layer with some greyish clay or layer of peat.

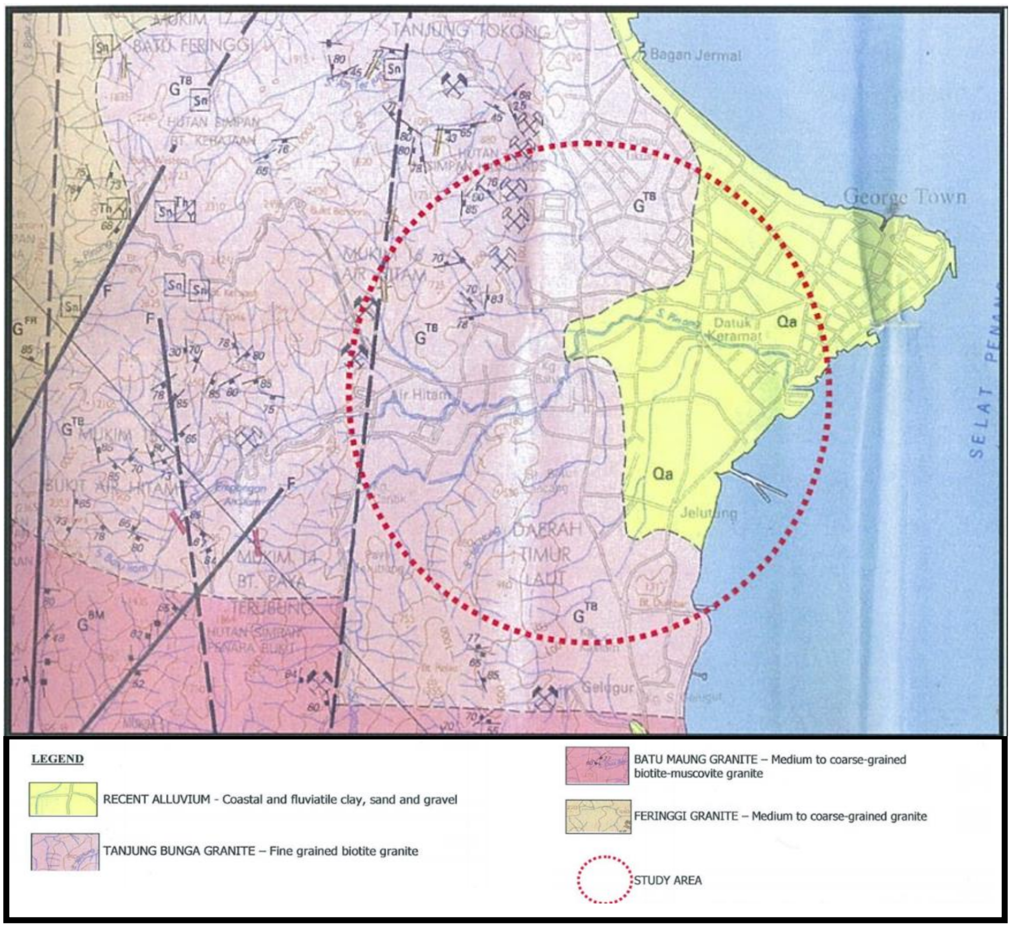


Figure 2.6: Geological Map of the Project Area

2.5 LANDUSE AND VALUE

2.5.1 The Current Landuse

The study area is highly developed area comprising more than 40% or urban areas in Penang Island. The majority of the built-up areas lies within the Georgetown Conurbation, Air Itam and Paya Terubong area. Georgetown is the state capital of Penang. The land uses under the category of 'built-up areas' include residential, commercial, industrial, administrative and institution, recreation/open spaces and cemeteries. The non-built up land uses include agriculture, forest/scrubs and forest reserve. The Land use map of the study area is as shown in **Figure 2.7**.

The map indicates urban land uses as residential, which cover approximately 1,475 ha (28.9%) followed by institutional, 457 ha (8.9%), commercial, 83 ha (1.6%) and industrial, 51 ha (1%). The large percentage if the built-up areas is expected to generate high amount of surface runoff and thus non-point source pollution. Agriculture activities cover a minor part of the study area, which constitute 565 ha or 11% of the total area. These agricultural lands are mostly located near the upper reaches of the river, providing buffer between the urban areas and the natural forest vegetation. Forest is the single largest land use type in the whole basin. The total area covered by forest is approximately 1,885 ha (36.9%) of the total basin area. Most of the forest areas are gazette forest reserves located at the upper reaches of the river and constitute part of the Air Itam dam water catchment.

2.5.2 Projected Landuse

As Georgetown has been well established over several hundred years, the study area therefore is well matured in terms of development with most of the available land having potential have already been developed. Areas left undeveloped mostly comprise of hilly and forested areas which are not suitable for development. Despite the land constraints, some land use changes have been observed in the project area. These changes are mostly re-development consisting of conversions of residential to commercial uses and the development of high-density apartments/flat replacing the traditional/low density settlements. There are also several vacant lands being developed for commercial and residential purposes. **Figure 2.8** shows the projected Land use for the project area.

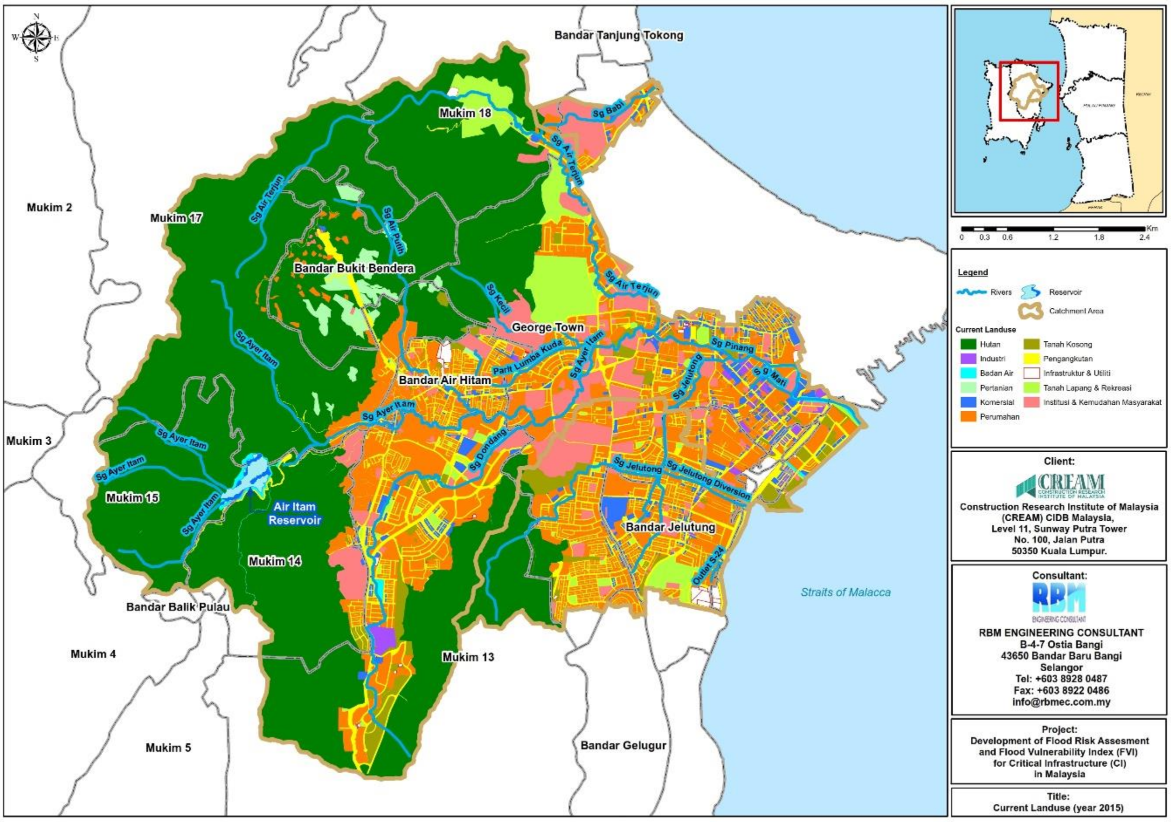


Figure 2.7: Current Land use Map of the Project Area

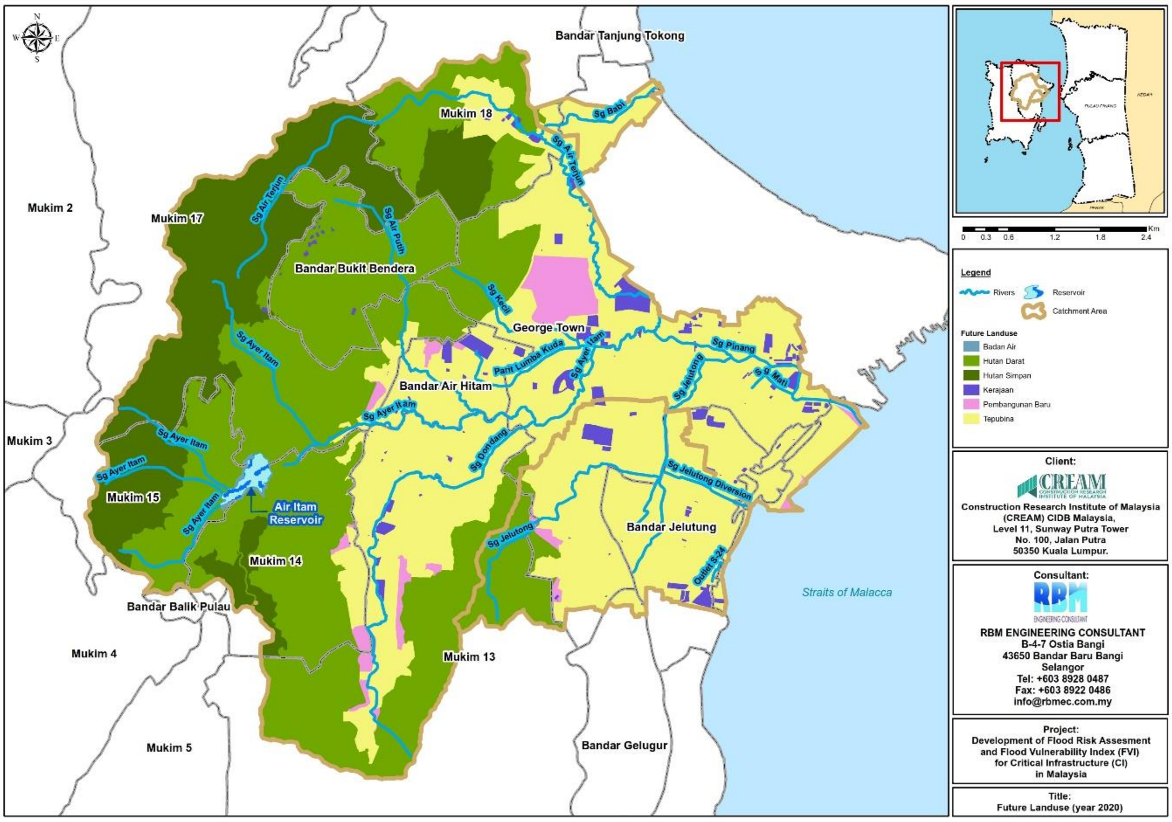


Figure 2.8: Projected Land use for the project area.

2.5.3 Land Values

The project area has among the highest urban land values in the country. Despite the small lots available, a typical commercial land at Chulia Street has an average value of RM20.9 million per hectare (*source: Rancangan Struktur Negeri Pulau Pinang, 2005. The figure will be updated during the inception report*). **Table 2.5** list the typical land values in the project area.

Table 2.5: Typical Land Values on the Project Area
(source: Rancangan Struktur Negeri Pulau Pinang, 2005)

Land use	Location	Average Area (ha)	Land Value (RM/ha)
Agricultural	Jln Sungai Pinang	0.92	437,000
	Jln Balik Pulau	5.21	1,902,000
	Off Jalan Balik Pulau	0.31	578,000
Residential	Green Road	0.09	6,400,000
	Jalan Lahat	0.95	8,440,000
	Jln P Ramlee	0.05	9,180,000
	Jln Boundry	0.17	5,050,000
	Jalan Tanjung Bunga	0.04	10,490,000
	Jalan Macalister	0.26	10,210,000
Commercial	Chulia Street	0.06	20,900,000
Industrial	Jln Sungai Pinang	0.16	8,380,000
	Jln Terusan	0.12	7,410,000

2.6 POPULATION AND HOUSING

2.6.1 Existing Scenario

According to the Population and Housing Census of Malaysia 2000, the population of the Project Area is 169,978 (this figure will be updated during inception report). This figure forms 38% of the population of the District of Timur Laut or 13% of the whole population of the State of Penang. The population is ethnically split between malays, Chinese and Indians, the largest of the three groups being the Chinese followed by the malays. The ratios of ethnic background among the races are 59.6% Chinese; 33% Malays and 11.4% Indian population.

The most populated area is the city of Georgetown followed by the Mukim of Paya Terubong and Mukim Ayer Itam, which form the immediate areas of the Sungai Pinang river basin. **Table 2.6** and **Table 2.7** shows the population at the mukim level (sub-district) and racial distribution within the Sungai Pinang river basin respectively.

Table 2.6: Distribution of Population by Mukim

Mukim	No. of Populations
Bandaraya Georgetown	72,541
Mukim 13 Paya Terubong	74,191
Mukim 14 Bukit Paya Terubong	1,817
Mukim 15 Bukit Air Itam	39
Mukim 16 Ayer Itam	18,532
Mukim 17 Batu Feringhi	167
Mukim 18 Tg Tokong	2,691

Table 2.7: Racial Distribution of Populations

Mukim	Malays	Chinese	Indian	Others	Total
Bandaraya Georgetown	36,578	120,765	14,612	907	172,862
Mukim 13 Paya Terubong	45,261	103,563	18,107	748	167,679
Mukim 14 Bukit Paya Terubong	4	1,761	23	1	1,789
Mukim 15 Bukit Air Itam	0	52	0	0	52
Mukim 16 Ayer Itam	1,873	14,464	1,809	68	18,214

Table 2.8 shows the distribution of households and the distribution of households and living qurters in the affected mukims. The number of households is highest in Georgetown City and Mukim 13 (Paya Terubong) with 43,889 and 42,590 respectively. Consequently, the number of living quarters is also highest in these two mukims with 52,537 and 57,899 respectively. However, all these figures will be updated during the inception report later.

Table 2.8: Households and Living Quarters according to Mukim

Mukim	Household	Living Quarters
Bandaraya Georgetown	42,889	52,537
Mukim 13 Paya Terubong	42,590	57,899
Mukim 14 Bukit Paya Terubong	429	539
Mukim 15 Bukit Air Itam	10	10
Mukim 16 Ayer Itam	5,105	6,439
Total	**91,023**	**117,424**

2.6.2 Future Population and housing trends

The population of the study area has been observed to increase every year. The increase is contributed among others by rural-urban migration and increase in accommodations as more traditional settlements are redeveloped into high-density residential areas. The rate of population increases for Daerah Timur Laut between 1990 to 2000, averages at 1.3% annually.

2.7 SUNGAI PINANG RIVER SYSTEM

The Sungai Pinang is the continuation of its tributaries that originates from the central hilly and undulating part of the catchment. The river generally flows eastwards and eventually drains into the Penang Straits through 3 outlets namely the main river mouth of Sungai Pinang, Sungai Jelutong Diversion river mouth and Sungai Air Terjun Diversion Tunnel through the Sungai Babi.

Other than the tributaries, Sungai Air Pinang itself is only approximately 3.6 km long. These tributaries are Sungai Jelutong (5.94km), Sungai Air Itam (12.88km), Sungai Air Terjun (9.30km), Sungai Dondang (6.97km), Sungai Air Putih (3.89km), Sungai Kecil (Parit Lumba Kuda) (2.64km) and Sungai Mati (0.6km). The river system along with its catchment boundaries are as shown in **Figure 2.9**. The river longitudinal section and a few typical cross-sections of Sungai Pinang and others are as shown in **Figure 2.10** and **Figure 2.11** respectively.

Among these tributaries, Sungai Air Itam is the largest and it has a length of 11 km. Sungai Kecil is the smallest tributary with its length of 4 km. The lengths, corresponding sub-catchment areas as well as average flows are shown in **Table 2.9**. Sungai Air Itam is regulated by a water supply dan located at the upstream part. Most of the Sungai Pinang and its tributaries have been channelized and lined during the development of the surrounding areas. Photos of the existing river condition along the river system of Sungai Pinang are illustrated in **Figure 2.12** to **Figure 2.18**.

Table 2.9: Physical Parameters of Sungai Pinang and its Tributaries

Rivers	Catchment Area (km2)	Length (km)	Slope (%)
Sungai Pinang	45.9	3.6	0.07
Sungai Jelutong	7.4	6.2	2.2
Sungai Air Itam	30.8	10.9	3.7
Sungai Air Terjun	10.3	10.3	6.9
Sungai Dondang	11.6	6.9	1.9
Sungai Air Putih	4.8	4.1	8.6
Sungai Kecil	1.6	2.3	8.8

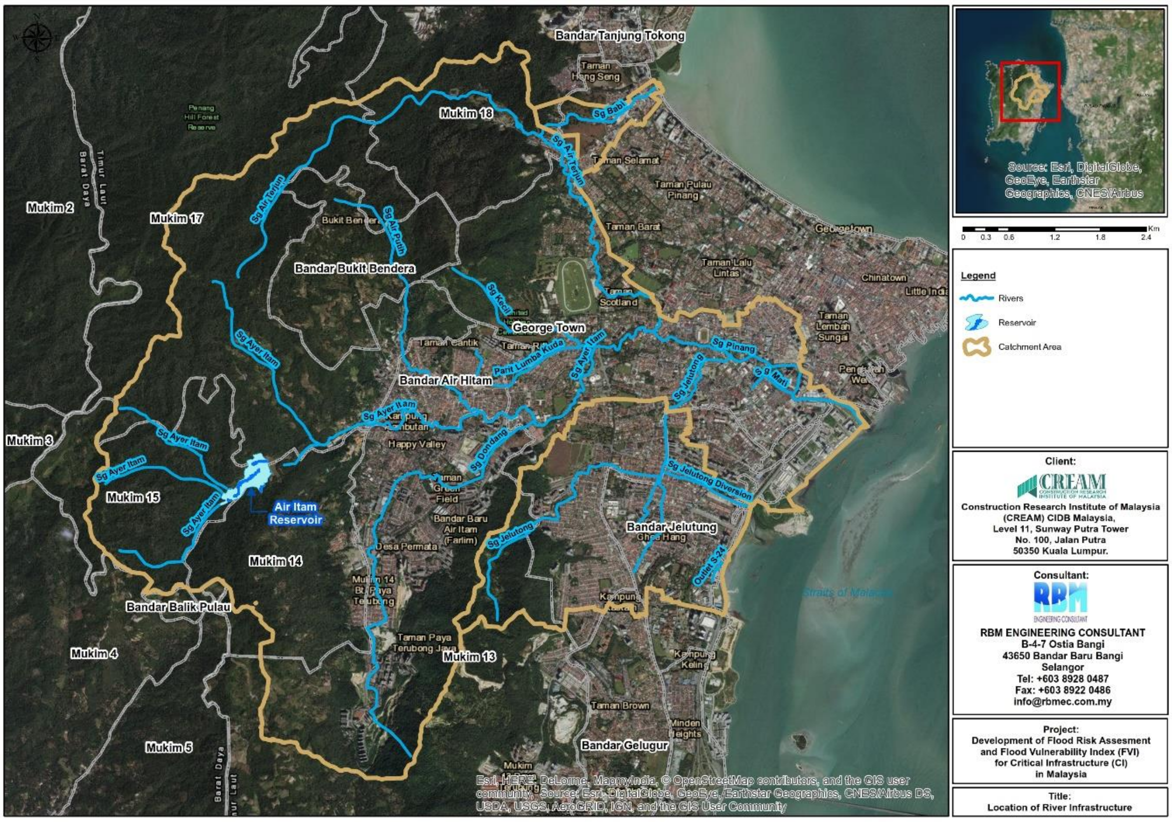
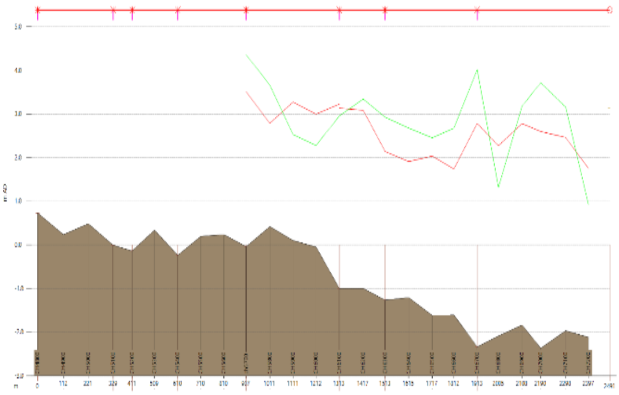
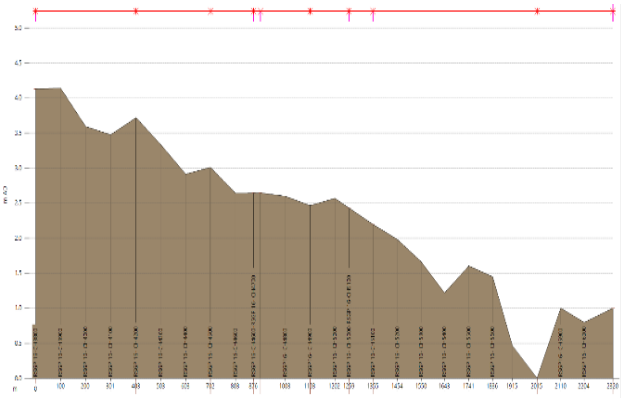


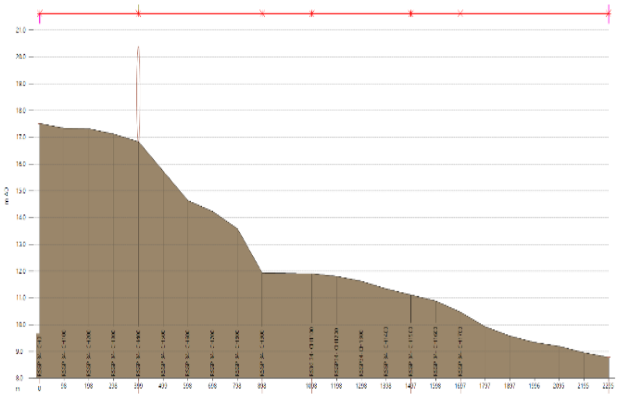
Figure 2.9: Sungai Pinang River System



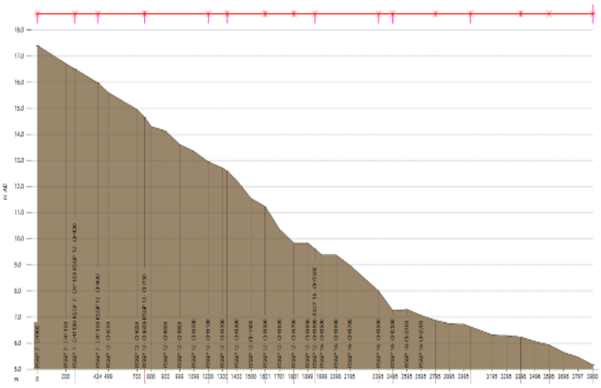
(a) Sungai Pinang



(b) Sungai Air Itam

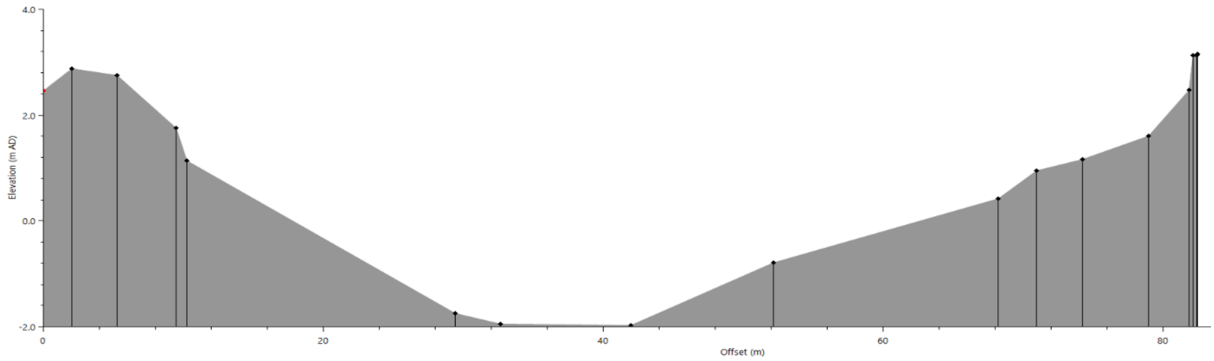


(c) Sungai Air Terjun

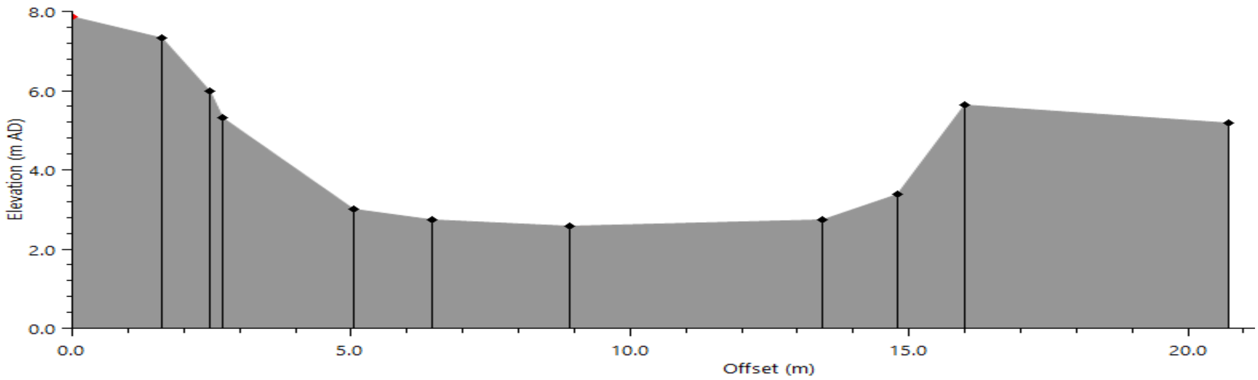


(d) Sungai Dondang

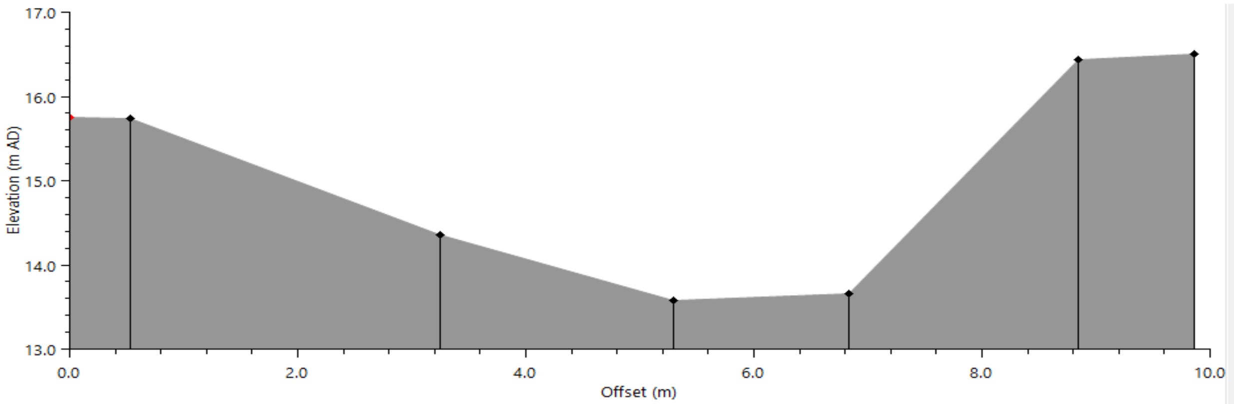
Figure 2.10: Longitudinal Sections



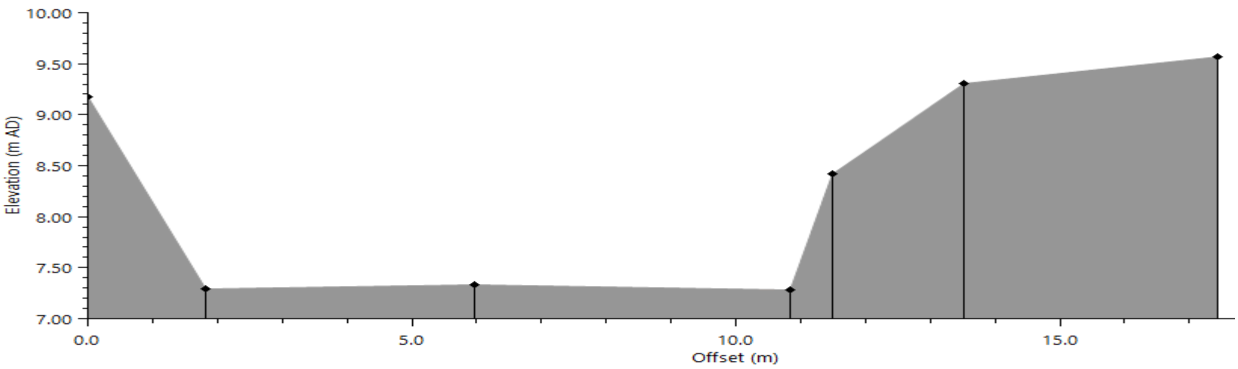
(a) Sungai Pinang



(b) Sungai Air Itam



(c) Sungai Air Terjun



(d) Sungai Dondang

Figure 2.11: Typical Cross Sections of Rivers

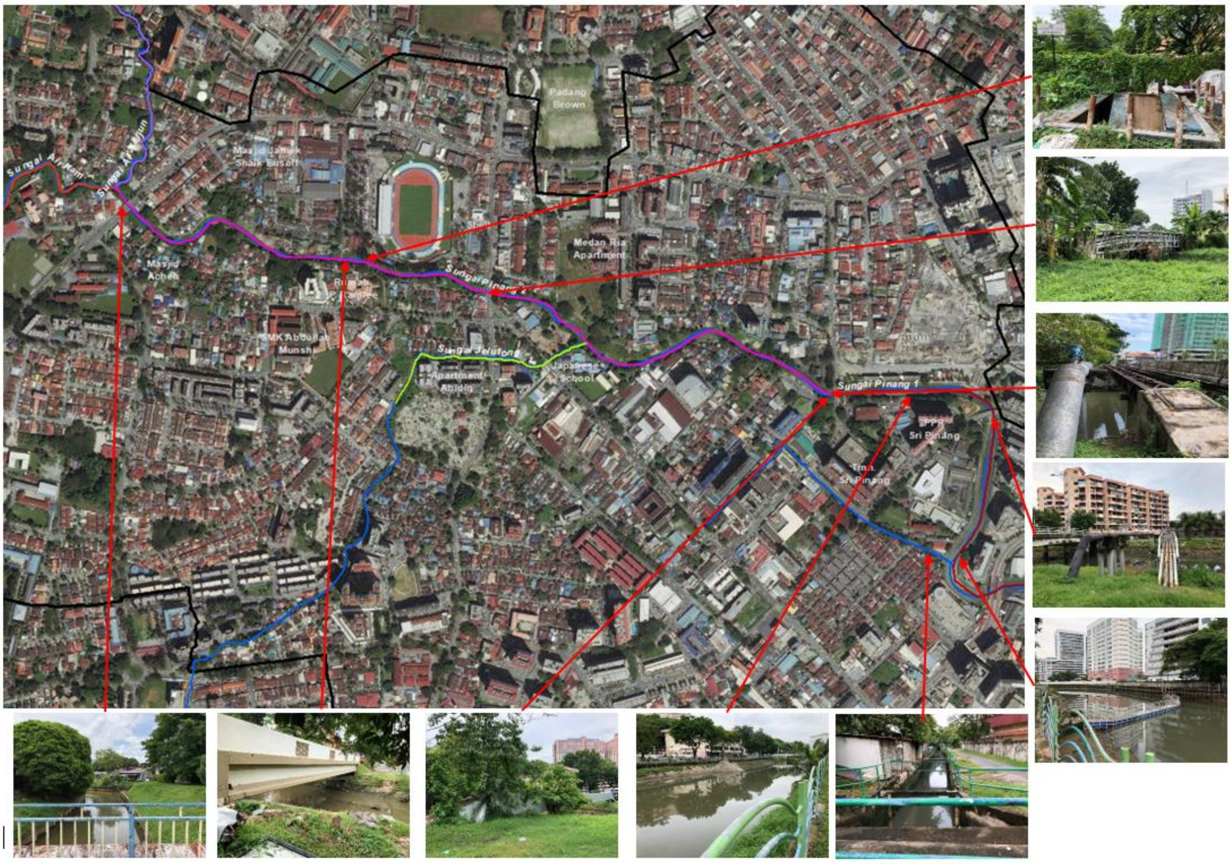


Figure 2.12: Sungai Pinang

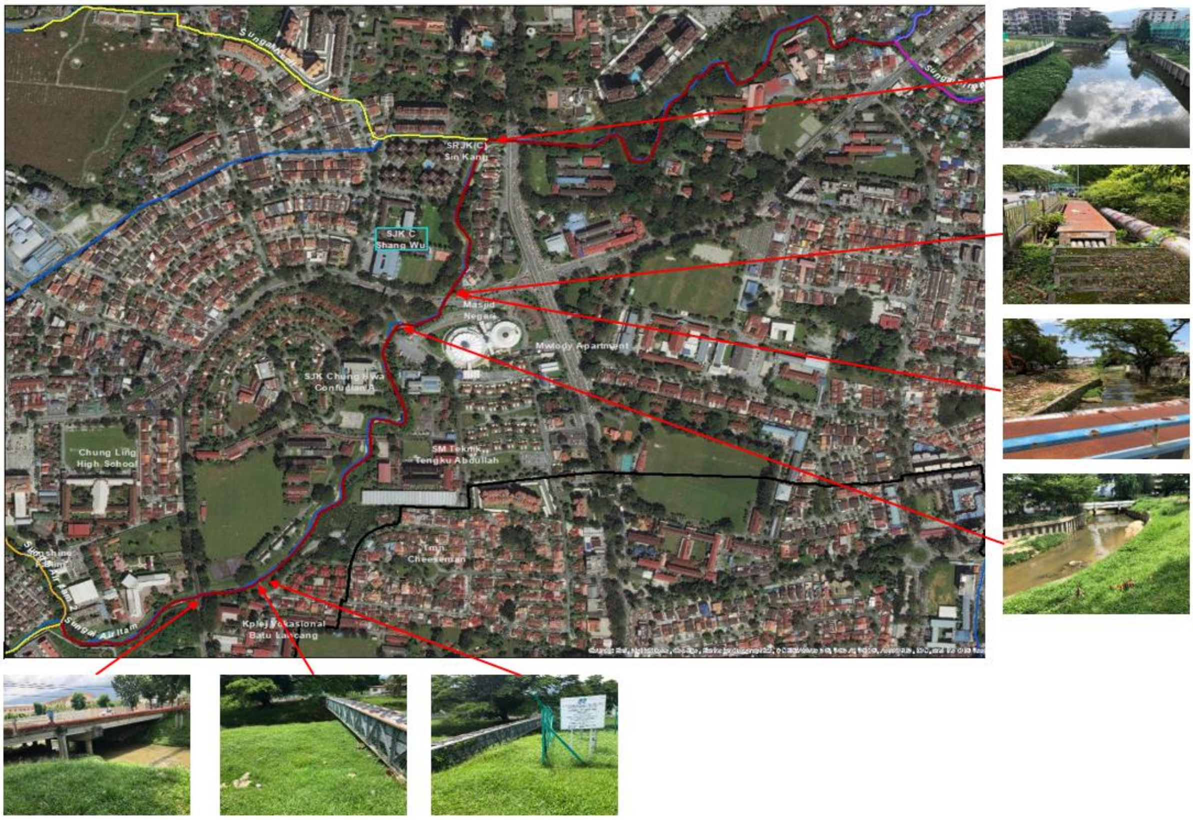


Figure 2.13: Sungai Air Itam 1

Figure 2.14: Sungai Air Itam 2

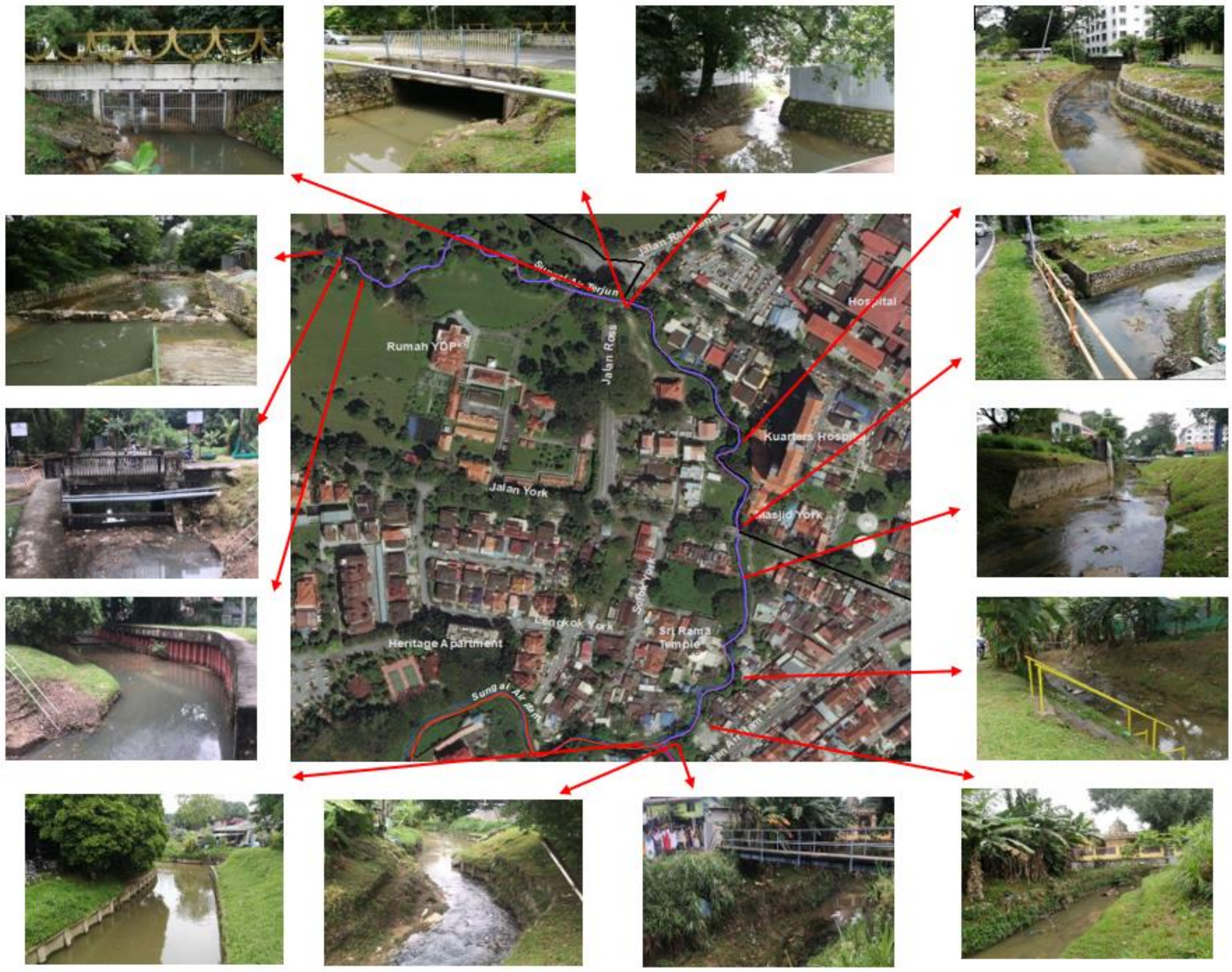


Figure 2.15: Sungai Air Terjun

Figure 2.16: Sungai Dondang

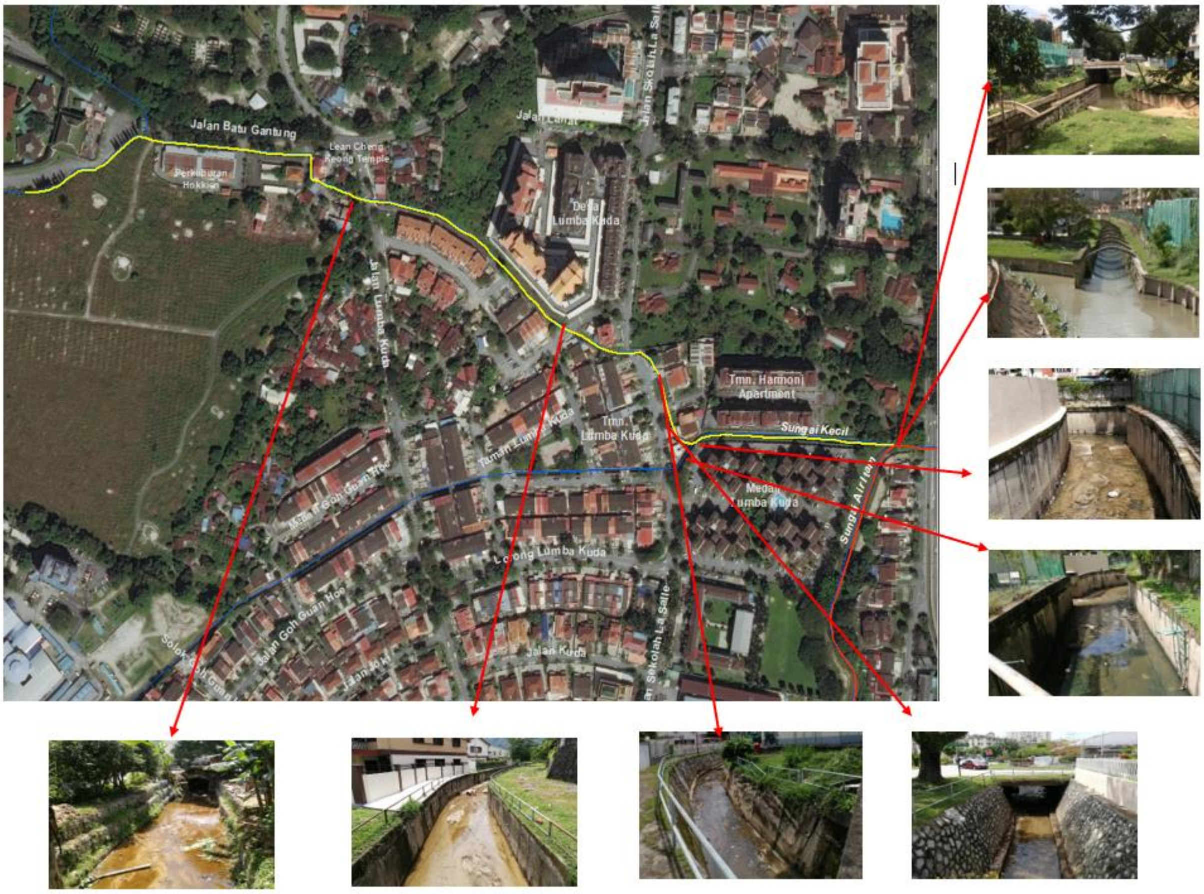


Figure 2.17: Sungai Kecil

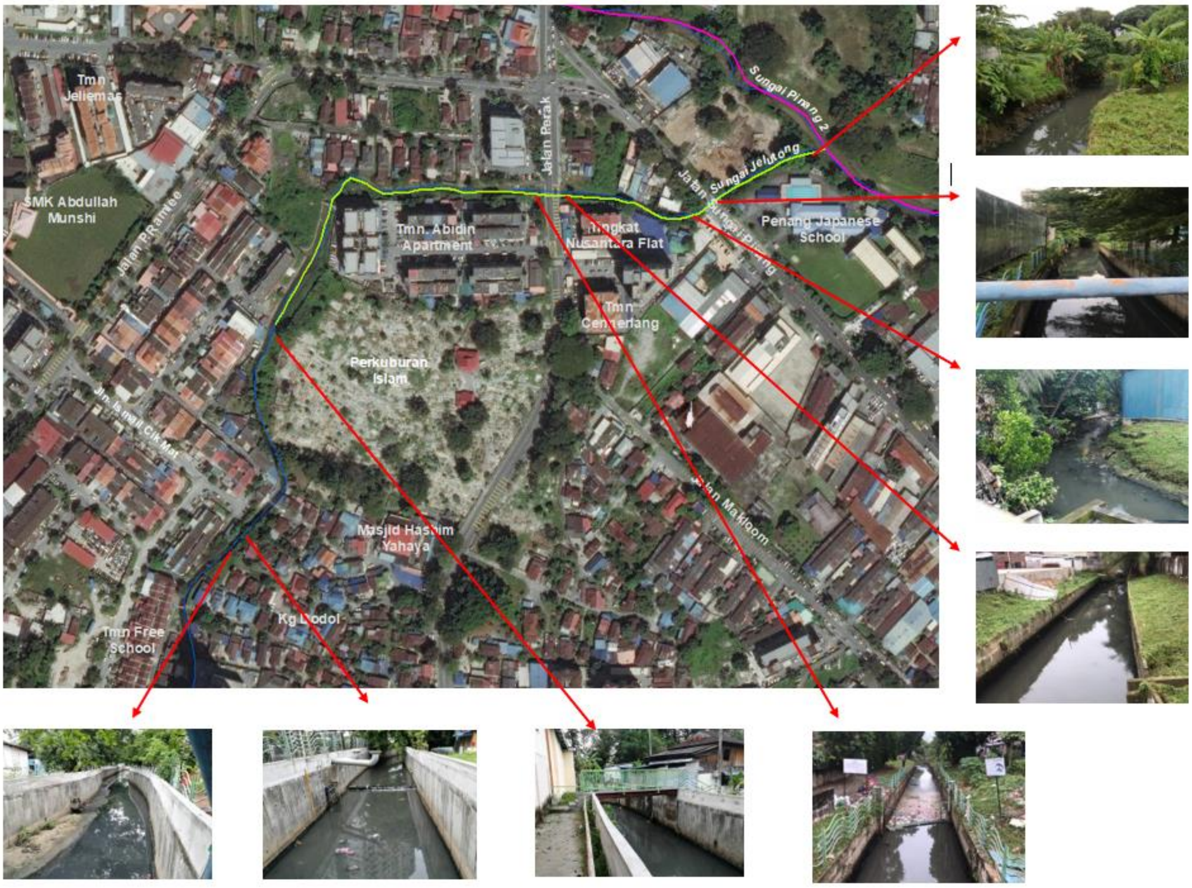


Figure 2.18: Sungai Jelutong

2.8 RIVER INFRASTRUCTURES

Based on the previous study on water quality for Sungai Pinang[1], the river infrastructure was built over the years for flood mitigation, water resources development, riverbank protection, garbage collection and to facilitate navigation. Brief description of few of these infrastructures are described below. **Figure 2.19** shows the location of the related infrastructures that were discussed herein.

[1] Study and Detailed Design for Pollution Prevention and Water Quality Improvement Project for Sungai Pinang, Pulau, Pinang, Interim Report 2006, Jurutera Perunding Zaaba, Unit Perundingan Universiti Malaya

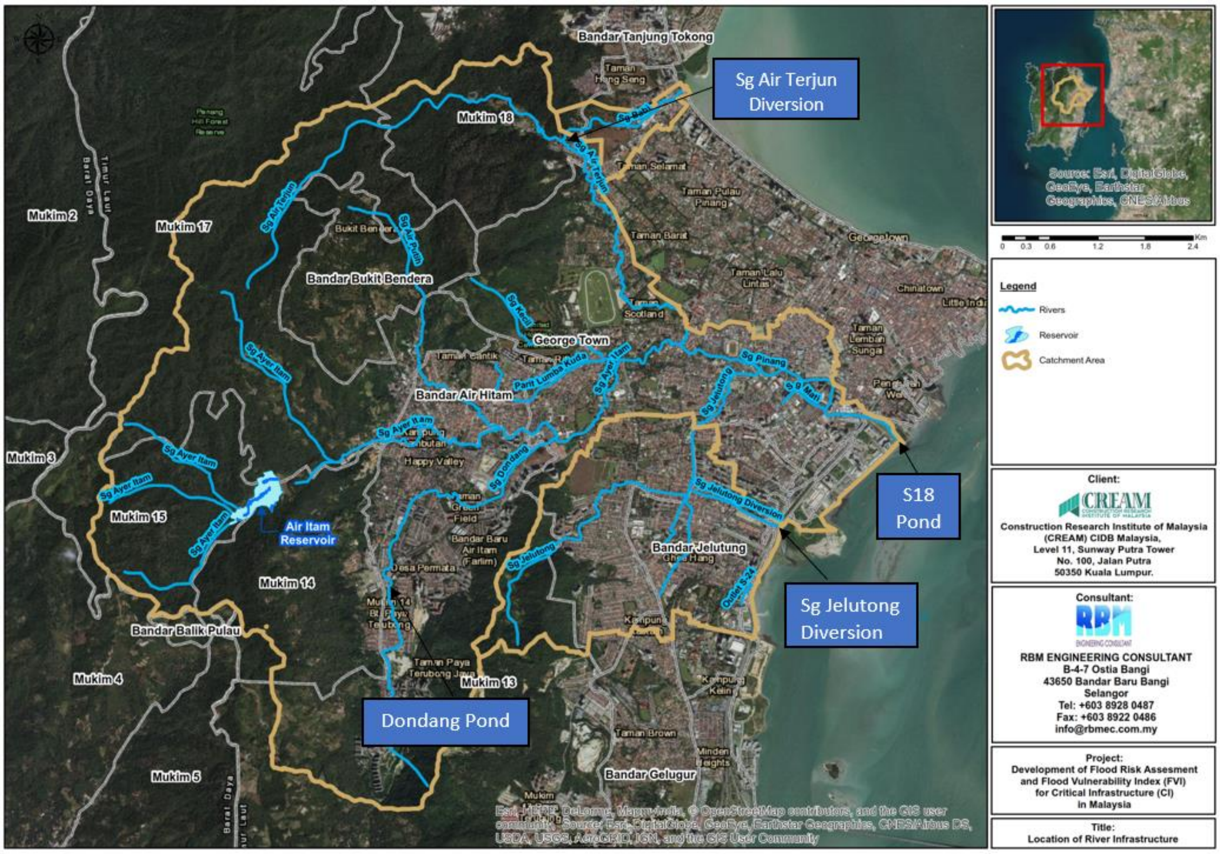


Figure 2.19: Location of River Infrastructure located in the project area

2.8.1 Air Itam Dam

The Air Itam Dam was constructed in 1962 at the upstream of the Sungai Air Itam for the Purpose of water supply. The dam is of the earth-fill type with a capacity of about 2.6 million m3. It has a catchment area of approximately 600 ha and when full the water surface area of the dam is approximately 20 ha. The crest length of the dam is 210 m with the maximum height of about 47 m. Please refer **Figure 2.20** of Air Itam Dam.

Figure 2.20: Air Itam Dam

2.8.2 S18 and Pumping Station

The S18 pond as shown in **Figure 2.21** comprise an area of 2.4 ha which is located on the seaward side along Lebuh Sandiland. The pond is built as a flood retention pond of about 2m deep and has a capacity of 56,000 m3. A pumping station together with twin 3.0 m x 3.1 m tidal gates along with associated mechanical and electrical facilities are also installed at the S18 pond for proper operation. Around 1 km new drain along Leboh Sandilands and parallel to Sungai Pinang were also constructed to divert runoff to the new retention pond. The location of the S18 pond is as shown in **Figure 2.19.**

Figure 2.21: S18 Pond and Pumping Station

2.8.3 Dondang Ponds

There are 3 offline retention ponds along Sungai Dondang as shown in **Figure 2.22** to reduce the flood impacts within the project area. The ponds were constructed by DID as well as on the maintenance and operation of the ponds. Two of the ponds are classified as dry ponds and doubles as recreational sites (as playground) during normal condition of no flooding. The basic properties of these flood detention ponds are summaries in **Table 2.10**. location of the ponds is as shown in **Figure 2.4**.

Table 2.10: Properties of Dondang Ponds

Pond	Storage Capacity (m3)	Ponding Area (m2)	Pond Depth (m)	Type of Pond
Pond A	79,000	30,500	4.24	Dry
Pond B	73,000	32,700	4.18	Wet
Pond C	46,500	21,200	4.77	Dry

(a)

(b)

(c)

Figure 2.22: Dondang Ponds (a) Pond A (b) Pond B (c) Pond C

2.8.4 Sungai Air Terjun Diversion

Sungai Air Terjun is a 1.55km of concrete box culvert which was constructed in year 2000. It diverts most of the flow of Sungai Air Terjun directly to the Terusan Utara via the Sungai Babi in order to reduce the flooding impact on downstream of Sungai Pinang. The inlet of this diversion is as shown in **Figure 2.23** and the location is as shown in **Figure 2.19**.

Figure 2.23: Inlet of Sungai Air Terjun Diversion beside the Forest Field Apartment

2.8.5 Sungai Jelutong Diversion

The Sungai Jelutong Diversion channel was constructed in 1976 for the purpose of diverting the discharge from the Sungai Jelutong Subcatchment directly to the Terusan Selatan. It has a catchment area of approximately 5 km2 which diverts almost 90% of the flow from the natural Sungai Jelutong catchment. The diversion channel consists of rectangular reinforced concrete channel with a width ranging from 8.22 m to 9.52 m, an average depth of 3.05 m and a gradient of 1 in 833.33. **Figure 2.19** shows the location of the Sungai Jelutong diversion and **Figure 2.24** shows some of the photos in the in the diversion channel before it is being rehabilitated currently.

Figure 2.24: (left) Outlet of Sungai Jelutong Diversion (right) Top of Sungai Jelutong Diversion, Jalan Tengku (bottom) Inside the Sungai Jelutong Diversion before it is currently being rehabilitated

2.9 GEOTECHNICAL CONDITIONS

Based on the JICA[2] Study which they have carried out the subsoil investigation and also the data collection, the summary of the findings of the geotechnical condition within the project area are listed as below: -

- In the coastal area there are soft alluvial deposits of sand and clay to a depth of 10 m to 16 m below ground level. Loose sandy and soft clayey sediments are deposited to a depth of about 50 m.
- The middle part of Georgetown is composed of loose to medium dense sand and silty sand with some gravel. Below these strata, there are stiff, silty clay layers and medium dense sand layers. The bearing layer is estimated to be deeper than 20 m.

[2] The Study on Flood Mitigation and Drainage in Penang Island, Main Report, March 1991, Japan International Coorperation Agency

2.10 SUNGAI PINANG RIVERMOUTH CONDITIONS

The bathymetry of Penang Straits at the confluence of Sungai Pinang and surrounding areas are as shown by the admiralty chart in **Figure 2.30** below. Generally, the depth contours of the channel are aligned with north south axis of the straits. A long shoal, known as Middle Bank, divides the channel into two channels which are know as Eastern and Western Channel. In general, the channel is shallow and mainly used by small boats. The depth varies considerably across any east west section, with a minimum of less that 1-meter ACD near the land boundary and about 10 to 20 meters ACD in the deeper part or center of the channel.

The maximum depth of the channel is about 25 m ACD located at the throat section of the channel. Easter channel is mainly used for navigation with the main port facilities located at Prai and Butterworth at the mainland.

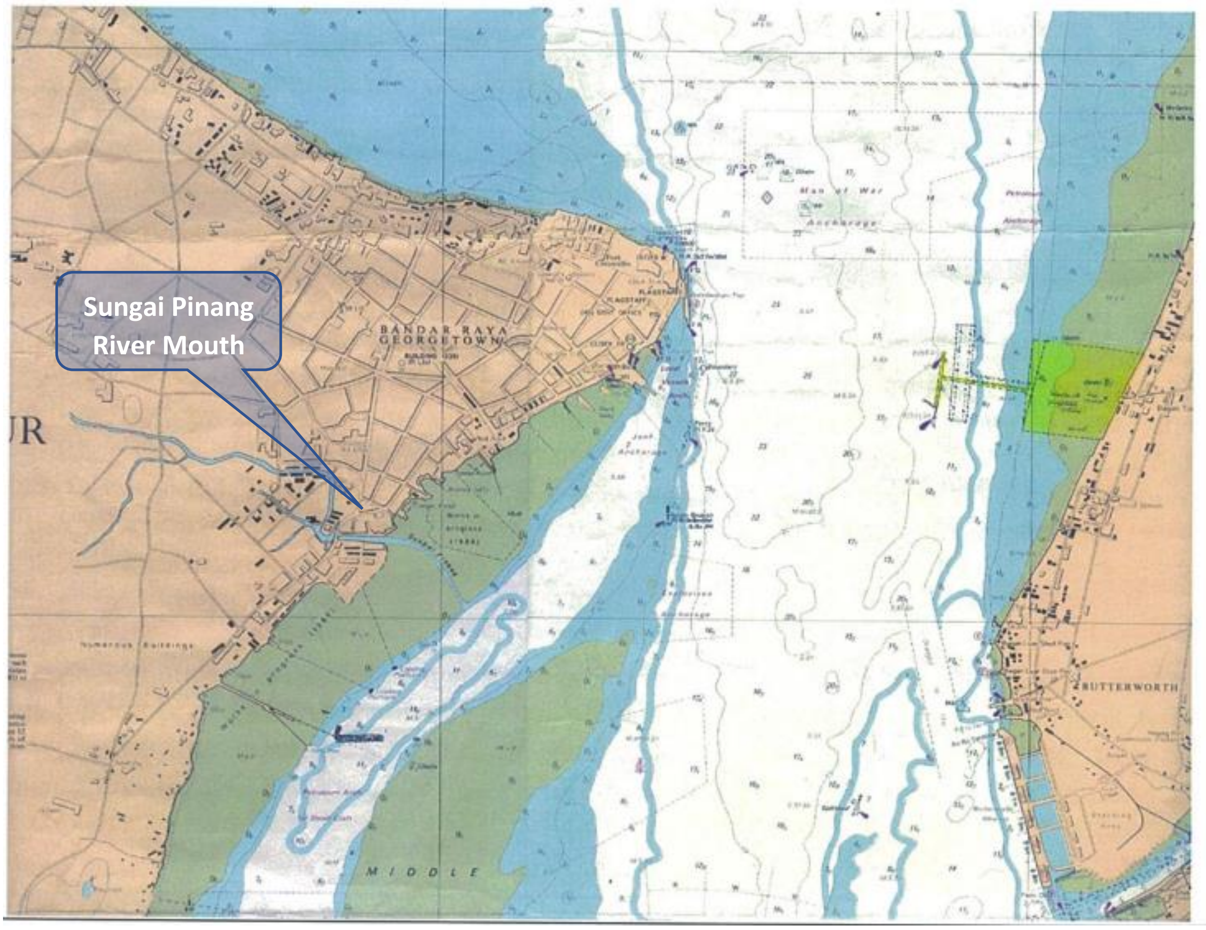


Figure 2.30: Admiralty Chart of Penang Straits

2.11 RIVER WATER QUALITY

Based on the water quality study[1] carried out in 2006/2007, extensive water quality sampling campaign has been executed in various location within the Sungai Pinang river basin as shown in **Figure 2.31**.

On top of that, the river water quality of Sungai Pinang and its tributaries was also assessed using the DOE's data between year 2001 to 2005 which were collected from 11 water quality stations along the river system. The result indicates that it has an overall water quality of Class I and II in upper reaches of Sungai Air Terjun, which represents clear water. All other tributaries other than Sungai Air Terjun, have a very bad quality of water with WQI of Class IV and V. **Figure 2.32** shows an approximation of the water quality classification for the whole river system in 2005.

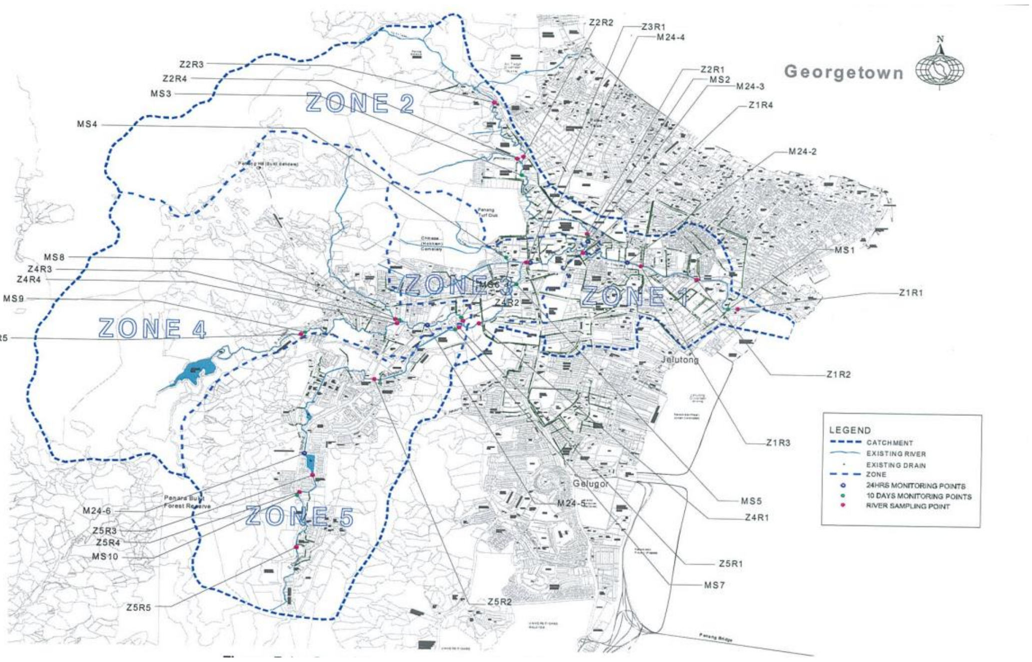


Figure 2.31: Sampling locations for River Water Quality Assessment
(Source: Study and Detailed Design for Pollution Prevention and Water Quality improvement Project for Sungai Pinang, Pulau Pinang, 2007)

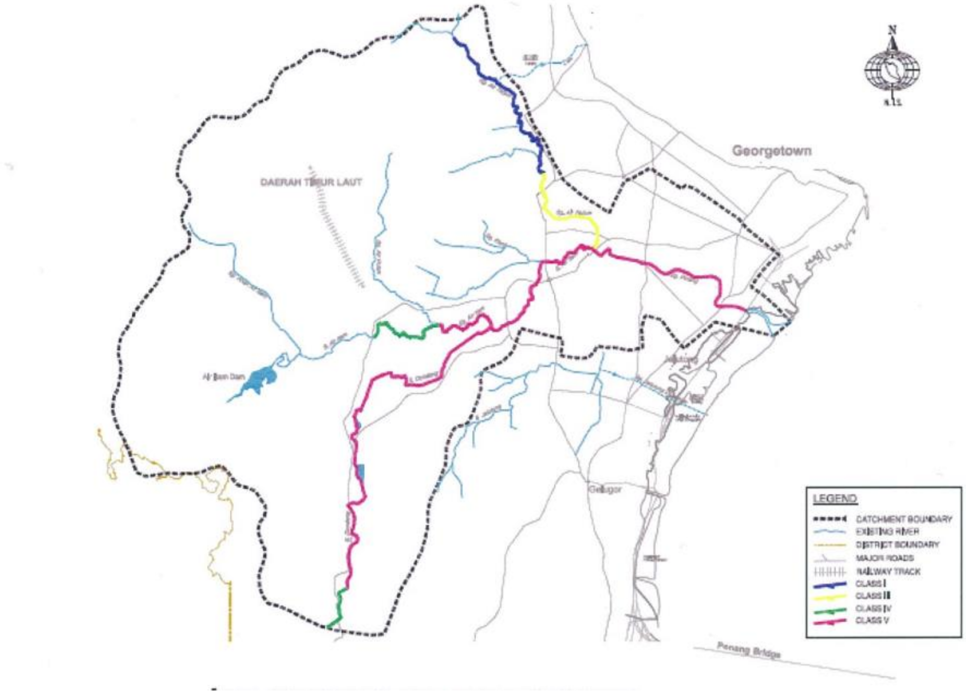


Figure 2.32: Water Quality Classifications along Main Rivers of the Study Area based on DOE Data (2005)

(Source: Study and Detailed Design for Pollution Prevention and Water Quality improvement Project for Sungai Pinang, Pulau Pinang, 2007)

CHAPTER 3

HYDROLOGICAL ANALYSIS

CHAPTER 3

HYDROLOGICAL ANALYSIS

3.1 INTRODUCTION

This chapter will describe the hydrological analyses and derivation of design hydrology parameter for the study area in Sungai Pinang. It involves numerous analyses and investigations related to hydrological subjects' matter that can be divided into three major components. The first component will be describing and analysing the hydrological data including rainfall and water level data from the available observed stations within and surrounding the study area. The main objective of this component is to describe the recent historical flood events which have occurred from the archived data provided by the JPS Malaysia. The analysed and identified data will be used in the calibration process that will be part of the hydrodynamic modelling procedure.

The second component will be the derivation of the various design storm events and durations for the study area by the development of relationship between rainfall intensity, duration and the frequency or also commonly known as Intensity-Duration-Frequency (IDF) Curve. The selected empirical methods described by various hydrological procedures particularly the latest Hydrological Procedure No. 1 (updated 2015) published by JPS Malaysia that widely have been used in Malaysia to estimate the design runoff for various Average Recurrence Intervals (ARI) and durations for each identified sub-catchments of the study area.

The third components will be described on the hydrological characterization process of the study area particularly into the sub-catchments or the hydrological response units of Sungai Pinang basin. It will involve the usage of Geographical Information System software which for this study will be applied the ArcGIS to analyse various type of spatial and non-spatial data which has been described in the data collection chapter. Amid the major output in this component are the delineated sub-catchments, the time of concentration values for each sub-catchment and the infiltration capacity for each of the sub-catchments. These are the important parameters required during the hydrodynamic modelling processes. It will be a major input during the execution of the respective modelling process.

The computation of rainfall runoff will be based from the landuse map produced by PLANMalaysia @ Pulau Pinang for year 2020. This is to reflect the current activity of landuse in the study area.

3.2 HYDROLOGICAL DATA COLLECTION

The hydrological data required for this study had been collected from Bahagian Sumber Air dan Hidrologi, JPS Malaysia Cawangan Ampang which was archived in digital format using the TIDEDA System. The system produces data in ASCII format which require extra effort in processing and checking in order to convert them into model compliant input format. The data collected for the study included rainfall, water level, gauging data and streamflow data. Various analyses were performed on the long-term data before being used as inputs to the model in order to check for consistency and reliability of the data.

3.2.1 Rainfall Data

Long term rainfall data from logging system rainfall station within and surrounding the Sungai Pinang basin were archived at BSAH in digital format collected using the TIDEDA system. These rainfall stations were plotted in GIS in order to visualize the spatial distribution of the rainfall station network within and adjacent to the study catchment. The hydrological data stations are shows in the **Figure 3.1**.

With the TIDEDA system, the archived raw rainfall data can be processed and presented in various formats for hydrological analysis and modelling purposes. Rainfall data from logging system rainfall station were collected on an hourly basis in raw text file format. The data formats for both the daily and hourly rainfall are illustrated in **Figure 3.2** and **Figure 3.3** respectively. Daily rainfall data extracted from JPS Ampang's TIDEDA system was prepared in tabular text file format. The preliminary analysis of the rainfall data at the stations are highlighted in **Figure 3.4** for the annual rainfall and **Figure 3.5** for monthly rainfall.

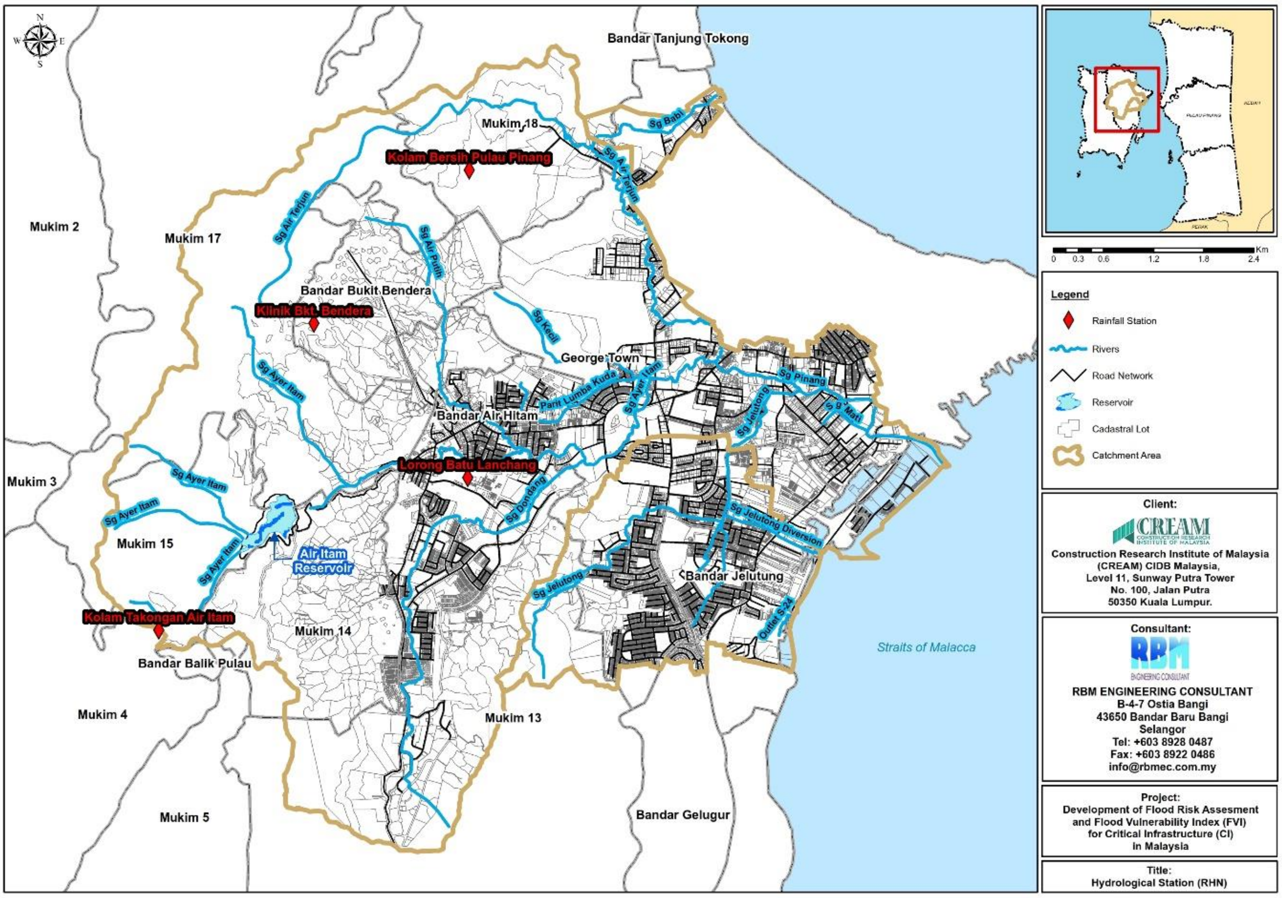


Figure 3.1: Distribution of Hydrological Stations within Project Area

	A	B	C	D	E
1	Site 5204049 LDG. BATU KAWAN at P.PINANG				
2	Date	Time	Rain mm		
3	6/12/1999	14:00:00	1.0#		
4	6/12/1999	15:00:00	1		
5	6/12/1999	16:00:00	0.5		
6	6/12/1999	17:00:00	0.5		
7	6/12/1999	18:00:00	0		
8	6/12/1999	19:00:00	0		
9	6/12/1999	20:00:00	0		
10	6/12/1999	21:00:00	0		
11	6/12/1999	22:00:00	0		
12	6/12/1999	23:00:00	0		
13	6/12/1999	24:00:00	0		
14	7/12/1999	1:00:00	0		
15	7/12/1999	2:00:00	0.5		
16	7/12/1999	3:00:00	0		
17	7/12/1999	4:00:00	0		
18	7/12/1999	5:00:00	0.5		
19	7/12/1999	6:00:00	0		
20	7/12/1999	7:00:00	0		
21	7/12/1999	8:00:00	0		
22	7/12/1999	9:00:00	0		
23	7/12/1999	10:00:00	0		
24	7/12/1999	11:00:00	0		

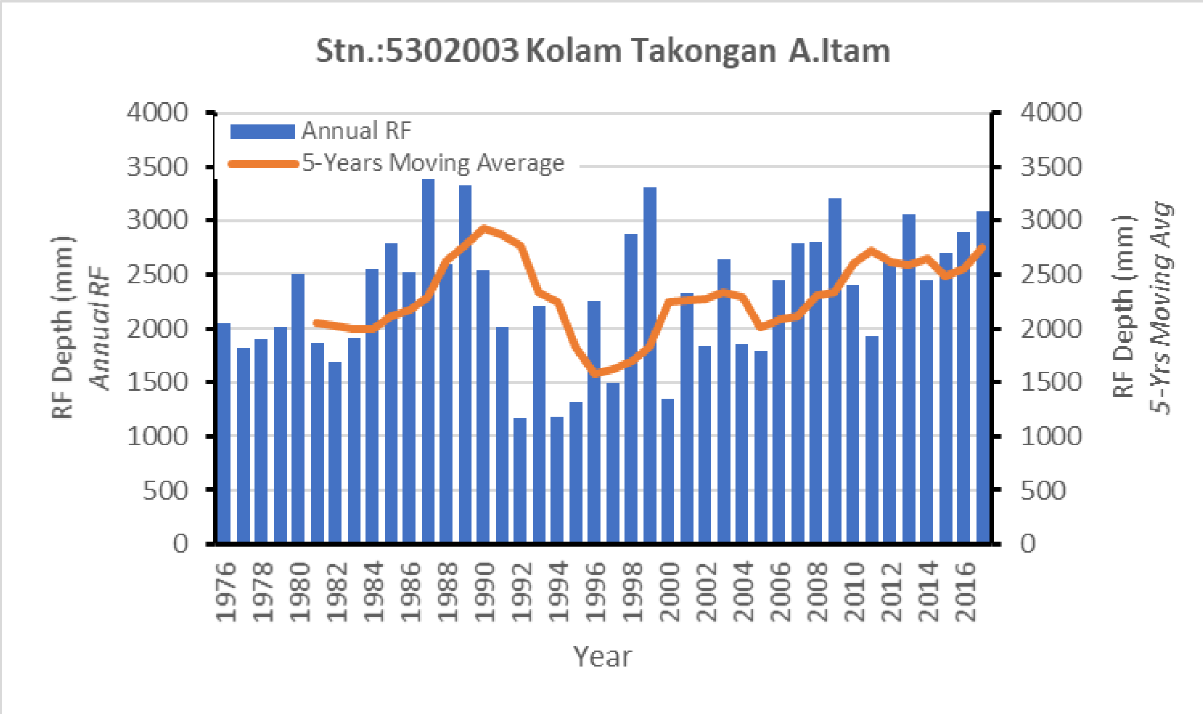
5204049

Figure 3.2: Rainfall raw data: Hourly intervals

Daily totals Year 2015 site 5302001 T/AIR BESAR SG. PINANG at P.PINANG
Rain mm

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	0.0	0.0	0.0	50.0	1.0	22.5	40.5	0.0	0.0	36.5	0.0	1.0	
2	0.0	0.0	0.0	33.0	0.0	21.0	0.0	17.0	7.0	0.0	4.5	1.0	
3	0.0	0.0	0.0	3.5	21.0	1.5	0.0	9.0	103.5	0.0	1.0	0.0	
4	0.0	7.0	0.0	2.0	29.5	0.0	0.0	0.0	2.5	0.0	4.5	0.5	
5	0.0	9.5	0.0	0.0	0.0	0.0	22.0	0.0	0.0	0.0	0.5	4.5	
6	0.0	0.0	0.0	14.5	0.5	0.0	0.0	11.0	0.5	0.0	27.0	0.0	
7	0.0	0.0	0.0	0.0	2.5	7.0	27.0	17.0	13.5	0.0	20.5	0.0	
8	0.0	0.0	10.5	66.5	0.0	0.0	2.0	20.0	1.0	0.0	14.0	0.0	
9	0.0	0.0	20.0	8.5	1.0	0.0	0.0	0.0	2.5	3.5	25.5	0.0	
10	0.0	0.0	9.0	22.5	0.0	0.0	0.0	15.5	32.0	0.5	1.0	0.0	
11	0.0	0.0	10.5	3.5	4.0	0.0	26.0	4.0	0.0	36.0	0.5	0.0	
12	0.0	0.0	0.5	3.0	2.0	0.0	0.0	0.0	0.0	0.0	9.0	0.5	
13	0.0	0.0	0.0	0.0	1.0	0.0	2.5	0.0	0.0	7.5	0.0	3.5	
14	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	49.0	8.5	4.0	14.0	
15	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.5	41.5	28.5	22.0	
16	0.0	0.0	0.5	0.0	0.0	0.0	0.0	9.0	0.0	0.0	99.5	0.0	
17	6.5	0.0	9.5	15.0	4.0	0.0	0.0	46.5	45.5	11.0	1.0	0.0	
18	0.0	0.0	64.5	0.0	21.0	0.0	3.0	0.0	6.5	10.0	3.0	0.0	
19	0.0	0.0	3.5	3.5	48.5	0.0	0.5	0.0	0.5	8.5	0.0	0.0	
20	0.0	1.0	22.0	2.0	20.0	27.0	0.0	0.0	0.0	1.5	8.0	0.0	
21	0.0	0.0	0.0	0.5	0.0	12.0	164.5	4.5	30.5	0.5	0.0	0.0	
22	0.0	5.0	3.5	3.5	0.5	0.0	12.5	34.5	0.0	90.0	0.0	0.0	
23	0.0	0.0	0.0	0.0	2.0	5.0	3.0	0.5	29.0	49.0	18.5	0.0	
24	0.0	2.0	7.0	38.0	0.5	5.5	23.0	0.0	0.0	12.5	0.0	0.0	
25	0.0	0.0	0.0	2.0	2.0	4.5	0.0	9.0	40.5	0.5	0.0	0.0	
26	0.0	0.0	0.5	0.0	17.0	7.0	10.5	79.0	5.0	5.0	0.0	0.0	
27	0.0	0.0	0.0	0.5	0.5	19.0	0.0	56.5	0.0	10.5	0.0	0.0	
28	0.0	0.0	16.5	36.0	0.0	2.5	61.5	30.0	0.0	18.0	1.0	0.0	
29	0.0		2.5	3.5	19.0	46.5	10.5	21.5	1.5	2.0	30.0	0.0	
30	0.0		0.0	0.5	86.5	33.5	0.5	4.0	9.0	0.5	9.5	0.0	
31	0.0		4.0		3.0		0.0	0.5		10.5		53.0	
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tot	6.5	24.5	184.5	335.0	287.0	214.5	409.5	389.0	380.0	364.0	311.0	100.0	3005.5
Max	6.5	9.5	64.5	66.5	86.5	46.5	164.5	79.0	103.5	90.0	99.5	53.0	164.5
NO>0.0	1	5	16	23	22	14	16	19	19	22	21	9	187

Figure 3.3: Rainfall raw data: Daily intervals



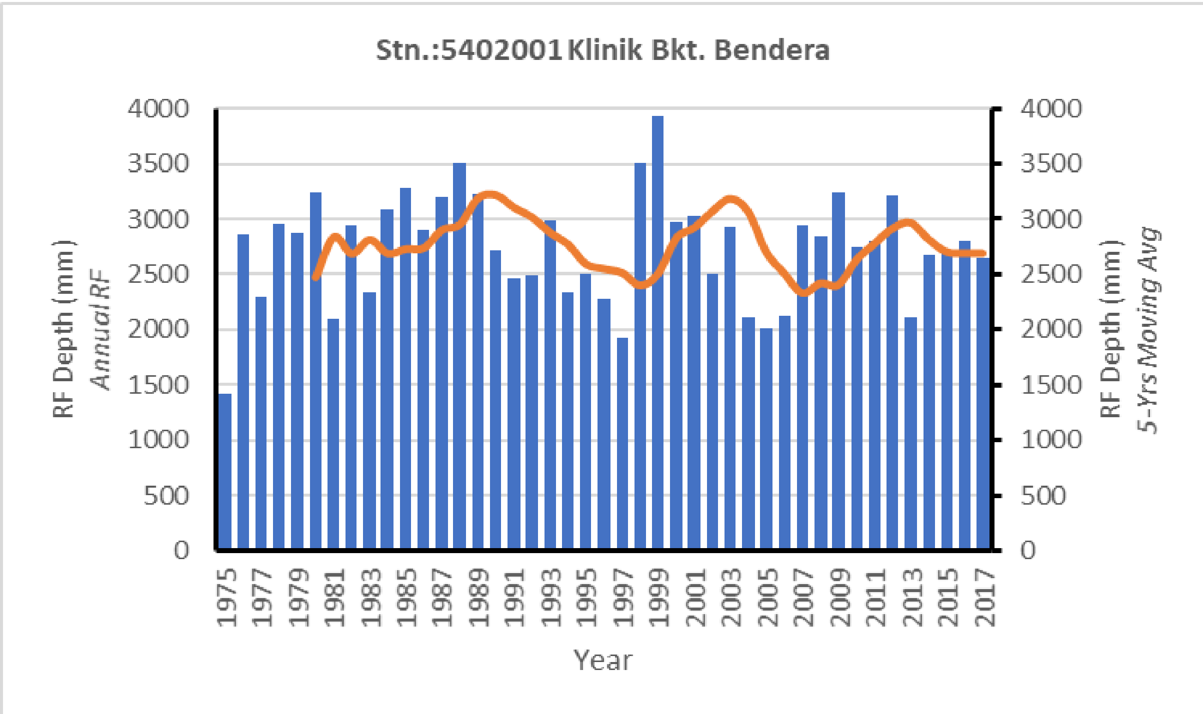
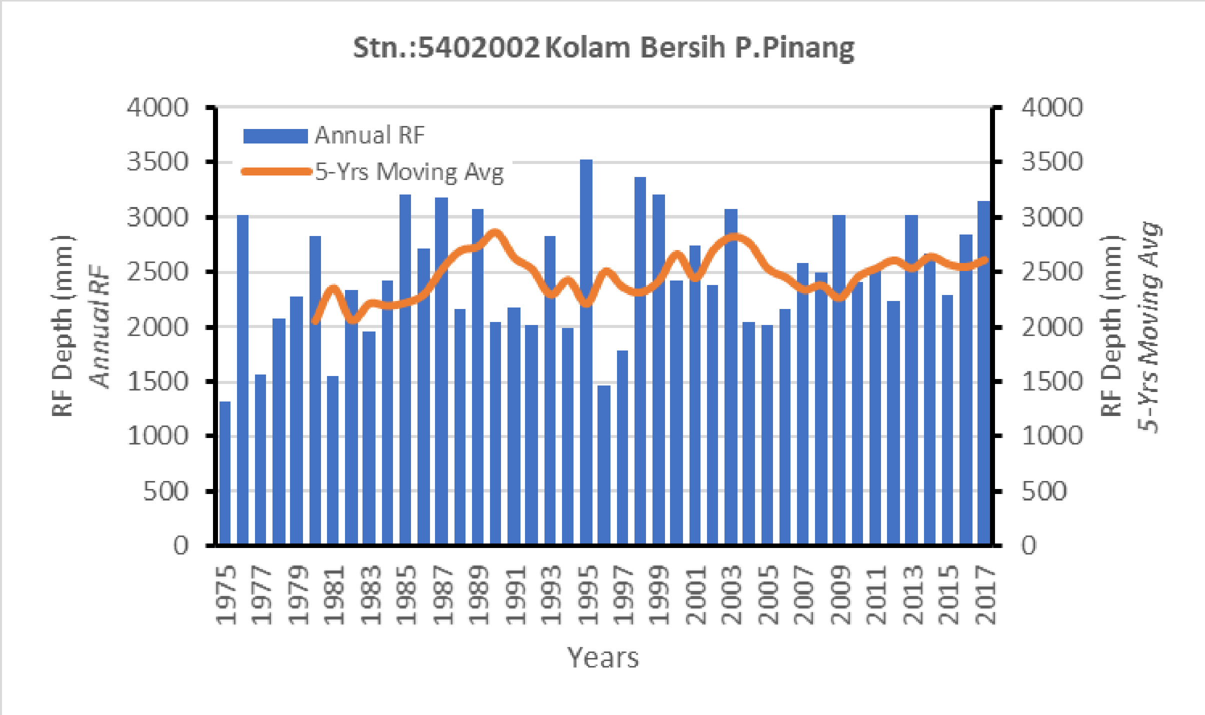


Figure 3.4: Annual rainfall at four stations



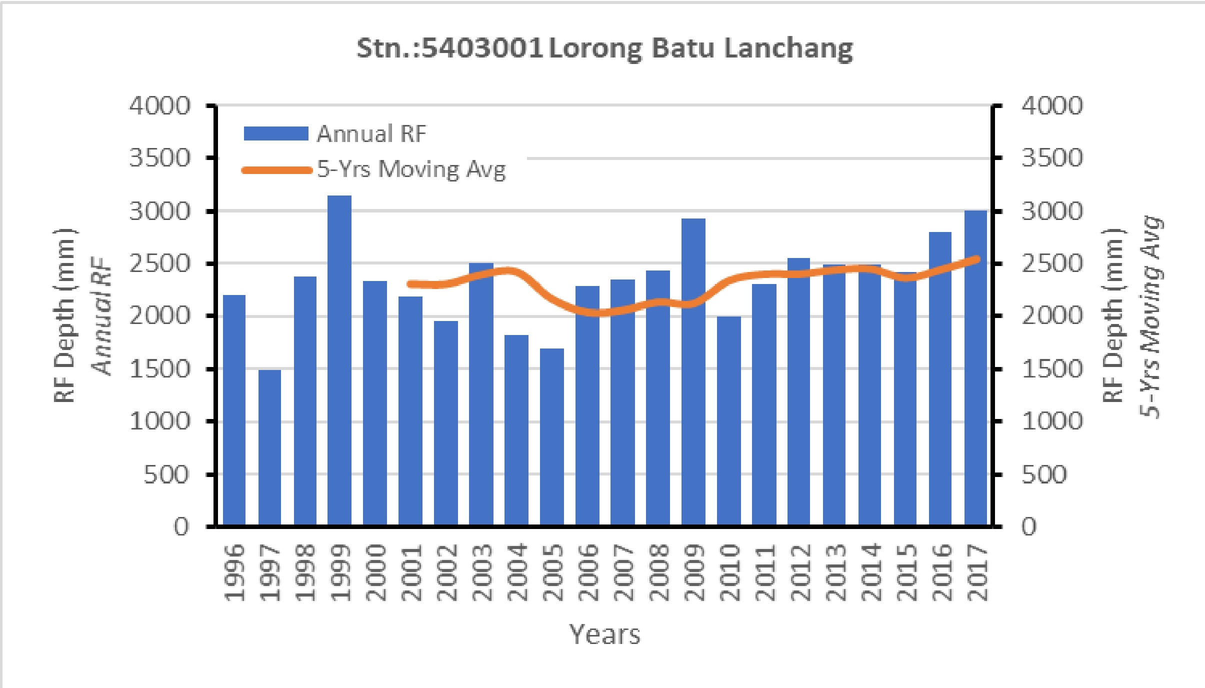
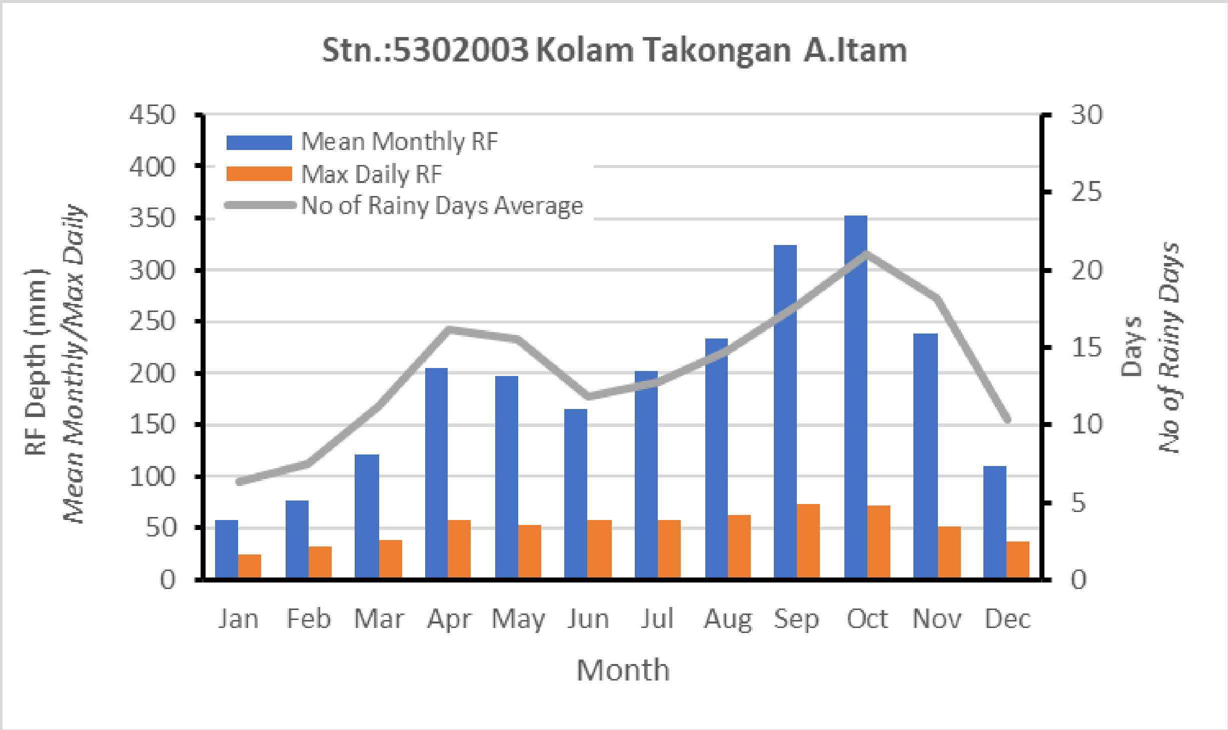


Figure 3.4: Annual rainfall at four stations (cont')



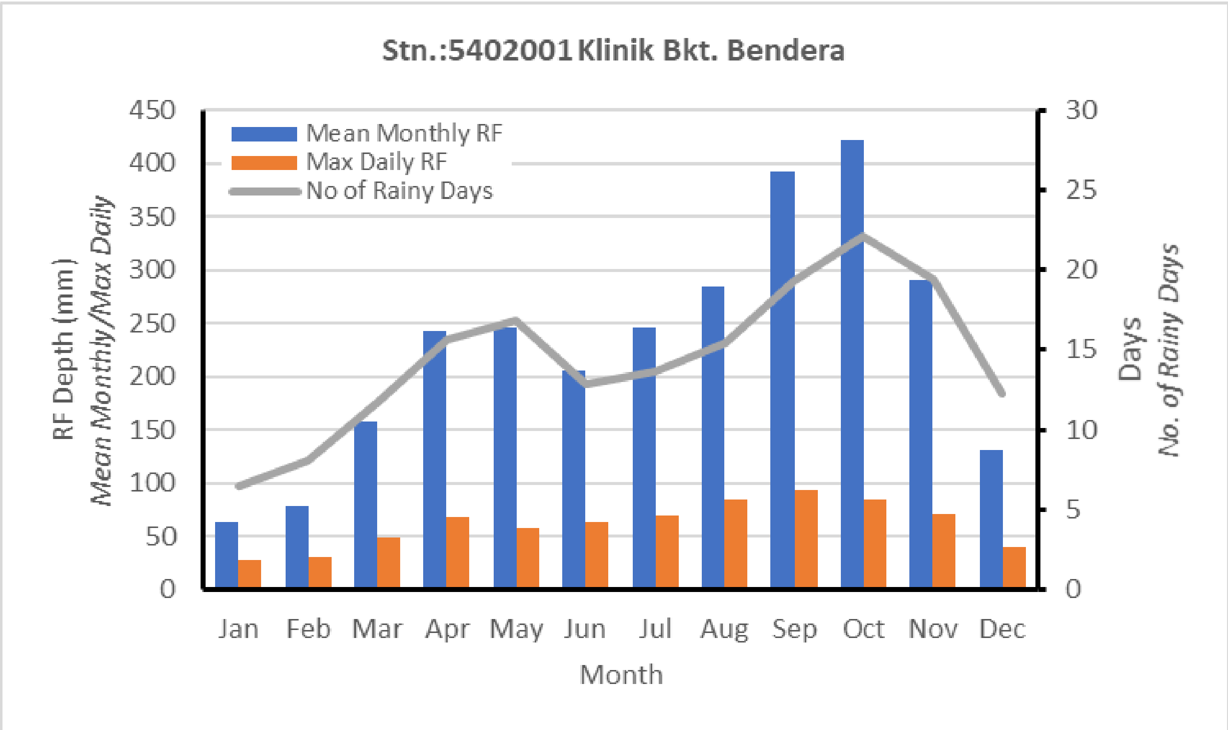
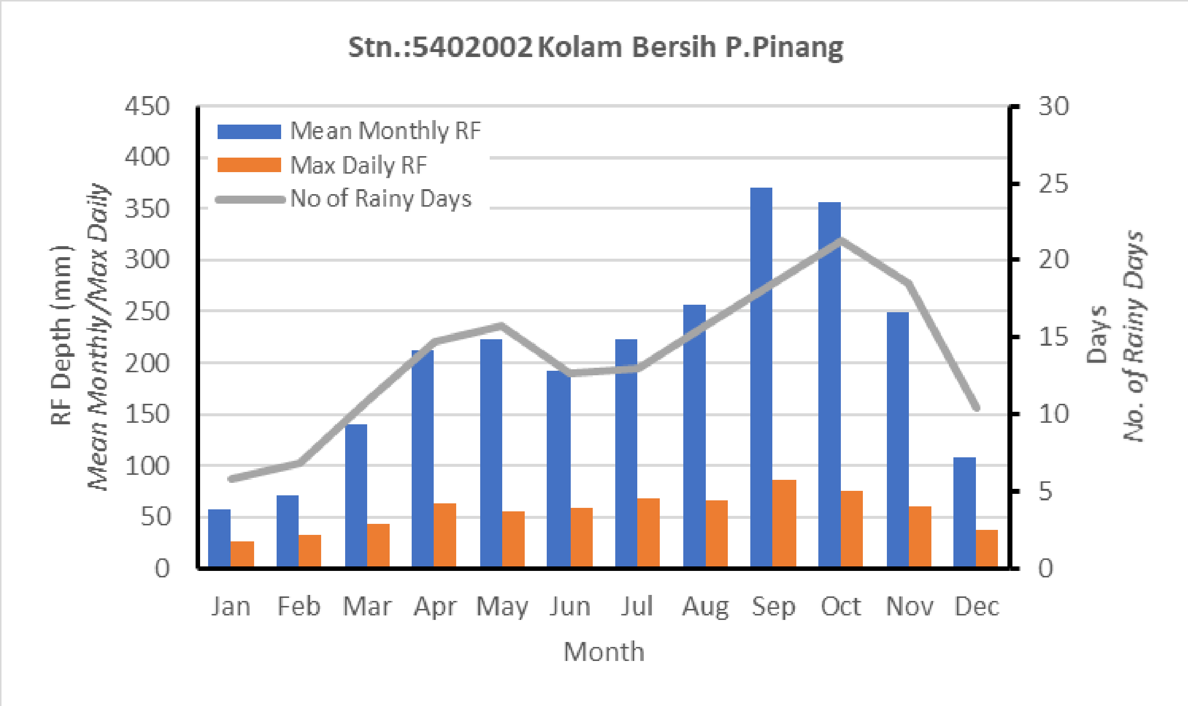


Figure 3.5: Mean monthly rainfall at four stations



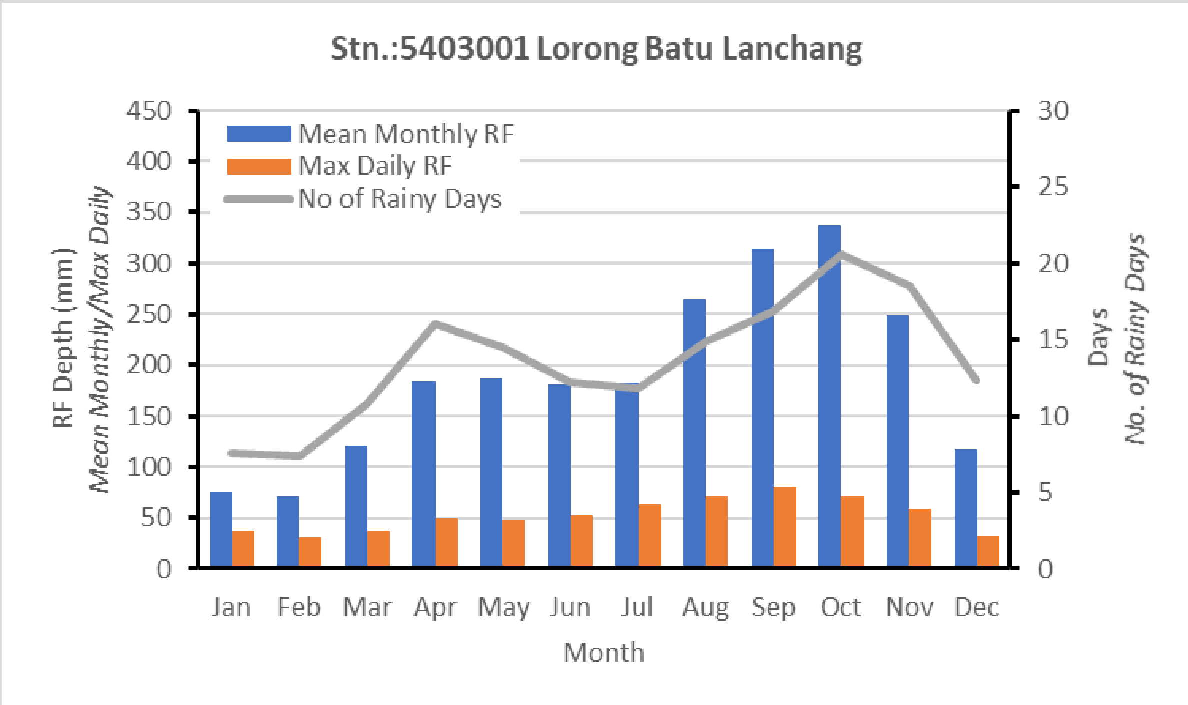


Figure 3.5: Mean monthly rainfall at four stations (cont')

3.2.2 Double Mass Curve

Double mass curve is a simple, visual and practical method, and it is widely used in the study of the consistency and long-term trend test of hydro-meteorological data. Generally, the curve is used to check the consistency of hydrologic data. The theory of the double mass curve is based on the fact that a plot of the two cumulative quantities during the same period exhibits a straight line so long as the proportionality between the two remains unchanged and the slope of the line represents the proportionality. This method can smooth a time series and suppress random elements in the series and thus shows the main trends of the time series.

In this report, the rainfall data collected from the rainfall stations located within the vicinity of the Sungai Pinang basin will be applied as the hydro-meteorological data for the double mass curve analysis. The double mass curve analysis is conducted to determine the consistency of the rainfall data collected from each hydrological station. The analysis is carried out by plotting the cumulative annual rainfall data for the target rainfall station against the average cumulative annual rainfall data obtained from the nearby rainfall stations.

Figures 3.6 to **Figure 3.9** shows the double mass curves derived for selected stations within the Sungai Pinang basin. It can be observed from these figures that the rainfall data collected from these hydrological stations are of high consistency and thus can be treated as homogeneous rainfall.

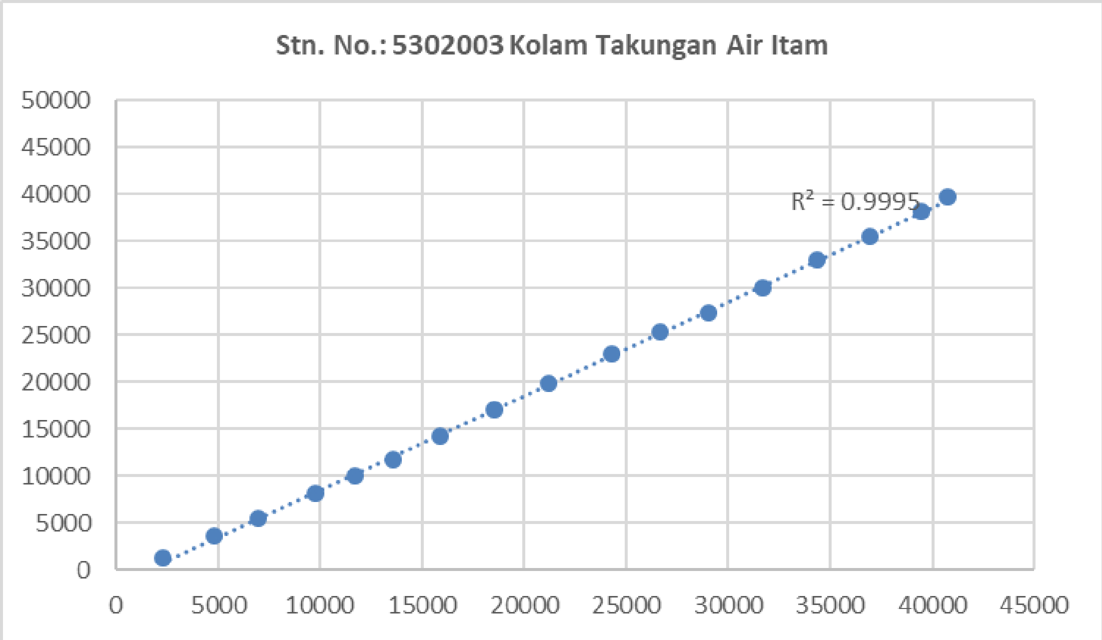


Figure 3.6: Double Mass Curve for Kolam Takungan Air Hitam (Stn no: 5302003)

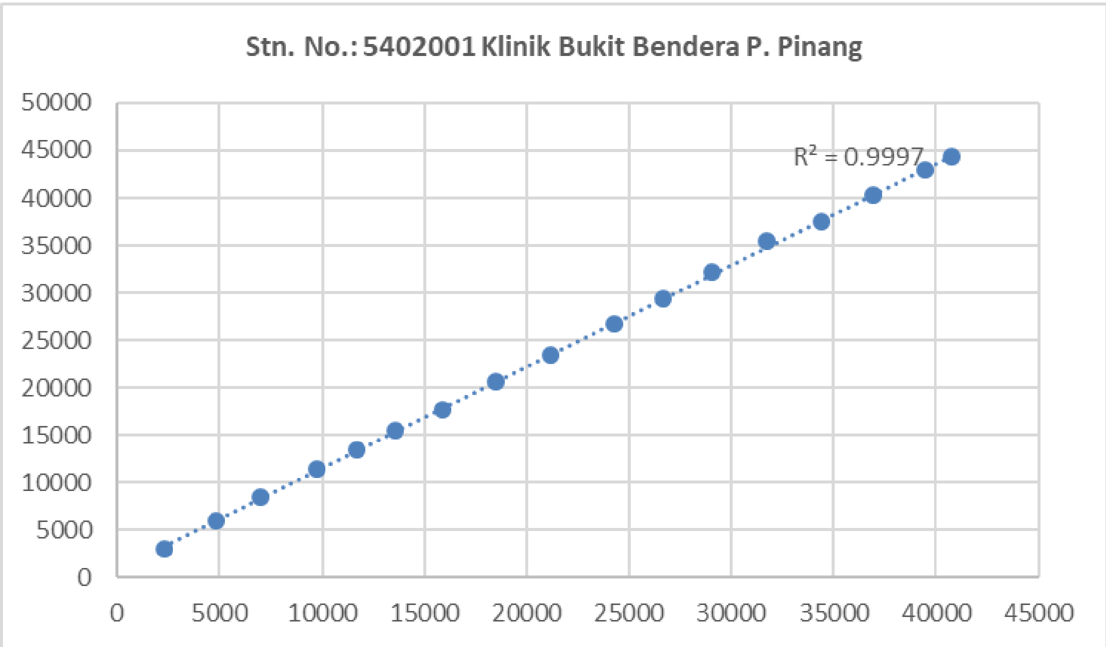


Figure 3.7: Double Mass Curve for Klinik Bukit Bendera (Stn no: 5402001)

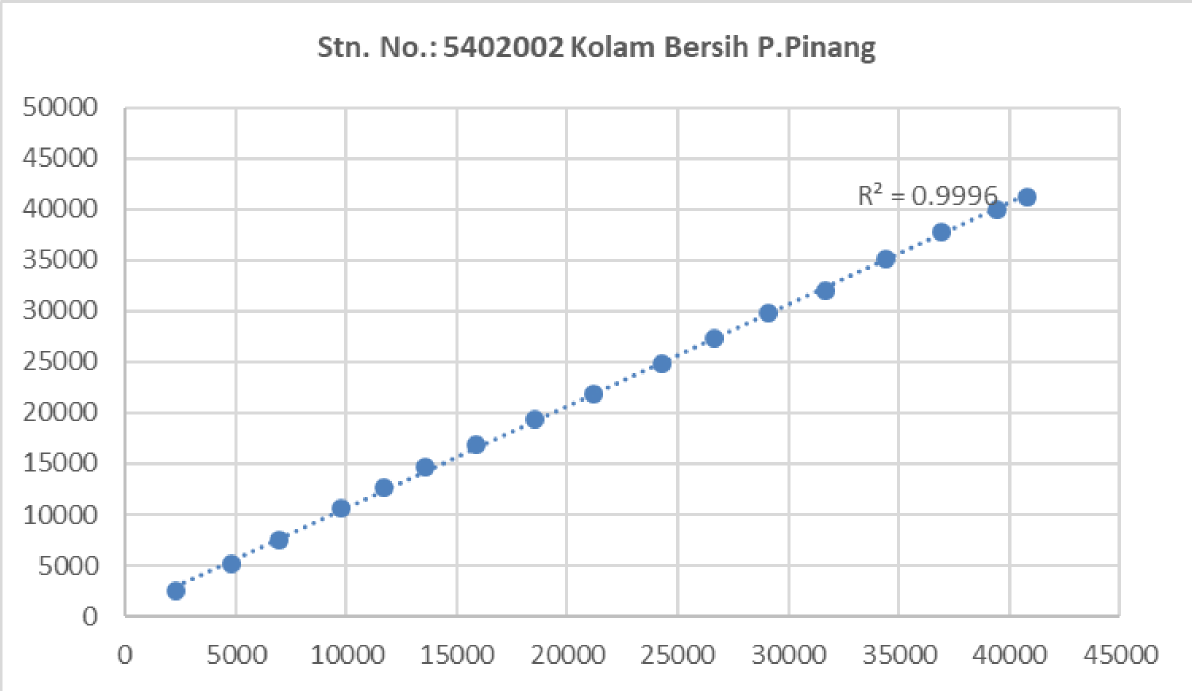


Figure 3.8: Kolam Bersih P. Pinang (Stn no: 5402002)

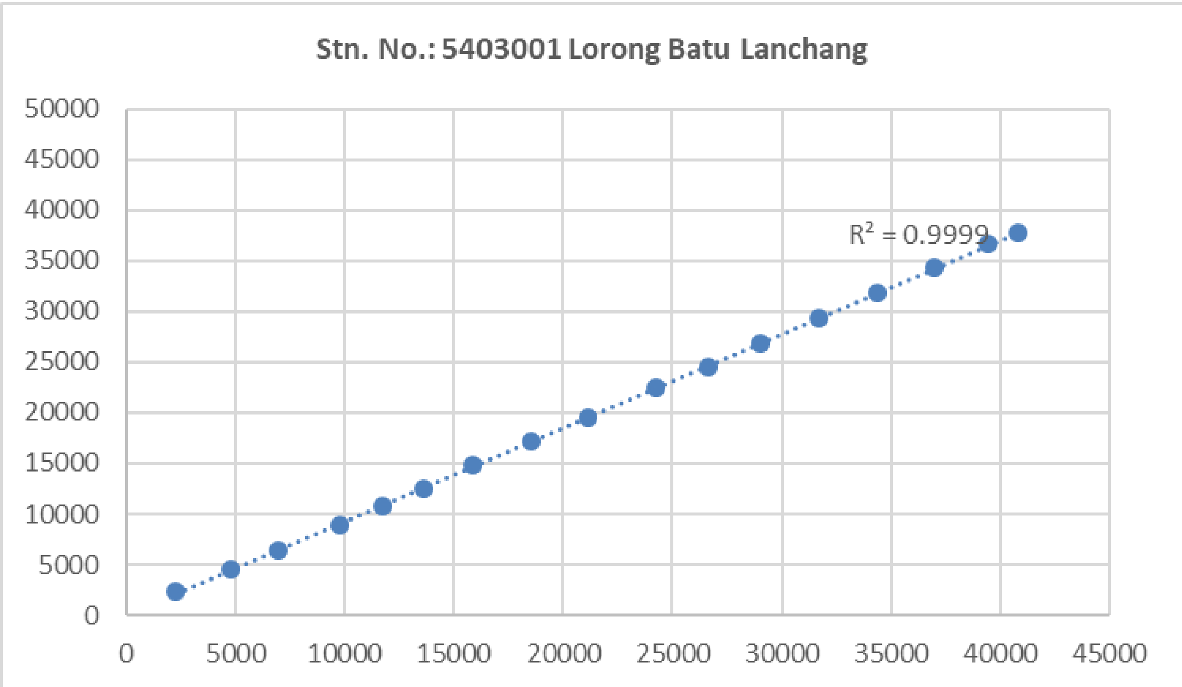


Figure 3.9: Lorong Batu Lanchang (Stn no : 5403001)

3.2.3 Water Level Data

Water level data required for this study will be collected in ASCII format in an hourly basis. **Table 3.1** list the water level stations located at Sungai Pinang (Source: Infobanjir). All the water level data has been processed and prepared in InfoWorks time series file which was then reviewed and used for the model calibration.

Table 3.1: Available Water Level at Sungai Pinang
(Source: InfoBanjir)

Station ID	Station Name	District	River
5302404	Kolam Sg.Dondang	Timur Laut	Sg.Pinang
5403403	Sg.Pinang di Jalan P.Ramlee	Timur Laut	Sg.Pinang
5403406	Sungai Air Itam @ Jalan Scotland	Timur Laut	Sg.Pinang

3.2.4 Streamflow Data

Unfortunately, the Sungai Pinang basin is an ungagged catchment. No measurement on streamflow parameter has been taken to quantify the amount of flow generated from this sub-basin or part thereof.

3.3 HYDROLOGICAL DATA PROCESSING

The hydrological data processing comprises of two main components. The first component will be the processing of the hydrological data retrieved from TIDEDA programme including the rainfall and water level for the calibration process of the hydrodynamic model. The specific flooding events were identified for the respective rainfall and water level stations. While the second component will be the derivation of the design rainfall for various storm events and durations for the study area. The long historical rainfall records from the TIDEDA programme was extracted and processed to develop the IDF Curve.

3.3.1 Processing of Hydrological Data for Calibration

For the calibration of hydrodynamic model it's require hydrological data including rainfall, streamflow and water level. However, as describe in the earlier para, the Sungai Pinang basin is an ungauged catchment and no streamflow data was available for this process.

The rainfall and water level data required for the calibration was retrieved from the TIDEDA program in hourly intervals of csv format which could not be read by InfoWorks ICM directly. It has to be converted to suit the software that allows the computation to be carried out. Besides that, the collected data was thoroughly processed in order to remove any data inconsistency, quality checking and error corrections.

3.3.2 Processing of Hydrological Data for Design Rainfall

Department of Irrigation and Drainage Malaysia (DID) had engaged National Hydraulic Research Institute of Malaysia (NAHRIM) to review and update Hydrological Procedure No. 1 (1982). The procedure was revised based on available long-term rainfall records up to year 2004. In the updated HP1 (2015), Intensity-Duration-Frequency (IDF) curves have been derived for 135 numbers of rain gauge stations throughout peninsular Malaysia at various return periods. For the study area, there three station is within the Sungai Pinang basin. **Table 3.2** lists the rainfall stations adopted in the IDF updating. Location of these stations is presented in **Figure 3.1**.

Table 3.2: List of rainfall stations within Sungai Pinang adopted in the IDF updating

No.	Station ID	District	Station Name
1	5302003	Timur Laut	Kolam Takungan Air Hitam
2	5402001	Timur Laut	Klinik Bukit Bendera P.Pinang
3	5402002	Timur Laut	Kolam Bersih P.Pinang

In the process of updating the IDF curves for the listed raingauge station above, the data required are retrieved and collected from the same source of TIDEDA program from Bahagian Sumber Air dan Hidrologi (BSAH) in JPS Ampang. The data were collected for the annual maximum for various durations ranging for the interval of, 15-min, 30-min, 1-hour, 3-hours, 6-hours, 12-hours, 24-hours, 48-hours and 72-hours.

3.4 DERIVATION OF DESIGN RAINFALL (HP1, UPDATED 2015)

For the study area, Rainfall frequency analysis has been carried out to estimate point rainfall depth/intensities for a range of storm duration and return periods. These rain gauges have reliable records of sufficiently long duration and suitable for deriving estimates of design rainfalls for durations of 5 mins to 72 hours. The nearest rainfall stations included in the analysis are listed in **Table 3.3** and their locations are shown in **Figure 3.1**.

The four parameters or coefficients derived from gauged sites which are λ, κ, θ and η can be separately generalized in order to produce the isopleths map of each parameters. The value of 4 parameter are shown in **Table 3.3**. The IDF relationship with corresponding to high return period for the project area were list in **Table 3.4** to **3.6**. **Figure 3.10** to **3.12** show IDF curve respectively.

Table 3.3: List of rainfall stations for Design Rainfall Estimation

Station ID	District	Station Name	λ	κ	θ	η
5302003	Timur Laut	Kolam Takungan Air Hitam	56.115	0.298	0.178	0.763
5402001	Timur Laut	Klinik Bukit Bendera P.Pinang	68.100	0.311	0.190	0.766
5402002	Timur Laut	Kolam Bersih P.Pinang	62.753	0.269	0.249	0.776

The new storm intensity estimation for various duration and ARI is based on Empirical equation below:

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)^{\eta}}$$

where,

i	=	Average rainfall intensity (mm/hr.);
T	=	Average recurrence interval - ARI
		(0.5 ≤ T ≤ 12 month and 2 ≤ T ≤ 100 year);
d	=	Storm duration (hours), 0.0833 ≤ d ≤ 72;
λ, κ, θ and η	=	Fitting constants dependent on the rain gauge location

Table 3.4: Design Rainfall for Various ARI and Duration at Kolam Takungan Air Hitam

	Average Recurrence Interval (ARI)													
	2		5		10		20		50		100		200	
Durations (Hr)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)
0.25	127.1	31.8	151.5	37.9	172.9	43.2	197.4	49.3	235.1	58.8	268.4	67.1	306.4	76.6
0.5	86.3	43.1	102.8	51.4	117.3	58.7	133.9	67.0	159.6	79.8	182.1	91.1	207.9	104.0
1	55.6	55.6	66.3	66.3	75.7	75.7	86.4	86.4	102.9	102.9	117.5	117.5	134.1	134.1
3	26.2	78.6	31.2	93.7	35.6	106.9	40.7	122.1	48.5	145.4	55.3	166.0	63.2	189.5
6	16.0	96.1	19.1	114.5	21.8	130.7	24.9	149.2	29.6	177.7	33.8	202.8	38.6	231.6
12	9.7	116.7	11.6	139.0	13.2	158.7	15.1	181.1	18.0	215.8	20.5	246.3	23.4	281.2
24	5.9	141.2	7.0	168.3	8.0	192.1	9.1	219.3	10.9	261.2	12.4	298.2	14.2	340.4
48	3.6	170.7	4.2	203.3	4.8	232.1	5.5	265.0	6.6	315.7	7.5	360.4	8.6	411.4
72	2.6	190.6	3.2	227.1	3.6	259.2	4.1	295.9	4.9	352.5	5.6	402.4	6.4	459.4

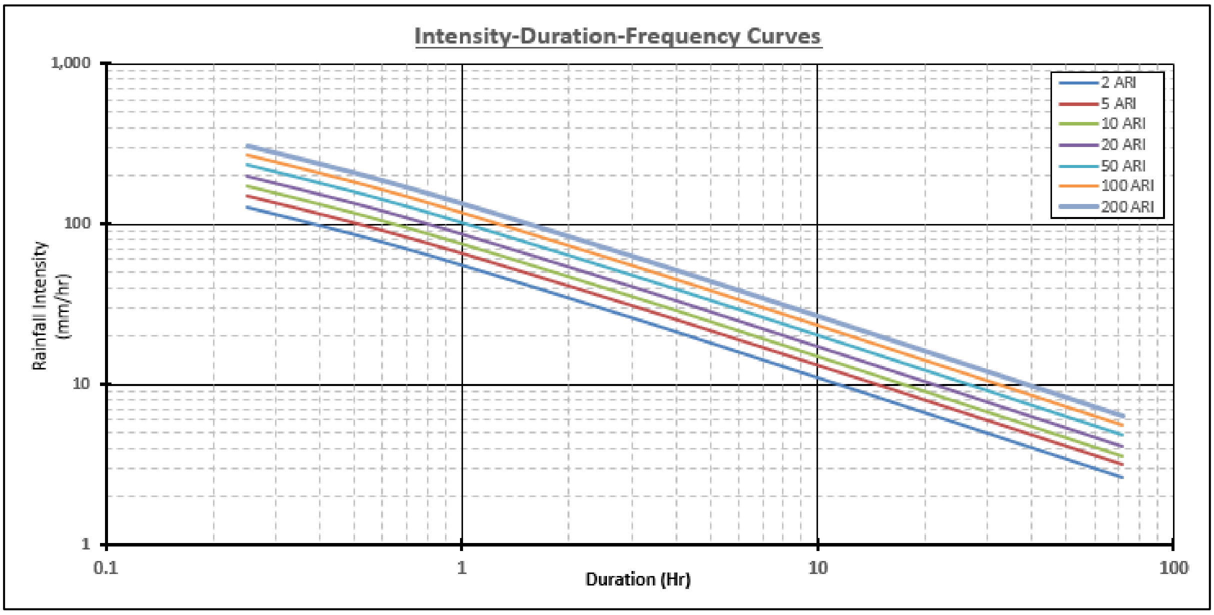


Figure 3.10: Intensity-Duration-Frequency Curve at Kolam Takungan Air Hitam

Table 3.5: Design Rainfall for Various ARI and Duration at Klinik Bukit Bendera P.Pinang

	Average Recurrence Interval (ARI)													
	2		5		10		20		50		100		200	
Durations (Hr)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)
0.25	143.6	35.9	171.8	43.0	196.8	49.2	225.5	56.4	269.8	67.5	309.1	77.3	354.1	88.5
0.5	101.0	50.5	120.9	60.4	138.5	69.2	158.6	79.3	189.8	94.9	217.4	108.7	249.1	124.5
1	66.8	66.8	80.0	80.0	91.6	91.6	104.9	104.9	125.6	125.6	143.9	143.9	164.8	164.8
3	32.2	96.7	38.6	115.8	44.2	132.6	50.6	151.9	60.6	181.8	69.4	208.2	79.5	238.5
6	19.9	119.2	23.8	142.7	27.2	163.5	31.2	187.3	37.3	224.1	42.8	256.7	49.0	294.1
12	12.1	145.8	14.5	174.4	16.7	199.8	19.1	228.9	22.8	273.9	26.1	313.8	30.0	359.5
24	7.4	177.4	8.8	212.3	10.1	243.2	11.6	278.6	13.9	333.4	15.9	381.9	18.2	437.5
48	4.5	215.4	5.4	257.8	6.2	295.3	7.0	338.3	8.4	404.9	9.7	463.8	11.1	531.3
72	3.4	241.2	4.0	288.7	4.6	330.7	5.3	378.8	6.3	453.3	7.2	519.3	8.3	594.9

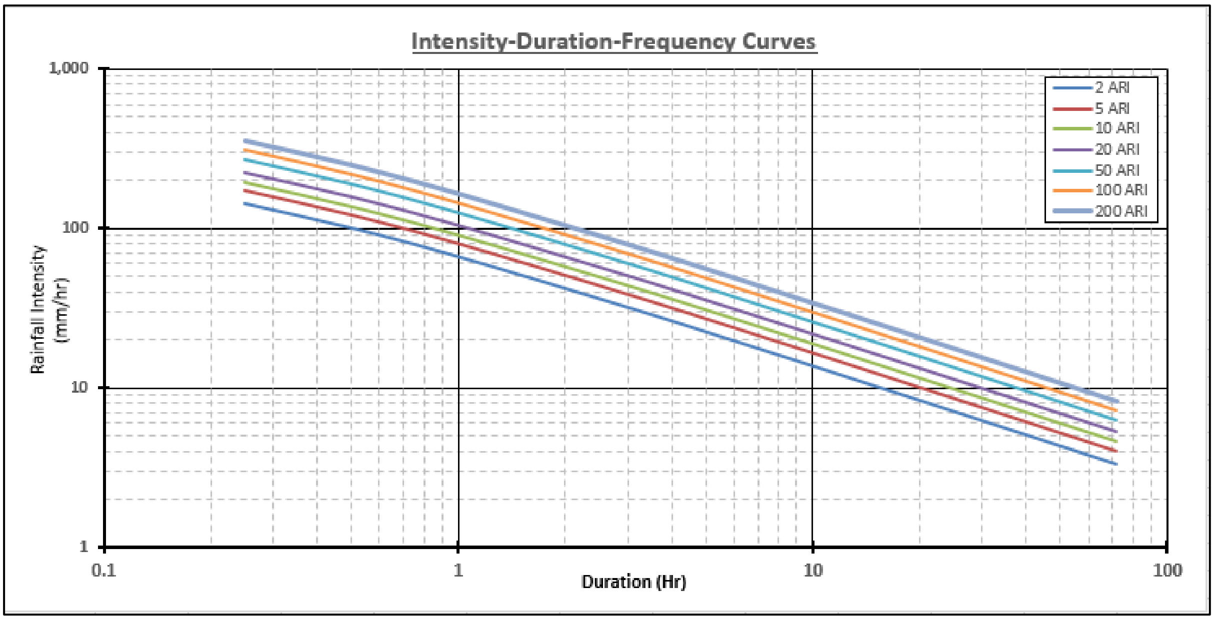


Figure 3.11: Intensity-Duration-Frequency Curve at Klinik Bukit Bendera P.Pinang

Table 3.6: Design Rainfall for Various ARI and Duration at Kolam Bersih P.Pinang

Durations (Hr)	Average Recurrence Interval (ARI) 2		5		10		20		50		100		200	
	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)	intensity (mm/hr)	depth (mm)
0.25	121.9	30.5	143.8	36.0	163.1	40.8	184.9	46.2	218.2	54.6	247.4	61.8	280.5	70.1
0.5	85.0	42.5	100.3	50.1	113.7	56.9	128.9	64.5	152.2	76.1	172.5	86.2	195.5	97.8
1	56.1	56.1	66.2	66.2	75.1	75.1	85.1	85.1	100.5	100.5	113.9	113.9	129.1	129.1
3	27.3	81.8	32.2	96.6	36.5	109.5	41.4	124.1	48.8	146.5	55.4	166.1	62.8	188.3
6	17.0	101.8	20.0	120.1	22.7	136.2	25.7	154.4	30.4	182.2	34.4	206.6	39.0	234.2
12	10.5	125.7	12.4	148.3	14.0	168.2	15.9	190.7	18.8	225.0	21.3	255.1	24.1	289.2
24	6.4	154.6	7.6	182.5	8.6	206.9	9.8	234.6	11.5	276.9	13.1	313.9	14.8	355.9
48	4.0	189.9	4.7	224.2	5.3	254.2	6.0	288.2	7.1	340.1	8.0	385.6	9.1	437.2
72	3.0	214.1	3.5	252.8	4.0	286.5	4.5	324.8	5.3	383.4	6.0	434.7	6.8	492.8

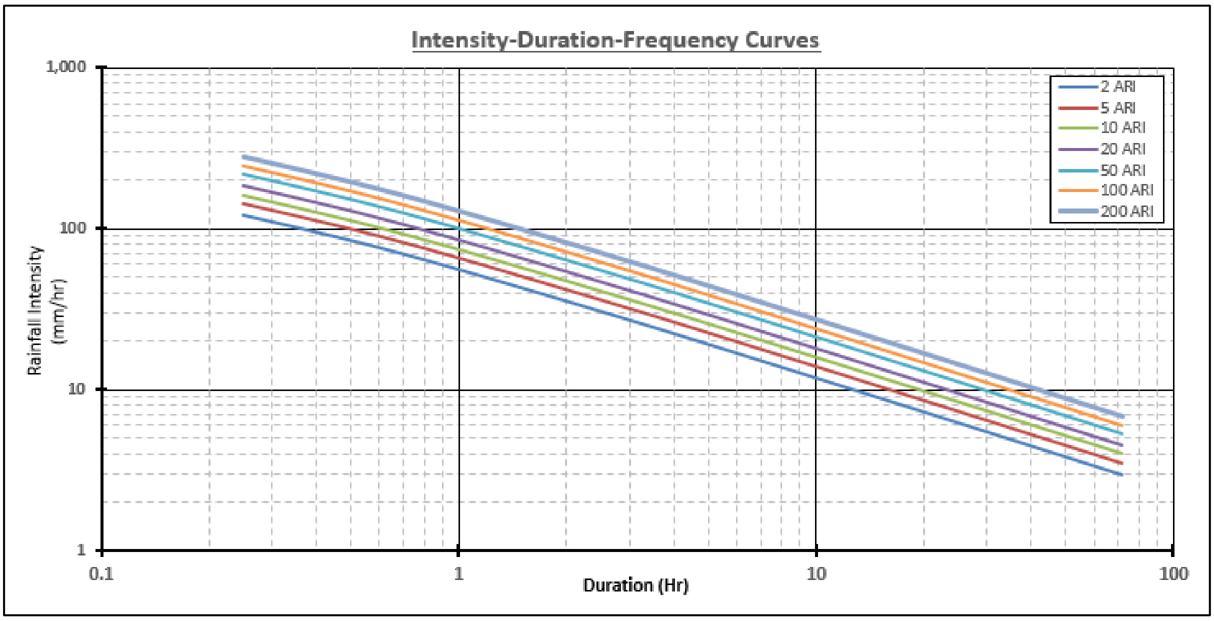


Figure 3.12: Intensity-Duration-Frequency Curve at Kolam Bersih P.Pinang

3.5 CHARACTERISATION OF SUBCATCHMENTS

In the preparation to carry out the hydrodynamic modelling for Sungai Pinang the catchment contributing to the major river will be delineated into sub-units or known as subcatchments. The delineation processes were based on the river networks and topographical data for the study area. Each of the subcatchments will be characterised its hydrological properties in the terms of permeability and response of each subcatchment to rain event by describing the time of concentrations. The following sub-Para will describe the process of delineating subcatchments, characterising the permeability ability by using US-SCS Curve Number Method and computation of time of concentration for each subcatchments. These values will be used as an input into the hydrodynamic modelling to characterise the hydrological properties for each subcatchment so the model would be able to compute the hydrograph from the given rainfall or design rainfall.

3.5.1 Delineation of subcatchments

The delineating of subcatchment for Sungai Pinang Catchment was developed using the ArcGIS Hydrology software based on the IFSAR and river network from JPS Malaysia. Subcatchment can be delineated from a DEM by computing the flow direction and using it in the ArcGIS tool.

3.5.2 Design Baseflow

In HP No.27, a relationship between the observed baseflow (for dry and moderate wet antecedent conditions) and catchment area was developed. A best fit equation was developed for general use which is as follow:

$$Qb = 0.11\ A^{0.85889}$$

Where:-

Qb = baseflow (m3/s)

A = catchment areas (km2)

3.5.3 Infiltration Model

The infiltration of rainwater to the soil can be modelled using various available and accepted method. For this study, during the inception stage, the proposing using the Curve Number (CN) Method has been accepted to model the infiltration for Sungai Pinang basin. This method is developed by National Resources Conservation Services (NRSC) or formerly known as Soil Conservation Service in U.S. Department of Agriculture.

The ability of the soil in each of the subcatchments to generate runoff during the rainy event will be described using the Curve Number Method based on the potential for the soil to absorb a certain amount of moisture. The method is to estimate rainfall excess from rainfall by defining the Curve Number for the respective subcatchments. Curve number is a function of the soil type and landuse and the initial degree of saturation known as antecedent moisture condition (AMC) of the subcatchment. For the case of calibration of the hydrodynamic model, the AMC III was chosen to represent the previous soil condition prior to the event selected.

The process of derivation of the curve number for each subcatchment will be based on these two parameters by using the ArcGIS software. The SCS curve number method is a simple, widely used and efficient method for determining the approximate amount of runoff from a rainfall even in a particular area. Although the method is designed for a single storm event, it can be scaled to find average annual runoff values. The curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition.

3.5.4 Time of Concentration

Time of concentration is another parameter required in estimating runoff using the US SCS Runoff Curve Number. It is used to compute the peak discharge for a sub-catchment. The peak discharge is a function of the rainfall intensity, which is based on the time of concentration. Time of concentration is the longest time required for a particle to travel from the subcatchment to the main river. For Hydrodynamic Modelling purpose, it is required to compute the required time for a drop of water to travel from the most hydrological remote point in the subcatchment to the point of collection. For the case of Sungai Pinang, the Bransby-William equation will be used in determining the value of time of concentration for each subcatchment. The equation is suitable for steep slope and well-defined river channel conditions like hilly and mountainous terrain. It is one of the suitable and widely used methods to describe the value of its type. The equation is as follows: -

$$T_c = 0.605 \frac{L}{S^{0.2} A^{0.1}}$$

Where:

T_c = *time of concentration (hours)*

L = *Gross length of main channel (km)*

S = *Net slope of main channel (%)*

A = *Watershed area (km²)*

3.5.5 Temporal Pattern

Temporal pattern distribution represents the variation of rainfall intensities/depth through the time of occurrence of a typical storm. With the design rainfall estimated for 1-hour, 3-hours, 6-hours, 12-hours, 24-hours, 48-hours and 72-hours duration, it is then necessary to determine the typical rainfall temporal pattern for different storm durations in order to translate the design depths into a time series for use in the hydrodynamic modelling simulations. Rainfall temporal pattern for various storm durations were derived from **Table 3.7** of HP1(2010) Region 3: Perak, Kedah, P Pinang & Perlis. **Figure 3.13 – Figure 3.19**. illustrate the normalised temporal pattern extracted from HP 1(2010) for DTL at 1-hour, 3-hours, 6-hours, 12-hours, 24-hours, 48-hours and 72-hours duration adopted in this study.

Table 3.7: Normalised Temporal Pattern for Region 3: - Perak, Kedah, P Pinang & Perlis

No. of Block	Duration								
	15-min	30-min	60-min	180-min	6-hr	12-hr	24-hr	48-hr	72-hr
1	0.215	0.141	0.077	0.085	0.047	0.040	0.048	0.021	0.044
2	0.395	0.173	0.064	0.100	0.041	0.046	0.033	0.045	0.026
3	0.390	0.158	0.098	0.086	0.070	0.036	0.034	0.060	0.063
4		0.161	0.087	0.087	0.099	0.066	0.033	0.086	0.074
5		0.210	0.068	0.087	0.081	0.066	0.034	0.039	0.021
6		0.158	0.074	0.088	0.113	0.060	0.036	0.028	0.050
7			0.078	0.100	0.121	0.081	0.031	0.020	0.058
8			0.072	0.100	0.099	0.092	0.044	0.026	0.049
9			0.075	0.085	0.078	0.119	0.036	0.015	0.008
10			0.104	0.063	0.076	0.114	0.027	0.014	0.031
11			0.106	0.060	0.129	0.113	0.023	0.028	0.030
12			0.099	0.059	0.045	0.166	0.035	0.017	0.044
13							0.041	0.057	0.025
14							0.053	0.039	0.022
15							0.039	0.044	0.044
16							0.055	0.035	0.024
17							0.032	0.038	0.024
18							0.031	0.052	0.025
19							0.039	0.069	0.023
20							0.080	0.046	0.070
21							0.076	0.056	0.078
22							0.044	0.046	0.081
23							0.042	0.045	0.028
24							0.056	0.073	0.058

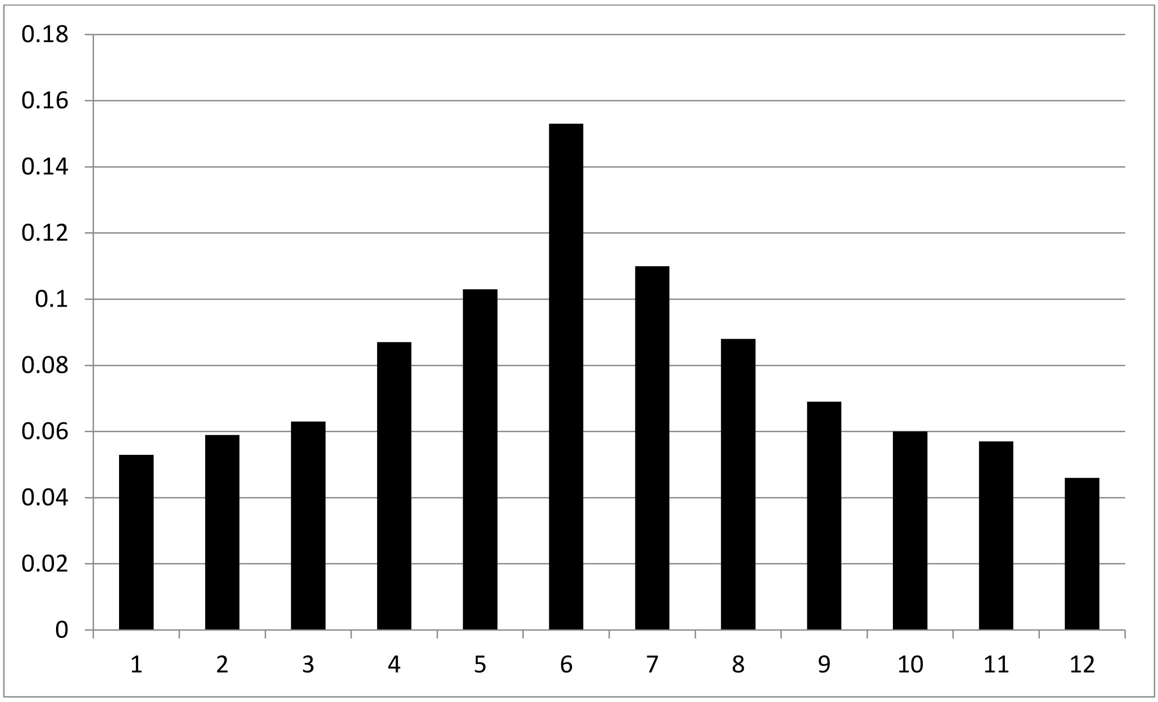


Figure 3.13: Normalized Temporal Pattern for Region 3 - Perak, Kedah, P Pinang & Perlis at 1 hour.

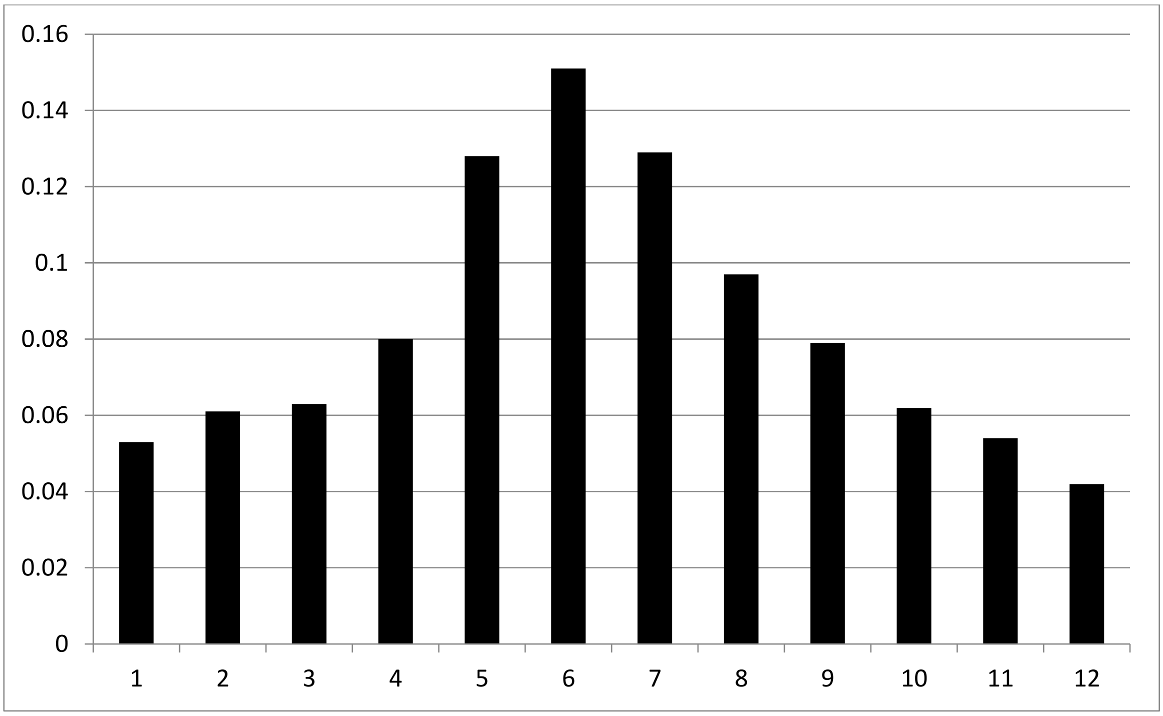


Figure 3.14: Normalized Temporal Pattern for Region 3 - Perak, Kedah, P Pinang & Perlis at 3 hours.

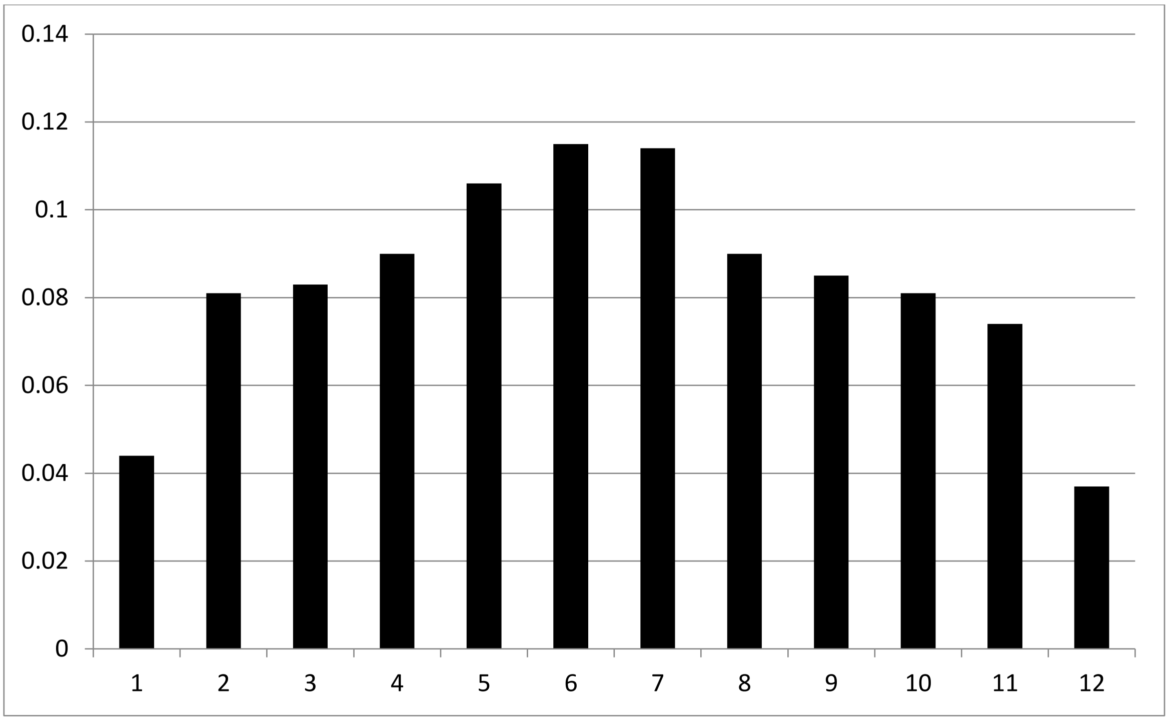


Figure 3.15: Normalized Temporal Pattern for Region 3 - Perak, Kedah, P Pinang & Perlis at 6 hours.

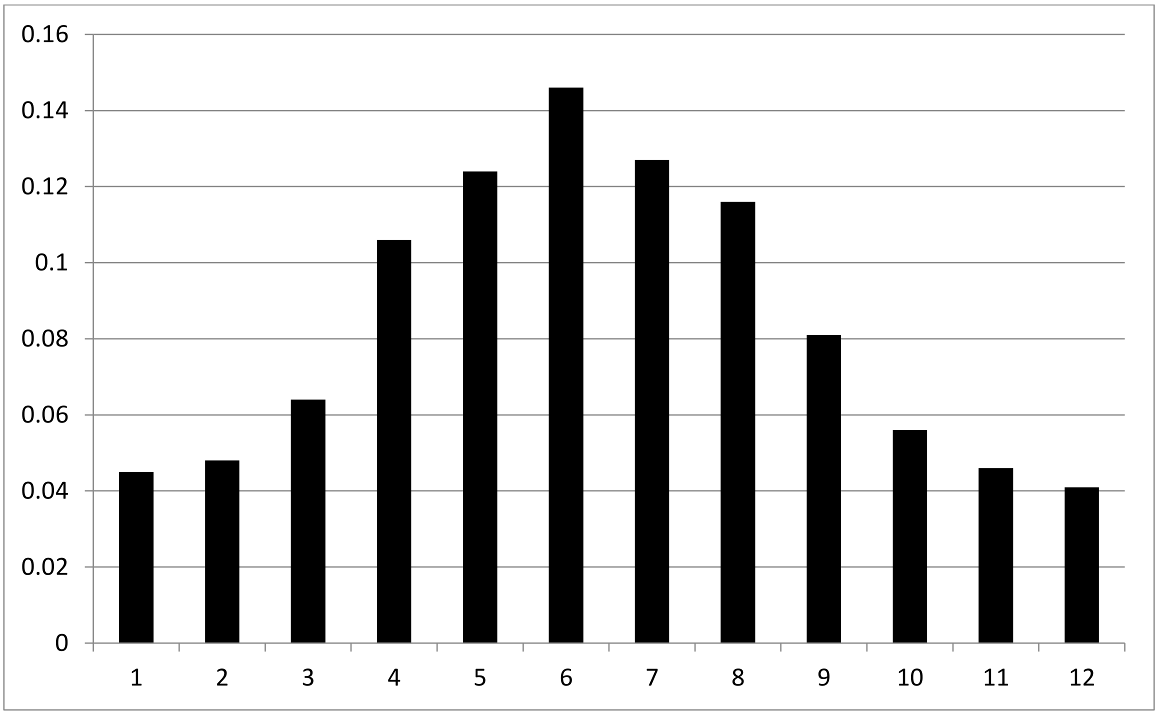


Figure 3.16: Normalized Temporal Pattern for Region 3 - Perak, Kedah, P Pinang & Perlis at 12 hours.

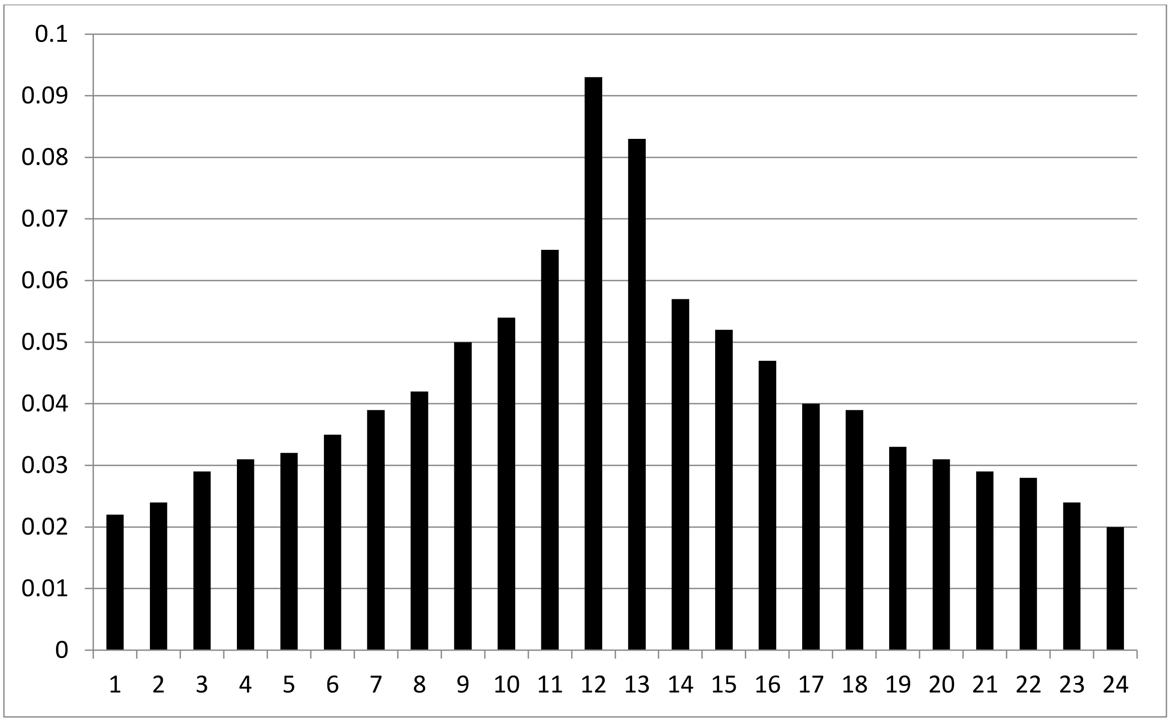


Figure 3.17: Normalized Temporal Pattern for Region 3 - Perak, Kedah, P Pinang & Perlis at 24 hours.

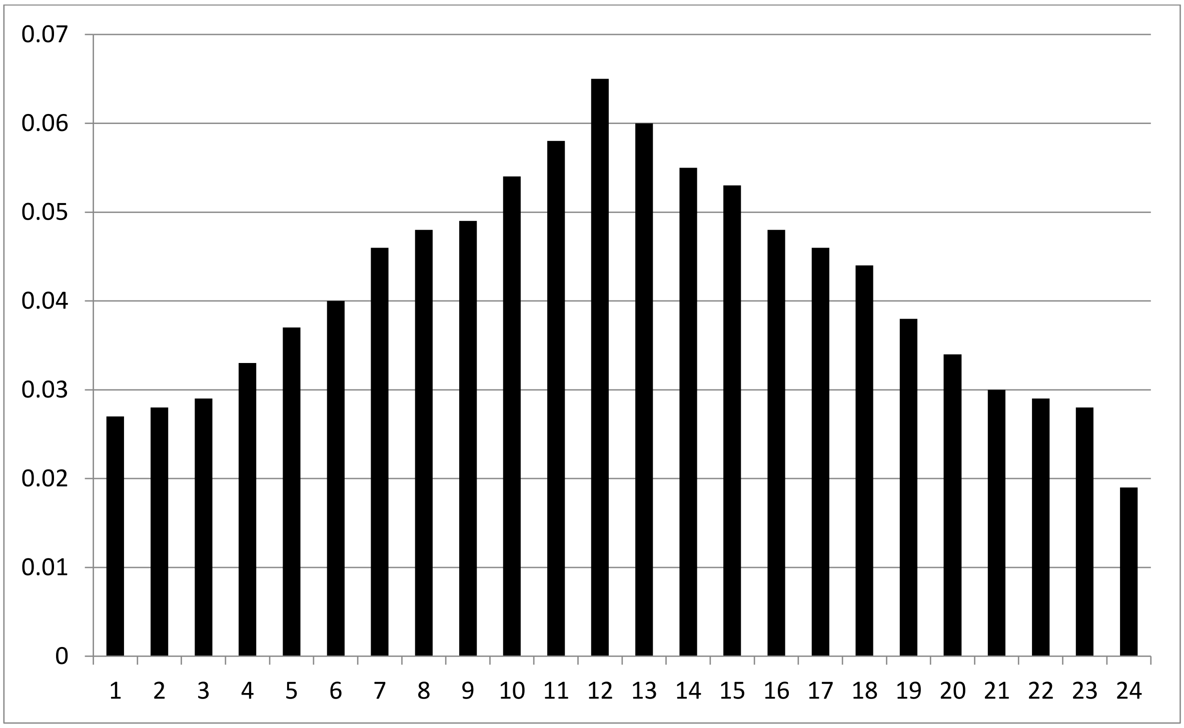


Figure 3.18: Normalized Temporal Pattern for Region 3 - Perak, Kedah, P Pinang & Perlis at 48 hours.

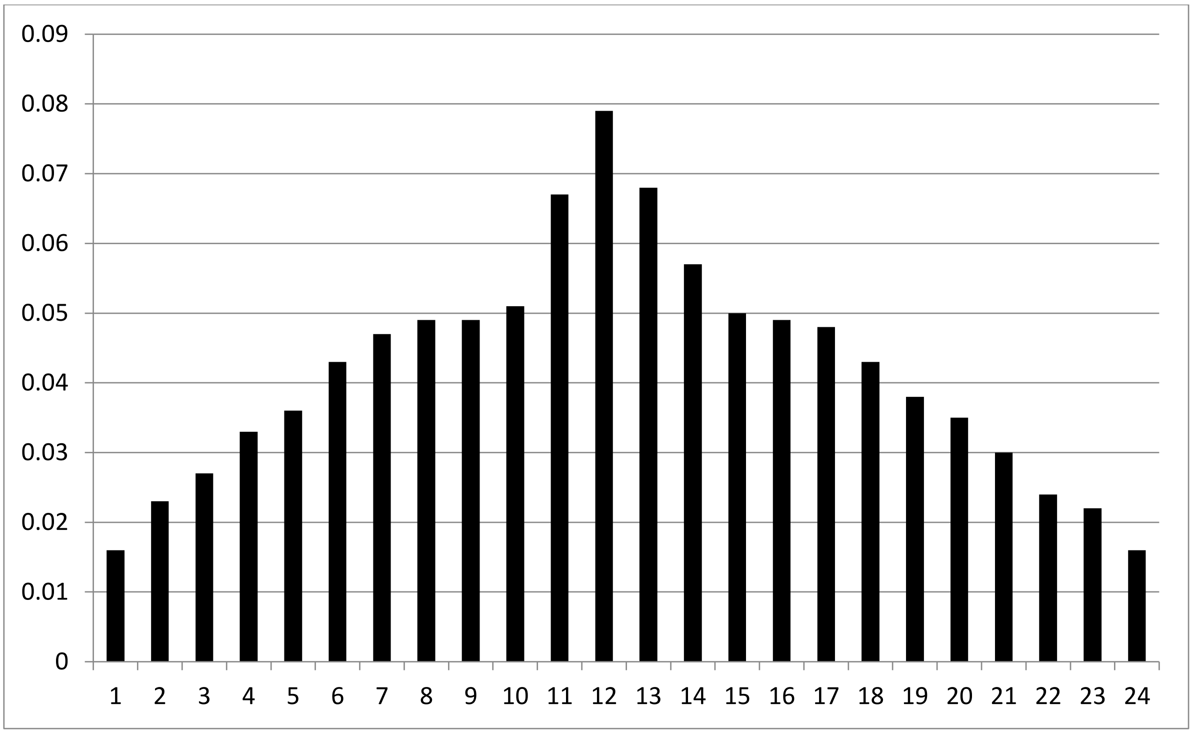


Figure 3.19: Normalized Temporal Pattern for Region 3 - Perak, Kedah, P Pinang & Perlis at 72 hours.

3.5.6 Areal Reduction Factor (ARF)

The conversion of point rainfall estimates to average catchment rainfall estimates should fore based on Hydrological Procedures No.1 (2015). **Table 3.8** show the ARF's estimated for Kuala Lumpur and **Figure 3.20** show the relationship of ARF values derive and rainfall duration for Kuala Lumpur.

Table 3.8: ARF's estimated for Kuala Lumpur

Area (km^2)	ARFs for various storm duration (hours)				
	1	3	6	12	24
50	0.76	0.78	0.80	0.82	0.83
100	0.68	0.70	0.72	0.75	0.76
150	0.63	0.66	0.68	0.70	0.71
200	0.60	0.63	0.65	0.67	0.68

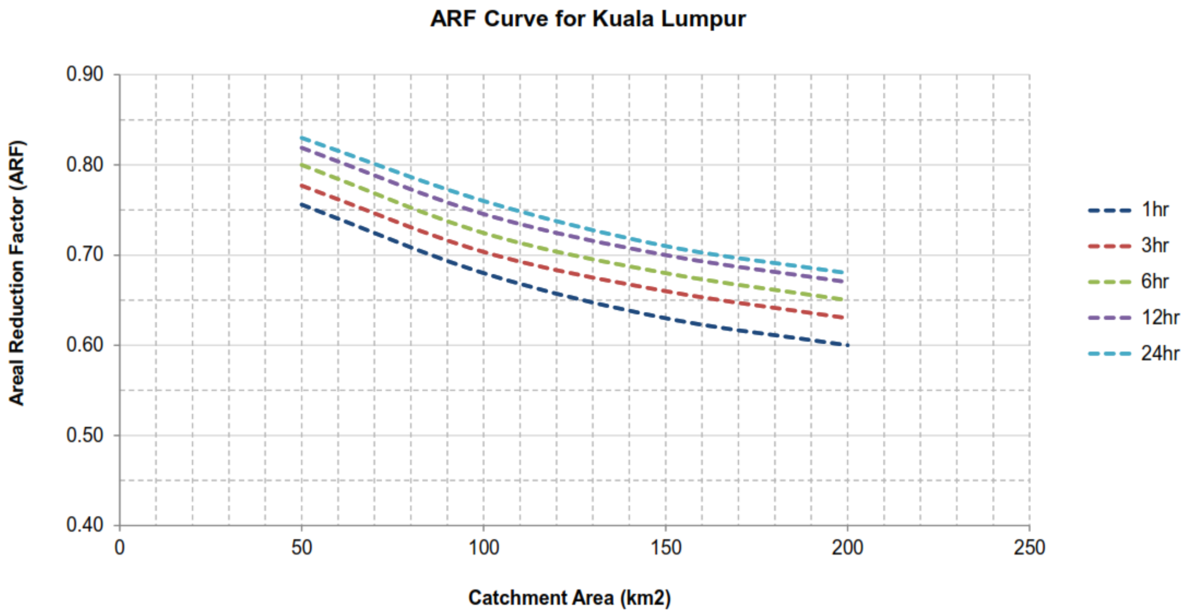


Figure 3.20 **:** Relationship of ARF values derive and rainfall duration for Kuala Lumpur.

3.6 RECENT FLOOD EVENT

Among the severe flood event that occurred recently was during 4th – 5th November 2017 between 2 pm to 6 am. Based on the Laporan Banjir Kilat[1] the precipitation summary depth at various rainfall station within the project area are listed in **Table 3.9** below: -

Table 3.9: 4th November 2017 Storm Event (depicted from Laporan Banjir Kilat[1])

Bil.	Lokasi Data Hujan	Kumulatif Hujan (mm)
1	Stesen Sungai Air Itam @ Jalan Scotland	151 mm
2	Stesen Lorong Batu Lanchang	159 mm
3	Stesen Kolam Bersih @ Sungai Air Terjun	126 mm
4	Stesen Sungai Pinang	150 mm

*** Nota : Beberapa stesen mencatatkan bacaan hujan kumulatif melebihi 60 mm (Very Heavy)

Concurrently occurred during the storm event, tidal condition in Sungai Pinang river mouth was at the high tide of which the tide level is approximately at +2.7 m @ 1:00 am. While the maximum recorded of water level in major rivers are as follows:

- Sungai Pinang = 4.07 m (danger level)
- Sungai Air Itam = 7.955 m (danger level)
- Sungai Dondang = 22.62 m (danger level)

[1] Laporan Banjir Kilat, Pejabat Jurutera Daerah Timur Laut, Jabatan Pengairan dan Saliran Negeri Pulau Pinang, November 2017

The affected areas: -

(1) Jalan P. Ramlee
(2) Sek. Abdullah Munshi
(3) Kampung Masjid.
(4) Kampung Makan
(5) Masjid Negeri, Air Itam
(6) Jalan kebun Lama
(7) Kampung Hashim Yahya
(8) Jalan Langkawi
(9) Parit Lumba Kuda
(10) Halaman Bukit Gambir
(11) Jalan Patani
(12) Jalan Singgora
(13) Astaka Stadium
(14) Persiaran Perak
(15) Jalan Trengganu
(16) Sungai Relau, Taman Sri Angsana
(17) Minden Height Jalan 3
(18) Pangsapuri Sri Saujana
(19) Klinik Kesihatan Sungai Dua
(20) Kampung Rawa
(22) Air Itam
(23) Lebuhraya Thein Teik
(24) Jalan Zoo
(25) Ladang Hong Seng
(26) Kg Baru Air Itam
(27) Kg Kubor, Bt Feringghi
(28) Jalan Abullah Arif
(29) Jalan Goh Guan Ho
(30) Klinik Jalan Perak
(31) Kampung Dodol
(32) Jalan Burma
(33) Lorong Macalister
(34) IPK
(35) Anson Road
(36) Jalan Nordin
(37) Flat Mutiara Indah, Bukit gambir
(38)Lebuh rambai, Paya Terubong
(39)Jalan Tiga Air Itam
(40) Jalan Thein Teik Shell Sheik madar
(41) balai Polis Bandar baru Air Itam

Several photos during the event was captured in the Laporan Banjir Kilat and shows in the following **Figure 3.21** to **Figure 3.26**.

Figure 3.21: Kampung Makam (Flood Event 4th - 5th November 2017)

Figure 3.22: Sungai Pinang (Flood Event 4th to 5th November 2017)

Figure 3.23: Kg Masjid (Flood Event 4th - 5th November 2017)

Figure 3.24: Lintang P Ramlee (Flood Event 4th - 5th November 2017)

Figure 3.25: Masjid Negeri Pulau Pinang (Flood Event 4th - 5th November 2017)

Figure 3.26: Pangsapuri Saujana (Flood Event 4th - 5th November 2017)

CHAPTER 4

HYDRODYNAMIC MODELLING

CHAPTER 4

HYDRODYNAMIC MODELLING

4.1 INTRODUCTION

Hydraulic analysis will describe process of preparing the required data for development of a physically-based hydrodynamic model for Sungai Pinang Basin. The basic data required are river cross-sections survey, structural details and digital terrain model (DTM). The setting up of the basic 1-D hydrodynamic modelling uses the river cross-section survey data as it is one of the main and important input used during the drainage numerical model development processes particularly for the river cross-sectional and alignment data. These data were acquired from the survey data which was carried out by Jurukur Ayob in January year 2018. **Figure 4.1** shows the whole Sungai Pinang river system including the main drainage discharging into the river system.

4.2 GENERAL APPROACH FOR HYDRAULIC ANALYSIS

The overall concept and approach for hydraulic analysis for this study are:

i. The establishment of hydraulic model – in order to use the hydraulic model, the establishment and setting up of the model was extremely vital to the overall simulation process. This formed the backbone of the study where various requirements of the model must be complied with and all the limitations of the model observed to provide accurate simulation;
ii. Various river survey data provided by clients will be analysed and made homogeneous in terms of horizontal projection so it can be mapped within the same base map and projections;
iii. The whole river system as given in **Figure 4.1** with all the survey data and information, is being modelled as one system;
iv. Critical storm duration was determined by simulating the model with various storm durations to distinguish the highest peak discharge value.
v. Simulation – to carry out various simulation cases with critical storm duration to analyse various conditions to predict the river flow processes.

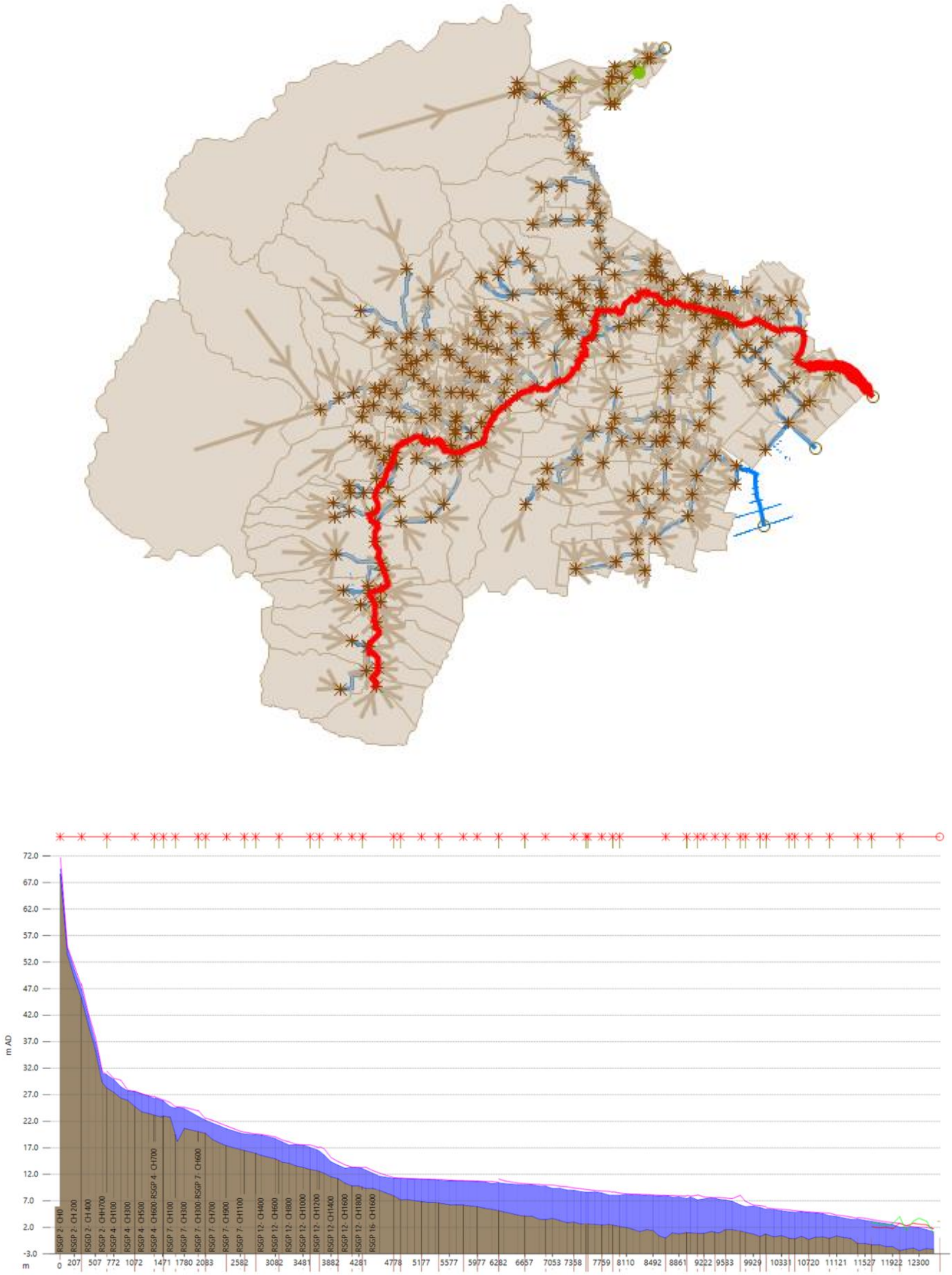


Figure 4.1: (above) Layout of Sungai Pinang hydrodynamic Model
(below) longitudinal section of Sungai Pinang and Sungai Air Itam

4.2.1 River and Drainage Survey Data

River and drainage survey data consists of cross sections and alignment data. These data play a major role and backbone in any development of hydrodynamic model, the river survey data for Sungai Pinang were provided by Jurukur Ayob. River engineering survey was carried out in January year 2018 with the cross-section interval of 100 m.

Figure 4.1 shows the river model in InfoWorks ICM. The black dotted lines as illustrated in the figure discretize the 100m interval of river cross-section information that has been linked to each other as a river model.

The final data provided by the surveyor in the AutoCad format will be processed and converted into the format recognized by the InfoWorks ICM which is in ASCII/text format. The conversion process requires various analyses before the data being used as input to the model development to check for consistency and reliability of the data. The stability of the model is an important factor need to be considered especially in determining the suitable interval of the river cross-sections.

4.2.2 Boundary Condition

The InfoWorks ICM hydrodynamic model is capable of simulates various types of preset boundary conditions. The upstream boundaries are defined by discharges at the upstream survey cross-section limit at each tributary while at the downstream end will be using the Stage-Discharge curve that will derive from the localized river cross section information where it will be used as the downstream boundary conditions.

Boundary conditions of the model system are necessary to define the conditions of the simulations. Although the model can simulate various types of preset boundary conditions, the optimum conditions normally applied to river systems are the downstream boundary defined by the variation of the water level with time and inflow discharge hydrographs at all the upstream boundaries of the main river and all its tributaries.

4.2.2.1 Manning Coefficient, *n*

The Manning coefficient '*n*' is a function of bed material, vegetation growth, channel irregularities, obstructions and shape and size of the channel. Manning's equation, which is empirically derived, is not based on rigorous physics and can provide unreliable results in cases where the overall shape of the flow cross section is complex, an example being a river in flood, with the much shallower flow on the floodplain than in the main channel. The factor used for channel and floodplain roughness for the model development is based on the manning's n coefficient. The river channel manning's n value was ranging between 0.3 and 0.5 and does not have fix value which can be constantly changes during calibration process.

4.2.2.2 Inflow

For the design flood discharges, design storms of various durations and return periods were used to simulate design discharges for the present land use condition. The derived catchment discharges were then defined in the model setup as the point inflow for sub-catchments with the exact tributary outfalls while the distributed flow boundary type is defined in the sub-catchments without actual river outfall.

Catchment discharges for historical events as well as design flood events are the main input to the hydrodynamic model. Historical discharges were simulated by applying historical storms into the rainfall-runoff model while design flood discharges were obtained using design storms as input. Long-term historical rainfall data were processed and used to simulate the catchment discharges in a long-term, continuous manner.

4.2.2.3 Tidal

Data on tide level of Penang Island are available in "Jadual Pasang Surut Malaysia 2018" which was published by the Pusat Hidrografi Nasional. The reference will be based from observed data at the Standard Port at Kedah Pier in Penang Island. The tidal level data obtained from this record is given in **Table 4.1** below: -

Table 4.1: Tide Level at Kedah Pier

Highest Astronomical Tide	+ 3.09 m CD
Mean High Water Spring	+2.69 m CD
Mean High Water Neap	+1.96 m CD
Mean Sea Level	+1.71 m CD
Mean Low Water Neap	+1.45 m CD
Mean Low Water Spring	+0.72 m CD
Lowest Astronomical Tide	0.00 m CD
Note: *LAT is 1.555m below Land Survey Datum*	

The tide influences the flow of Sg Pinang up tp about 2 km above the river mouth. The tidal water level records indicate that the Extreme High Water is 1.615 m LSD while the Lowest Astronomical Tide is -1.22 m LSD. Parts of the Georgetown near the Sg Pinang river mouth is relatively low in elevation, which are occasionally inundated during high tide[1].

4.3 THE HYDRODYNAMIC MODELLING

One-dimensional hydrodynamic modelling of rivers is now commonplace in engineering practice. Hydrodynamic models are needed when information is required on the water level as well as the discharge in the river. The starting point for the development of 1-D hydrodynamic models are the well-known St. Venant equations of open channel flow. These equations are derived from the conservation of mass (volume) and momentum of flow in a straight, prismatic open channel.

To apply them to a natural river which meanders and has irregular cross-section geometry requires some additional coefficients to account for the co-ordinate transformation implicit in treating the centreline of the river channel as the “x” axis in the 1-D model and the hydraulic properties of natural river cross-sections. In this Study, the hydrodynamic modelling serves as one of the tools that provide computational methods in the simulation of flood flows along rivers and its floodplains. It can predict the design water levels and providing flow velocity in the river cross sections and other hydraulic structures besides its main function of routing the

[1] Study and Detailed Design for Pollution Prevention and Water Quality Improvement Project for Sg Pinang, Pulau, Pinang, Interim Report 2006, Jurutera Perunding Zaaba, Unit Perundingan Universiti Malaya

inflow discharge hydrographs along the river system. Its main advantages over other methods, such as physical modelling, are: -

i. great flexibility in assessing various situations;
ii. it simulates proposals in a very short time; and
iii. the cost incurred is lesser compared to other methods.

With accurate data used in the calibration of the model parameters, the accuracy of the simulated results obtained is comparable with other methods. The reasons for choosing the hydrodynamic model can be summarised as below: -

i. The model requires the design inflow hydrographs obtained from the hydrological analysis to be routed for the whole river system until the river mouth. This is beyond the steady state model capability;
ii. The hydrodynamic model provides the routing of design discharge hydrographs and the water levels along the modelled rivers so that an evaluation of the river capacity and design of the river cross sections can be carried out; and
iii. The velocity obtained from the analysis can be used in the evaluation of the possible areas affected due to high velocities along the rivers;

From the above justifications, the model adopted in this Study is the InfoWorks ICM (Integrated Catchment Modelling) computer model developed by the Innovyze. InfoWorks ICM is the first truly integrated modelling platform to incorporate both urban and river catchments. With full integration of 1D and 2D hydrodynamic simulation techniques, both the above- and below-ground elements of catchments can be modelled to accurately represent all flow paths. InfoWorks ICM enables the hydraulics and hydrology of natural and man-made environments to be incorporated into a single model. The equations used by a Manning Section are the mass conservation or continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q$$

Where:

Q	= flow (m3/s)
A	= cross section area (m2)
q	= lateral inflow (m3/s/m)
x	= longitudinal channel distance (m)
t	=time (s)

and the momentum conservation or dynamic equation: -

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{\beta Q^{x}}{A}\right) + gA\frac{\partial H}{\partial x} - g\frac{\frac{AQ}{Q}}{K^{2}} + q\frac{Q}{A}cos\alpha = 0$$

Where:

H	=water surface elevation above datum (m)
β	= momentum correction coefficient
g	= gravitational acceleration (m/s^2)
α	= angle of inflow
K	= channel conveyance
K2	= A^2 $R^{4/3}$ / n^2
n	= Manning's roughness coefficient
R	= hydraulic radius = (A/P)
P	= wetted perimeter

4.2.2 Data Requirements for Setting Up Hydrodynamic Model

The data required for setting up the hydrodynamic model are: -

I. River and channel cross sectional data. The interval of the data is estimated using the stability criteria of the models and normally, the larger the interval, the more stable the simulation becomes;
II. Floodplains geometry is used to represent overbank flows so that discharge, storage, and attenuation in the floodplain can be accurately simulated;
III. Roughness factor;
IV. Initial conditions used to specify the state of the waterbody at the beginning of the simulation, it is required only when a time dependent simulation is conducted.
V. Configuration and hydraulic parameters of each hydraulic structure and, if any, the operation procedures of the hydraulic structures.

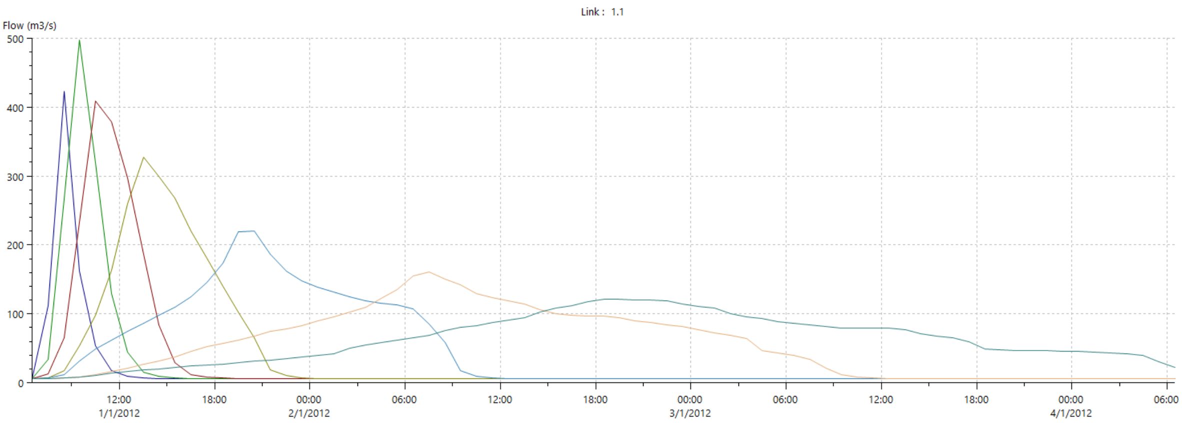
4.4 MODEL SETUP

The model setup is geared towards the intended requirements of the study as well as in accordance to the stipulations in the InfoWorks ICM manual. For this project, the simulation of the hydraulic model was carried out based on existing drainage condition for both current and future land use.

Output from the hydrological and hydraulic analysis will be gathered in the InfoWorks ICM for development of Sungai Pinang model. The model shall comprise all component including river cross sections, river alignments, time series data as boundary condition, initial water level, characterised sub catchment with hydrological parameters i.e. Rainfall Runoff, Curve Number, time of concentrations (Tc) and Manning's roughness.

4.5 CRITICAL STORM DURATION ANALYSIS

With the above hydrodynamic model setup, the sensitivity analysis to identify the most significant storm duration has been carried out. **Figure 4.2** illustrated the results of the simulations for various storm durations on the plotted water level profiles. This storm was adopted in the subsequent runs for various ARIs to obtain the flood depth and extent in the preparation for forecast model.



		Flow	
		Min	Max
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 1H		5.837	423.404
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 3H		5.837	497.588
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 6H		5.837	409.120
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 12H		5.837	327.357
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 24H		5.837	219.748
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 48H		5.837	160.262
>Sg Pinang 31082018>Sg.Pinang>1Ds!!!!!!!!!!!!!!!!!!!!!!!!!>100ARI 72H		5.837	121.358

Figure 4.2: Critical storm duration analysis for Sungai Pinang: 3-Hours

4.6 SUMMARY OF SUBCATCHMENT PARAMETER

The summary subcatchment parameter for hydrodynamic model development for Sungai Pinang Basin is as listed in **Table 4.2** below.

Table 4.2: Characterisation for each delineated subcatchment

Zone	Subcatchment	Total Area (ha)	Curve Number	Baseflow (m3/s)	Time of concentration, Tc (minutes)
Sungai Pinang	SJ 24	3.08	85	0.02	20
	SJ 47	5.322	80	0.00888	15.73
	SJ 56	6.456	75	0.0104	37.02
	SJ 73	8.344	85	0.02	20
	SJ 80	10.519	85	0.02	20
	SP 102	1.386	85	0.00271	4.49
	SP 103	1.396	85	0.00274	17.91
	SP 105	8.265	85	0.00277	10.25
	SP 108	3.105	85	0.00557	7.78
	SP 109	3.627	85	0.00637	16.72
	SP 11	7.072	85	0.01131	22.33
	SP 111	1.442	85	0.00283	2.99
	SP 113	10.803	85	0.01627	20.89
	SP 115	1.47	85	0.00288	6.59
	SP 116	1.473	85	0.00288	10.79
	SP 117	1.477	85	0.00289	4.38
	SP 119	1.486	85	0.00289	6.09
	SP 12	1.987	85	0.0038	3.95
	SP 120	1.503	85	0.00289	13.07
	SP 121	1.52	85	0.00291	5.56
	SP 128	3.252	85	0.0058	14.98
	SP 129	3.88	85	0.00675	5.3
	SP 13	6.488	85	0.0105	15.9
	SP 133	4.38	85	0.00749	6.77
	SP 134	7.256	85	0.01156	8.96
	SP 136	1.663	85	0.00313	6.58
	SP 137	1.673	85	0.00316	10.42
	SP 141	1.701	85	0.00324	11.23
	SP 143	1.711	85	0.00328	6.37
	SP 144	1.713	85	0.00328	10.96
	SP 145	4.257	80	0.00731	15.05
	SP 146	1.728	85	0.00329	15.34
	SP 147	1.733	85	0.00332	9.58
	SP 148	1.75	85	0.00333	8.93
	SP 15	2.965	85	0.00536	27.49
	SP 150	20.317	60	0.02798	5.87
	SP 152	4.4	85	0.00752	14.8

Table 4.2: Characterisation for each delineated subcatchment (cont…)

Zone	Subcatchment	Total Area (ha)	Curve Number	Baseflow (m3/s)	Time of concentration, Tc (minutes)
Sungai Pinang	SP 153	1.782	85	0.00341	12.03
	SP 154	3.885	85	0.00676	8.45
	SP 155	1.827	85	0.00342	7.28
	SP 158	1.872	85	0.00346	2.6
	SP 159	1.878	85	0.00348	7.67
	SP 160	1.884	85	0.00354	6.21
	SP 162	4.054	85	0.00701	30.09
	SP 163	1.907	85	0.00361	7.87
	SP 165	1.925	85	0.00363	8
	SP 166	9.597	85	0.01469	10
	SP 16a	1.555	85	0.02	10
	SP 16b	2.055	85	0.00391	10.29
	SP 171	1.984	85	0.0037	7.54
	SP 173	1.997	85	0.00371	22.97
	SP 174	2.016	85	0.00376	7.54
	SP 175	2.034	85	0.00376	35.98
	SP 177	4.35	85	0.00745	19.35
	SP 178	2.054	85	0.00382	4.69
	SP 179	2.065	85	0.00385	8.93
	SP 18	2.616	85	0.00481	5.94
	SP 180	8.109	85	0.01272	18.9
	SP 181	2.083	85	0.00388	9.44
	SP 184	2.129	85	0.00393	5.83
	SP 185	4.761	85	0.00805	8.89
	SP 186	2.15	85	0.00396	8.36
	SP 187	2.155	85	0.00397	8.47
	SP 189	9.971	85	0.01519	31
	SP 19	9.484	85	0.01455	14.04
	SP 191	2.188	85	0.00407	9.46
	SP 193	2.216	85	0.00409	10.75
	SP 194	2.22	85	0.00412	4.11
	SP 197	4.711	85	0.00798	9.47
	SP 198	10.653	85	0.01607	20.78
	SP 199	2.285	85	0.00418	5.33
	SP 2	5.559	85	0.00919	7.78
	SP 20	5.026	85	0.00843	14.5
	SP 204	7.767	85	0.01225	8.41
	SP 206	2.377	85	0.00432	4.8
	SP 208	2.406	85	0.00434	6.47
	SP 21	0.702	85	0.00141	3.5
	SP 210	2.45	85	0.0044	8.31

Table 4.2: Characterisation for each delineated subcatchment (cont...)

Zone	Subcatchment	Total Area (ha)	Curve Number	Baseflow (m3/s)	Time of concentration, Tc (minutes)
Sungai Pinang	SP 211	2.453	85	0.00443	15.61
	SP 213	2.463	85	0.00448	6.66
	SP 214	5.034	85	0.00844	12.7
	SP 215	2.479	85	0.00455	7.56
	SP 218	2.49	85	0.00458	11.58
	SP 219	2.507	85	0.00459	30
	SP 22	2.579	85	0.00475	4.18
	SP 222	6.235	85	0.01015	14.94
	SP 224	2.611	85	0.00469	12.27
	SP 226	2.636	85	0.00475	5.07
	SP 229	2.656	85	0.00482	10.45
	SP 23	4.488	85	0.00765	7.88
	SP 231	2.664	85	0.00485	10.05
	SP 232	2.688	85	0.00487	16.51
	SP 233	6.595	85	0.01065	13.35
	SP 234	2.698	85	0.00488	10
	SP 235	7.692	80	0.01215	21.29
	SP 236	2.739	85	0.00493	5.17
	SP 238	2.829	85	0.00494	4.85
	SP 239	9.13	65	0.01408	30
	SP 24	6.909	85	0.01108	8.43
	SP 240	2.87	85	0.00501	15.39
	SP 242	2.883	85	0.00515	8.26
	SP 243	2.903	85	0.00516	9.36
	SP 244	2.917	85	0.00521	14.55
	SP 247	9.871	85	0.01505	31.62
	SP 25	3.324	85	0.00591	12.36
	SP 251	2.988	85	0.00535	15.12
	SP 252	2.999	85	0.00538	20.93
	SP 253	3.042	85	0.00538	15.86
	SP 255	3.064	85	0.00539	12.48
	SP 256	3.072	85	0.00541	24.78
	SP 259	6.241	85	0.01015	32.6
	SP 26	7.515	85	0.01191	10.02
	SP 262	11.723	85	0.01745	10.33
	SP 263	3.271	85	0.00565	14.97
	SP 265	3.278	85	0.00571	14.2
	SP 267	10.35	85	0.01568	8.9
	SP 268	3.324	85	0.00584	14.92
	SP 269	3.375	85	0.00584	10.53
	SP 271	3.388	85	0.0059	10.04

Table 4.2: Characterisation for each delineated subcatchment (cont...)

Zone	Subcatchment	Total Area (ha)	Curve Number	Baseflow (m3/s)	Time of concentration, Tc (minutes)
Sungai Pinang	SP 272	3.408	85	0.00591	6.52
	SP 273	3.41	85	0.00599	6.35
	SP 275	6.893	85	0.01106	24.54
	SP 276	3.435	85	0.00604	12.24
	SP 279	3.475	85	0.00606	28.11
	SP 28	4.112	85	0.0071	7.76
	SP 280	3.484	85	0.00608	17.53
	SP 282	3.6	85	0.00614	27.08
	SP 284	3.674	85	0.00615	35.05
	SP 285	3.674	85	0.00617	22.7
	SP 286	3.68	85	0.00633	42.61
	SP 29	6.797	85	0.01093	19.8
	SP 290	3.767	85	0.00645	12.27
	SP 291	3.814	85	0.0065	15.09
	SP 293	41.088	60	0.05124	26.53
	SP 294	3.897	85	0.00658	7.49
	SP 296	3.947	85	0.00673	27.3
	SP 297	12.785	85	0.0188	19.09
	SP 298	3.957	85	0.00678	16.35
	SP 299	3.96	85	0.00678	8.78
	SP 3	3.997	85	0.00693	9.53
	SP 300	3.96	85	0.00685	8.32
	SP 301	4.044	85	0.00686	29.73
	SP 302	4.046	85	0.00687	18.21
	SP 303	4.072	85	0.00687	5.12
	SP 304	4.084	85	0.00687	13.24
	SP 305	4.117	85	0.007	14.09
	SP 306	4.189	85	0.007	14.61
	SP 308	17.45	65	0.02456	30
	SP 309	4.251	85	0.0071	13.21
	SP 31	3.771	80	0.00659	13.79
	SP 310	4.291	85	0.00721	18.94
	SP 311	4.327	85	0.00721	8.78
	SP 312	4.36	85	0.00722	10.83
	SP 314	4.405	85	0.00736	8.73
	SP 315	4.421	85	0.00741	12.46
	SP 316	4.423	85	0.00746	21.62
	SP 317	4.449	85	0.00749	2.63
	SP 318	4.486	85	0.00753	13.61
	SP 319	4.516	85	0.00755	9.47
	SP 32	2.425	85	0.00451	9.62

Table 4.2: Characterisation for each delineated subcatchment (cont...)

Zone	Subcatchment	Total Area (ha)	Curve Number	Baseflow (m3/s)	Time of concentration, Tc (minutes)
Sungai Pinang	SP 320	4.569	85	0.00755	7.67
	SP 321	4.594	85	0.00759	10.35
	SP 322	4.614	85	0.00765	18.31
	SP 323	4.615	85	0.00769	7.9
	SP 324	4.623	85	0.00777	8.25
	SP 325	4.699	85	0.0078	13.01
	SP 326	4.747	85	0.00783	13.89
	SP 328	92.341	60	0.10272	25.46
	SP 329	4.853	85	0.00796	30.3
	SP 33	3.347	80	0.00595	5.51
	SP 330	4.919	85	0.00803	17.48
	SP 332	5.004	85	0.00811	4.96
	SP 333	5.029	85	0.00818	0.67
	SP 336	5.114	85	0.0084	19.55
	SP 338	5.157	85	0.00846	13.83
	SP 34	2.017	85	0.00385	12.92
	SP 340	5.213	85	0.00856	13.74
	SP 341	5.28	85	0.00861	6.21
	SP 342	5.282	85	0.00862	9.86
	SP 343	20.088	70	0.02771	40
	SP 344	5.312	85	0.0088	11.28
	SP 345	5.349	85	0.0088	3.65
	SP 346	5.361	85	0.00883	15.44
	SP 347	5.379	85	0.00884	17.03
	SP 348	5.428	85	0.00889	9.76
	SP 35	2.285	85	0.00428	7.98
	SP 350	5.537	85	0.00894	16.34
	SP 352	34.347	85	0.00903	10.3
	SP 353	12.351	85	0.01825	50.77
	SP 357	5.889	85	0.00958	15.94
	SP 358	5.995	85	0.00961	24.03
	SP 36	0.918	85	0.00178	4.12
	SP 360	6.092	85	0.00966	16.51
	SP 361	6.113	85	0.00981	11.29
	SP 362	6.134	85	0.00986	30.19
	SP 364	6.192	85	0.00998	19.39
	SP 365	6.226	85	0.01	12.11
	SP 368	6.445	85	0.01013	27.54
	SP 37	3.569	85	0.00628	13.9
	SP 371	6.614	85	0.01044	21.97
	SP 372	6.64	85	0.01062	19.94

Table 4.2: Characterisation for each delineated subcatchment (cont...)

Zone	Subcatchment	Total Area (ha)	Curve Number	Baseflow (m^3/s)	Time of concentration, Tc (minutes)
Sungai Pinang	SP 373	6.692	85	0.01067	15.31
	SP 375	6.763	85	0.01071	27.53
	SP 376	6.776	85	0.01078	35.36
	SP 377	6.809	85	0.01083	10.41
	SP 378	6.83	85	0.01088	11.19
	SP 38	2.297	85	0.0043	2.73
	SP 380	6.928	85	0.01094	20.93
	SP 381	6.944	85	0.01097	6.95
	SP 382	7.005	85	0.011	11.38
	SP 383	7.026	85	0.01111	17.68
	SP 385	7.179	85	0.01121	6.02
	SP 387	7.364	85	0.01125	21.54
	SP 389	7.601	85	0.01145	27.35
	SP 390	87.93	60	0.0985	22.15
	SP 391	7.79	85	0.0117	16.02
	SP 392	7.805	85	0.01177	15.34
	SP 395	8.146	85	0.01228	28.34
	SP 397	8.329	55	0.01244	4.48
	SP 398	25.167	70	0.03363	23.03
	SP 399	8.378	85	0.01278	22.18
	SP 4	0.414	85	0.00457	20.39
	SP 40	2.973	85	0.00537	10.96
	SP 402	8.579	85	0.01303	12.61
	SP 403	8.726	85	0.01308	17.82
	SP 404	8.827	85	0.01322	48.51
	SP 408	9.326	85	0.01385	14.05
	SP 409	9.341	85	0.01414	19.14
	SP 41	2.942	85	0.00532	8.5
	SP 411	10.552	85	0.01436	19.33
	SP 412	10.6	55	0.01562	19.41
	SP 413	10.625	85	0.01594	13.83
	SP 414	10.643	85	0.016	19.77
	SP 415	10.699	85	0.01604	19.38
	SP 416	10.824	85	0.01606	35.18
	SP 417	10.856	85	0.01613	29.98
	SP 419	10.889	85	0.01432	17.65
	SP 420	11.163	85	0.01636	6.82
	SP 421	39.302	60	0.04932	26.53
	SP 422	11.342	85	0.0145	18.56
	SP 423	11.378	85	0.01673	30.18
	SP 424	11.446	85	0.01688	14.63

Table 4.2: Characterisation for each delineated subcatchment (cont…)

Zone	Subcatchment	Total Area (ha)	Curve Number	Baseflow (m^3/s)	Time of concentration, Tc (minutes)
Sungai Pinang	SP 426	12.178	85	0.01701	8.42
	SP 427	12.568	85	0.01798	15.83
	SP 428	12.777	85	0.01803	20.9
	SP 429	38.837	85	0.0102	10.58
	SP 43	13.622	85	0.01985	29.15
	SP 432	14.157	55	0.01986	24.96
	SP 433	14.246	85	0.02007	17.57
	SP 435	14.918	85	0.02063	13.17
	SP 436	14.932	85	0.02081	26.03
	SP 437	15.413	80	0.02146	40
	SP 438	62.368	60	0.07333	18.24
	SP 439	15.976	85	0.02208	15.42
	SP 44	4.515	85	0.00769	5.17
	SP 440	16.241	85	0.02253	26.63
	SP 441	16.354	85	0.02276	17.65
	SP 442	16.661	85	0.02309	17.56
	SP 445	17.566	85	0.02365	61.07
	SP 446	17.689	85	0.0238	11.8
	SP 447	18.078	85	0.0247	16.55
	SP 448	18.304	55	0.02485	20.53
	SP 450	18.661	55	0.02559	15.5
	SP 452	18.847	55	0.02601	14.58
	SP 453	19.199	85	0.02619	13.23
	SP 454	19.683	85	0.02624	40
	SP 456	20.676	85	0.02723	18.46
	SP 457	20.875	85	0.02832	22.97
	SP 458	24.251	85	0.02841	26.39
	SP 459	52.727	85	0.02864	22.57
	SP 46	1.012	85	0.00199	12.29
	SP 460	25.425	85	0.03258	24.93
	SP 461	25.964	85	0.0334	35.12
	SP 462	27.011	85	0.03393	30.73
	SP 465	28.571	75	0.03659	28.84
	SP 467	31.714	85	0.03751	15.44
	SP 468	33.304	85	0.03759	14.41
	SP 469	34.057	85	0.04102	22.89
	SP 47	1.015	85	0.00202	8.33
	SP 471	38.616	55	0.04361	20.04
	SP 472	39.807	85	0.04583	9.88
	SP 473	41.908	55	0.04858	14.29
	SP 475	53.711	55	0.05212	32.36

Table 4.2: Characterisation for each delineated subcatchment (cont...)

Zone	Subcatchment	Total Area (ha)	Curve Number	Baseflow (m^3/s)	Time of concentration, Tc (minutes)
Sungai Pinang	SP 476a	7.218	70	0.16224	25.65
	SP 476b	59.238	60	0.07016	28.87
	SP 477a	36.94	65	0.16224	40
	SP 477b	17.528	65	0.16224	25.65
	SP 478	58.946	85	0.06522	17.32
	SP 479	70.622	85	0.06528	25.18
	SP 481	128.984	65	0.16224	25.65
	SP 482	157.21	55	0.08159	30.56
	SP 483	701.61	55	0.58627	112.05
	SP 485	234.312	65	0.16224	35
	SP 487	604.493	85	0.16224	40
	SP 5	6.613	85	0.01067	21.66
	SP 51	4.782	85	0.00808	28.58
	SP 52	2.151	85	0.00407	12.69
	SP 55	6.854	85	0.01101	11.88
	SP 56	1.085	85	0.00219	14.28
	SP 57	1.09	85	0.0022	8.6
	SP 6	2.635	80	0.00484	7.81
	SP 60	7.272	85	0.01158	21.89
	SP 63	6.804	85	0.01094	20.43
	SP 64	6.693	85	0.01078	10.52
	SP 67	3.438	85	0.00608	9.95
	SP 7	3.665	85	0.00643	12.85
	SP 73	7.441	85	0.01181	10.44
	SP 75	1.17	85	0.00233	3.96
	SP 76	2.612	85	0.00481	5.43
	SP 79	5.636	85	0.0093	19.8
	SP 8	1.707	85	0.00333	4.89
	SP 80	1.214	85	0.00238	3.91
	SP 83	20.048	80	0.02767	21.43
	SP 84	18.1	55	0.02534	17.9
	SP 87	4.536	85	0.00772	9.35
	SP 88	2.666	85	0.00489	14.97
	SP 89	1.271	85	0.00253	5.38
	SP 9	5.328	85	0.00886	13.12
	SP 90	6.857	85	0.01101	12.49
	SP 91	1.287	85	0.00256	6.94
	SP 94	1.331	85	0.00258	5.34
	SP 95	1.338	85	0.00259	6.4
	SP 96	32.599	60	0.04026	26.06
	SP 98	1.36	85	0.00265	6.62

4.7 MODEL CALIBRATION

For calibration of the hydrodynamic model for Sungai Pinang, the 2-D simulation to replicate the 4th November 2017 to 5th November 2017 storm event has been carried out. The 2D simulation allows the overbank flow along all modelled river and drainage alignment into the flood plain represented by digital terrain model in Sungai Pinang basin. Comparison of simulated water level and discharge was made to secondary data acquired from *Laporan Banjir Pulau Pinang Pada 4 & 5 November 2017, JPS Malaysia, 2017* which the calibration of Sungai Pinang model during the same event was deliberately written.

4.7.1 In-stream Calibration

Figure 4.3 is depicted from the *Laporan Banjir Pulau Pinang Pada 4 & 5 November 2017, JPS (2017)* produced by JPS Malaysia. It shows the calibration of the same event for Sungai Pinang model was made to the flood event of 4th to 5th Nov 2017. The blue line is the simulated water level and orange line is the observed water level at Telemetry Water Level Stn. No.: 5403403 Sungai Pinang at Jalan P. Ramlee.

Figure 4.4 is the best simulated flood profile at Telemetry Water Level Stn. No.: 5403403 Sungai Pinang at Jalan P. Ramlee from Sungai Pinang model for this study. There is a good agreement between the simulated result from this study, *Laporan Banjir Pulau Pinang Pada 4 & 5 November 2017, JPS Malaysia, 2017 and observed data.*

Figure 4.5 shows the maximum discharge at the same station from *Laporan Banjir Pulau Pinang pada 4 & 5 November 2017, JPS Malaysia, 2017* while **Figure 4.6** shows the maximum discharge simulated from this study.

For both simulated water level and discharge acquired from this study are having a good agreement with the result from *Laporan Banjir Pulau Pinang Pada 4 & 5 November 2017, JPS Malaysia, 2017,* thus the model will be used in further analysis for this study.

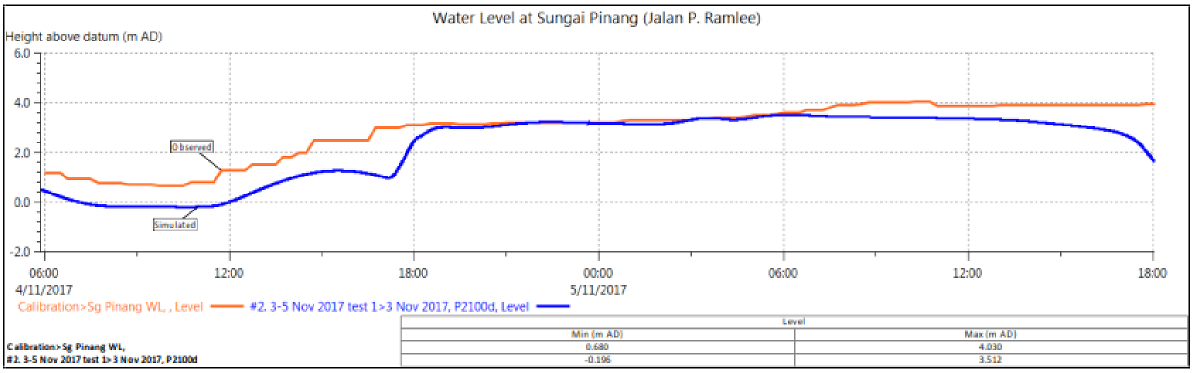


Figure 4.3: Comparison of simulated and observed water level during the flood event of 4th – 5th Nov 2017 by the *Laporan Banjir Pulau Pinang Pada 4 & 5 November 2017, JPS Malaysia, 2017*

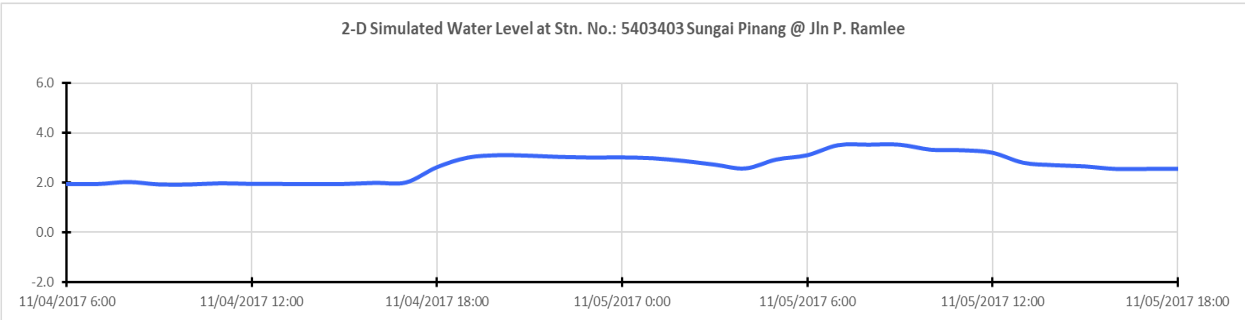


Figure 4.4: Simulated water level from this study at Station Sungai Pinang Jalan P Ramlee from Hydrodynamic Model

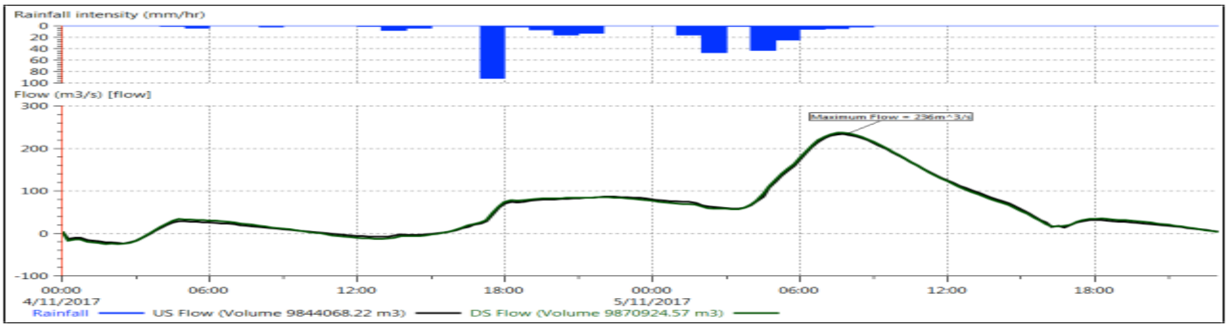


Figure 4.5: Flow at Station Sungai Pinang Jalan P Ramlee
(Source: Laporan Banjir Pulau Pinang pada 4&5 November 2017, JPS (2017))

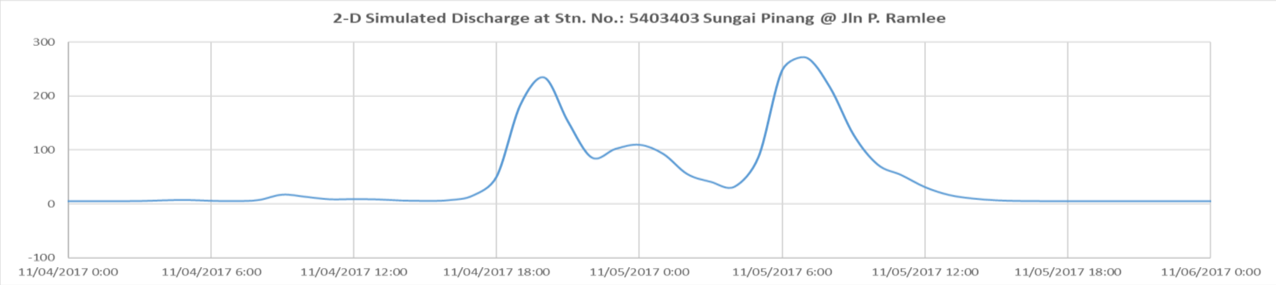
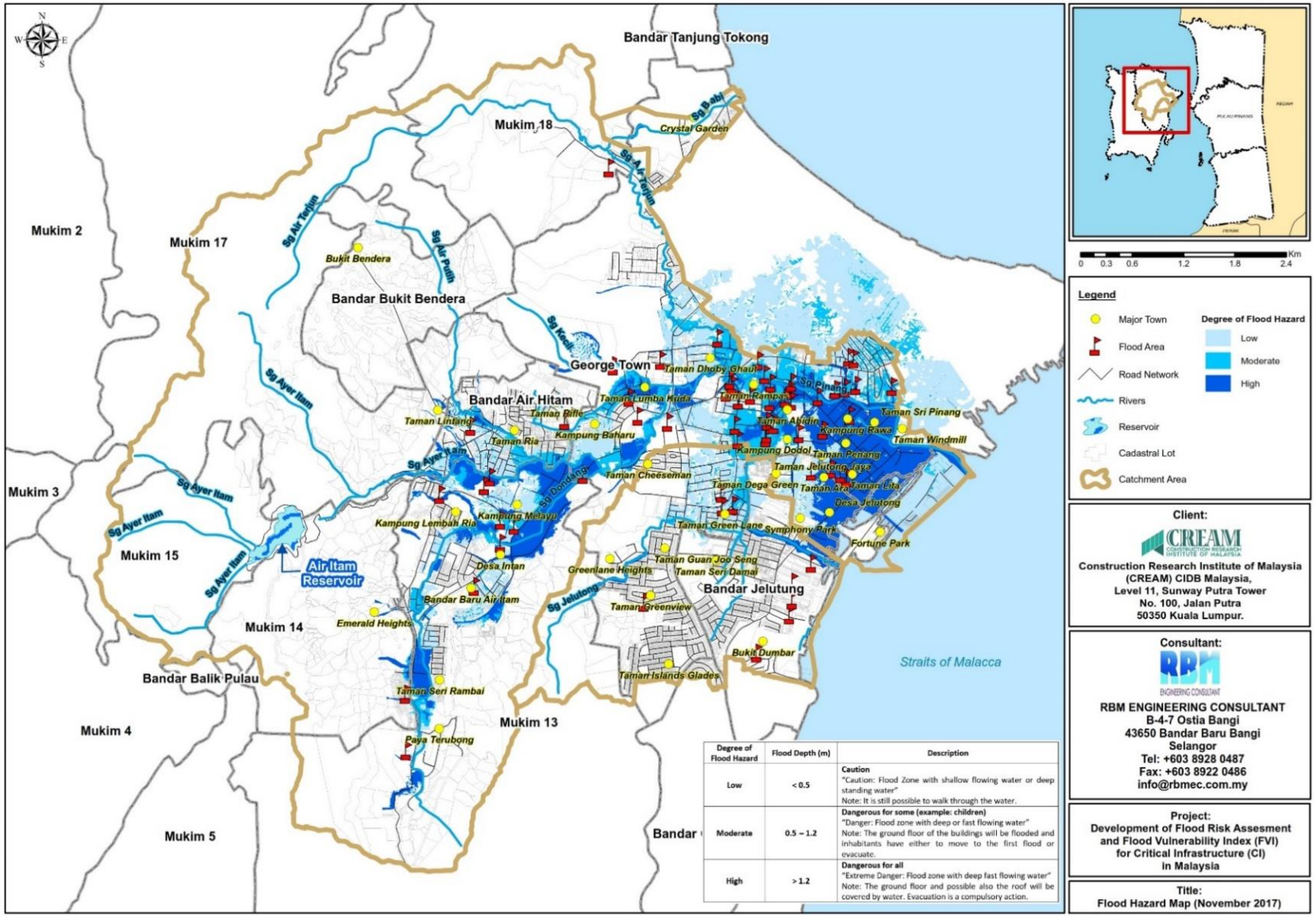


Figure 4.6: Simulated discharge at Station Sungai Pinang Jalan P Ramlee



Degree of Flood Hazard	Flood Depth (m)	Description
Low	< 0.5	**Caution** "Caution: Flood Zone with shallow flowing water or deep standing water" Note: It is still possible to walk through the water.
Moderate	0.5 – 1.2	**Dangerous for some (example: children)** "Danger: Flood zone with deep or fast flowing water" Note: The ground floor of the buildings will be flooded and inhabitants have either to move to the first flood or evacuate.
High	> 1.2	**Dangerous for all** "Extreme Danger: Flood zone with deep fast flowing water" Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

Figure 4.7: Maximum Flood Inundation Maps Prior to Storm Event between 4th to 5th November 2017

4.7.2 Calibration of Flood Inundation Map

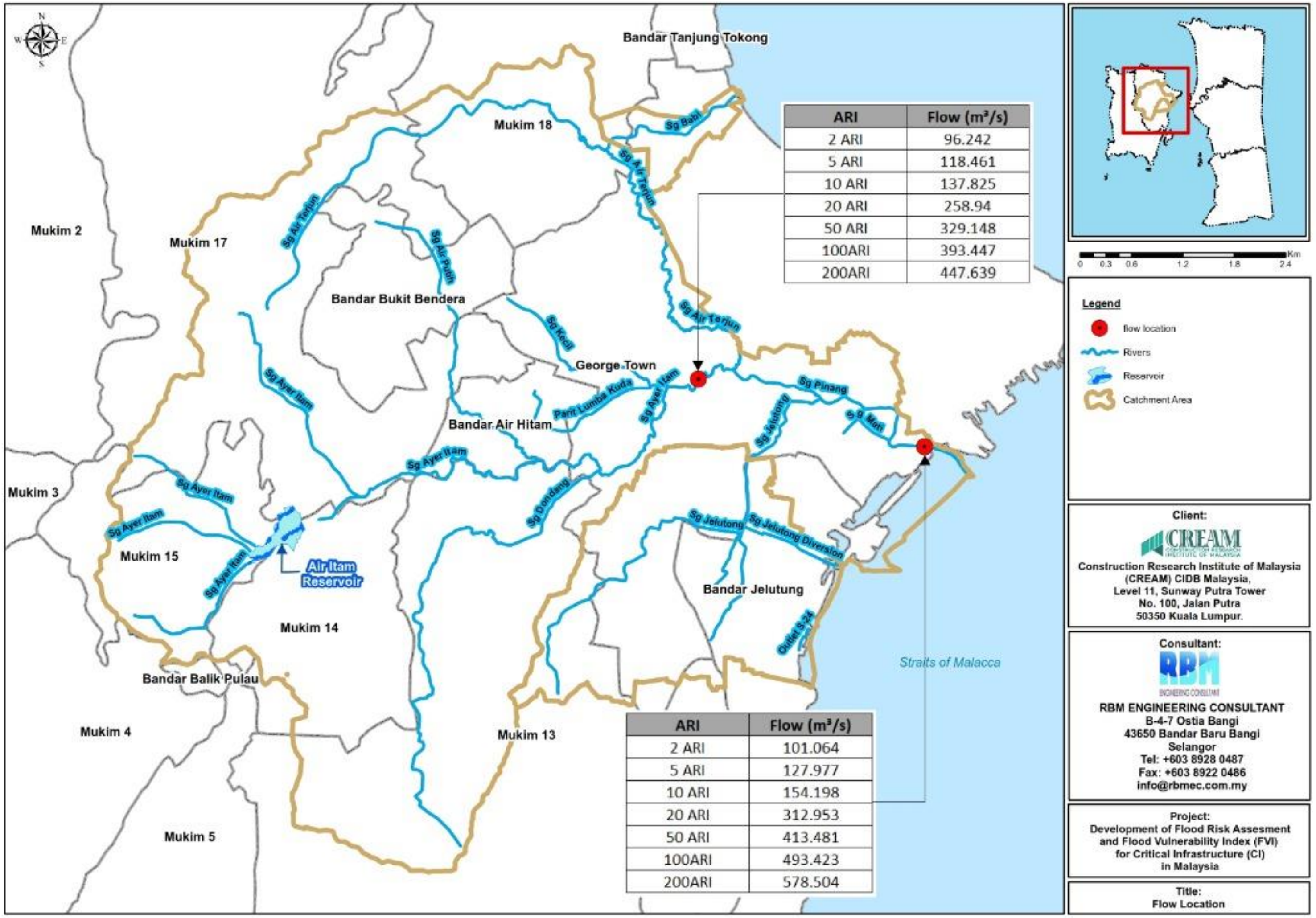
The 2D hydrodynamic simulation will also produce the flood inundation map as shown in **Figure 4.7** above. The inundation shall be calibrated by means to compare the flood depth from the model and observation on site. The flood depth during the flood event at various location has been list in the the *Laporan Banjir Pulau Pinang Pada 4 & 5 November 2017, JPS Malaysia, 2017*. Therefore, the records will be compared to what has been modelled in this study. The result of the comparison is listed in **Table 4.3** below at 13 locations.

Table 4.3: Comparison between Observations data and hydrodynamic model

No	Location	x	y	Flood depth (Observed)	Flood depth (Simulated)
1	Sungai Pinang Georgetown	258708.49	599147.35	0.60	0.5
2	Jalan P.Ramlee	258778.23	598963.69	1.40	1.37
3	Hadapan Sek. Men. Abdullah Munshi	258634.88	598817.45	1.80	1.73
4	Kampung Masjid	258731.34	598612.10	2.18	2.4
5	Masjid Negeri	257473.46	598700.00	0.48	0.32
6	Jalan Langkawi	258246.59	599161.90	1.10	0.91
7	Jalan Terengganu	258267.33	598564.81	0.89	0.61
8	Flat Kampung Rawa	259623.25	598779.94	0.51	0.82
9	Kampung Rawa	259630.23	598795.31	0.48	0.7
10	Jalan Patani	259742.44	599099.33	0.71	0.61
11	Kampung Baru Air Hitam	256726.68	598925.41	0.89	1.09
12	Air Hitam	255705.71	598338.06	1.70	1.2
13	Paya Terubong	254602.63	597139.40	1.00	0.6

4.8 FLOW MAP

Hydrodynamic analysis was a crucial component in developing flood map for Sungai Pinang basin. Hydrodynamic analysis is an essential prerequisite for any project involving the implementation works in river and channel. The output of hydrodynamic model such as, flow, velocity, level and inundation area were used to justify and propose any new water related projects as in flood mitigation and others. From the model, design discharge for various return period for critical storm duration of 3-hours are shown in **Figure 4.8** as for reference.



ARI	Flow (m³/s)
2 ARI	96.242
5 ARI	118.461
10 ARI	137.825
20 ARI	258.94
50 ARI	329.148
100ARI	393.447
200ARI	447.639

ARI	Flow (m³/s)
2 ARI	101.064
5 ARI	127.977
10 ARI	154.198
20 ARI	312.953
50 ARI	413.481
100ARI	493.423
200ARI	578.504

Figure 4.8: Various Return Period Flow Discharge for Sungai Pinang (Critical Storm Duration 3-Hours)

CHAPTER 5

FLOOD HAZARD, FLOOD DAMAGE & FLOOD RISK ANALYSIS

CHAPTER 5

FLOOD HAZARD, FLOOD DAMAGE & FLOOD RISK ANALYSIS

5.1 GENERATION OF FLOOD HAZARD MAPS

The production of flood maps required the combination input from several sources including the results hydraulic model and GIS data input. With the results of the 2D hydraulic analysis, the flood extent and flood depth were calculated directly. The flow of the map generation is as shown in **Figure 5.1** below.

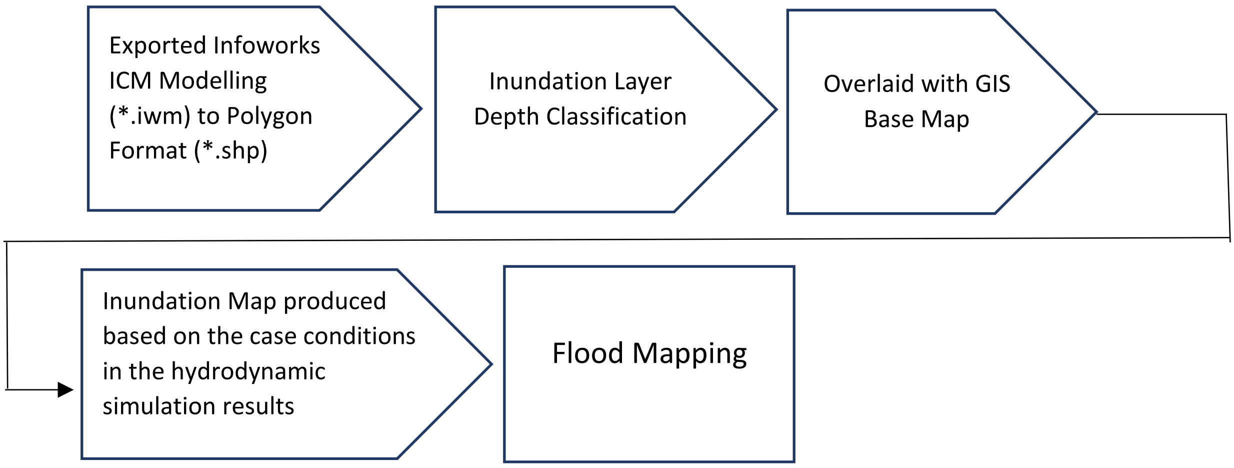


Figure 5.1: Work Flow for Flood Hazard Maps Generation

5.2 FLOOD MAP

All maps should have consistent information (e.g. consistent extents for given event probability) although the content, format and dissemination may differ depending on the purpose and target audience. Flood hazard maps shall be produced based on 2, 5, 10, 20, 50 ,100 and 200-year ARIs at the scale of 1:25,000 for present and future land use conditions as clearly stated in the Scope of Works. The flood hazard maps for the specified ARIs must clearly indicate flood depth and flood extent. The flood depth shall be denoted by the colour scheme as showed in **Table 5.1** below:

Table 5.1: Flood Hazard Map Colour Scheme

Colour	Degree of Flood Hazard	Flood Depth	R	G	B
	Low	0–0.5m	190	232	255
	Moderate	0.5–1.2m	0	197	255
	High	1.2m-2.5m	0	92	230

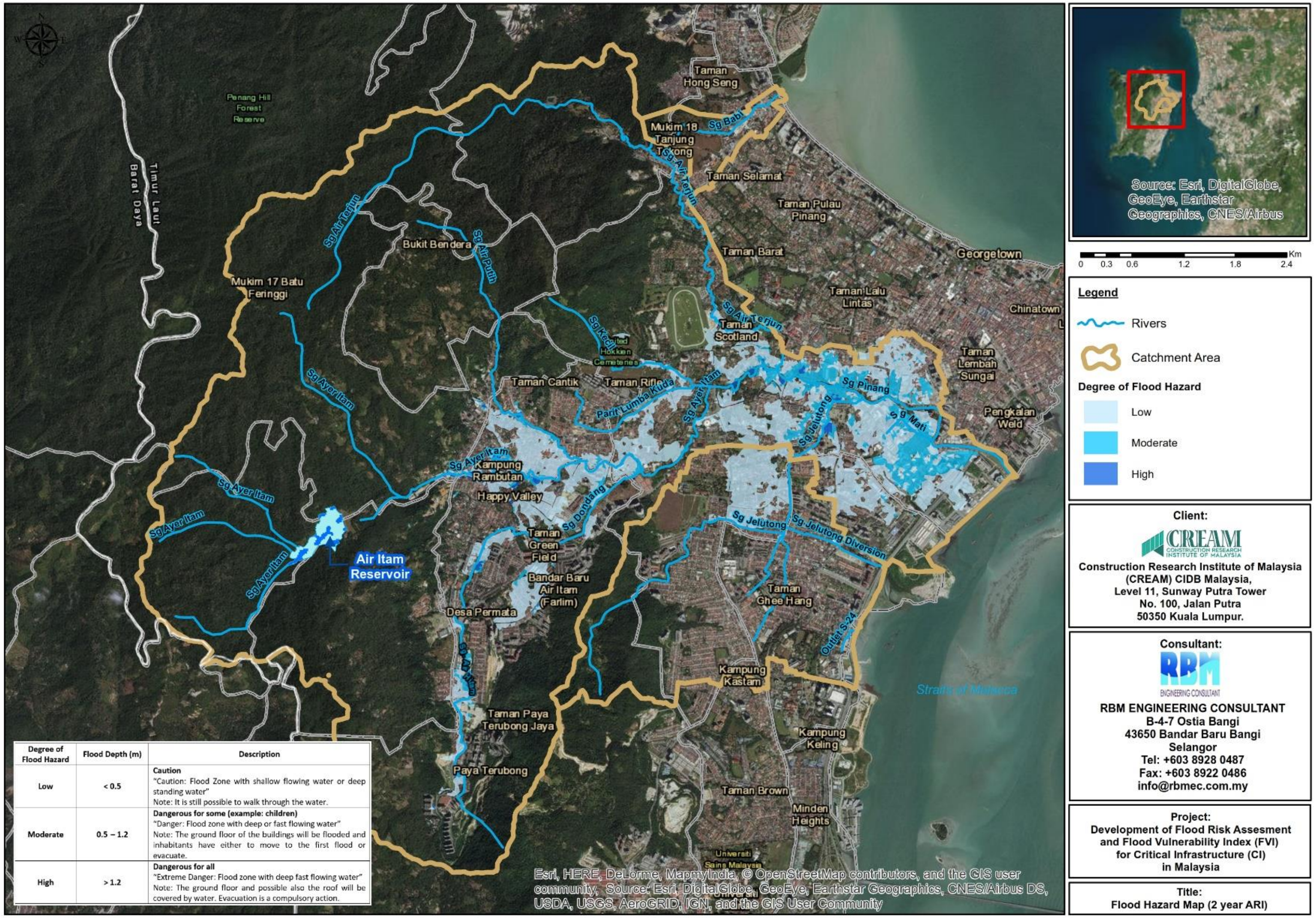
Table 5.2: Description of Flood Hazard Degree

Degree of Flood Hazard	Flood Depth (m)	Description
Low	<0.5	Caution “Caution: Flood zone with shallow flowing water or deep standing water” Note: It is still possible to walk through the water
Moderate	0.5-1.2	Dangerous for some (example: children) “Danger: Flood zone with deep or fast flowing water” Note: The ground floor of the buildings will be flooded, and inhabitants have either to move to the first floor or evacuate.
High	>1.2	Dangerous for all “Extreme Danger: Flood zone with deep fast flowing water” Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

Note: The choice of those depth classes is based on ‘human characteristics’ (Source: DID)

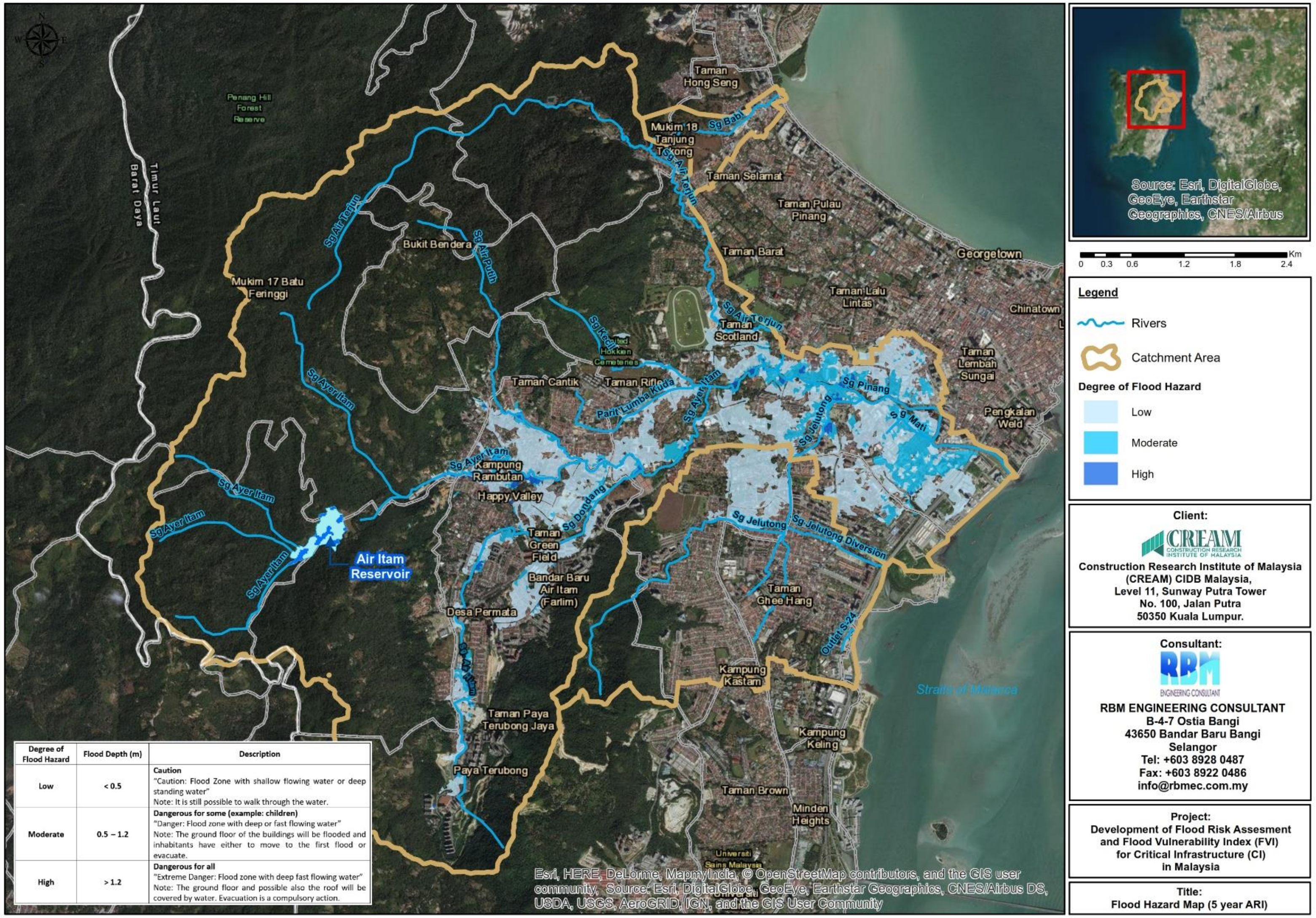
The flood hazard maps area presented in **Figure 5.2** to **Figure 5.8** with the following arrangement:

1. Flood Hazard Map of 2 years ARI Design Flood.
2. Flood Hazard Map of 5 years ARI Design Flood
3. Flood Hazard Map of 10 years ARI Design Flood
4. Flood Hazard Map of 20 Years ARI Design Flood
5. Flood Hazard Map of 50 years ARI Design Flood
6. Flood Hazard Map of 100 years ARI Design Flood
7. Flood Hazard Map of 200 years ARI Design Flood



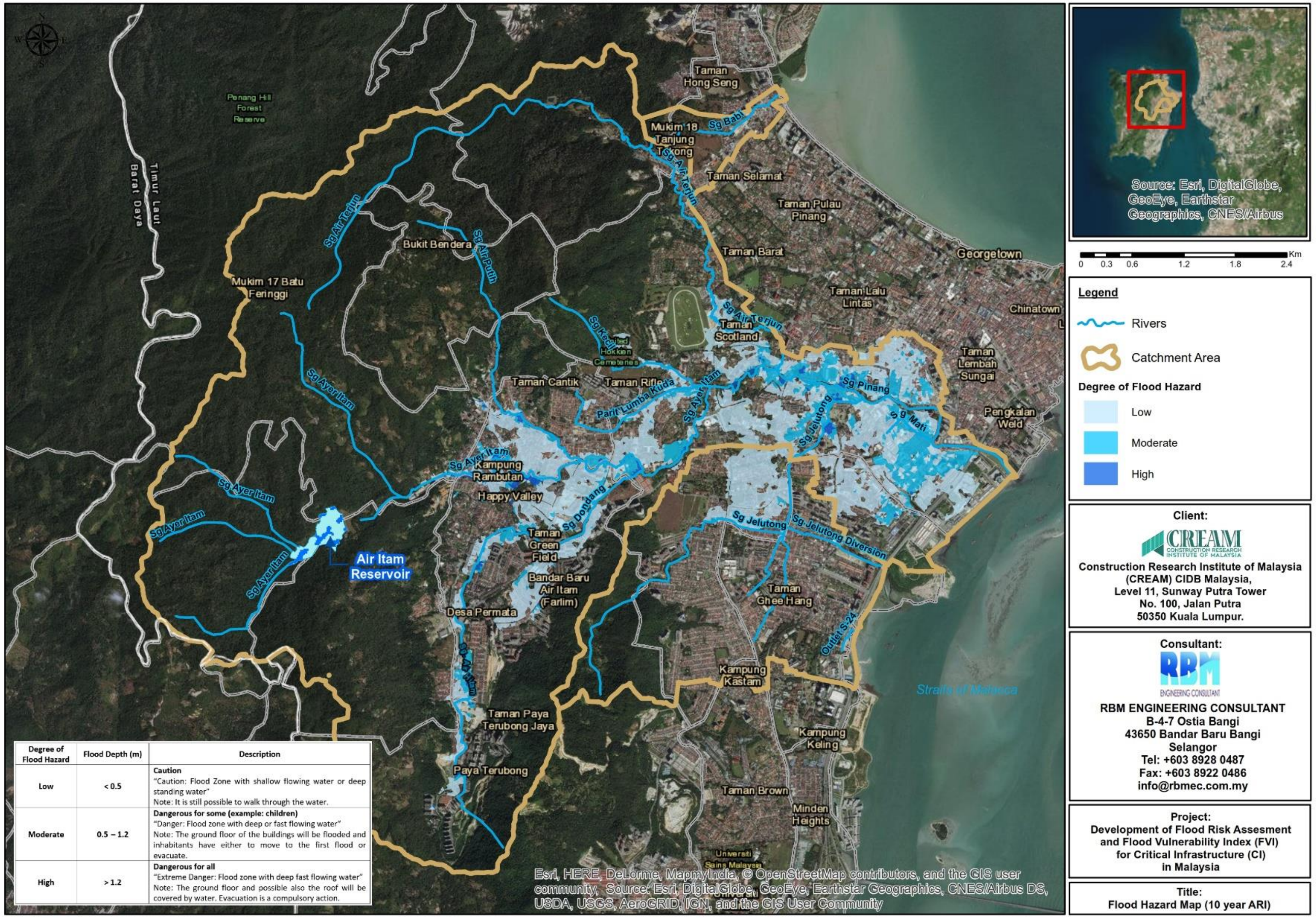
Degree of Flood Hazard	Flood Depth (m)	Description
Low	< 0.5	**Caution** "Caution: Flood Zone with shallow flowing water or deep standing water" Note: It is still possible to walk through the water.
Moderate	0.5 – 1.2	**Dangerous for some (example: children)** "Danger: Flood zone with deep or fast flowing water" Note: The ground floor of the buildings will be flooded and inhabitants have either to move to the first flood or evacuate.
High	> 1.2	**Dangerous for all** "Extreme Danger: Flood zone with deep fast flowing water" Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

Figure 5.2: Flood Hazard Map 2ARI Design Flood



Degree of Flood Hazard	Flood Depth (m)	Description
Low	< 0.5	**Caution** "Caution: Flood Zone with shallow flowing water or deep standing water" Note: It is still possible to walk through the water.
Moderate	0.5 – 1.2	**Dangerous for some (example: children)** "Danger: Flood zone with deep or fast flowing water" Note: The ground floor of the buildings will be flooded and inhabitants have either to move to the first flood or evacuate.
High	> 1.2	**Dangerous for all** "Extreme Danger: Flood zone with deep fast flowing water" Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

Figure 5.3: Flood Hazard Map 5ARI Design Flood



Degree of Flood Hazard	Flood Depth (m)	Description
Low	< 0.5	**Caution** "Caution: Flood Zone with shallow flowing water or deep standing water" Note: It is still possible to walk through the water.
Moderate	0.5 – 1.2	**Dangerous for some (example: children)** "Danger: Flood zone with deep or fast flowing water" Note: The ground floor of the buildings will be flooded and inhabitants have either to move to the first flood or evacuate.
High	> 1.2	**Dangerous for all** "Extreme Danger: Flood zone with deep fast flowing water" Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

Figure 5.4: Flood Hazard Map 10ARI Design Flood

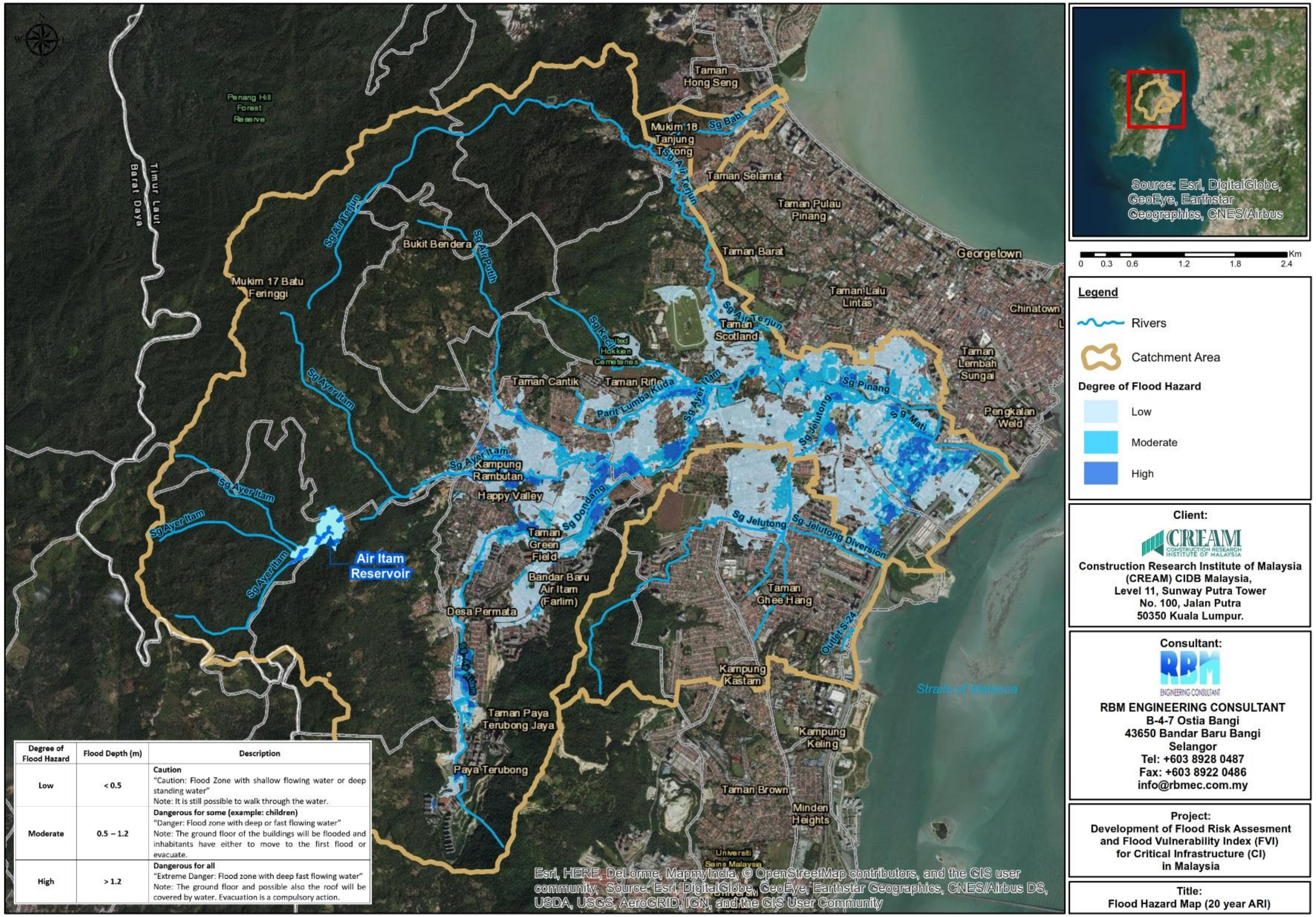


Figure 5.5: Flood Hazard Map 20ARI Design Flood

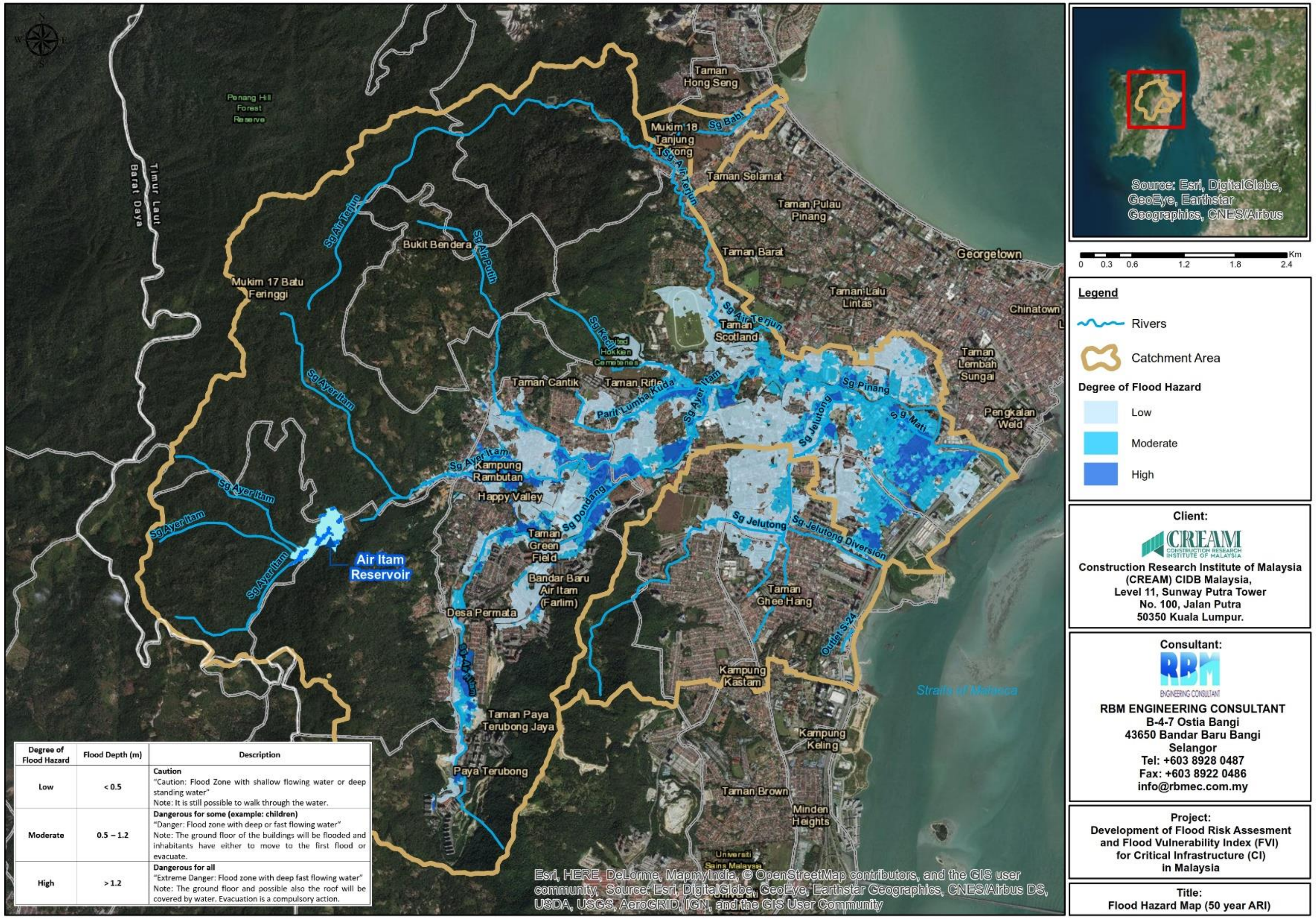


Figure 5.6: Flood Hazard Map 50 ARI Design Flood

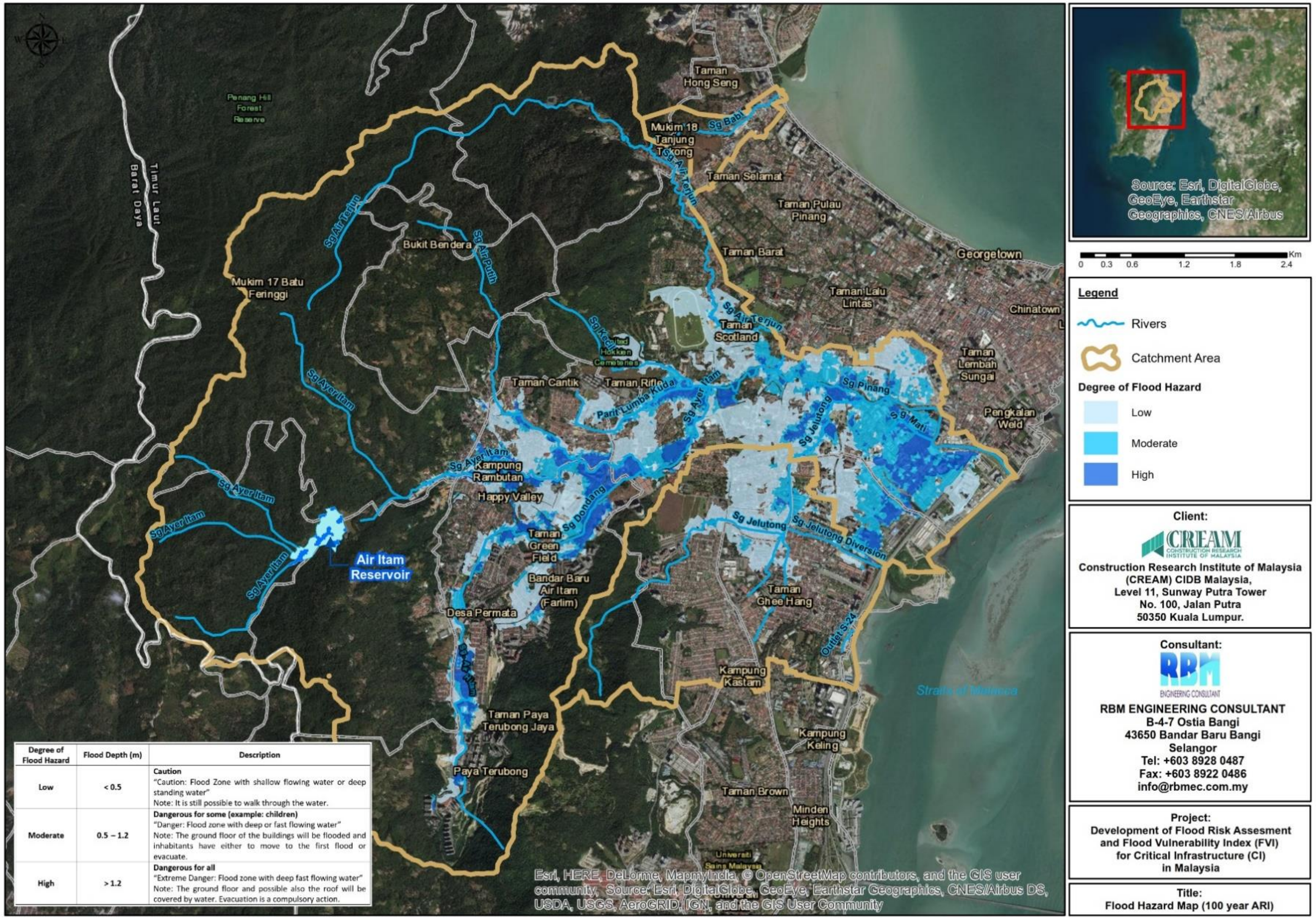
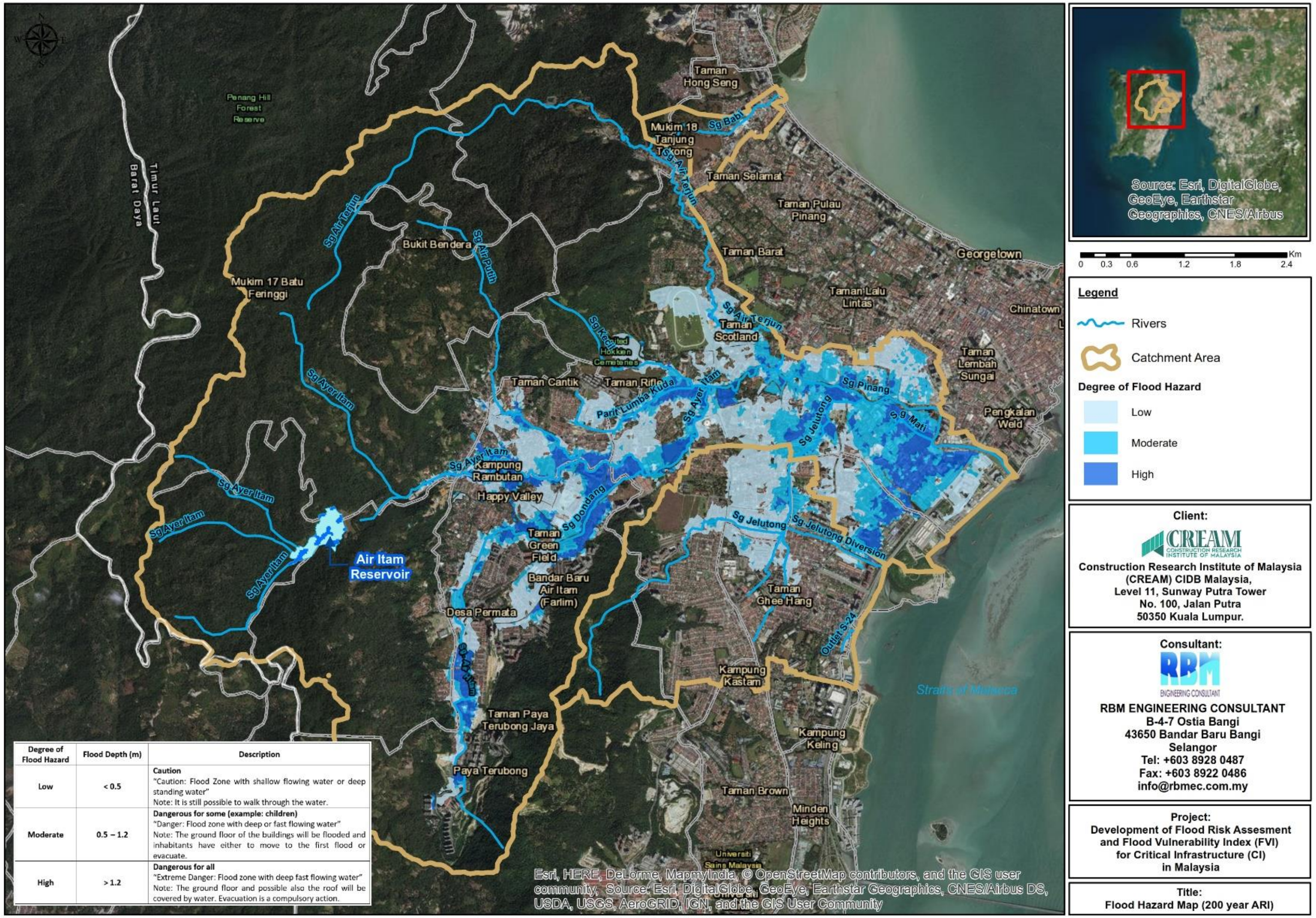


Figure 5.7: Flood Hazard Map 100ARI Design Flood



Degree of Flood Hazard	Flood Depth (m)	Description
Low	< 0.5	**Caution** "Caution: Flood Zone with shallow flowing water or deep standing water" Note: It is still possible to walk through the water.
Moderate	0.5 – 1.2	**Dangerous for some (example: children)** "Danger: Flood zone with deep or fast flowing water" Note: The ground floor of the buildings will be flooded and inhabitants have either to move to the first flood or evacuate.
High	> 1.2	**Dangerous for all** "Extreme Danger: Flood zone with deep fast flowing water" Note: The ground floor and possible also the roof will be covered by water. Evacuation is a compulsory action.

Figure 5.8: Flood Hazard Map 200ARI Design Flood

5.3 FLOOD DAMAGE ASSESMENT

Flood is natural phenomenon occurs in everywhere. Flood damages may affect to urban, residential, industrial, agriculture and other low area. Indeed, flood assessment is an important part for mitigating, controlling and preventing floods problems due to an action. The economic demand for flood control is measured by the different between the expected flood damages before and after flood mitigation measures are installed. Without an assessment, flood may cause damages to properties, loss of life, loss of utility services, loss of trading and others.

When flooding occurs in developing nations, they can effectively wipe out decades of investments in infrastructure and the personal wealth of many of its people, not to mention the countless loss of lives, physical injuries, sickness and psychological trauma that result from the disasters.

5.4 METHODOLOGY

i. A review of the Updating of condition of flooding and flood damage assessment in Malaysia, JPS Malaysia (2012) report was made to understand the methodology used for flood damage estimation an also to extract the pertinent baseline flood damage information.

ii. Literature study of the most relevant documentation on flood damage assessment, review of the latest methodologies and the selection of the most appropriate method were undertaken and implemented.

iii. Site investigations and socio-economic surveys which are related to flooding, socio-economic and land use activities were conducted. Selections of the sites were made based on areas that had experienced floods in recent years, at least in the last three years with basic criterion related to flooding, land use, hierarchy of growth conurbation and the socio-economic level. The main output of this step comes in the form of a compilation of the socio-economic profiles and data of flood damages suffered by the respondents during the flood events at the selected sites. This information was also used as input to form the unit damage values computation which is then adopted for all the flooded areas in Malaysia.

iv. Compilation of the latest available land use data and environmentally sensitive areas for the assessment. The derivation of flood area statistics is based on different types of land use and functions. The land use data and inundation areas are intercepted in order to estimate which parts of the land use are likely to be affected. This information was used as input to the total flood damage estimation for each RBMU catchment. The land use data for the flood damage assessment is classified under two main categories, namely "Structures/Properties" and "Agricultural Industries".

v. Compilation of the latest available socio-economic and demographic data such as the number of people and households affected in the flooded areas. The data is divided into two categories, namely "Urban" and "Rural". This information was used as input for the total flood damage estimation for each RBMU catchment.

vi. Based on the information compiled, data processing, assessment and analyses for flood damage assessment were done for the establishment of the unit damage values for crops production and properties. The computation of flood damage assessment for each RBMU in the country is then updated based on the worst flood event.

5.4.1 Procedure for Estimating the Flood Damage of flood Event in River Basin

i. The flood inundation map associated with the worst flood event is then prepared. The delineation of the flooded areas in the flood map involves judgement, considering the information reported in the JPS Annual Flood Report for the flood event, the peak flood levels recorded at river gauging stations in the RBMU and interpolation of the contours on the flood maps.

ii. The flood map is then overlaid on the latest available land-use map

iii. From the overlaid maps, the flood area statistics due to the worst flood event is then derived. The flood area statistics comprised of 7 classified land-use categories that are flooded.

iv. An estimate of the monetary flood damage due to the flood event can be computed from the latest unit values of properties and agriculture industries for each land use category and appropriate choices of flood damage factors. The flood damage factors are weighting factors used to quantify the severity of flood damages for the various properties and agriculture industries due to the depth and duration of flooding of a flood event.

v. The flood damage for each land-use category is then computed from the information derived in steps iv and v above. The damages can be divided into three categories: structural and properties damage, agriculture industries damage and indirect damages arising from the disruption to economic activities. The total estimated flood damages for the flood event can then be computed.

5.4.2 Land Use Categories

By overlaying the flood inundation area on the digital land use map, the flooded areas for six (6) classified land use categories can be derived. The 12 classified land use categories are as listed below:

1. Residential Area
2. Commercial Area
3. Industrial Area
4. Institutional
5. Infrastructure and Utilities
6. Transportation

Current Landuse based on above six categories for Sungai Pinang Basin are shown in **Figure 5.9**. However, this study is concerned the flood risk analysis will be carried out at along the Sungai Pinang area as shown in **Figure 5.10**

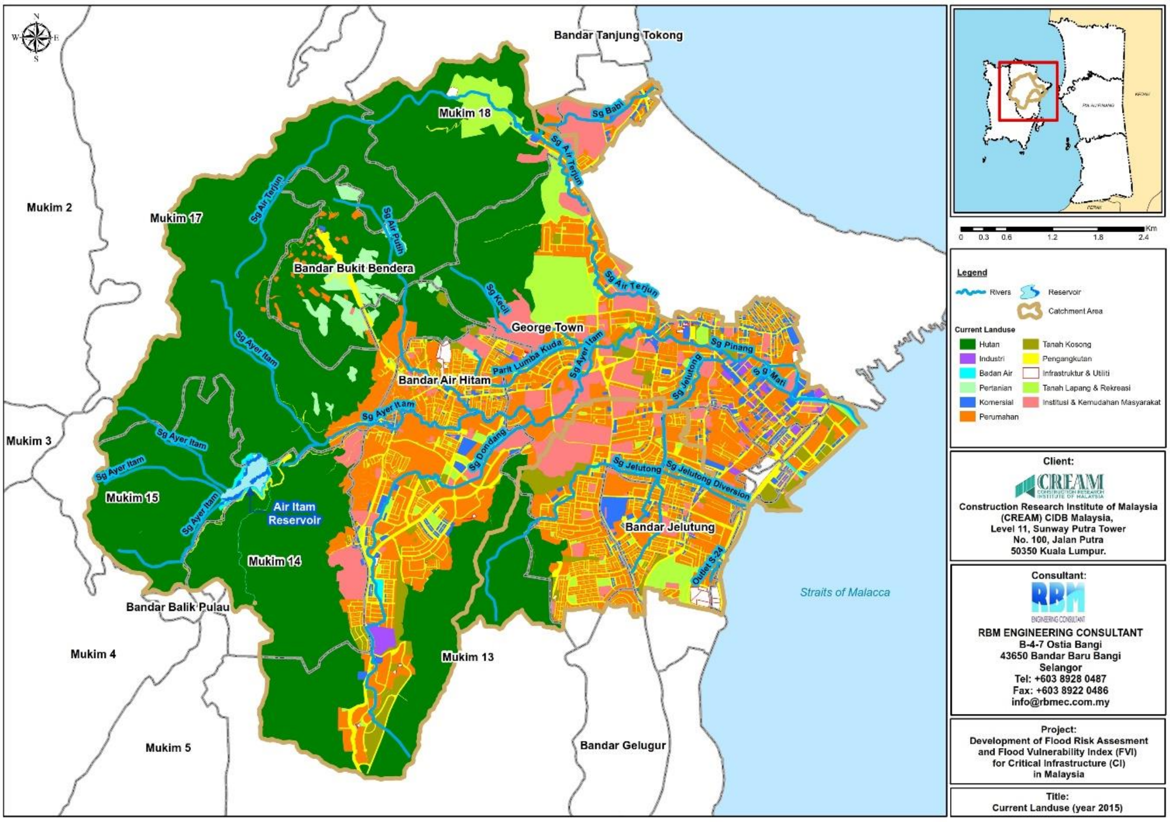


Figure 5.9: Current Landuse for Sungai Pinang basin

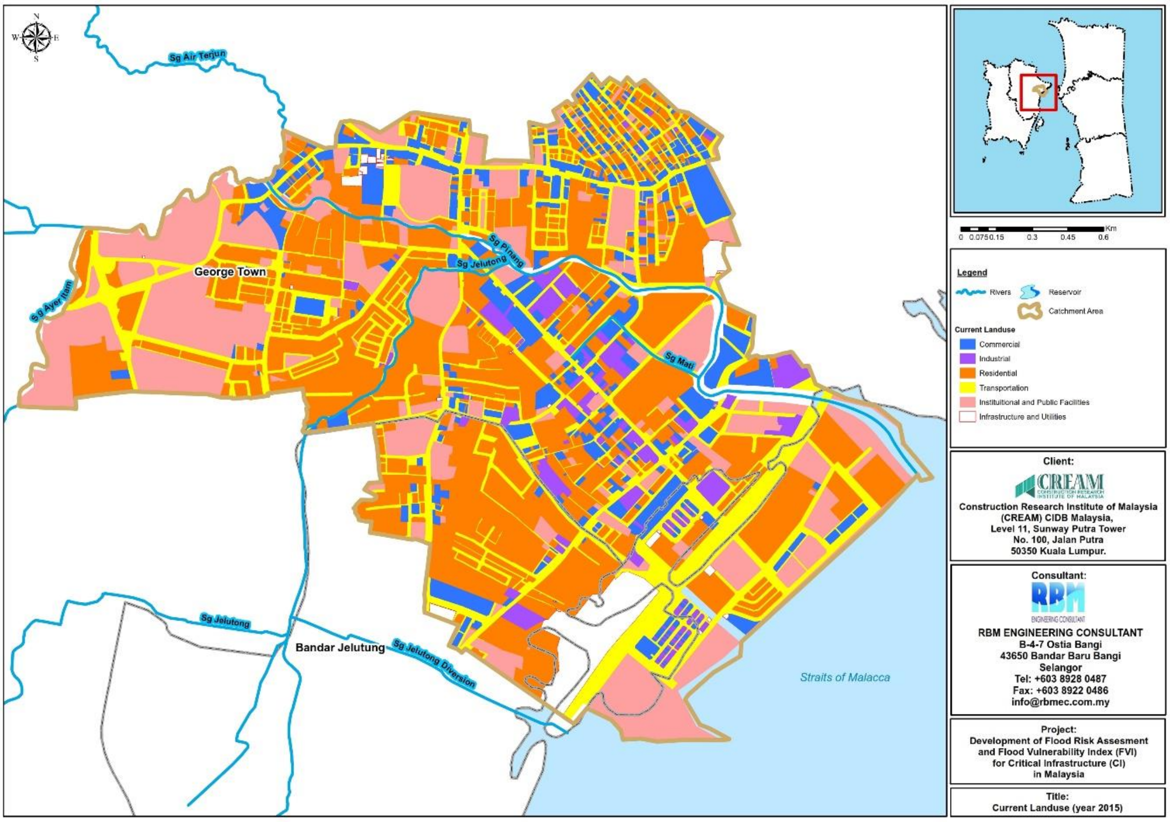


Figure 5.10: Current Landuse in Study area

5.5 UNIT DAMAGE RATE

A. Residential

The flood damage assessment for residential properties is conducted on a per-unit of household basis. Flood damages can be classified into direct and indirect damages. Direct damages are those which occur due to the physical contact of flood water with humans and property. Indirect damages on the other hand are cost consequences induced by the direct impacts of the flood event. Both types of damages can then be further classified into tangible and intangible damages, depending on whether or not they can be assessed in monetary values (e.g. Parker et al., 1987; Smith Nat. Hazards Earth Syst. Sci., 10, 1697– 1724, 2010; and Ward, 1998). Tangible damages are damage to manmade capital or resource flows which can be easily specified in monetary terms, whereas intangible damage is damage to assets which are not traded in a market and are difficult to transfer to monetary values.

Based on Study Updating of Condition of Flooding and Flood Damage Assessment, JPS (2012) the mean damage per unit of residential household in Penang is RM1,757.19. However, to differentiate the total flood damage per unit of both urban and rural households, this value is multiplied by the total damage factor. The total damage factor is a function of:

i. Rural/Urban strata
ii. Flood depth
iii. Flood Duration

B. Unit Damage Rate-Commercial/Industrial

Based on Study Updating of Condition of Flooding and Flood Damage Assessment, JPS (2012), the mean damage values per unit commercial and industrial used for the flood damage computations are RM 3,110.00.

C. Institutional Buildings and Facilities

The unit values for the institutional and public facilities were derived for four different types of building. Based on previous study (JPS,2012) stated that Construction cost for different building types were sourced from Institiut Penilaian Negara (Kajian Kos Binaan Bangunan - 2009/2010). The reference document contains construction costs on a per square metre basis for different types of building and facility over the reported period. These are actual construction costs for institutional buildings and facilities implemented by the Public Works Department.

The building types are:

i. Public building
ii. Education building
iii. Health building
iv. Religious building

The average value and mean damage per square hectare of the built-up area for the building are listed in **Table 5.3**. The average value for a property type was computed by finding the arithmetic mean of different implemented projects by property type. The mean damage is assumed to be approximately 4.5 percent of the average floor value of the properties.

Table 5.3: Mean Value and Damage for Institutional Buildings and Facilities

Type	Average Value/Hectare	Mean Damage/Hectare
Public Building	RM 8,922,000/ha	RM 401,500/ha
Educational Building	RM 6,876,000/ha	RM 309,300/ha
Health Building	RM 9,588,000/ha	RM 431,400/ha
Religious Building	RM 15,558,000/ha	RM 700,100/ha

(Source : Updating of Condition of Flooding and Flood Damage Assessment, JPS (2012))

Therefore, the average mean damage value for Institutional Building and Facilities that has been used in this study for Sungai Pinang is RM 460,575/ha.

D. Infrastructure and Utilities

Statistics on the flood damage values for infrastructure and utilities are very scarce. Establishing unit values therefore have to rely on whatever reliable data there is available such as data for the states of Perlis, Penang, Johor and Pahang for five flood events occurring between 2003 to 2010.

Table 5.4 provides available data that can be considered reliable for five flood events occurring between 2003 to 2010.

Table 5.4: Damage to Infrastructure/Utilities

	Year	Infrastructure/Utilities Damage (RM)	Area (ha)
Perlis	2005	12,421,739	65.0
Perlis	2010	107,330,000	65.0
Penang	2003	11,414,290	256.3
Johor	2007	3,119,286,431	730.1
Pahang	2009	37,192,170	14.5

(Source: Updating of Condition of Flooding and Flood Damage Assessment, JPS (2012))

Therefore, mean damage value for Infrastructure/Utilities for this study is RM 44,534.88/ha.

E. Transportation

Flood damage statistics were obtained from various JKR's offices across the country for a fairly large sample (178) of flood events that caused damage to the transportation network and infrastructure.

Based on Study Updating of Condition of Flooding and Flood Damage Assessment, JPS (2012), off the road infrastructure that was inundated by floods, result of the analysis found that 49.5% of inundated infrastructure suffered some kind of damages to pavements, bridges, road furniture, drains and slopes. The estimated mean damage per km run is RM 428,550.44. This value of mean damage for transportation based on the whole Malaysia.

5.6 DAMAGE FACTOR

A. Damage Factor for Structures and Properties

Damage factor refers to the adjustment to be made on the base damage value to take into account the fact that the magnitude of damage per unit is a function of the severity and duration of flood, as well as the value of structures and properties that vary by location.

Further analysis using the multiple regression technique reveals that the magnitude of damage to residential, commercial, industrial and institutional properties is also a function of:

i. Rural/Urban strata
ii. Flood depth
iii. Flood duration

The mean damages and functions for residential, commercial, industrial and institutional are based on data obtained from the flood damage survey and from relevant agencies. The mean values are given in **Table 5.5** and **Table 5.6**.

Table 5.5: Mean Values for Residential, Commercial and Industrial

	Type of Building		
	Residential Households	Commercial	Industrial
Mean Damage (RM/unit)	3,274.00	3,967.00	9,433.00
Mean Strata Value	0.25*	-	-
Mean Depth (m)	0.93	0.76	0.76
Mean Duration (Day)	2.83	2.45	2.45

*Note: *Strata Value: Urban =1 and Rural = 0*

Table 5.6: Mean Values for Institutional

	Type of Building			
	Public Building	Educational Building	Health Building	Religious Building
Mean Damage (RM/ha)	401,500.00	309,300.00	431,400.00	700,100.00
Mean Depth (m)	0.76	0.76	0.76	0.76
Mean Duration (Day)	2.45	2.45	2.45	2.45

Hence, the total flood damage factors of the structures and properties are computed as follows:

i. Residential Household

Total Damage Factor = ((Depth in metre – Mean Depth) X 0.32)) + ((Duration in days – Mean Duration) X 0.08)) + ((Strata Value – Mean Strata) X 0.33)) + 1

ii. Commercial and Industrial Unit

Total Damage Factor = ((Depth in metre – Mean Depth) X 0.06)) + ((Duration in days – Mean Duration) X 0.15)) + 1

iii. Institutional Building

Total Damage Factor = ((Depth in metre – Mean Depth) X 0.32)) + ((Duration in days – Mean Duration) X 0.08)) + 1

B. Infrastructure, Utilities and Transportation

Unlike residential units and commercial establishments, data on flood damage for infrastructure, utilities, institutions and transportation network is lacking. It is therefore not possible to use regression technique to simultaneously estimate the impact of flood depth and duration on damage. It can however be argued that the damage factor that can be applied to infrastructure, utilities, institutions and transportation network should be fairly similar to that of the commercial establishment. This assumption does not of course say that the absolute value of damage is similar to both types of properties, since they are not obviously the same. What it says is that the two types of properties should share similar damage factor.

Notice that the disruption to the provision of services obtainable from infrastructure, utilities, institutions and transportation networks are in principal similar to the disruption to production/services produced by commercial following a flood event. In the absence of sufficient data for analysis, this study adopts the damage factor for commercial establishment to be applied to infrastructure, utilities, institutions and transportation networks. The damage factor is to be computed as follows:

Total Damage Factor = ((Depth in metre – Mean Depth) X 0.32)) + ((Duration in days – Mean Duration) X 0.08))

The mean depth and duration are 0.76m and 2.45 days respectively.

5.7 FLOOD RISK ANALYSIS

According to (Leonard Shabman, 2014), flood risk is the likelihood (or often referred to as probability of occurrence) and the adverse consequences of flooding. Flood risk for assets and people at any location in a floodplain is a function of flood hazard at that location and their exposure and vulnerability to the flood hazard see an illustration as **Figure 5.11** below.

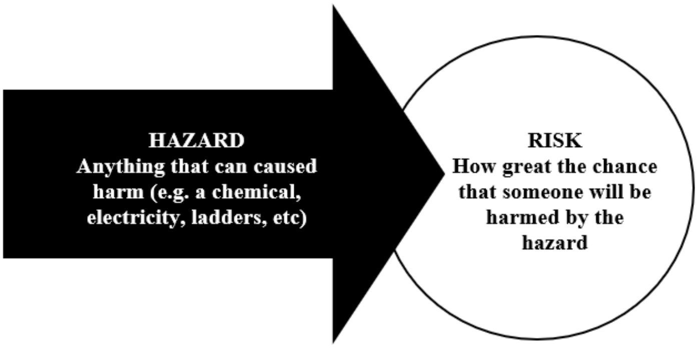


Figure 5.11: Hazard and Risk relationship

Flood risk is a measure of the statistical probability of flooding combined with the adverse consequences of the flooding. The practical determination of future flood risk is made up of four major components (DRB HICOM, 2017):

a) the probability of flooding;
b) the exposure of the receptors-at-risk to different flood characteristics;
c) the value of receptors-at-risk; and;
d) the vulnerability of these receptors-at-risk.

(Sabri, Ratnarajah, Adnan, Wan Hazdy Azad, & Mohd Fisham, 2018) described Flood Risk Assessment to determine the flood risk index is based on flood damage. Flood damage refers to all varieties of harm caused by flooding. It encompasses a wide range of harmful effects on humans, their health and their belongings, on public infrastructure, cultural heritage, ecological system, industrial production and the competitive strength of the affected economy. Although the terminology differs occasionally, flood damages are mostly categorized firstly in direct and indirect damages and, secondly, in tangible and intangible damages.

(Sabri, Ratnarajah, Adnan, Wan Hazdy Azad, & Mohd Fisham, 2018) suggested the formulae and methodology for carry out the flood risk assessment as follows: -

$$R = \sum_{i=1}^{n} \frac{1}{i} D_i$$

Where,

R = Flood Risk

i = Return Period (2yr, 5yr, 10yr, 20yr, 50yr,100yr, 200yr ARIs)

D_i = Damage for Return Period *i*

Operating the formulae requires the implementation of a 3-step procedure as illustrated in **Figure 5.12** in order to produce the flood risk value.

Step 1: Determine the *unit damage rates* for a range of return periods.

Step 2: For each return period, multiply the corresponding *unit damage rates* with the relevant *damage factors* to produce the *estimated flood damage*.

- *The applicable factors are flood depth, duration and strata (urban and rural).*

Step 3: Multiply the *estimated flood damage* for each return period with the probability of occurrence to compote the flood risk index.

- *The probability of occurrence is, of course, equal to 1/Return Period. For each return period, multiply the probability with the corresponding estimated flood damage.*

The *Unit Damage Rates* will be referred from study carried out by JPS Malaysia, December 2012[1]

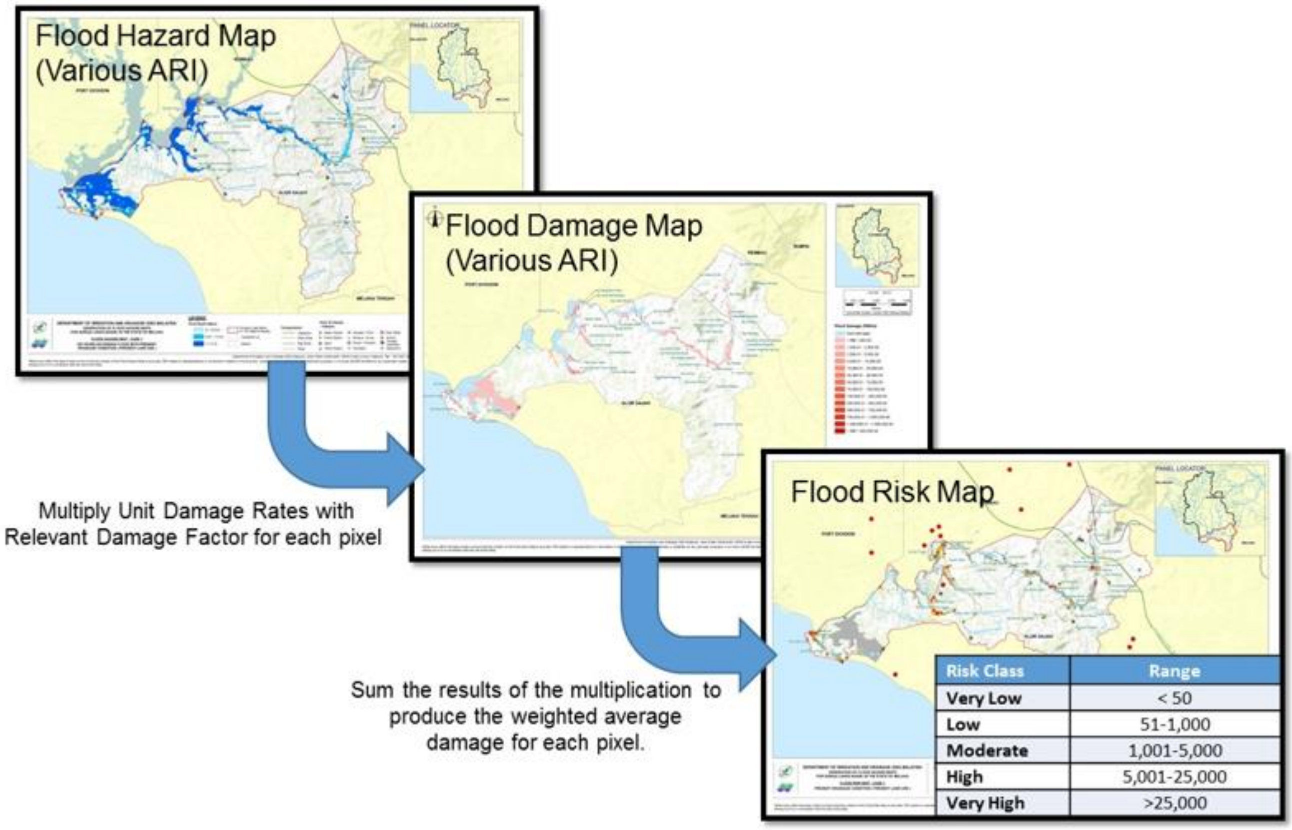


Figure 5.12: Procedure for Generating Flood Risk Index and Producing Map

5.7.1 Production of Flood Risk Maps

Probability of occurrence for a flood event is the reciprocal of its return period. The various return periods will be converted into probabilities as shown in **Table 5.7** below.

Table 5.7: Return Period vs Probability

Return Period	Probability
2	0.5
5	0.2
10	0.1
20	0.05
50	0.025
100	0.001

[1] Updating of Condition of Flooding and Flood Damage Assessment in Malaysia, JPS Malaysia, December 2012

The production of flood maps requires combination input from several sources including the results hydraulics model and GIS data input. With the results of the 2D hydraulic analysis, the flood extent and flood depth will be calculated directly. Processing and producing flood hazard maps using GIS software requires combination input from several essential sources including the results of hydrodynamic models, Digital Elevation Model (DEM) and GIS base maps. The flow of the map generation is as shown in **Figure 5.13** below.

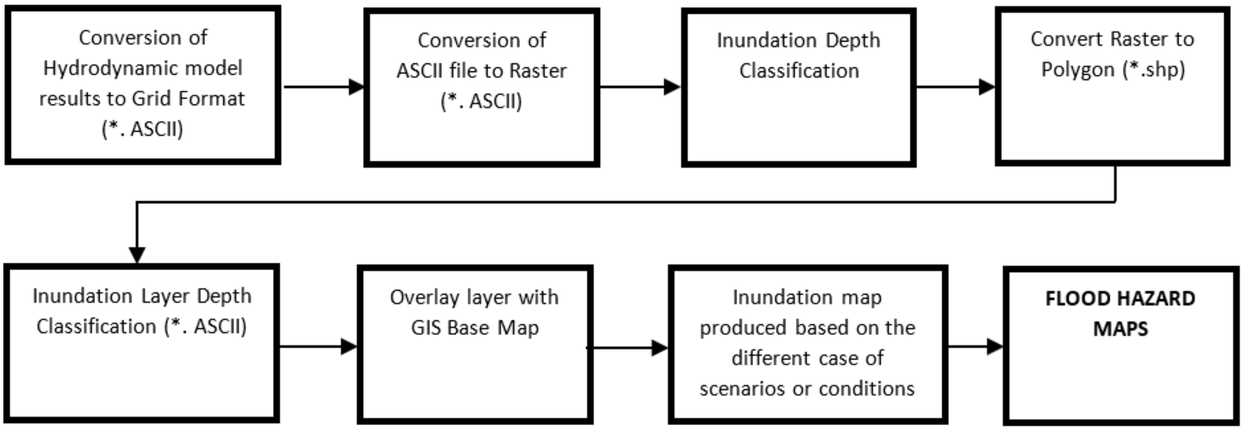


Figure 5.13: Work Flow for Flood Maps Generation

The computation and mapping of flood risk involves six (6) steps as illustrated as **Figure 5.14**. For each flooded pixel (location) that we set to 100m x 100m or 1 hectare per pixel, the following computational steps can be adopted in order to produce the flood risk map (DRB HICOM, 2017):

Step 1: Determine the unit damage rates for each pixel for a range of return periods

↓

Step 2: For each return period, multiply the corresponding unit damage rates with the relevant damage factors to produce the estimated flood damage for the pixel

↓

Step 3: Multiply the estimated flood damage for each return period with the probability of occurrence

↓

Step 4: Sum the results of the multiplication in Step 3 to produce the weighted average damage for each pixel

↓

Step 5: Classify the estimated damage into several flood risk classes

↓

Step 6: Colour-code the classes to produce the flood risk map

Figure 5.14: Computational Steps for Flood Risk Map Production

The flood risk maps for the specified ARIs must clearly indicate flood risk zone, flood extent, location of flood evacuation centres, major towns, transportation network and points of interest. The flood risk zone shall be denoted by the colour scheme as shown in **Table 5.8** below:

Table 5.8: Flood Risk Map Colour Scheme

Colour	Flood Risk Class	Range	Colour Name	R	G	B
	Very Low Risk	< 50	Grey	178	178	178
	Low Risk	51–1,000	Sky Blue	135	206	235
	Medium Risk	1,001–5,000	Yellow Green	154	205	50
	High Risk	5,001–25,000	Orange	255	170	0
	Very High Risk	> 25,000	Red	225	0	0

The categorization of flood risk values into five risk classes requires end values (range) to be determined from a large set of data points (pixels of weighted average damage). In order to ensure that the range for all risk classes is valid, the set of data points must not only represent a variety of return periods, but also derived from river basins that cover all land uses. This is especially pertinent since the end values obtained in this Study will be used as a basis for classification of flood risk for the entire country. The end values (range) must be determined using a rich enough data set that covers all land uses of interest. **Figure 5.15** shown the result of flood risk analysis in study area and **Table 5.9** shown the summary of flood risk analysis.

Table 5.9: Summary flood risk analysis

Degree of Flood Risk	Area		No of Lot	Location
	ha	ac		
Very Low Risk	48.472	119.777	756	The Summer Place, The Spring Condominium, Fortune Park, Symphony Park, Taman Windmill,
Low Risk	37.792	93.386	594	The Ocean View, Desa Jelutong, Taman Jelutong Jaya, Taman Dega Green,
Medium Risk	201.976	499.093	3495	The Jelutong Sewage Treatment Plan, Taman Lita, Taman Ara, Taman Penang, Taman Sri Pinang, Kampung Rawa, Sunshine City, Georgetown, Kampung Makam, Kampung Dodol, Taman Free School, Taman Kampar, Taman Wangi, Irama Villa Apartment, Rapid Penang HQ, Taman Sri Husin, Taman P Ramlee, Taman Rampas
High Risk	8.514	21.039	95	Pos Malaysia Dato Keramat
Very High Risk	80.085	197.894	96	Taman Abidin, Taman Jeliemas, SMK Abdullah Munshi, City Stadium Penang, Penjara Pulau Pinang, SMK Perempuan Sri Mutiara, Han Chiang Independent High School, SMKA Al Mashoor, Han Chiang University Collage of Communication, Padang Brown, SMK (L) Methodist, APM Pulau Pinang.

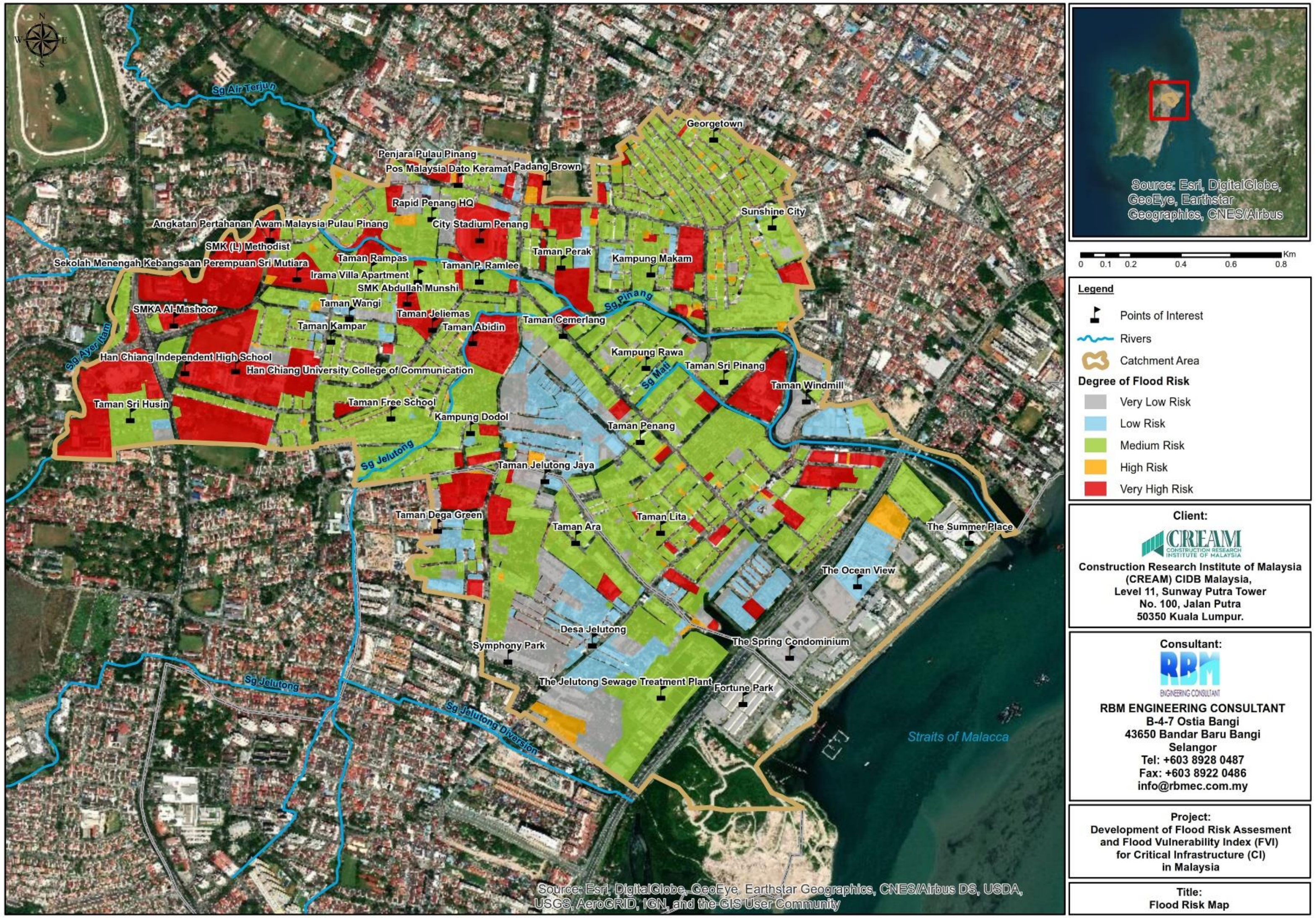


Figure 5.15: Flood Risk Analysis

CHAPTER 6

FOCUS GROUP DISCUSSIONS

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FOCUS GROUP DISCUSSIONS

6.1 FLOOD RISK ASSESSMENT AND VULNERABILITY INDEX

In line with the study, the consultant has completed a Focus Group Discussions (FGD) participated by relevant governmental agencies as part of the stakeholders. The agencies included:

Respondent 1: SPAN
Respondent 2: MBPP (Planning)
Respondent 3: MBPP
Respondent 4: PDRM SPU
Respondent 5: MBPP (Engineering)
Respondent 6: MBPP (Services)
Respondent 7: IWK
Respondent 8: MBPP (Planning)
Respondent 9: IWK

The purpose of the FGD is to capture the SOP implementation of these agencies before and during the flood and to invoke their opinion on assessing the risk and vulnerability of Sg Pinang in flood situations. Specifically, it is to relate issues brought about by flood management and monitoring to the river's risk of flooding and its vulnerability to flooding. Data and information are analyzed using transcribing techniques through keyword components of the discussions. The main component of flood management is the identification of issues and problems that would have arisen before, during and after the flood. It is necessary for these issues to be dealt with to reduce the risk and vulnerability of the river to future flooding.

The output of the FGD is revealed in a simplified matrix (**Table 6.1**) showing the issues of flood management before, during and after the flood. In addition to that, a score of Expected

Impact of each issue/problem is measured based on the severity of the issues as revealed by the data and information gathered during the study.

6.2 ISSUES AND PROBLEMS OF FLOOD MANAGEMENT

6.2.1 Pre – flood Preparation

Flood Information

According to the FGD, the relevant agencies are normally responsible to gather and disperse crucial information to the relevant authorities and citizens, especially to those in the affected flooding areas.

Respondent 1 stated that, "*…kami akan balas surat seperti musim tengkujuh kepada semua operator air untuk menghantar kepada pihak kontigensi, jadi pihak operator air ini akan mengklasifikasikan semua pegawai yang terlibat bila berlaku banjir dan menjalankan penyelenggaraan secara terbaik."*

This is especially important to manage the flooding situation even before it started. In addition to that, it is also informed that there is an MOU between the neighboring states to extend flood aids to cross borders during the crisis. **Respondent 1** again stated that, "*Selepas banjir besar pada 2014, kami telah menandatangani satu MOU dengan semua operator apabila berlaku banjir dimana semua negeri-negeri ini akan bantu negeri yang terlibat dengan banjir ini".*

Flood Monitoring

The process of monitoring vulnerable flooding areas are also parts of the flood management activities. **Respondent 8** iterated that, his department is responsible to identify and monitor areas vulnerable to flooding constantly using software applications such as ARCGIS. He stated that, "*Bahagian Perancangan peringkat sebelum banjir banyak terlibat dengan penyediaan ARCGIS berbanding dengan perancangan pembangunan secara terperinci."*

On another note, **Respondent 2** also mentioned that his department is on constant monitoring of on-going development projects to curb flooding. In his statement, "*Penyediaan sebelum banjir bagi mengelakkan berlaku banjir. Bagi bidang tugasan saya lebih kepada membuat pemantauan ke atas projek-projek pemajuan yang sedang dijalankan seperti mana yang diketahui pembangunan di sekitar Sungai Pinang dan Jelutong tengah rancak…"*

It is crucial to monitor existing projects since they might contribute to the flooding. **Respondent 2** continued that, "*… beberapa tapak pemajuan adakalanya menyumbang banjir di kawasan setempat, …sebelum kerja pembangunan dijalankan pihak MBPP akan meminta pihak pemaju supaya untuk menyediakan parit tanah dan juga longkang-longkang atau kawasan tadahan air bagi mengelakkan banjir bila berlakunya hujan lebat, air dari tapak pemajuan akan melimpah keluar. Ini salah satu langkah yang kami ambil bagi tapak pemajuan."*

Flood Resistance

Some agencies are concerned with ways and methods to resist flooding effects by utilizing current approaches and practices within the development realm. In order to resist and reduce flooding occurrences, it is important to plan effectively, spatially. As explained by **Respondent 8** that there is an on-going effort to link recreational activities to the river to reduce flooding threats. He iterated that," *…kami mendapati beberapa idea (masih dalam perancangan) untuk menghubungkan antara koridor biru dan koridor hijau maksudnya menghubungkan kawasan rekreasi dengan sungai ini dengan pelbagai aktiviti. Mungkin kalau ada ruang untuk nak eksploitasi koridor biru ini iaitu sungai-sungai ini untuk kegunaan kerana sekarang ini masih kurang penggunaan sungai ini."*

Another approach is to integrate flood mitigation projects with sustainable (recreational) development, although it is still at an infancy stage. **Respondent 8** again clearly mentioned that, "…*kami ingin mengintegrasikan antara projek-projek tebatan banjir ini sekali dengan sungai yang dirancangkan itu tetapi masih belum kelihatan mana-mana tindakan masih di peringkat awal."*

The use of appropriate construction materials would contribute to the flood resistance efforts as well. As stated by **Respondent 8**, buildings in flood prone areas should also be equipped with resistant building materials as alternatives to assessing cost of damages to the buildings. According to **Respondent 8**, "*Dalam RFN 3 ini, diwujudkan satu garis panduan supaya sesuatu kawasan dapat bertahan dengan sesuatu bencana apabila bencana terjadi. Jadi antara benda yang dilihat ialah jika sesuatu pembangunan itu tidak boleh menyelesaikan masalah banjir, maksudnya bangunan tersebut mestilah kebal daripada banjir. Maksudnya, pembangunan tidak dapat dikurangkan, jadi perancangan pembangunan perumahan yang dijalankan di kawasan banjir tersebut mestilah menggunakan bahan pembinaan perumahan tersebut seperti batu atau simen tersebut dapat bertahan air banjir*…"

The SMART CITY concept is another approach that was brought up in the FGD. The use of such concept would prove to be useful to the monitoring of river and flooding situations. CCTV and Censors as aids for the authorities and public during flooding are among the effective mediums employed by the concept. **Respondent 6** stated that, "*Usaha yang dilakukan oleh pihak MBPP dalam memantau masalah banjir, dalam proses menyediakan SMART CITY yang mempunyai sensor dan CCTV di kawasan yang sering berlaku banjir. Jadi pemantuan akan sentiasa dilakukan kerana terdapat pegawai yang boleh access kepada CCTV tersebut dan pegawai lain turut bersedia dalam pemantauan ini."*

6.2.2 During and Post – Flood

Physical Amenities

During the flood, one of the most frequent occurrences is the cutting off the supply of electricity to the affected areas which has caused recuuring problems especially to the public. The electricity cut-off by TNB is necessary to avoid further difficulties due to the fact that most water and sewerage tanks are either shut-off or malfunction during flooding. According to **Respondent 1**, "*Skop kerja lebih tertumpu kepada bekalan air dan pembentung. Oleh itu, ketika mengalami banjir yang teruk ada beberapa loji pembentung yang tidak berfungsi dan sistem pembentungan tersebut akan mengalami kerosakan. Manakala, bekalan air yang* *datangnya dari sumber takungan air banyak yang telah ditenggelami air banjir. Bagi pihak TNB pula, mereka akan memotong sistem bekalan elektrik dan perkara ini telah memberi kesan kepada penduduk."*

This statement is supported by **Respondent 6** who iterated that," *Semasa banjir besar pada tahun 2017, TNB telah potong bekalan elektrik. Jadi get set tidak berfungsi telah menyebabkan pihak yang bertanggungjawab tidak boleh access. Perkara ini membawa kepada masalah logistik dan lebih tertumpu kepada kerja-kerja dari pihak JPS."*

The supply of water is also badly affected during and after the flooding. The forced closure of water tanks to avoid contamination would pose difficulties to all parties involved. **Respondent 5** stated that during flooding, the operation of pump houses is activated to replace the water tanks as temporary solutions to supply water to the affected areas. As he put it," *Bagi pihak kejuruteraan, apabila mengalami liputan banjir yang lebih besar telah menyebabkan bekalan air dipotong dan kawasan banjir akan bergantung kepada rumah pam."*

<u>Operation Procedures</u>

During and post flooding pose yet another issue on the logistics of the operational procedures of the authorities. The police would normally be invloved in preaparing and making available safety boats to the rescuers while the city council would be preparing the transportation logistics and the opening of rescue centers. As stated by **Respondent 4**, "*Bagi pihak polis pula, bekalan bot akan disediakan bagi menghadapi banjir jika ada aduan. Kalau banjir yang teruk, pihak MPAJ dan FRU akan turut terlibat."* **Respondent 6** continued that," *MBPP juga yang banyak membantu seperti penyediaan lori dan ketika banjir banyak lori akan disediakan bagi tujuan pembersihan. Semasa banjir, sebuah pusat operasi akan dibuka dan perbincangan akan diadakan tentang isu-isu banjir yang berlaku."*

The agencies are also responsible for the welfare of the victims during and post flooding periods. Some affected occupants would normally be paid certain amount of compensations to ease the difficulties. In this instance, **Respondent 2** implied that," *Bagi skop kerja kawalan* *pembangunan pula, banjir kerap berlaku di Sungai Pinang pampasan akan diberikan kepada penduduk…"*

As preparation, one of the agencies, the IWK is solely responsible for the cleaning and maintaining water and sewerage tanks which can be considered as a crucial operational component during and post flooding. **Respondent 7** iterated that," *Dalam skop sosial, bagi pihak IWK, kami menyediakan perkhidmatan selepas banjir…, pihak kami juga akan melakukan kerja pengosongan tangki. Semasa banjir berlaku, tempat yang menggunakan tangki septik akan dipenuhi air sehingga banjir surut tetapi tangka tu masih penuh dan melimpah. Perkhidmatan kosongkan tangki ini dilakukan di kawasan yang terlibat sahaja."*
Similarly, SPAN is also responsible to prepare mobile/portable water tanks or water supply to the affected areas. These amenities are needed to compensate the closure and malfunction of water tanks. As **Respondent 1** stated, "*Selain itu, SPAN juga mempunyai usaha dalam membeli mobile unit tangki untuk memudahkan pengurusan ketika banjir dan boleh digunakan ketika darurat."*

<u>Cleaning of Wastes</u>

The leftover garbages and wastes pose a big task to be fulfilled by the relevant agencies. **Respondent 6** revealed that the cleaning of wastes is a big part of their flood operations, "*Ketika berlaku banjir yang besar, pihak MBPP yang terdiri daripada 13 jabatan dan jabatan yang akan bertanggungjawab dalam masalah banjir ialah jabatan perbandaran yang akan melakukan pembersihan, pengurusan sampah dan sebagainya."*

Respondent 7 on the same token stated that it is their social duty to be part of the cleaning team during and after flooding. He added that," *…kami menyediakan perkhidmatan selepas banjir semakin surut seperti kerja-kerja pembersihan di Sungai Pinang dan kawasan perumahan yang terlibat."*

Health Risks

The closure and malfunction of the water supplies during flooding pose some health threats to the public. The incoming of contaminated water into the water supply system would normally be considered as dangerous since it would be potentially spreading various kind of diseases. According to **Respondent 6**, "*Secara teknikalnya, apabila bekalan air dipotong, loji tidak akan berfungsi dan perkara ini boleh membawa kepada isu penyakit. Air kumbahan akan melimpah dan bercampur menyebabkan masalah kesihatan berlaku.*"

Impact Observation

Table 6.1 shows the simplified matrix of impacts gathered by the FGD with the government agencies which is targeted to reveal their SOP implementation in pre-flood (before), during the flood and post-flood (after) to invoke their opinion on assessing the risk and vulnerability of Sg Pinang in flood situations.

The matrix is divided into several sections namely the issues/problems (in flood management), the respondent's responses, the outcome of the responses, the expected impact and its score.

EXPECTED IMPACT/SCORE

1=Low

1.5=Low to Moderate

2.0=Moderate

2.5=Moderate to High

3.0=High

The FGD discussions has generated 18 issues/problems that the agencies have had experiences in dealing with in previous floodings. Out of these issues, 15 are expected to have some positive impacts while 3 are negatives. The issues/problems that are being viewed as negative are those with costly implementation effects such as the cutting off of the electrical supply would surely be problematic to all involved. The cleaning process in post-flood situations would also prove to be costly not only to the authorities but also the public while the appearance of various diseases as a consequent of flooding cannot be taken lightly by all parties since it would be a serious threat to the public.

The matrix also shows that out of the Total Score of 54, the positive impacts is placed at 39 points/54 total points (or 72.2%) while the negative impacts is at 9 points/54 total points (or 16.8%). Thus, it can conclude that the FGD has shown that the expected positive impacts outweigh the negatives which means that the current ways of managing and monitoring flood situations (particularly within the Sg Pinang basin) commendable as they generate positive impacts.

6.3 SUMMARY

The FGD with the government agencies has shown that before, during and after flooding, the agencies have a huge task to manage and monitor the effects. It seems that most relevant agencies are fully prepared in terms of their operational procedures. The gathering and dispersion of information about the flood are normally taken care of with the help of modern technology such as the GIS. The preparation and availability of rescue centers, transportation logistics and safety boats for examples, have been noted as parts of the responsibilities of the agencies. Additionally, the agencies are constantly monitoring the on-going development projects which might be contributing to the causes of flooding through water run-offs particularly.

Nevertheless, the agencies (and the public) would also be facing contaminated water supplies due to the closure and malfunctioning of water tanks. There are also health risks to the usage of contaminated water during and after flooding. In addition to that, the agencies would be spending time and efforts to the cleaning and managing of solid wastes especially after the flooding. It is apparent that the longer the durations of the flood, the more risks would be faced by the stakeholders.

Table 6.1: Focus Group Discussion Matrix

Issues/Problems	Responses	Outcome	Score	Expected Impact
Pre-flood				
Flood information				
• **Informing all contingency parties prior and during flood**	Respondent 1 SPAN	Moderate to High	2.5	Positive
• **MOU of flood aids between neighboring states**	Respondent 1 SPAN	Moderate to High	2.5	Positive
Flood Monitoring				
• **Identification of vulnerable flooding areas**	Respondent 8 MBPP	High	3.0	Positive
• **Monitoring of on-going development projects**	Respondent 2 MBPP	Moderate to High	2.5	Positive
• **Preparation of temporary drainage systems by developers**	Respondent 2 MBPP	Low to Moderate	1.5	Positive
Flood Resistance				
• **Linking of recreational activities and rivers**	Respondent 8 MBPP	Moderate	2.0	Positive
• **Integration of flood mitigations and sustainable development**	Respondent 8 MBPP	High	3.0	Positive
• **Utilization of SMART CITY concept**	Respondent 6 MBPP	High	3.0	Positive

Table 6.1: Focus Group Discussion Matrix (cont')

Issues/Problems	Responses	Outcome	Score	Expected Impact
During and Post Flood				
Physical Amenities				
• **Electrical supply cut-off**	Respondent 1 SPAN Respondent 6 MBPP	High	3.0	Negative
• **Operation of pump houses as temporary water supply**	Respondent 5 MBPP	Moderate to High	2.5	Positive
Operational Procedures				
• **Preparation of safety boats**	Respondent 4 PDRM SPU	High	3.0	Positive
• **Compensation for the victims**	Respondent 2 MBPP	Moderate to High	2.5	Positive
• **Transportation logistics**	Respondent 6 MBPP	High	3.0	Positive
• **Opening of rescue centers**	Respondent 6 MBPP	High	3.0	Positive
• **Cleaning and maintainance of water tanks**	Respondent 7 IWK	Moderate to High	2.5	Positive
• **Preparation of mobile/portable water supplies**	Respondent 1 SPAN	Moderate to High	2.5	Positive
Cleaning Wastes				
• **Cleaning of leftover solid wastes**	Respondent 6 MBPP Respondent 7 IWK	High	3.0	Negative
Health Risks				
• **Contaminated water supplies and spreading of diseases**	Respondent 6 MBPP	High	3.0	Negative

6.4 THE FOCUS GROUP DISCUSSION FOR RANKING OF CRITICAL INFRASTRUCUTRE AND INDICATOR FOR VULNERABILITY ASSESSMENT

6.4.1 Critical Infrastructure

Infrastructure refers to systems that physically tie together metropolitan areas, communities, and neighbourhoods, as well as facilitate the growth of local, regional, and national economies. Infrastructure may also be described as the basic facilities, services, and installations needed for the functioning of a community or society such as transportation and communications systems, water and power lines, and public institutions including schools, post offices and prisons. Meanwhile, critical infrastructure consists of physical and information technology facilities, networks, services and assets which, if disrupted or are destroyed, would have a serious impact on the health, safety, security or economic well-being of communities. Critical infrastructure includes all networks and buildings that are essential for the functioning of society during events of flood and for the recovery from such an event. Critical infrastructure is considered ‘critical’ because an outage of the infrastructure has a serious effect on many people over a long period. Based on the literature review that was undertaken, there are seven (7) indicators that are related to critical infrastructure which are industrial area, infrastructure and utilities, institution and public facilities, commercial area, transportation, residential area, and open space and recreational area (**Refer Table 6.2**).

Table 6.2: Ranking of Critical Infrastructure

Indicator	***No. of FGD Panellist***												***Total***	***Rank***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***		
RESIDENTIAL AREAS	7	8	8	9	9	7	6	9	5	7	9	8	165	**1**
INSTITUTION AND PUBLIC FACILITIES	7	7	8	7	9	7	9	8	8	5	9	9	160	**2**
INFRASTRUCTURE AND UTILITIES	9	9	9	9	9	7	8	9	8	9	7	9	102	**3**
TRANSPORTATION	9	9	9	9	9	6	7	9	8	8	8	9	100	**4**
COMMERCIAL AREAS	6	4	7	5	5	5	4	5	5	6	6	7	65	**5**
OPEN SPACES AND RECREATIONAL AREAS	3	9	5	4	5	3	4	9	8	6	1	7	64	**6**
INDUSTRIAL AREAS	6	5	7	6	1	6	5	5	6	1	5	5	58	**7**

The indicators were ranked during the focus group discussion by professionals from local authorities and government agencies in the state of Pulau Pinang which are concerned with and related to critical infrastructure. These indicators were ranked by the most important level of critical infrastructure which are **1) residential area, 2) institution and public facilities, 3) infrastructure and utilities, 4) transportation, 5) commercial area, 6) open space and recreational** and **7) industrial area** (**refer Table 6.2**).

The results show that residential area has the highest result of 165 marks and is placed as the first rank in terms of important critical infrastructure. This is because residential areas are places where people live and inhabit. If there are any residential areas that are disrupted or damaged, this could lead to further detrimental consequences. Damage to residential areas during flooding can cause people to face losses for their respective properties. In addition to this, residential areas also have a strong relationship with society and communities. Flooding can cause negative effects on residential area mainly by the virtue of people residing within these areas.

The second ranked indicator is institution and public facilities which have total of 160 marks. This is because some of the educational institutions also act as a food supply collection centre and flood victims relocation centre. This clearly demonstrates the importance of institutions and public facilities during flooding events.

The third ranked indicator is infrastructure and utilities which scored 102 marks. This is mainly due to the fact that loss of power supply can seriously impede the health service of an entire urban community. This is followed by the fourth ranked indicator, transportation which has a score of 100 marks. Disruptions to public transportation systems and infrastructure may hamper relief efforts to the affected areas which in turn may cause more inconveniences to the displaced communities. Commercial areas come in as the fifth ranked indicator with a score of 65 marks. These areas may not be as significant as the residential areas as these commercial areas are only populated during office hours and are not inhabited continuously. The cascading effects of flood to these areas are not as critical when compared to the other higher ranked indicators.

The indicator ranked sixth, with a score of 64 marks, is open space and recreational areas. The lower place ranking of this indicator is mainly due to the fact that these areas are not utilized on a permanent basis but rather more for temporary activities within the communities. These areas also do not have much high value assets that may be damaged by floods.

The lowest ranked indicator is industrial area which recorded a score of 58 marks. During flooding events, industrial areas are usually less affected or damaged. While it is still vital that industrial areas are also protected during floods, the total loss of critical infrastructure aspects may be less than the other more critical areas.

In conclusion, direct damages to the infrastructure itself are of minor importance when compared to the indirect effects of their outage. The indirect effects, such as loss of income due to an electricity outage, loss of lives in hospitals due to communication interruptions, loss of property in residential areas, damaged roads or electricity service interruptions are more relevant than the damage to the cables and power utility stations themselves. Furthermore, when assessing critical infrastructure, the secondary effects of outage outside of the flooded areas as well as the interdependencies and cascading effects to other sectors are relevant and significant. Failure of the power grid for example, may affect a wide range of other infrastructure, for instance water supply and information technology. Vulnerability assessments need to determine the consequences and damages of such interdependencies.

6.4.2 The Social Vulnerability Assessment

There are five components for measuring flood vulnerability index in the study, which are hydrogeological, social, economic, socio-behavioural and politico-administrative. In this study, 12 indicators from the social component have been selected to be ranked by the panel members during the Focus Group Discussion. The indicators consist of **1) population under 20 years old, 2) population above 65 years old, 3) female headed household, 4) low income household, 5) female population, 6) population of renting tenants, 7) level of education, 8) employment, 9) percentage of disabled people, 10) awareness and preparedness, 11) past experience or knowledge about flood hazard** and **12) social security for flood hazard.** The development of indicators and target values can be seen as a tool for vulnerability reduction. The indicators have been scored from 1 until 9, where score number 1 will be less important and score number 9 will be the most important indicators (**Refer Table 6.3**).

Table 6.3: Ranking of Social Vulnerability Assessment

Indicator	***No. of FGD Panellist***												***Total***	***Rank***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***		
Population above 65 years old	9	9	9	9	9	9	7	9	9	7	4	9	99	**1**
Percentage of disable people	8	8	9	8	2	9	7	9	9	8	7	7	91	**2**
Awareness and preparedness	9	9	9	7	9	3	5	9	6	5	9	9	89	**3**
Female headed household	6	7	8	9	5	8	7	9	9	5	5	9	87	**4**
Low income household	7	6	8	6	2	7	7	9	9	4	6	9	80	**5**
Population under 20 years old	2	4	7	9	9	8	8	6	9	3	3	9	77	**6**
Past experience/knowledge about flood hazard	7	9	8	5	9	2	8	6	6	2	8	7	77	**6**
Social security for flood hazard	8	6	8	6	9	4	8	9	5	4	1	8	76	**7**
Female population	6	7	8	8	2	6	6	9	8	6	2	8	76	**7**
Level of education	4	8	7	7	2	5	5	7	5	4	1	8	63	**8**
Employment	8	2	7	4	2	5	5	7	5	3	3	8	59	**9**
Population of renting tenants	5	5	0	5	2	3	5	6	5	5	1	5	47	**10**

In the social component, the indicator that has been ranked as number 1 was population above 65 years old with a score of 99 marks which showed that this is the most critical group that needs more attention during floods.

The second highest ranked indicator is percentage of disabled people. This is another critical group that needs to be focused on by stakeholders especially in taking precautionary steps within flood prone areas. The indicator will assess the ability of people to move or flee if necessary and help the immobile people. Disabled groups may not be able to move freely by themselves and as such may rely on the local community for assistance. Therefore, communities should be aware of the presence of these disabled groups within their area which in turn will be beneficial in times of evacuation due to flood.

The awareness and preparedness indicator comes in as the third ranked indicator with 89 marks. This is a crucial indicator which needs attention from all levels of community. Communities within flood prone areas need to be aware and prepared towards the occurrences of flood. These communities need to be always aware of the local weather forecast, which will enable them to be physically and mentally prepared to face floods. Awareness consists of the actual awareness of the community and of any training they have received or undergone, including instructions or guidelines to inform them of what to do when the floods do happen. Teamwork is very important in raising awareness within the community. Preparedness in a community can be attributed to having awareness, solutions and taking necessary measures such as storing essential food and items in times of flooding. For example, if the weather forecast indicates the possible occurrence of heavy rain or the start of the monsoon season, the community can prepare food and other basic elements when floods do happen. Belongings and other moveable assets in their property can be shifted early to other locations and certain mitigating steps may also be put in place to avoid significant property loss. Members of the community member can also raise funds to procure food and basic necessities in preparing for the flood season. The availability of clean water is also important as water supply breakdown may occur during floods. As a solution, the community can prepare and distribute bottled water to flood victims in ensuring clean drinking water is available as well as allowing access to sanitation.

The next indicator, with a score of 87 marks is female headed household. This group needs attention as they are more vulnerable when compared with the other family groups. Low income households also share a similar situation and this indicator is ranked fifth with a score of 80 marks.

Two indicators, population under 20 years old and past experience or knowledge about flood hazard are ranked sixth, both with 77 marks. The age group may need more assistance compared to adults during floods. Meanwhile, past experience or knowledge about flood hazard will be an added advantage in times of critical situations. Similarly, two indicators are ranked in the seventh position with 76 marks, namely female population and social security for flood hazard. The female population may need additional assistance but social security for flood hazard such as disaster insurance will be an advantages during floods. Level of education comes in at the eighth position with a score of 63 marks. Educational level may help people be more prepared in handling disaster situations and is seen as less critical when compared to the other indicators. Ranked ninth, employment recorded a score of 59 marks. Employed members of community as seen as being less vulnerable as they may have sufficient income in times of need. The least important ranked indicator at the tenth position is population of renting tenants with a score of 47 marks. This indicator is seen as the least vulnerable as they may not suffer significant losses when compared to property owners or permanent residents.

6.4.3 The Economic Vulnerability Assessment

In the economic component, six indicators have been taken into account based on their importance to the stakeholders and community members. The indicators are **1) building structure type, 2) premises close to the river, 3) recovery time, 4) recovery cost, 5) affected dwellers** and **6) type of economic activities** (**Refer Table 6.4**).

Table 6.4: Ranking of Economic Vulnerability Assessment

Indicator	***No. of FGD Panellist***												***Total***	***Rank***
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***		
Recovery cost	9	9	8	8	9	7	7	7	9	4	8	9	94	**1**
Recovery time	8	8	8	7	9	7	7	7	9	5	7	9	91	**2**
Affected dwellers	8	9	8	8	5	6	7	9	9	4	9	7	89	**3**
Premises close to the river	9	8	8	8	3	8	8	9	9	6	1	9	86	**4**
Building structure type	6	7	8	8	5	7	8	9	9	4	6	7	84	**5**
Type of economic activities	7	6	8	8	5	6	6	7	9	3	5	6	76	**6**

The highest ranked indicator was recovery cost with a score of 94 marks. Recovery cost indicates the amount of cost needed for to recover losses and to remedy losses to the previous state. Floods will cause damages towards property as well as other assets owned by community members. Damages on a larger scale, especially to public infrastructure may take years to recover making cost recovery a highly vulnerable economic component. This is logically followed by recovery time which comes in as the second ranked indicator with a score of 91 marks. Recovery time indicates the amount of time needed for recovery to the previous efficient state and consists of recovery of infrastructure, communication lines, businesses, jobs and property. Similar to cost recovery, the element of time is also crucial to allow damages to be rectified and repaired, where large scale damages may take a long time to be restored to their previous functional state.

The third ranked indicator is affected dwellers with a score of 89 marks. While cost and time are significantly important, the effects of flood on residents and members of community can also be substantial as it deals with trauma and health issues of the displaced communities. Assistance may have to be focused in getting these individuals to recover from their respective losses.

Premises close to the river comes in at the fourth position with 86 marks. Location of premises near or within the vicinity of rivers and other bodies of water contribute directly to the amount of losses suffered during flood. Damages to these properties may be higher than those located at other areas and as such need more focused attention as well as assistance.

The fifth ranked economic indicator is building structure type with a score of 84 marks. This indicator will determine the magnitude of losses and damage suffered by the property owners. This indicator is deemed to be slightly less significant than the others as the building structure may either mitigate against or contribute towards damages and losses.

The least significant indicator, ranked sixth with a score of 76 marks, is economic activities. This indicator comes in at the last position mainly because the effects of flood may significantly vary from one economic activity to another.

6.4.4 The Physical Vulnerability Assessment

The Physical Vulnerability Assessment usually refers to the capacity of the built environment (e.g. buildings, infrastructure, etc.) to cope with floods and flood-related disasters and it encompasses the characteristics of objects to sustain or resist potential physical damage. The risk of a flood to occur and to cause damage depends on the existence of a hazard and of people and objects that are in the hazard zone and that do not have sufficient capacities to avert the damage. Based on literature review, there are six (6) indicators for physical vulnerability assessment which are **1) flood depth, 2) duration of flood, 3) accessibility, 4) flood warning system, 5) telecommunication** and **6) surrounding drainage system** (**Refer Table 6.5).**

Table 6.5: Indicator of Physical Vulnerability Assessment

Indicator	*No. of FGD Panellist*												*Total*	*Rank*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*		
Accessibility	8	9	9	9	9	7	7	9	9	7	9	9	101	**1**
Telecommunication	9	9	7	7	9	9	8	9	8	5	9	9	98	**2**
Flood depth	7	9	9	9	9	7	9	7	8	6	6	9	95	**3**
Surrounding drainage system	9	9	9	6	9	8	7	9	9	3	8	7	93	**4**
Duration of flood	7	8	8	9	9	6	8	7	8	9	7	6	92	**5**
Flood warning system	9	9	7	8	9	8	6	9	8	4	5	9	91	**6**

Results from the Focus Group Discussion ranks accessibility as the highest indicator with a score of 101 marks. Accessibility is important to make sure the roads and other pathways can be accessed or used during floods. The lack of accessibility may hamper any flood relief efforts and as such is very significant in terms of physical vulnerability.

The second ranked indicator is telecommunication with a score of 98 marks. As with accessibility, telecommunication plays an important role during times of disaster especially in maintaining contact with the affected communities.

Flood depth is ranked third with 95 marks. Flood depth will have a direct effect on the magnitude of damage to lives, property and infrastructure. Surrounding drainage system which comes in at the fourth position with 93 marks is also considered important in terms of flood mitigation. The fifth ranked indicator is duration of flood with 92 marks. The length and duration of floods will directly influence the amount of damages as well as losses suffered by the affected community members. The lowest ranked indicator is flood warning system with 91 marks. This indicator is also important as an early warning system to the surrounding areas for them to get ready to face floods or natural disasters.

6.4.5 Summary

The Focus Group Discussion involving relevant professionals from local authorities and government agencies were responsible in ranking the critical infrastructure and indicators of vulnerability assessment from social, economic and physical components. From the social component, 12 indicators were ranked compared to 6 indicators within the both the economic and physical components. The purpose of the ranking is to give priority among all indicators in terms of the levels of importance during floods. This will ensure that the recovery and relief process on the critical infrastructure could be conducted based on the levels of importance of the indicators. This will further ensure that economic, social and physical aspects of the surrounding areas during floods will be considered and taken care of in the most effective manner possible.

APPENDIX A

DEVELOPMENT OF FLOOD RISK ASSESSMENT (FRA) AND FLOOD VULNERABILITY INDEX (FVI) FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA (SUNGAI PINANG)

FOCUS GROUP DISCUSSION – 31 January 2019

RANKING OF CRITICAL INFRASTRUCTURE

Please RANK each item based on the highest priority (Level of importance: 1–9)

No.	Indicator	1	2	3	4	5	6	7	8	9
1	INDUSTRIAL AREAS									
2	INFRASTRUCTURE AND UTILITIES									
3	INSTITUTION AND PUBLIC FACILITIES									
4	COMMERCIAL AREAS									
5	TRANSPORTATION									
6	RESIDENTIAL AREAS									
7	OPEN SPACES AND RECREATIONAL AREAS									

INDICATOR OF VULNERABILITY ASSESSMENT – Physical

Please RANK each item based on the highest priority (Level of importance: 1 – 9)

No.	Indicator	1	2	3	4	5	6	7	8	9
1	Population under 20 years old									
2	Population above 65 years old									
3	Female headed household									
4	Low income household									
5	Female population									
6	Population of renting tenants									
7	Level of education									
8	Employment									
9	Percentage of disable people									
10	Awareness and preparedness									
11	Past experience/knowledge about flood hazard									
12	Social security for flood hazard									

INDICATOR OF VULNERABILITY ASSESSMENT – Economic

Please RANK each item based on the highest priority (Level of importance: 1 – 9)

No.	***Indicator***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
1	Building structure type									
2	Premises close to the river									
3	Recovery time									
4	Recovery cost									
5	Affected dwellers									
6	Type of economic activities									

INDICATOR OF VULNERABILITY ASSESSMENT – Social

Please RANK each item based on the highest priority (Level of importance: 1 – 9)

No.	***Indicator***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***
1	Flood depth									
2	Duration of flood									
3	Accessibility									
4	Flood warning system									
5	Telecommunication									
6	Surrounding drainage system									

CHAPTER 7

FLOOD VULNERABILITY INDEX

CHAPTER 7

FLOOD VULNERABILITY INDEX

7.1 RESULTS OF THE FLOOD VULNERABILITY INDEX (FVI)

Over the past few years, Malaysia has suffered severe flooding, especially in the states of Kelantan, Pahang and Kedah. One of the most important parts of flood risk management is to evaluate the vulnerability to floods (Hadi *el al,.* 2017). The proposed methodology for the estimation of FVI can be a useful tool for the mitigation of the devastating impact of floods. Vulnerability is defined as being susceptible to physical or emotional injury. To be able to sum up all the different factors, we have again to convert them into a common scale. Flood vulnerability model maps are generated based on social, economic, and physical components using the Analytical Hierarchical Process (AHP) method as shown in **Figures 7.2** to **Figure 7.10**.

Vulnerability expresses the level of foreseeable consequences of a natural phenomenon on certain issues (Mate, 2001; Danumah, 2016) and on the other hand, is the most crucial component of risk where it determines whether or not exposure to a hazard constitutes a risk (Ouma & Tateishi, 2014; Danumah, 2016). Flood vulnerability mapping is the process of determining the degree of susceptibility and exposure in the occurrences of flooding (Danumah, 2016)

7.2 PHYSICAL & PHYSICAL WEIGHTED VULNERABILITY

A map of Physical FVI was produced and categorised into six classes (**Figures 7.2, Figure 7.3 and Figure 7.4**) using the Vulnerability Scale as indicated in **Figure 7.1**. The generated map demonstrated that approximately 75% of the study area was classified into moderate to very high FVI, whereas very low and low FVI covered 25%. **Tables 7.1** and **Table 7.2** show that Infrastructure and Utilities recorded the highest value (0.248797124) and Industrial Areas indicated the least value (0.076768036) as derived from the AHP analysis.

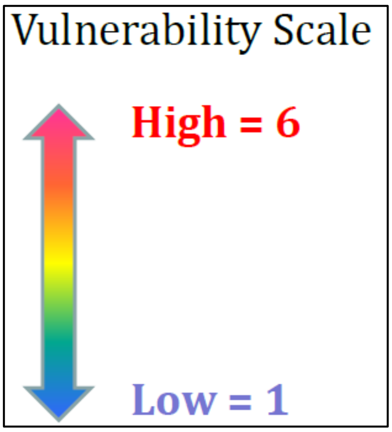

Figure 7.1: Vulnerability Scale

Table 7.1: AHP for Critical Physical Infrastructure

#	Infrastructure and Utilities	Transportation	Institution and Public Facilities	Residential Areas	Commercial Areas	Industrial Areas
Infrastructure and Utilities	1.0000	1.0200	1.0968	1.1921	1.8540	6.5437
Transportation	0.9804	1.0000	1.0753	1.0870	1.5552	3.5295
Institution and Public Facilities	0.9118	0.9300	1.0000	1.0109	1.4308	2.2695
Residential Areas	0.8388	0.9200	0.9892	1.0000	1.4154	1.5862
Commercial Areas	0.5394	0.6430	0.6989	0.7065	1.0000	1.1207
Industrial Areas	0.1528	0.2833	0.4406	0.6304	0.8923	1.0000
Total	**4.4232**	**4.7963**	**5.3008**	**5.6269**	**8.1477**	**16.0496**

Table 7.2: AHP for Critical Physical Infrastructure (Additional Results)

Indicator	Total	Rank	Average	FVI	Lambda
Infrastructure and Utilities	102	1	8.5	0.25	1.10
Transportation	100	2	8.33	0.21	0.99
Institution and Public Facilities	93	3	7.75	0.18	0.96
Residential Areas	92	4	7.67	0.17	0.96
Commercial Areas	65	5	5.42	0.12	0.96
Industrial Areas	58	6	4.83	0.08	1.23

As a means to determine if the analyses are consistent with the scoring, Saaty (1980) proposed what is called the Consistency Ratio, which is a comparison between Consistency Index (CI) and Random Consistency Index (RI), as stated in the formula: CR = CI / RI. If the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable (**Table 7.3**).

Table 7.3: Critical Physical Infrastructure Consistency Ratio

Consistency Index (CI)	0.038788036
Random Consistency Index (RI)	1.35
Consistency Ratio (CR)	0.028731878

In the category of Physical Building Type (**Table 7.4**), Infrastructure and Utilities (0.2488) is the most vulnerable whereas Industrial Areas recorded the lowest score (0.0768) thus making it the least vulnerable.

Table 7.4: Building Type (Physical)

Building Type (Physical)		
Type	Score	Vulnerability
Infrastructure and Utilities	0.2488	6
Transportation	0.2062	5
Institution and Public Facilities	0.1809	4
Residential Areas	0.1697	3
Commercial Areas	0.1177	2
Industrial Areas	0.0768	1

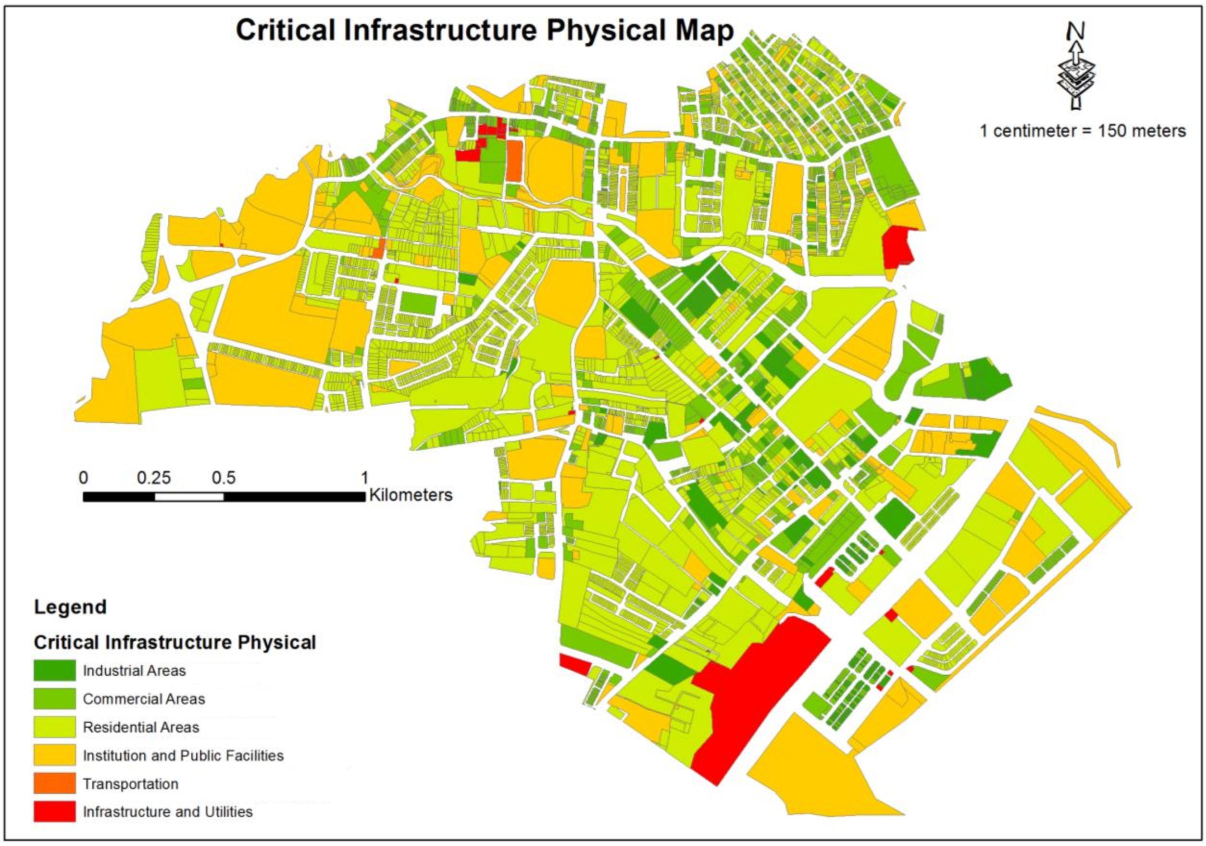

Figure 7.2: Critical Physical Infrastructure Map

The results from the Critical Physical Infrastructure Map (**Figure 7.2 & Tables 7.1, 7.2, 7.4 and 7.5**) demonstrate that the more vulnerable areas are mainly from the Infrastructures & Utilities category while the least vulnerable areas are from the Industrial Areas (0.076768) category. **Figure 7.3** indicates that the minimum depth of the study area is 0.248m with a maximum depth of 2.4m.

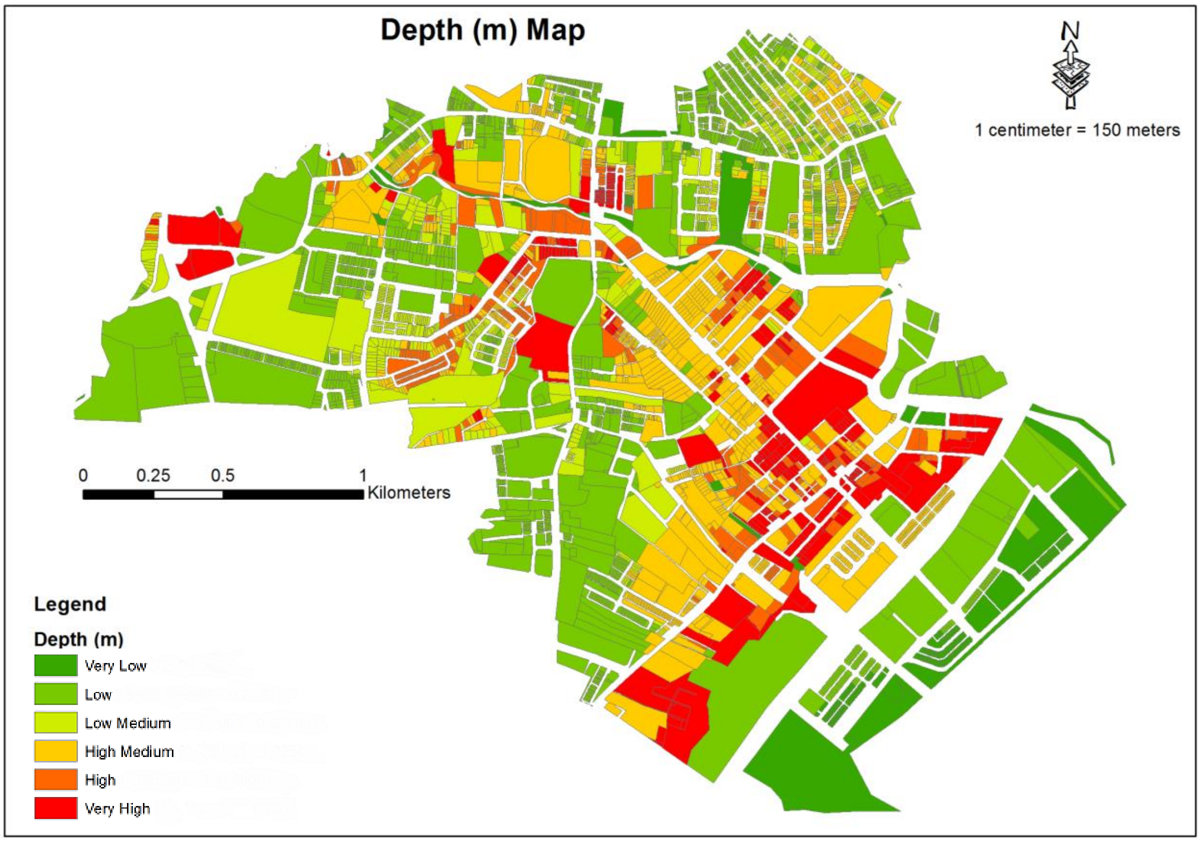

Figure 7.3: Depth (m)

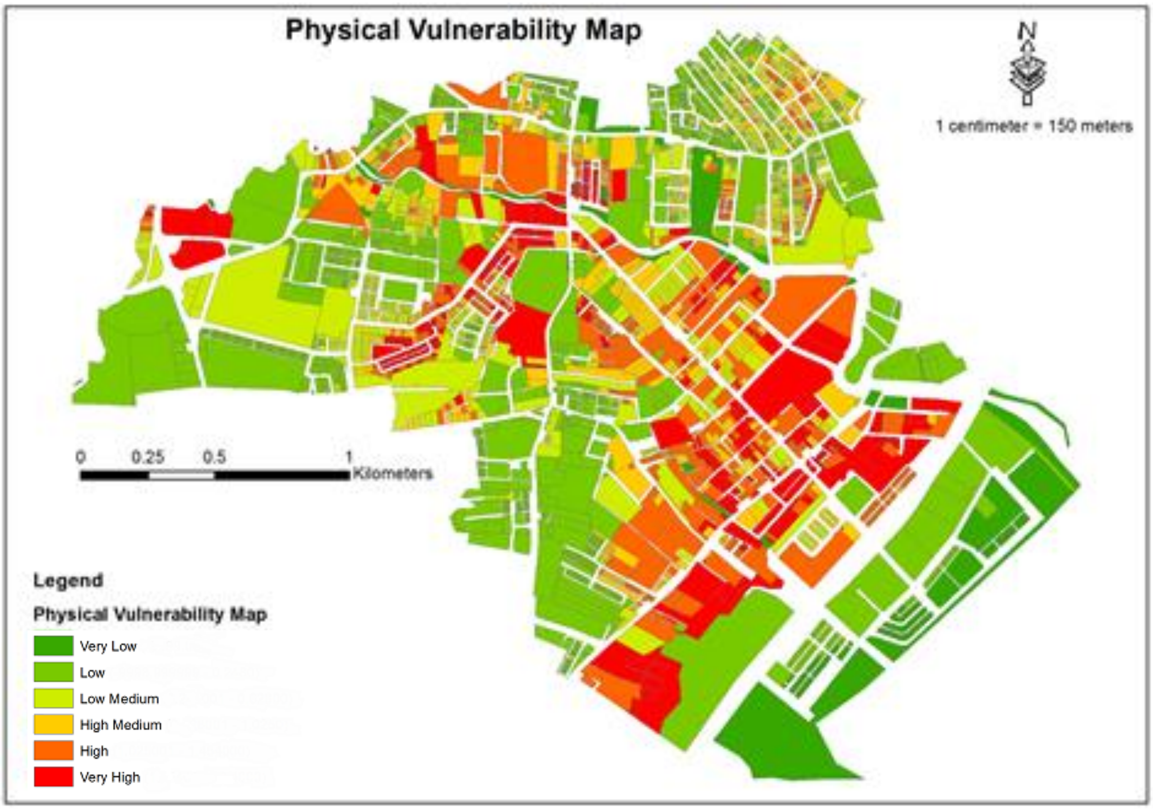

Figure 7.4: Physical Vulnerability Map

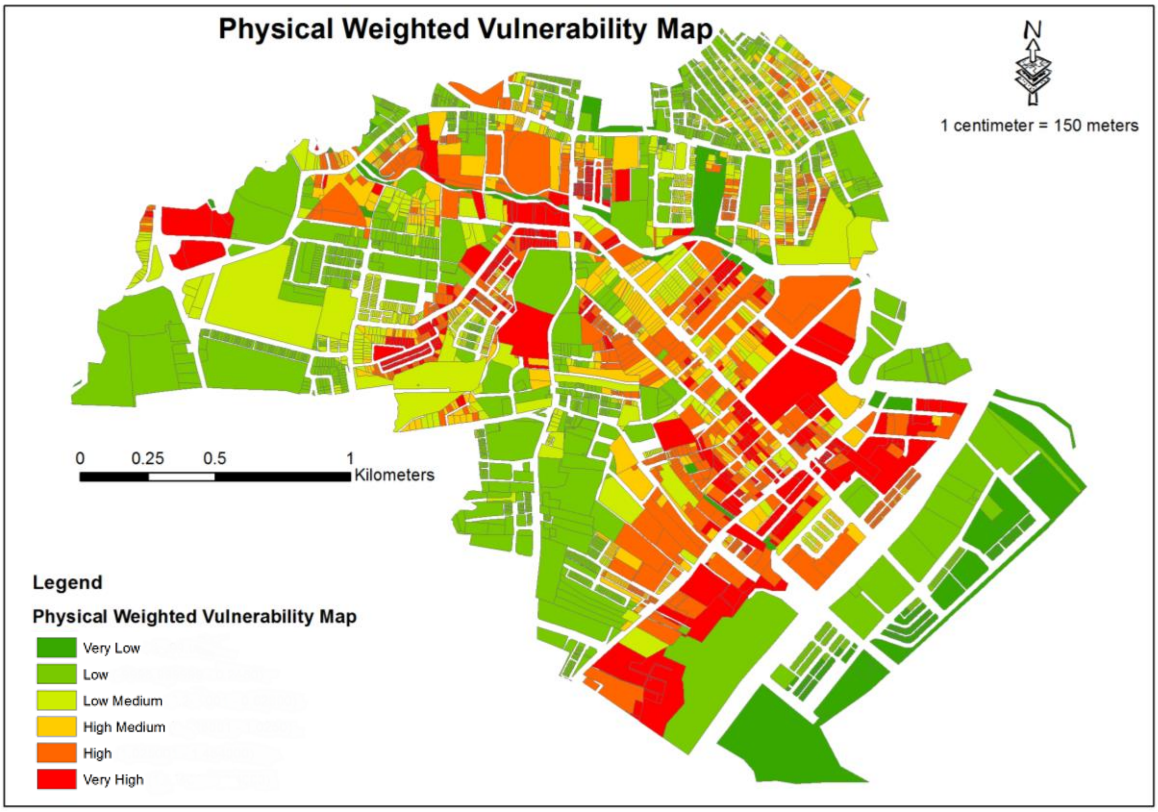

Figure 7.5: Physical Weighted Vulnerability Map

Figure 7.4, Figure 7.5 & Table 2.5 show the comparison between the weighted and non-weighted maps. 0.407 is highest value (non-weighted) meanwhile 0.127046 is the highest value (weighted).

Table 7.5: Comparison between Physical Vulnerability Map & Physical Weighted Vulnerability Map

Categories	Without Weight %	Area (m^2)	With Weight %	Area (m^2)
Very Low	5.0688	361005.109	5.0688	361005.1
Low	33.0507	1564197.973	33.0507	1564198
Low Medium	18.7677	610225.016	18.7677	610225
High Medium	14.0946	345855.928	14.0946	345855.9
High	19.5214	649808.512	19.5214	649808.5
Very High	9.4969	530933.581	9.4969	530933.6
Total	**100.00**	**4062026.119**	**100.00**	**4062026.119**

Results as shown in **Figure 7.4 and 7.5** are derived through the equation shown in **Equation 7.1.** Critical Infrastructure Physical * Depth * Weighted (0.31) =Physical Weighted Vulnerability Map

Equation 7.1: How to Calculate Physical Weighted Vulnerability Map

In this study, the equation is as follows:

*Critical Physical Infrastructure (**Figure 7.2**) * Depth (**Figure 7.3**) * Weighted (0.31) (**Table 7.16**) = Physical Weighted Vulnerability Map.*

7.3 ECONOMIC AND ECONOMIC WEIGHTED VULNERABILITY MAP

Table 7.6 shows that Institution and Public Facilities returned the highest value (0.44307) and Infrastructure and Utilities recorded the least value (0.02123) as derived from the AHP survey.

Table 7.6: AHP Critical Infrastructure (Economic)

#	Institution and Public Facilities	Commercial Areas	Residential Areas	Industrial Areas	Transportation	Infrastructure and Utilities
Institution and Public Facilities	1.0000	1.2083	1.5263	2.6165	9.4694	202.5748
Commercial Areas	0.8276	1.0000	1.2632	1.7143	3.6190	21.3926
Residential Areas	0.6552	0.7917	1.0000	1.3571	2.1111	5.9111
Industrial Areas	0.3822	0.5833	0.7368	1.0000	1.5556	2.8000
Transportation	0.1056	0.2763	0.4737	0.6429	1.0000	1.8000
Infrastructure and Utilities	0.0049	0.0467	0.1692	0.3571	0.5556	1.0000
Total	**2.9755**	**3.9064**	**5.1692**	**7.6880**	**18.3107**	**235.4785**

Table 7.7: AHP Critical Physical Infrastructure (Additional Results)

Indicator	Rank	Total Score	FVI	Total	Lambda
Institution and Public Facilities	1	29	0.44307	30.4430729	1.318355589
Commercial Areas	2	24	0.21499	26.2149944	0.839853027
Residential Areas	3	19	0.15554	22.1555381	0.804003537
Industrial Areas	4	14	0.10787	18.1078725	0.829320814
Transportation	5	9	0.05729	14.0572896	1.049009614
Infrastructure and Utilities	6	5	0.02123	11.0212324	4.999781815

Table 7.6 and 7.7 indicate the results of the AHP analysis. As mentioned earlier, the Consistency Ratio is employed to verify if the analyses are consistent with the scoring, where if the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable (**Table 7.8**).

Table 7.8: Critical Infrastructure (Economic) Critical Ratio

Consistency Index (CI)	0.768064879
Random Consistency Index (RI)	1.35
Consistency Ratio (CR)	0.568936948

Results from the Critical Economic Infrastructure Map (**Figure 7.6 & Tables 7.6, 7.7, 7.8 and 7.9)** demonstrate that the most vulnerable areas are mainly located within the Institution and Public Facilities areas (0.44307) while the least vulnerable areas are situated around the Infrastructure and Utilities areas (0.02123).

Table 7.9: Building Type (Economic)

Building Type (Economic)		
Type	**Score**	**Vulnerability**
Institution and Public Facilities	0.44307	6
Commercial Areas	0.21499	5
Residential Areas	0.15554	4
Industrial Areas	0.10787	3
Transportation	0.05729	2
Infrastructure and Utilities	0.02123	1

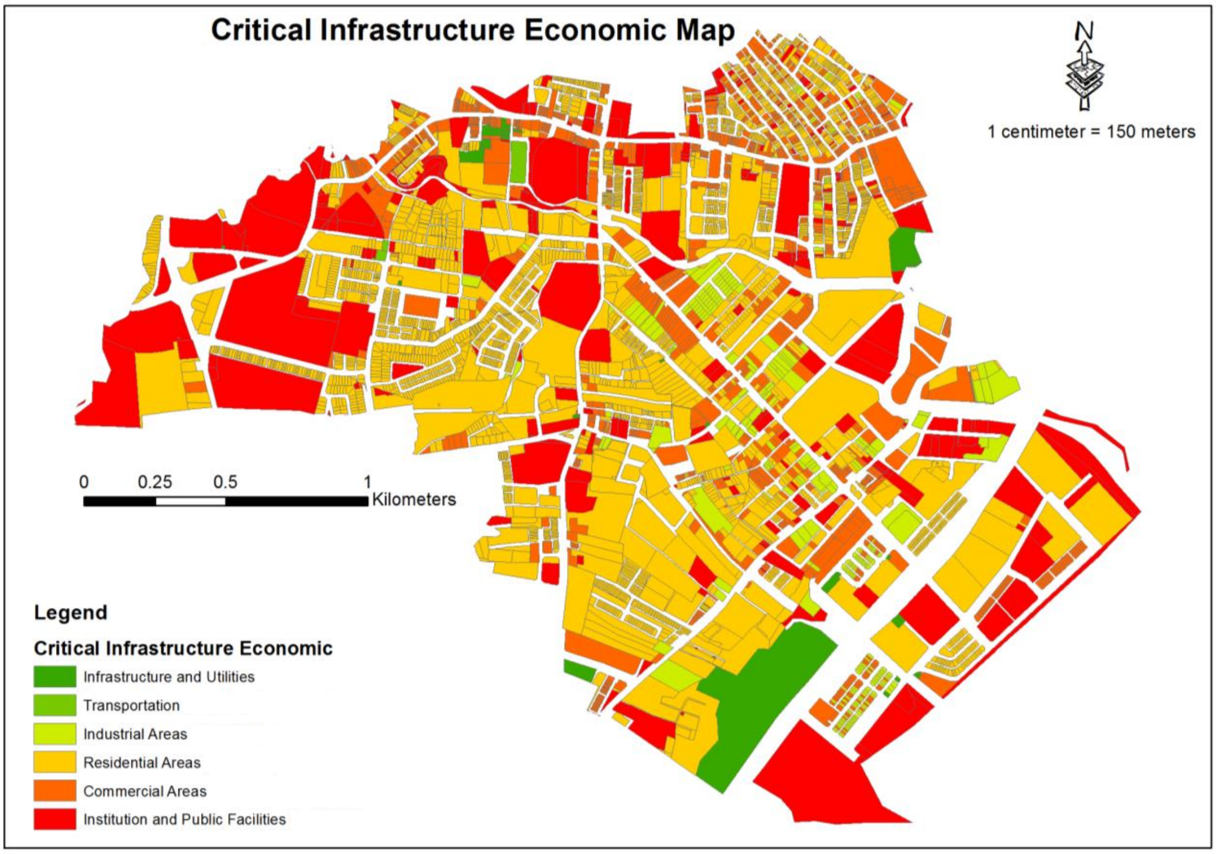

Figure 7.6: Critical Infrastructure (Economic) Map

Results from the Critical Economic Infrastructure Map (**Figure 7.7, 7.8 & Tables 7.6, 7.7 7.8 and 7.9**) demonstrate that the most vulnerable areas are mainly located within the Institution and Public Facilities areas (0.44307) while the least vulnerable areas are situated around the Infrastructure and Utilities areas (0.02123).

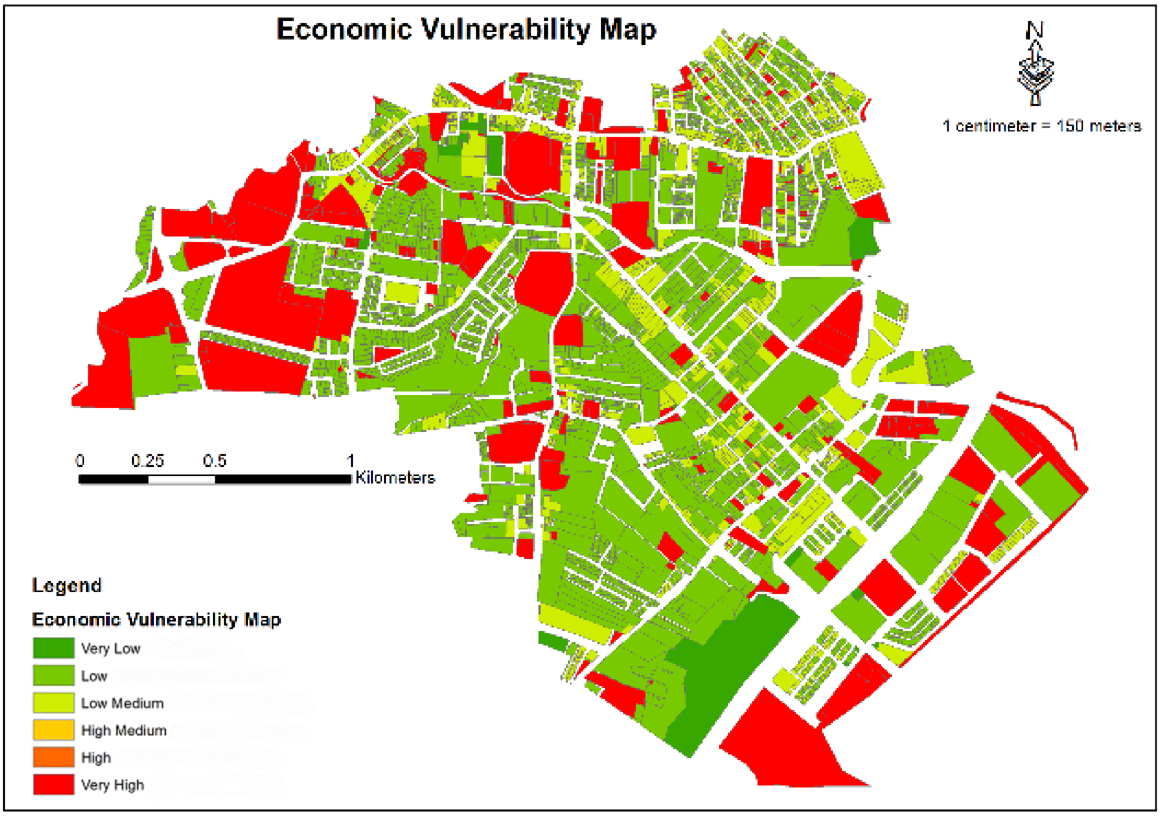

Figure 7.7: Economic Vulnerability Map

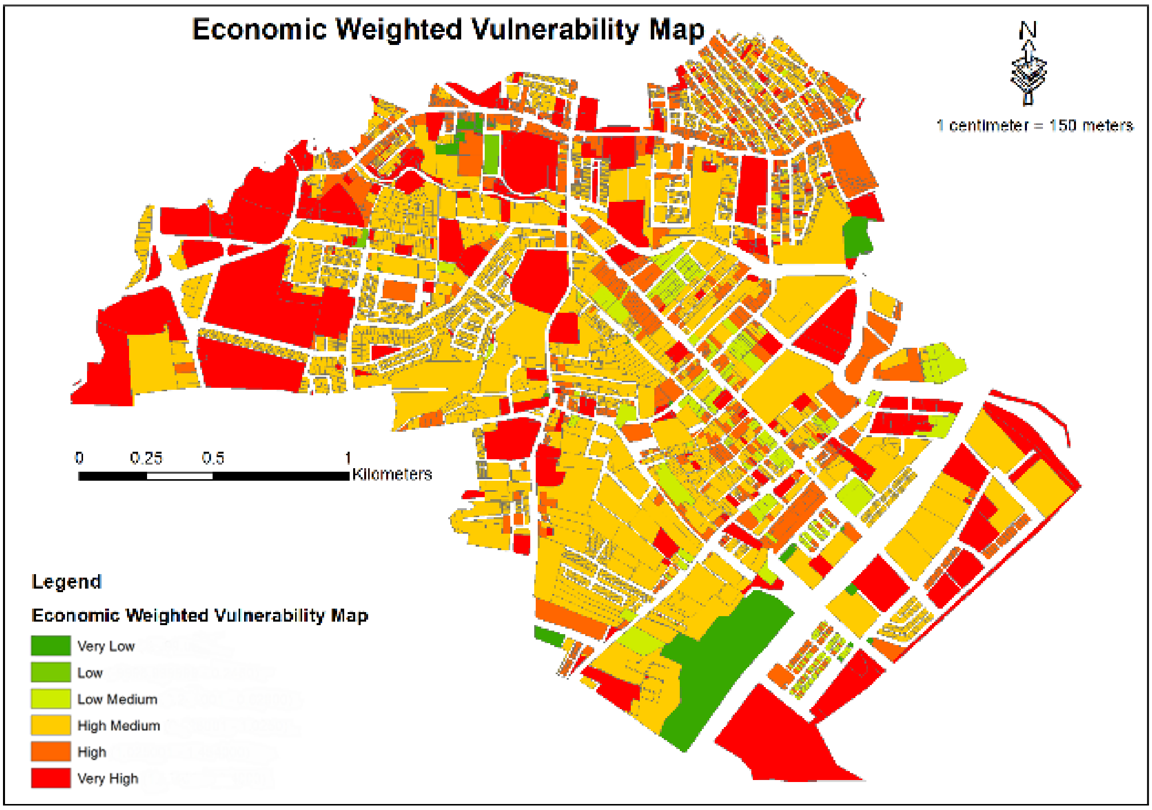

Figure 7.8: Economic Weighted Vulnerability Map

Table 7.10: Comparison between Economic Vulnerability Map & Economic Weighted Vulnerability Map

Categories	Without Weight %	Area (m^2)	With Weight %	Area (m^2)
Very Low	0.6407	158910.906	0.7160	169044.7
Low	0.0754	10133.768	68.2683	2172035
Low Medium	5.8413	188333.969	24.6279	542241.5
High Medium	62.4270	1983700.625	0	0
High	24.6279	542241.518	0	0
Very High	6.3878	1178705.333	6.3878	1178705
Total	**100.00**	**4062026.119**	**100.00**	**4062026.119**

Results shown in **Figure 7.6** and **Table 7.10** are derived via the equation in **Equation 7.2**.

*Critical Infrastructure (Economic) * Weighted (0.21) = Economic Weighted Vulnerability Map*

Equation 7.2: How to Calculate Economic Weighted Vulnerability Map

In this study, the equation is as follows:

*Critical Infrastructure (Economic) (**Figure 7.5**) * Weighted (0.21) (**Table 7.16**) = Economic Weighted Vulnerability Map (**Figure 7.6**)*

7.4 SOCIAL AND SOCIAL WEIGHTED VULNERABILITY MAP

Social vulnerability is, often, described as the population/individual characteristics comprising of age, race, health, poverty and employment (Cutter et al. 2003; Fekete, 2009; Fekete, 2010). The information pertaining to losses incurred due to vulnerabilities of social aspects are largely ignored due to the difficulty in quantifying them (Cutter et al. 2003). Studies normally assume that the areas with maximum density of population will have a higher associated physical structures and livelihood options (Pramojanee et al., 1997), and therefore, higher weightages are assigned to dense population centres in the case of socio-economic vulnerability (Sharma et al., 2018). In addition, the socio-economic condition of the communities in these areas is good (Hoque *et al,.* 2019) thus making their losses much more significant and damaging.

Several criteria were selected to assess the social vulnerability of communities to floods. A social vulnerability index was then subsequently generated from the processed criteria. The produced social vulnerability index values were categorised into six levels for creating a social vulnerability map (**Figure 7.8** & **Figure 7.9**). The resulting map indicates that communities living in the centre parts of the study area are in highly to very highly vulnerable zones.

Table 7.11: AHP for Critical Social Infrastructure

#	Residential Areas	Industrial Areas	Transportation	Commercial Areas	Infrastructure AHP Utilities	Institution and Public Facilities
Residential Areas	1.0000	1.2083	1.5263	2.6165	9.4694	202.5748
Industrial Areas	0.8276	1.0000	1.2632	1.7143	3.6190	21.3926
Transportation	0.6552	0.7917	1.0000	1.3571	2.1111	5.9111
Commercial Areas	0.3822	0.5833	0.7368	1.0000	1.5556	2.8000
Infrastructure and Utilities	0.1056	0.2763	0.4737	0.6429	1.0000	1.8000
Institution And Public Facilities	0.0049	0.0467	0.1692	0.3571	0.5556	1.0000
Total	**2.9755**	**3.9064**	**5.1692**	**7.6880**	**18.3107**	**235.4785**

Table 7.12: AHP for Critical Social Infrastructure Social (Additional Results)

Indicator	Rank	Total Score	Average	Lambda
Residential Areas	1	29	0.44307	1.318355589
Industrial Areas	2	24	0.21499	0.839853027
Transportation	3	19	0.15554	0.804003537
Commercial Areas	4	14	0.10787	0.829320814
Infrastructure and Utilities	5	9	0.05729	1.049009614
Institution and Public Facilities	6	5	0.02123	4.999781815

Table 7.13: Critical Social Infrastructure Consistency Ratio

Consistency Index (CI)	0.768064879
Random Consistency Index (RI)	1.35
Consistency Ratio (CR)	0.568936948

The Consistency Ratio is again utilized to verify if the analyses are consistent with the scoring where a Consistency Ratio value that is smaller or equal to 10% indicated that the inconsistency is acceptable (**Table 7.13**). **Tables 7.11** and **7.12** list the results of AHP after calculation.

Table 7.14: Building Type (Social)

Building Type (Social)		
Type	**Score**	**Vulnerability**
Residential Areas	0.44307	6
Industrial Areas	0.21499	5
Transportation	0.15554	4
Commercial Areas	0.10787	3
Infrastructure and Utilities	0.05729	2
Institution And Public Facilities	0.02123	1

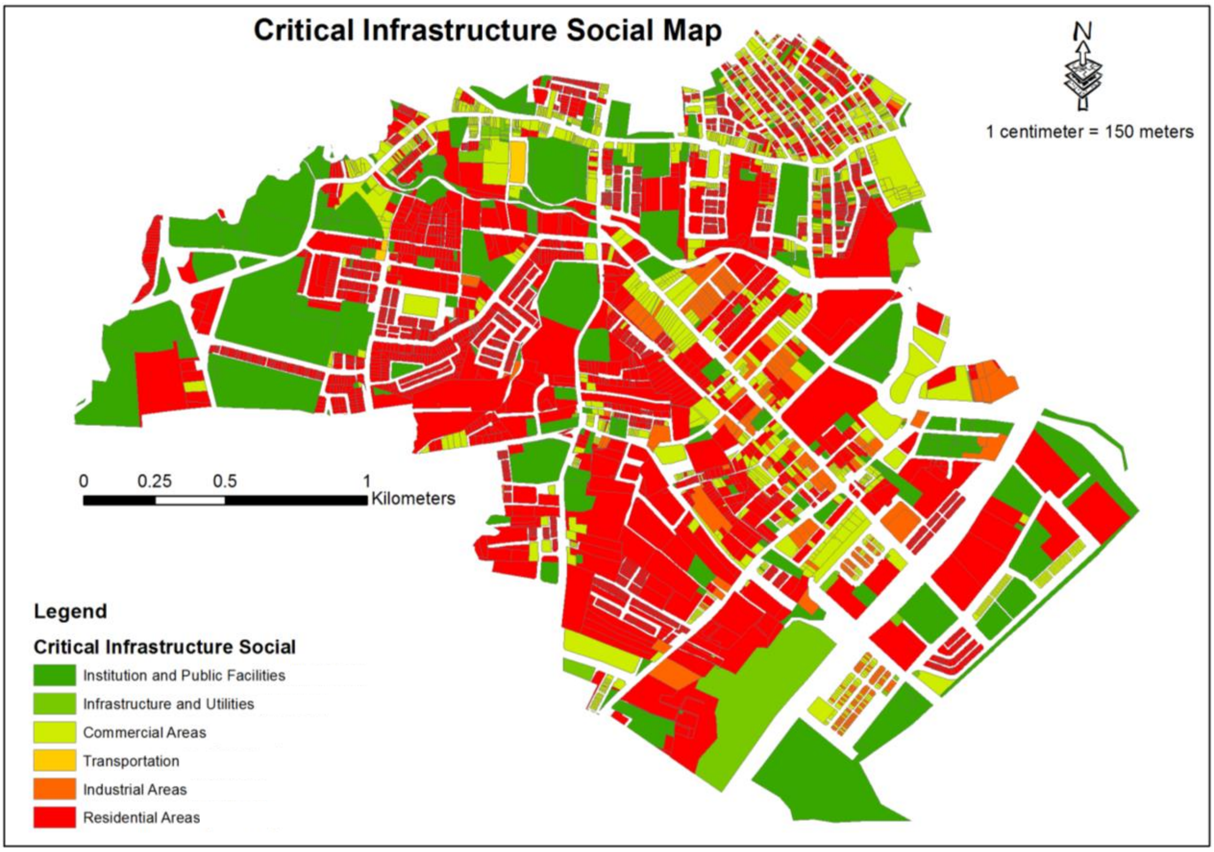

Figure 7.9: Critical Social Infrastructure Map

The results from the Critical Social Infrastructure Map (**Figure 7.9** & **Tables 7.11**, **7.12**, **7.13** & **7.14**) show the most vulnerable areas are mainly the Residential Areas (0.44307) while Institution and Public Facilities (0.02123) are deemed to be the least vulnerable areas.

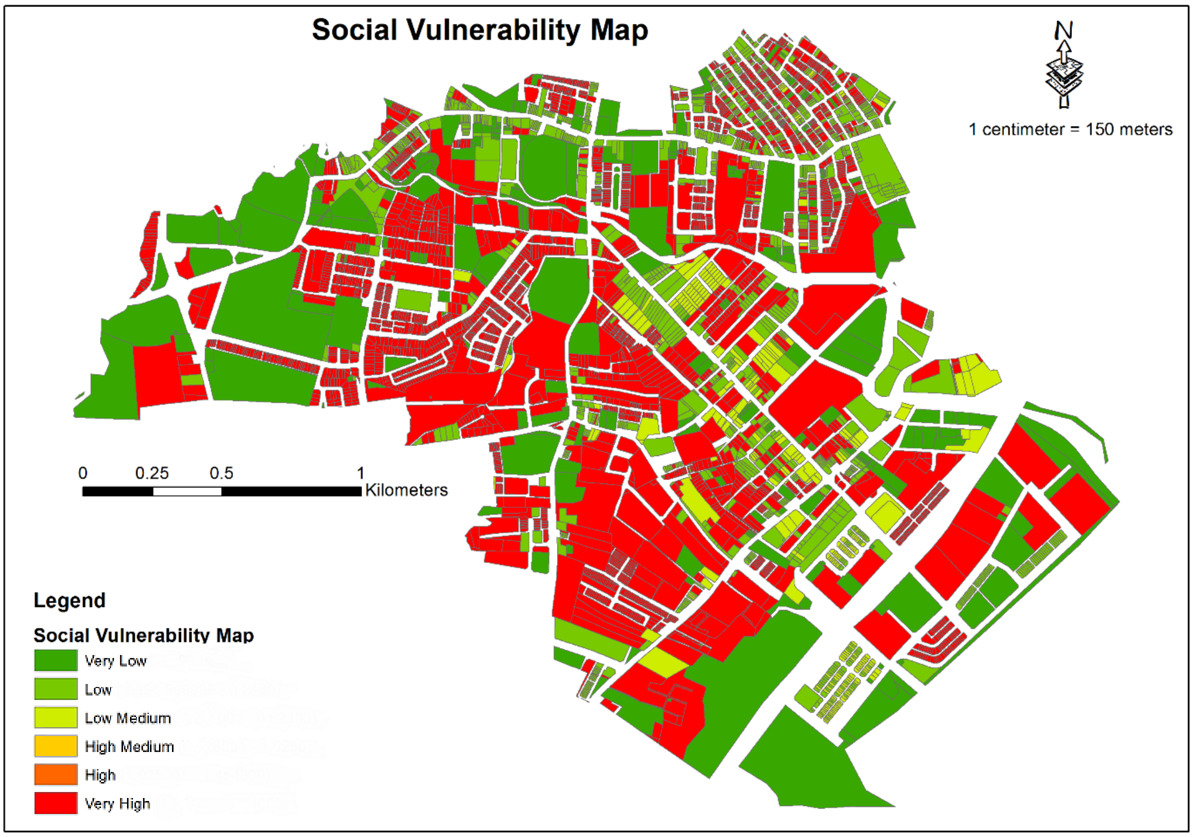

Figure 7.10: Social Vulnerability Map

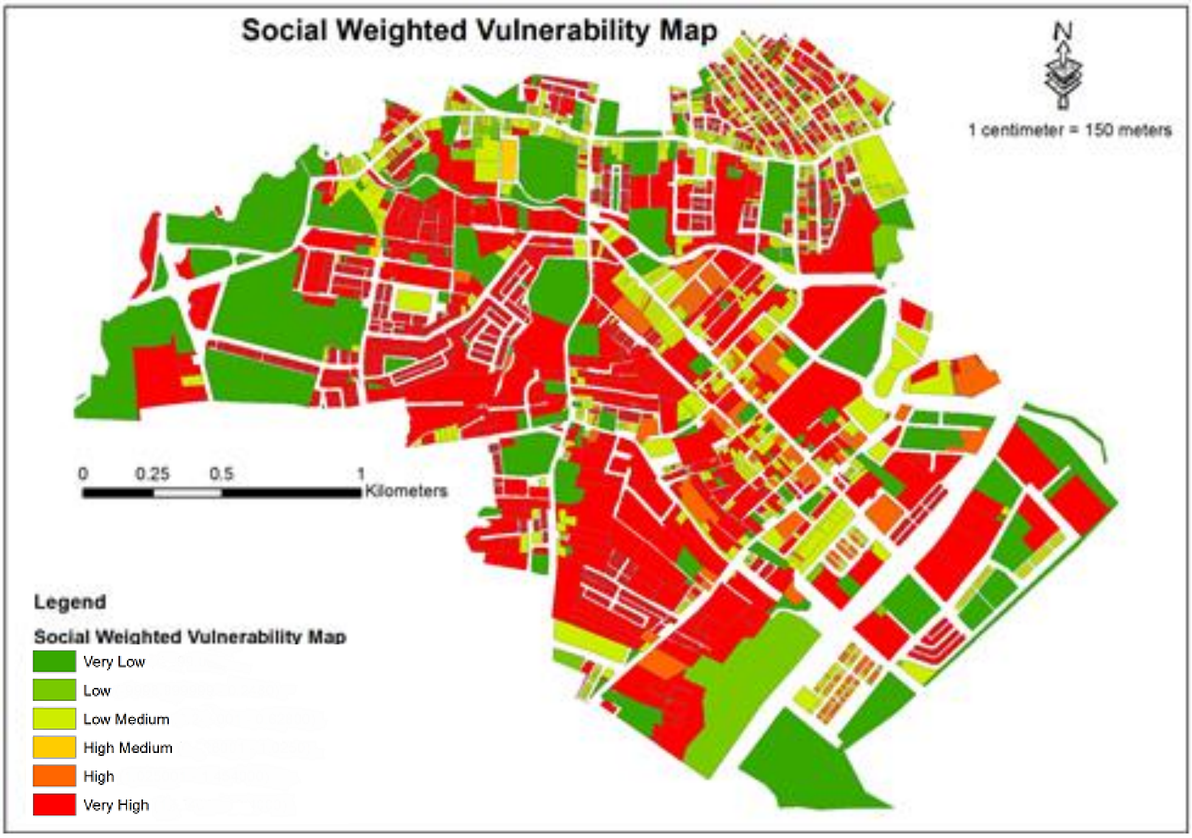

Figure 7.11: Social Weighted Vulnerability Map

Table 7.15: Comparisons between the Social Vulnerability Map & Social Weighted Vulnerability Map

Categories	Without Weight %	Area (m²)	With Weight %	Area (m²)
Very Low	6.3878	1178705.333	6.3878	1178705.333
Low	0.6407	158910.906	7.0285	1337616.239
Low Medium	24.6279	542241.518	24.6279	542241.518
High Medium	0	0	0.0754	10133.768
High	0.0754	10133.768	5.841	188333.969
Very High	68.2683249	2172034.59	62.4270	1983700.625
Total	100.00	**4062026.119**	**100.00**	**4062026.119**

Results in **Figure 7.11** and **Table 7.15** are derived using the formula as shown in **Equation 7.3**.

*Critical Infrastructure Social * Weighted (0.48) = Social Weighted Vulnerability Map*

Equation 7.3: How to Calculate Social Weighted Vulnerability Map

In the context of this study, the equation is as follows:

*Critical Social Infrastructure (**Figure 7.9**) * Weighted (0.48) (**Table 7.16**) = Social Weighted Vulnerability Map (**Figure 7.8**).*

Figures 7.2 to **7.8** show the flood vulnerability model maps based on social, economic and physical components using the Rank Sum method.

7.5 VULNERABILITIES MAP (WEIGHTED AND NON-WEIGHTED)

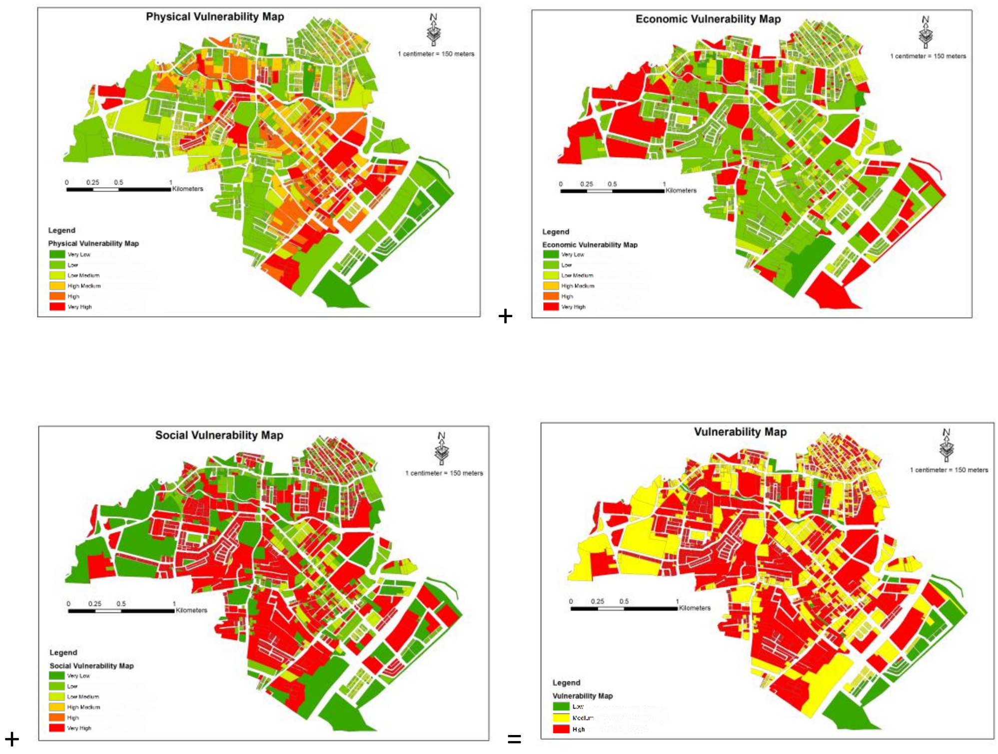

Figure 7.12: Calculation Results (Non-Weighted)

Using the average values from **Figure 7.12** and **Table 7.16**, the total sum of all three indicators (Physical, Economic and Social) equals to 1 as shown in the combined Vulnerabilities Map.

Table 7.16: The PES Vulnerability Assessment

Indicator	Total	Rank	AHP Result	Average
P	0.38156438	2	0.381564377	0.31
E	0.25461779	3	0.254617786	0.21
S	0.58719236	1	0.587192357	0.48

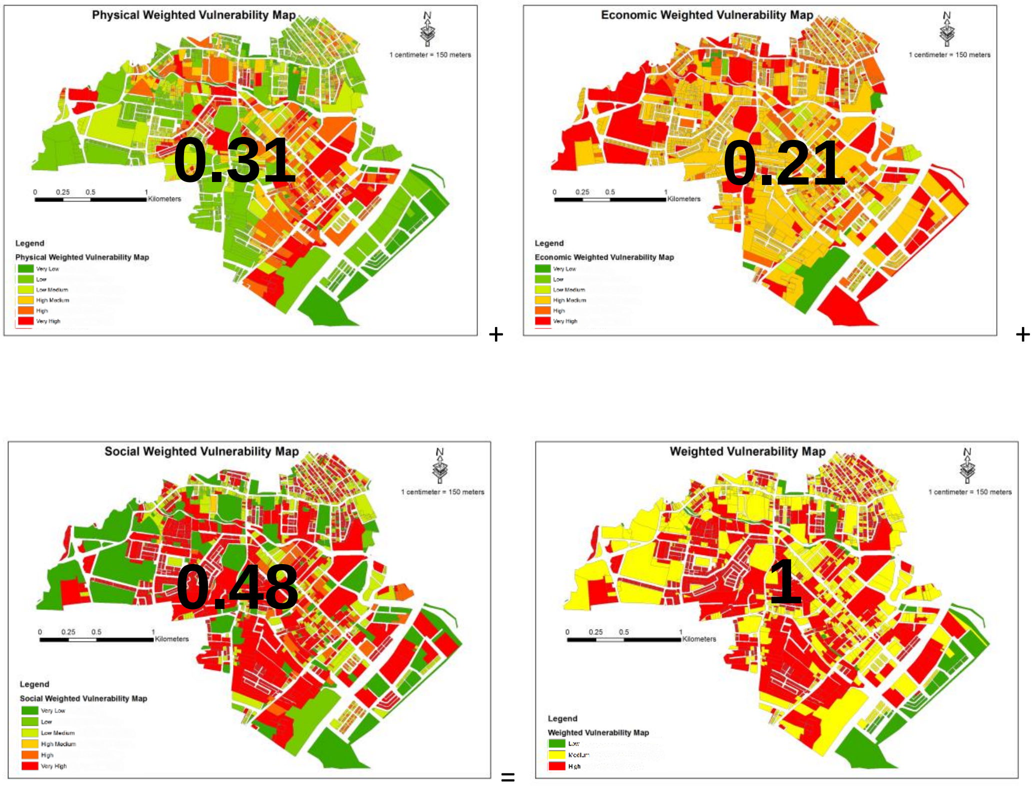

Figure 7.13: Calculation Results (Weighted)

The combined total value for AHP of each component; Physical (0.31) + Economic (0.21) + Social (0.48) returns a sum of 1 as indicated in the combined Vulnerabilities Map (Figure 7.10). The results also indicated that the Social component as being the most dominant component as it recorded the highest weighted value of 0.48 (Figure 7.13 & Table 7.16) when compared to the other two components.

7.6 COMPARISON BETWEEN THE VULNERABILITIES MAPS

After the final flood index vulnerability is obtained, the area of flood vulnerable areas for each district/region is calculated based on the FVI interpretation (**Table 7.14** and **Figure 7.14**).

Figure 7.14, **7.15** and **Table 7.14** show that both weighted and non-weighted maps do not demonstrate a significant difference as the available data is relatively limited and the weightage employed does not have a significant influence on the maps. Nonetheless, there are slight differences between the maps, as shown in **Figure 7.11** but largely at a minimal level.

The result of this analyses is what is known as a continuous map of suitability (Drobne & Lisec, 2009; Khalid, 2013). In this study, the output map through the Multi Criteria Evaluation (MCE) analysis was used to identify areas as prescribed by the Framework for Identifying Areas Suitable for Flood Vulnerability Index. These are areas that are expected to experience critical infrastructure vulnerability in the next few years (Khalid, 2013).

The generated hazard map highlights three categories as shown in **Figure 7.11**. The very low and low vulnerability areas (Institution) cover 4.504% of the total area while the very high FVI (Public Facilities) is 60.4673% out of a total number of 5,307 polygons (100%) within the study area (**Table 7.17**).

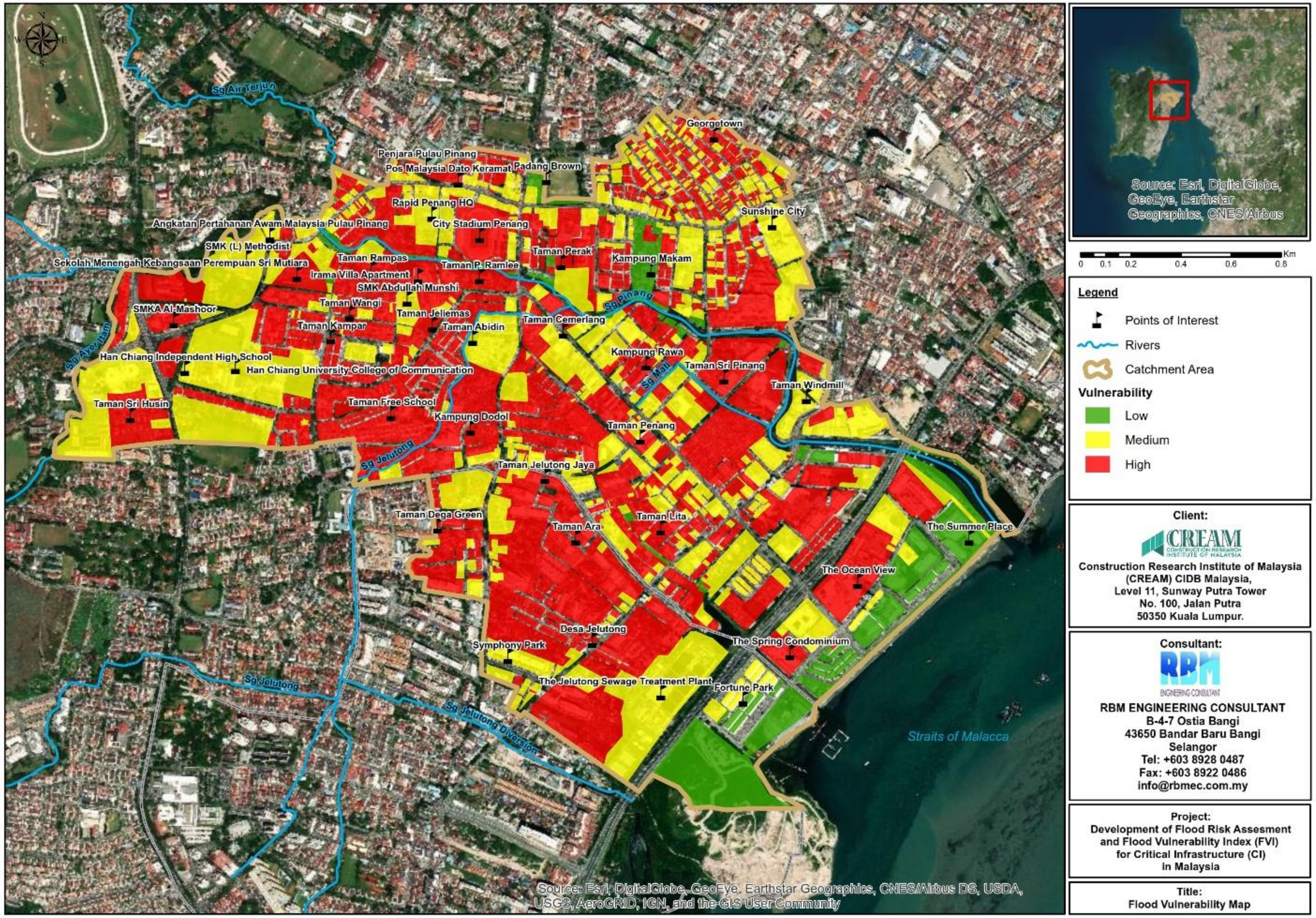

Figure 7.14: Vulnerability Map

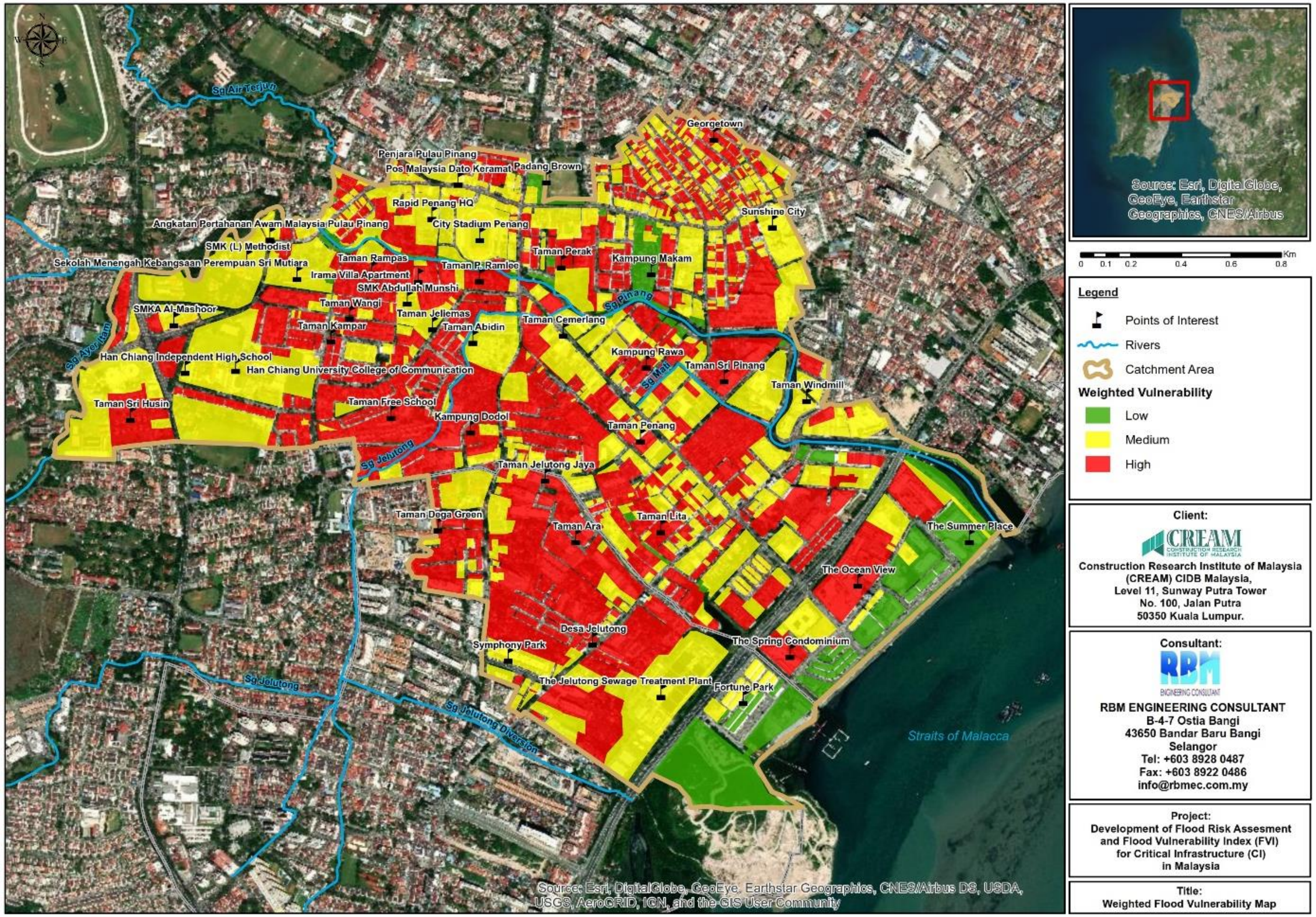

Figure 7.15: Weighted Vulnerability Map

Table 7.17: Comparisons between the Resulting Maps

Categories	Without Weight %	Area (m^2)	With Weight %	Area (m^2)
Low	4.22	351135.272	4.504	351135.272
Medium	32.6558	1501807.505	35.0287	1795120.208
High	63.1242	2209083.342	60.4673	1915770.639
Total	**100.00**	**4062026.119**	**100.00**	**4062026.119**

7.7 CONCLUSION

In recent times, Malaysia has experienced and suffered severe flooding, especially in the states of Kelantan, Pahang and Kedah. One of the most important part of flood risk management is to evaluate the vulnerability to floods. This study intended to highlight the potential vulnerability, integrating Geographic Information System (GIS) and Multi Criteria Decision Analysis (MCDA) to develop a Flood Vulnerability Index (FVI) map. For this study, three different vulnerability components, i.e. social, economic, and physical were considered. The criteria for each of these components were determined based on expert opinions and literature review. For this study only Pair-wise Comparison and Analytical Hierarchy Process (AHP) techniques within the MCDA were used. Based on these MCDA techniques, FVI models were developed and FVI maps were generated. The FVI is a powerful tool for mapping areas vulnerable to flooding which is crucial for future development or redevelopment efforts.

This study presents the methodology and technique used in mapping the flood vulnerable areas within Georgetown, Penang. This study aimed at providing expertise for preparing public-based flood mapping and estimating flood risks in growing urban areas. As mentioned, three different components of flood vulnerability (physical, economic and social) were utilized in this study. Two different MCDA techniques, namely, Rank Sum and AHP were used to calculate weights of each criteria. GIS was then used to model and map the FVI. The vulnerability criteria were then combined to determine the overall flood vulnerability index.

Findings have shown that the most vulnerable areas are mainly located at the Residential Areas (Social component score of 0.44307) as indicated in **Table 2.12**; Institution and Public Facilities (Economic component score of 0.44307) as shown in **Table 2.8**; and Infrastructure and Utilities (Physical component score of 0.2488) as recorded in **Table 2.4**, within the entire study area. Identifying areas with high flood vulnerability may guide decision makers and planners towards a better way of dealing with floods for the local communities as well as government flood related agencies for efficient flood risk management (Hadi *et al,* 2017).

The flood risk vulnerability mapping follows a multi-criteria approach for physical infrastructure such as Accessibility, Telecommunication, Flood Depth, Surrounding drainage system, Duration of flood and Flood warning system. Economic components that were considered were such as Recovery cost, Recovery time, affected dwellers, Premises close to the river, Building structure type and Type of economic activities. The Social component incorporated elements such as Population above 65 years old, Percentage of disabled people, Awareness and Preparedness, Female headed households, Low income households, Population under 20 years old, Past experience/knowledge about flood hazards, Social security for flood hazards, Female Population as well as Population of renting tenants.

From the vulnerability mapping within the case study area, the degree of vulnerability and exposure is also derived. The results are validated using flood depth measurements, with a minimum average difference of 0.248m and a maximum average difference of 2.4m in depth of observed flooding in the different flood prone areas.

In addition, the Consistency Ratio (CR) for critical social and economic infrastructure recorded an acceptable level of 0.568936948, while the CR for critical physical infrastructure was calculated at 0.028731878, thus further validating the strength of the proposed approach (Ouma & Tateishi, 2014).

Comprehensive flood vulnerability and risk analysis requires detailed information on field conditions. This approach proposed and employed in this study can aid decision and policy makers in the rapid assessment and evaluation of flooding phenomenon in urban municipalities (Ouma & Tateishi, 2014). The findings suggested that this approach is capable in assessing the spatial vulnerability of flood effects in flood-affected areas for developing effective mitigation plans and strategies, as prescribed by Hoque *et al.* (2019). However, it should be noted that collecting spatial data at the local scale and processing as well as integrating them for the spatial decision-making process in data-poor countries are highly challenging.

The AHP was useful for weighting the selected multi-criteria and spatial decision-making process. Results showed that vulnerability was greatly influenced when coping capacity was incorporated. Furthermore, validation of the results by providing reliable vulnerable information enhanced the applicability of this approach. This study presented a framework for the overall spatial flood vulnerability assessment that integrates physical and social vulnerabilities and coping capacity. The outcomes of this study were accompanied by a number of drawbacks. Numerous criteria are required to process and map effective vulnerability assessment. This verified approach can be applied in other similar environments for mapping spatial flood vulnerability by modifying the criteria, data type and scale if necessary (Hoque *et al,.* 2019). Improving vulnerability measurement is a necessary initial stage towards studying its main causes and the formulation of more accurate descriptions that can better decrease the loss of life and possessions (Hajar Nasiri *et al,* 2016).

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