

Flood Hazard Risk Matrix for Urbanization Control Area of Flood Plain

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Abstract. Identification and understanding the potential flood risk area are important elements in disaster risk reduction through development planning control plan. The development growth in Merlimau area causes demand for new urbanization area for residential, commercial and public infrastructure. Therefore, the risk of flood should evaluate to identify the possible future flood hazard-risk area based on future land use in Merlimau. This paper describes an approach to produce flood hazard and risk matrix and map using a combination of flood numerical modelling and Geographical Information System (GIS) analysis in Merlimau River Basin. The result from this study is a flood hazard risk map that provides information on flood risk level in Merlimau basin, which further can contribute to future development planning. This matrix and map identified as the risk areas that suggested being an Urbanization Control Area (UCA) to control future development. Six locations identified as the UCA that involved about 26.27 hectares. The analysis also shows almost 80% or 21.03 hectares of UCA already been planned for residential area and about 18% or 4.78 hectares for industrial area. There are only about 2% or 0.46 hectare of UCA remain in the future development plan.

1. Introduction

In recent decades, the process of human interaction with physical elements in the land has caused various problems including floods, landslides and soil erosion. Humans have the power to change the landscape of the earth to meet their needs; however, there is a need to consider the environmental impact. Sustainable land use in the development planning and any activities can reduce the risk of threatening human security [1]. In Malaysia, flood is one of the major disasters that show increasing trend in term of frequency and impact to people in the prone area year by year. Based on study by Department of Irrigation and Drainage Malaysia, 10% of Malaysia land is prone to the flood. It involves about 5.7 million people that vulnerable to flood. The Annual Average Flood Damage for Malaysia estimated about RM 1.15 billion [2]. Land-use changes and the way that land-use are occupied has a major influence on the flood damage potential and the degree of vulnerability of local communities. Urban developments along rivers induce a higher exposure to risk of newly developed



areas, with subsequent increases in the value of elements-at-risk. The overall economic output from flood plain areas can be significantly higher than in other areas.

The town of Merlimau in Melaka and its surrounding areas experiences rapid urbanization process. According to Department of Statistic Malaysia for the urbanization growth rate for Malaysia is about 71% in 2010 and for Melaka state is about 86.5% [3]. In Merlimau there is a high demand on residential, industrial and public institutional area. Therefore, it is essential to identify potential high-risk flood prone area in the Merlimau's future development planning in order to reduce flood exposure and vulnerability. In line with Sendai Framework, under seven global target items (d) & (g): that, identification and understanding of the potential flood risk area is the important element in disaster risk management and reduce the potential damage [4]. It can be one of disaster-risk reduction strategy through development planning control plan in the sustainable development approach. So that, a good mechanism needs to create in this case to ensure the development can balance to meet the requirement of people need and at the same time taking into account the safety of the people and their properties from the disaster risk.

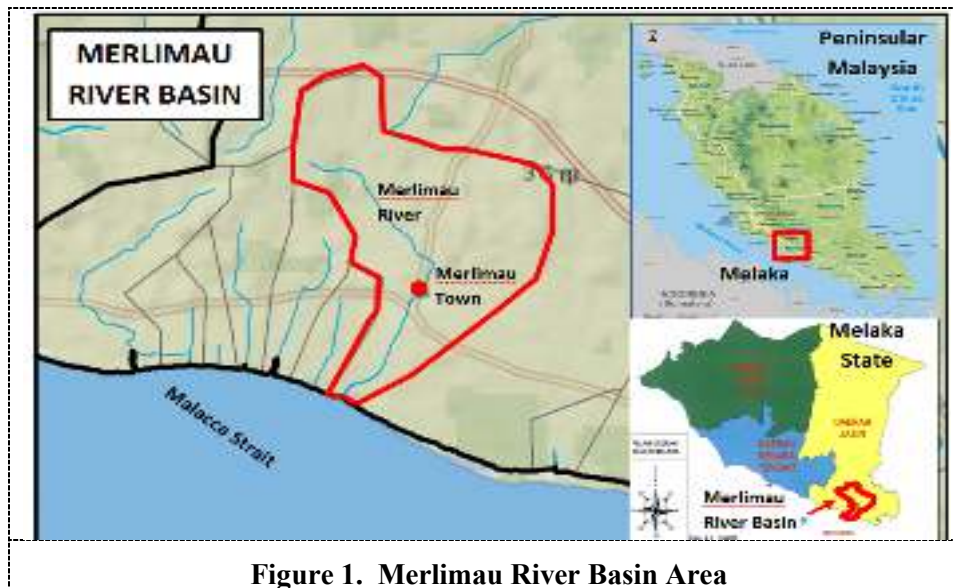
An integrated approach for development planning and control land use planning is helpful for reducing disaster risk of infrastructure systems, such as water-related infrastructure, which comprises different components and potentially crosses diverse geologic areas. This is to make sure the continuity between the national policy and the implementation on the ground through the development planning and local plan to achieve the objective. With controlling the development and land use, it can be an effective tool to regulate development in hazard-prone areas and thereby reduce the exposure of people and property to hazards. For example, we can impose on unstable slopes that development can be restricted. The area may suitable for open recreational purpose or open green space for public use. In case of the areas with flood risk especially in flood plain area, the zoning planning can require the ground floor of news building to build above the base flood elevation. If there is existing building, the municipalities can imposed or give an initiative to the owners to prevent the building with the flood proofing measure [5].

The aim of this study is to identify the flood risk area and flood plain control based on Flood Hazard Risk Matrix and Flood Hazard Risk Map for flood plain management and planning. The matrix development based on combination of the probability of a flood event, flood depth and flood velocity. Here, flood hazard maps identify the flood extent, flood depth and flood velocity in Merlimau flood plain with various probabilities through the hydrodynamic analysis. The identified potential flood risk area formed an Urbanization Control Area (UCA) in a flood plain based on the analysis of Flood Hazard Risk Base Map.

2.0 Study Area and Flood Plain Mangement Model

2.1 Study Area

Sungai Merlimau basin is located in Jasin District southern part of the state of Melaka, Malaysia. The catchment is approximately 12.84 km². It flows approximately 7.4 km toward the southwest to the Straits of Melaka. This basin is small river system and is a part of Sg Kesang catchment. This catchment mainly covered with residential area and plantation while the southern part are generally swamp and flat with paddy as the main agriculture activities. There are series of flood event in Merlimau on 2001, 2006, 2008 and 2009. Flood occurs several times in the year due to existence of narrow and shallow river sections, compounded by constricted culvert, bridges and irrigation weir [2]. Figure 1 shows the location of the Merlimau River Basin.



2.2 Flood Plain Management Model

The model for flood plain management for this study was referring to the hazard risk matrix that based on the damage severity. The hazard risk matrix consists of the vulnerability classification and probability of flood occurrence. The vulnerability classification for the matrix is referring to damage level. It based on flood depth and velocity that referred to several literature reviews. In most countries, flood damage is a function of flood depth. The higher the flood depth, the higher the estimated flood damage for a particular property or land use type. A sample of a flood damage/depth table and curve from the Multi Coloured Manual (MCM) handbook used in the United Kingdom is show in Figure 2. All other countries use a similar depth/damage curve approach to estimate flood damage onto properties and land uses including Singapore, Australia and the US. This damage-level used to set the beginning of the flood depth that gives minimal damage until the severe damage [6]. The Shiga Prefectural, Japan has made a basic policy for flood plain management in order to reduce flood impact. The prefecture formulates one ordinance in March 2014 was known as integrated flood management ordinance that covers land use and building regulation based on the new development risk evaluation method. This method has replaced the existing method that lacks of flood high-risk area. To improve the existing method, the Shiga Prefecture formulate flood hazard risk matrix that can determine the potential hazard/risk area. The matrix incorporated in implementing the Shiga Integrated Flood Management Ordinance to plan the land use activities and building regulation for the risky area. The ordinance states the areas whose estimated submerge higher than 0.5 m in a 10-year flood probability prohibited from inclusion in the urbanized promotion area. The area will be under Urbanization Control Area (UCA) as stipulated by the City Planning Law. The fluid force also being used as a parameter to determine the damage level which fluid force exceeded $2.5\text{m}^3/\text{s}^2$ will classify under level 5 [7].



Figure 2. Example Flood Stage-Damage Curve for retail building in MCM Handbook (Penning-Roswell et al., 2013)

3.0 Methodology

Before producing flood hazard risk matrix and maps, hydrodynamic modelling of the Merlimau River basin has to be carrying out first. Hydrodynamic modelling of the catchment is a crucial stage in which state-of-the-art computer hardware, software, GIS and programming technologies. These hardware and software are applied to simulate the hydrological responses of the catchment, as well as the hydrodynamic flow characteristics of the of flood, flows in the rivers and flood plains in order to represent as closely as possible the actual site conditions of the study area. The development of flood hazard risk matrix and map workflow shown in Figure 3.

The process involved in this stage includes data collection and site investigation. Among the available and relevant data and information are previous reports, flooding records, rainfall records, hydrological data, flooding extent, river survey, topographic maps, and development planning land use maps, Digital Terrain Model data, engineering survey data, and other related data and information. The site visits and field investigations process are to identify the flood historical information and data from target group. All the necessary site visits and field investigations carried out to ensure a better understanding of the present state of flood conditions and to determine the related flood issues within the flood-affected areas.

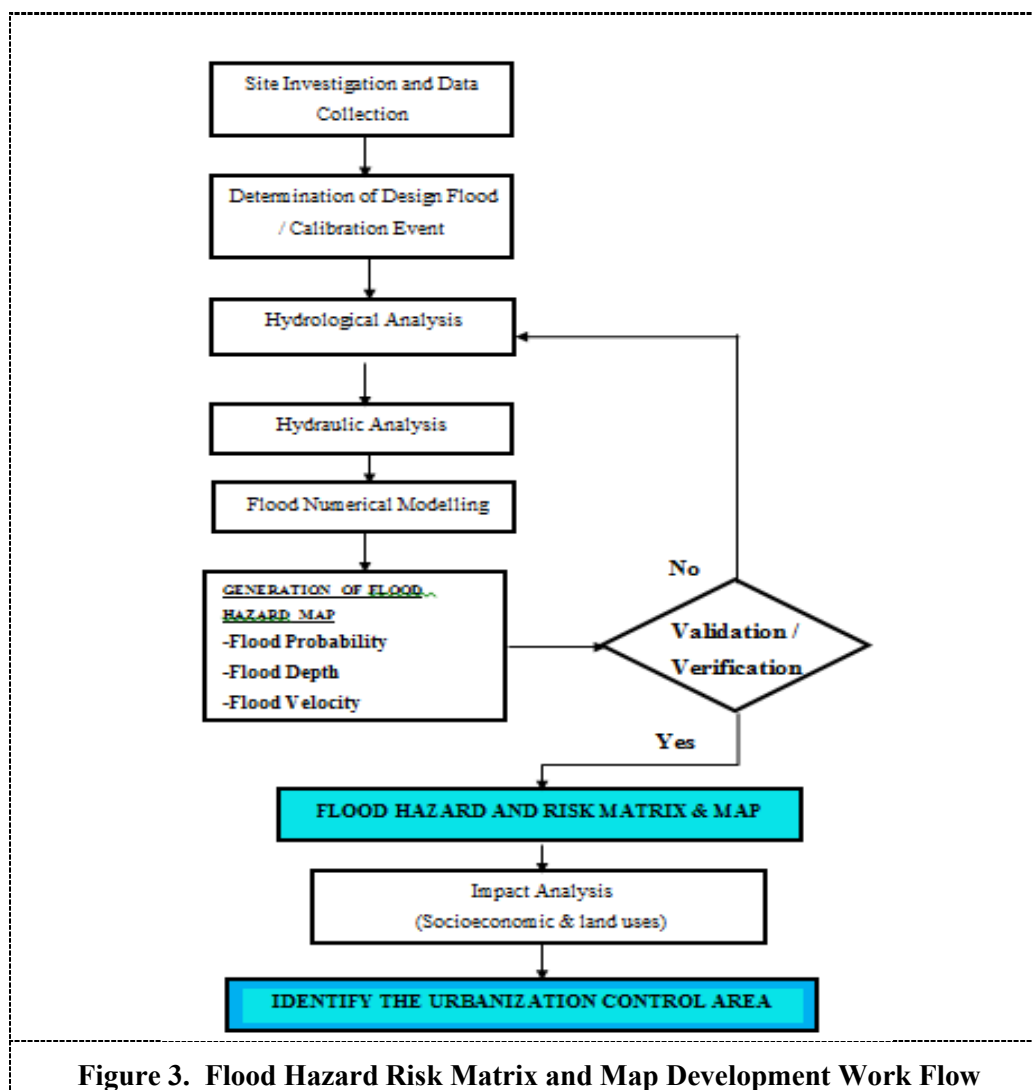


Figure 3. Flood Hazard Risk Matrix and Map Development Work Flow

3.1 Hydrology and Hydraulic Analysis for Flood Modelling

The hydrological analysis is a vital process to determine the potential flood area. The rainfall record and the hydrological parameters are the need to identify for the catchment in order to get a better flood potential area. There are various techniques in estimating design flood discharges. The techniques broadly categorized such as Regional Methods, flood frequency analysis using various methods and rainfall-runoffs simulating in order to obtain the inflow hydrograph. This repeated for various average recurrence intervals (2, 10, 20, 50, 100 and 200-year ARIs). For this study, the design rainfall based on Hydrological Procedure (HP1) that produces by the Department of Irrigation and Drainage Malaysia [8].

Hydraulic analysis and modelling require precise data of the river characteristics such as hydraulic structures across the river. Hydraulic equations used to calculate water depth and velocity. Depending on the size of the river system, the hydraulic model can be one dimensional (1D), two-dimensional (2D), or three-dimensional (3D). The parameters that produce from hydraulic analysis and modelling are floodwater depths, flow velocities, flood extent and flow propagation for various ARI. The input hydrographs from the hydrological analysis used for the hydraulic analysis. Flood simulation models may have different requirements, depending on their objectives. The flood simulation modelling software used in this study is InfoWorks ICM. In preparing the flood maps and deciding the best flood mitigation solution, integrated use of one-dimensional (1D) and two-dimensional (2D) hydrodynamic (HD) models is utilized as it can simulate the river and the flood plain interaction. The 1D model used for water level assessment along the axis of the water body. In generating flood flows at the flood plains, which requires more complex computations, a 2D model is used [9].

3.2 Flood Hazard Risk Matrix and Map Generation

The production of flood hazard map was used input from several sources including the results hydraulics model and GIS data. With the results of the 2D hydraulic analysis, the flood extent, flood depth and flood velocity 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 development of flood hazard risk matrix will base on the probability of flood occurrence that The development of flood hazard risk matrix was based on the probability of flood occurrence that refers to the return period for rainfall size. The probability was on y-axis or and the x-axis will be damage level. Determination of damage level will adapt from several literature reviews including The Shiga Prefecture's Risk Matrix for Land Use Regulation. The damage level represented the vulnerability level for the urbanization that refers to residential, public building and commercial building. The potential damage level was set to depend on the depth and velocity that will causes of losses in term of damage of building and unsafe to the people. The damage was be classified into five (5) levels. The Level 1 would indicate no damage and the Level 2 indicates minimal damage from inundation of ground level of the building. Meanwhile, Level 3 indicates severe damage from inundation that exceeded the Level 2 but not fully submerged and Level 4 indicates severe damage from fully submerged. Level 5 is depends on the high velocity that will destroy the building. If the flood velocity for the certain area is above the velocity that set in Level 5 the damage level will fall under the Level 5 stage even though the depth is shallow. The potential area to be in Flood Plain Control area is base from damage Level 3 and above under the two probabilities which are 2 ARI and 10 ARI [7].

Flood hazard risk map produced based on the hazard map output and the matrix. The hazard maps that generated from various probabilities will produce all the information about depth and velocity. Various depth and velocity from 2-D flood plain analysis represent in a mesh point. The 2D zone area is using mesh type and the area for each mesh is set around 2500m². The different mesh will produce different depth and velocity base on the flood behaviour on the flood plain. This information was determined the damage level base on the vulnerability criteria. The Flood Hazard Risk Map presented

in different colour coding base on the degree of risk. Darker colour will represent higher risk and the lower risk with brighter colours. To identify flood plain control area that to being suggested as UCA in development planning, the Flood Hazard Risk Map was overlaid with the existing land use in Geographical Information System (GIS) application. The selected area to be UCA normally is the agriculture area, river reserve, rural area, and forest. Existing urbanization area excluded from these criteria.

4.0 Result and Discussion

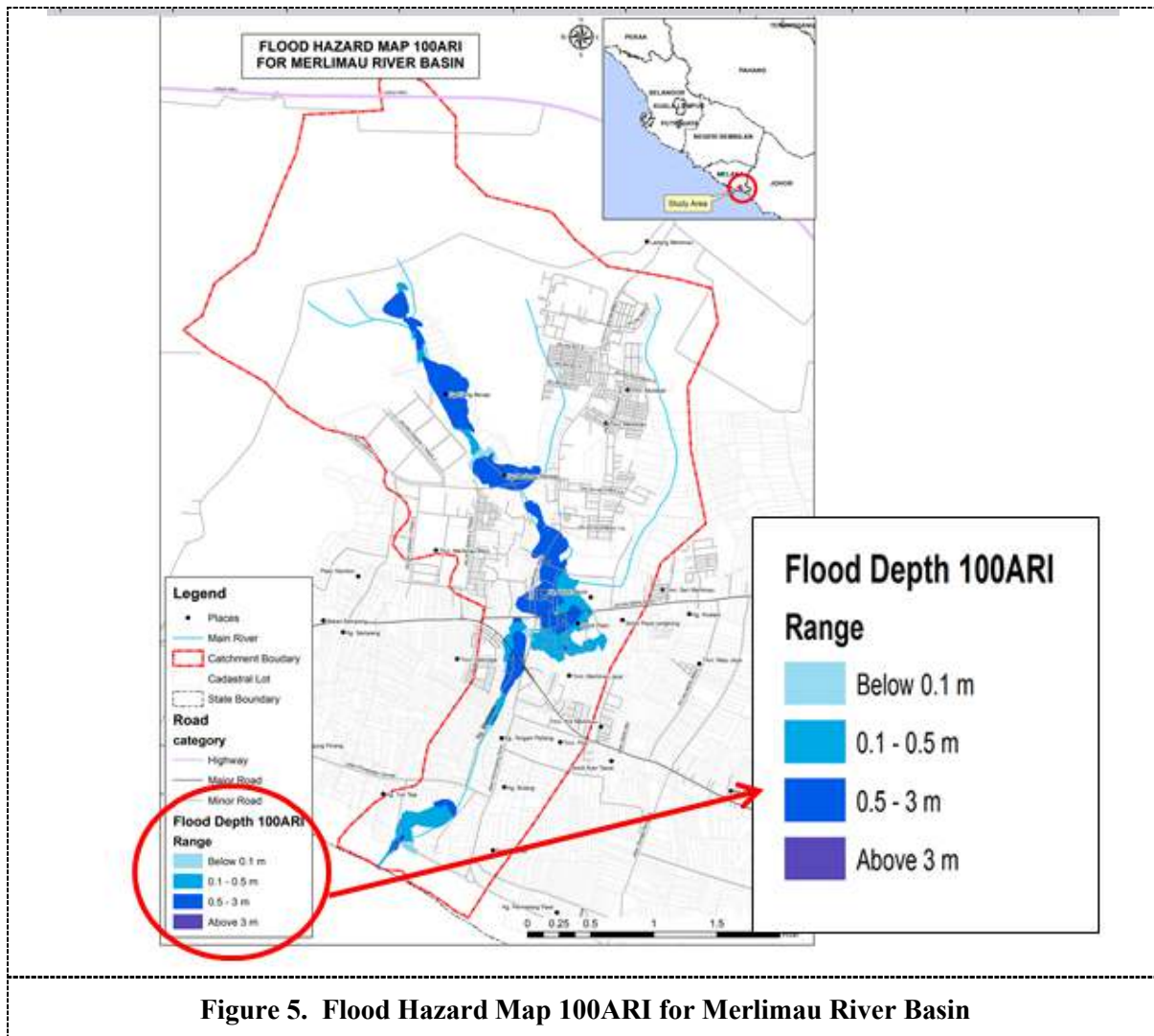
The final production of flood hazard risk matrix is based on the probability of flood and the damage level that based on two parameters, which are depth and the depth time velocity. The probability is on y-axis or and the x-axis is damage level. Determination of damage level is adapted from several literature review including The Shiga Prefecture’s Risk Matrix for Land Use Regulation and Australia’s hazard vulnerability classification. The overall concept is based on the second parameter for damage level which is depth time velocity (h x v) the value adapted from Australia’s hazard vulnerability classification. The damage level represented the vulnerability level of potential losses in term of damage to building and unsafe to the people. Figure 4 shows the final hazard risk matrix that been used for this study in determined the potential flood risk area in Merlimau basin.

2 ARI (0.500) 10 ARI (0.100) 20 ARI (0.050) 50 ARI (0.020) 100 ARI (0.010) 200 ARI (0.005)	Probability			High Risk		
			Medium Risk			
		Low Risk				
		Very Low Risk				
Note: Flood Plain Control Area / Urbanization Control Area	Vulnerability Classification	Damage Level				
		1	2	3	4	5
	Depth (h)	$h < 0.1m$	$0.1m < h < 0.5m$	$0.5m < h < 3.0m$	$h > 3m$	
Depth (h) x Velocity (v)		$< 4 m^2/s$			$\geq 4m2/s$	

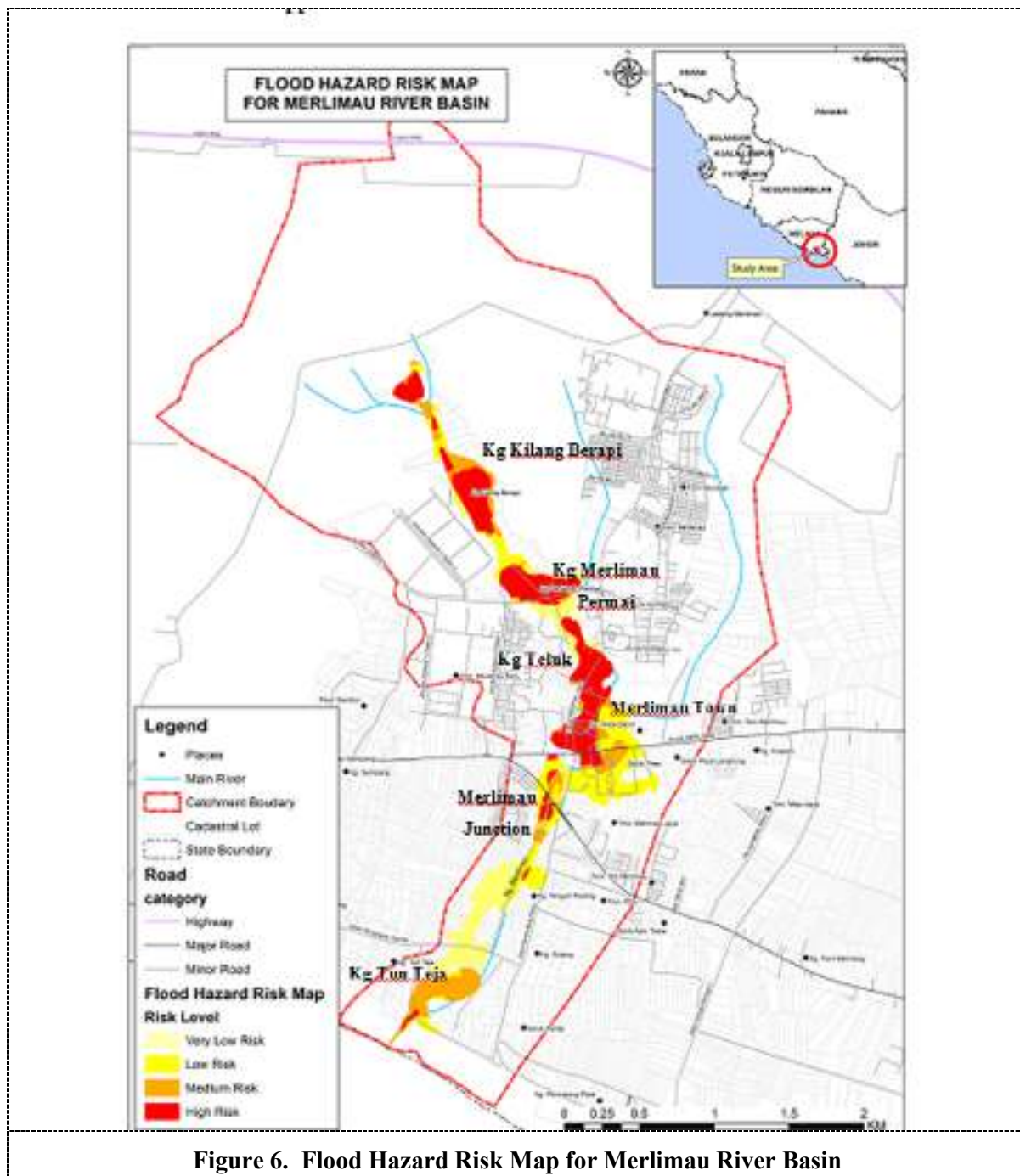
Figure 4. Final Hazard Risk Matrix for Merlimau River Basin

4.1 Flood Hazard Map and Flood Hazard Risk Map

The results of the 2D hydraulic analysis from the numerical model including the flood extent, flood depth and flood velocity exported to the GIS software for the processing and producing flood hazard maps. The map produced for various probabilities begin from 2ARI until 200ARI. The flood depth range that shows in the flood hazard map based on hazard risk matrix following the damage level category. There are four (4) levels in flood depth range as shown in Flood Hazard Map in Figure 5.



In determination level of risk, it will rely on the damage level and the probability flood to occur. If the damage level on Level 3 but the probability is 0.01, (100ARI) or 1% floods to occur, the risk level in on ‘low risk’ classification. The potential risky area to be in UCA area is set from damage Level 3 and above under the two probabilities which are 2 ARI and 10 ARI (Ichidate et. al., 2016). Four ranges are set in this result of matrix development, which are Very low risk, low risk, medium risk and high risk. The flood data were analysed in the attributes table in GIS for each probability. The depth, velocity and combination of depth and velocity were calculated and analysed. The value sorted and range based on the matrix that been developed. The hazard risk matrix map has been produced based on the data that been analysed. The level of risk range will be set in GIS software based on the matrix for each probability. Then the map for each probability combined with overlapping the entire layer. The high-risk layers arranged in the upper position while the low risk layer in the bottom position. Figure 6 shows the final hazard risk matrix for the Merlimau River Basin



4.2 Urbanization Control Area (UCA)

The hazard risk map that has been produced for Merlimau River Basin produce the high-risk area for all probability. To identify flood plain control area that suggested as UCA in development planning, the area is located in the high-risk area overlaid with 2ARI and 10ARI probabilities. Besides that, the high-risk area also overlaid to the existing land use / current activities in Geographical Information System (GIS) application. The objective to identify UCA is to avoid and prevent in any new urban development planning exposed to the high-risk flood impact. The UCA is about 26.27 hectare that involved six (6) locations. Figure 7 shows the UCA for Merlimau River Basin.

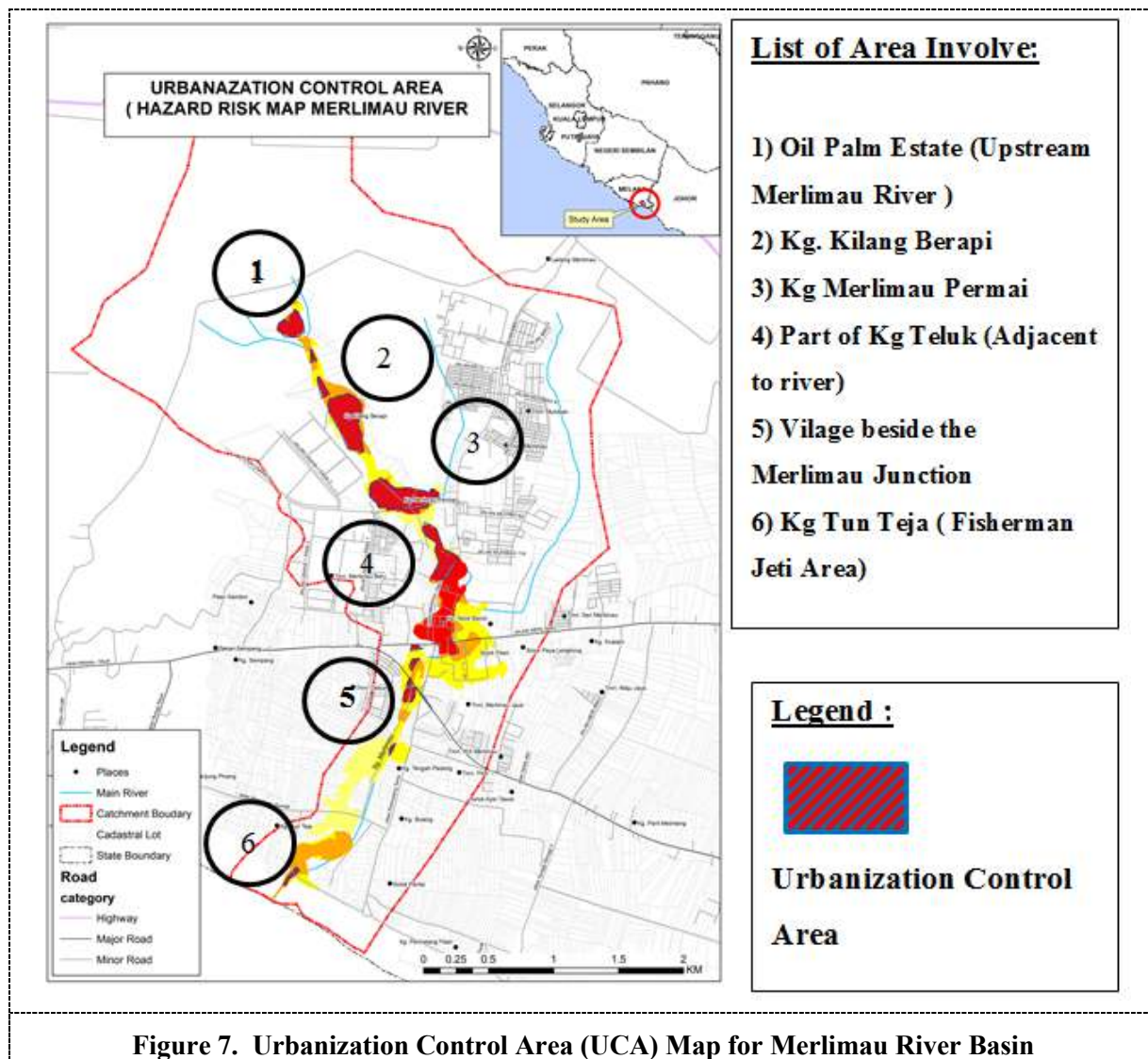


Figure 7. Urbanization Control Area (UCA) Map for Merlimau River Basin

The identifying of potentially high-risk area can be one of tool to make sure the development planning in a local plan did not give adverse impact to the people especially in a disaster. In this study, besides identifying the flood plain control area also known as UCA, it also had done some analysis with comparing between the future land use planning. The UCA map overlaid with the future land use planning for Merlimau River Basin to identify the level of exposure to the risk. From the analysis on the map, it found almost 80% or 21.03 hectares of UCA been planned for residential area and about 18% or 4.78 hectares for industrial area. The balance 2% or 0.46 hectare of UCA remain as water body and forest at Kg Tun Teja as before. The location of Kg. Tun Teja is in the downstream part of Merlimau River. This matter needs to be review and take into further action on the development planning policy in this area. The potential high risk area should take into account in the development planning in a local plan especially in assess the vulnerability level in facing the disaster risk for certain area. As an example in Merlimau area itself, the development of a new town known as Bandar Baru Merlimau Utara is a good development planning because the area is free from flood. The topography at the area is quite high and the location is strategic to the main access. The new town also has a new polytechnic and new residential area. The urbanization should focus on that area rather than chose the high-risk area, especially in the low-lying area.

5.0 Conclusion

A good development planning can be an effective tool to regulate development in hazard-prone and risk areas and thereby reduce the exposure of people and property to hazards. In this study, the development of hazard risk map can provide insights and help relevant agencies in planning future development. Additionally, by identifying high-risk areas for floods, planning can be making more sustainable where it not only takes into account current needs but also towards a safer and environmentally friendly future. The objective aim in this study has achieved with the development of flood hazard map, hazard risk matrix, and map and identify the high-risk area that suggesting being UCA. From the analysis, there six (6) area identify as UCA which are at oil palm estate at the upstream Merlimau river, Kg. Kilang Berapi, Kg Merlimau Permai, Kg. Teluk,, at village area at the Merlimau junction and Kg Tun Teja.

This study has resulted in a faster and easier mechanism or method in assessing the risk level of an area. The use of matrix in assessing risk is an easy-to-understand way that allows it to be widely used more quickly. The development of this flood hazard risk map, allowed planners to re-evaluate the future development planning especially at the flood plain area. If it is not possible to change the plans, the maps and recommendations of the UCA also may use as guidance in giving approval to the committed development.

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