Research Journal of Earth Sciences 1(1): 22-27, 2009
ISSN 1995-9044

Integration of 1-d Hydrodynamic Model and GIS Approach in Flood Management Study in Malaysia

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Abstract: Understanding of flooding behaviors required both spatial and numerical approaches. This can be achieved by integrating powerful spatial data management such as Geographic Information System (GIS) with hydrologic and hydraulic models. This article discusses the development of hydraulic model using XP-SWMM, a 1-D hydrodynamic model to simulate flood water of Damansara River at TTDI, Selangor. The simulation was focused on the time of water filling and volume of flood discharge (m^3/s) over the floodplain. The result showed that time travel for flood water to reach crest level of 1.23m is only 1 hour 30 minutes. This when converted to flood volume are approximately 100 m^3/s covers an area of approximately 107 hectares of flooding area. The hydrograph indicates that time travel to rise is only 30 minutes. The results demonstrate the advantage of the integrated tools of ArcView GIS and XP-SWMM as hydraulic software in producing a Flood Hazard Mapping for Urban Area (FHMUA) in the study area.

Key words: Geographical Information System % XP-SWMM % Flash flood % River hydrodynamic model % Flood Hazard Mapping

INTRODUCTION

Since 1973 national flood disaster, floodwater management became a growing topic of discussion among government, researchers and private industries in Malaysia. Over 35 years, flood magnitude and frequency were increased tremendously especially triggered by human activities in many circumstances change flood behavior [1-3]. Activities in the flood plain and catchment including land clearing for urbanization or agriculture, construction of infrastructures such as highway, road and bridges in the flood plain were altered the magnitude of flood [5].

Report from Department of Irrigation and Drainage, Malaysia stated that about 29,000 km^2 or nine percent of total land area and more than 4.82 million people (22%) is affected by flooding annually with damage cause by flood is estimated about RM915 million [6]. Residents lived in low land, close to river bank and flood prone areas were identified as most vulnerable to flood hazard. The impact relatively is bigger especially when it happened in urban areas. Area such as Damansara River catchment, the low land areas have suffered from severe flood damages every year. It has resulted in loss of life, damage to property and had negative impacts on human welfare. Flooding associated with so called "flash floods" is common in Malaysia. Most of the major urban areas experienced in flash floods which normally occurred during monsoon seasons from November to March (North-East monsoon) and May to September (South-West Monsoon). The basic cause is the incidence of heavy monsoon rainfall and the resultant large concentration of run-off, which exceeds river systems [7, 8]. Rapid urbanization within urban river catchments have also served to compound the problem with higher run-off and deteriorated river capacity that have resulted in increased flood frequency and magnitude.

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Table 1: Details of Damansara River system and its tributary

River/tributary	Length (km)	Catchment area (km^2)
Damansara	16.20	41.90
Kayu Ara	13.00	32.45
Air Kuning	09.20	19.69
Rumput	08.50	17.68
Pelampas	09.00	21.17
Payong	04.50	07.03
Pelumut	05.50	07.99
E	65.90	148.00

In this circumstance, urban activities were causing more and more urban areas becoming sensitive to short duration with high intensity rainfall that lead to flash flood (2 to 5 hours). With heavy rain between 2000mm to 3000mm a year, flash floods are one of the most common hazards after monsoon floods. The hazard brought much disruption to the livelihood of the urban people. In many incidents, homes were flooded and residents were forced to evacuate. In addition, traffic flows were disrupted and occasionally, some lives were lost due to drowning. Several special episodes of flash flood were occurred and recorded over the Damansara areas namely on December 1995, 6 December 1999, 5 January 2000 and the current was on Sunday, 26 February 2006.

In Damansara, the depth of the flood water was reported to vary from 0.3 to 2 metres forcing more than 11,000 peoples to evacuate during the flood event [9]. Every year, Government through their agencies is keen to provide up to date information on flood hazards and related program. One of them is through non-structural approach by promoting the Flood Hazard Mapping for Urban Area (FHMUA). The project conducted by Government agencies in collaboration with international bodies with the aim to provide better understanding not only of general knowledge on flash flood hazard but also professional knowledge and techniques in preparing flood hazard map. These techniques included flood routing, topographical maps, GIS and Inundation analysis. This paper presented the work carried out in Damansara River, specifically the Taman Tun Dr Ismail (TTDI) residential area using XPSWMM for hydrodynamic model and GIS tools for generation of FHMUA.

Study Area: Damansara River (CA = 148 km^2) is one of the major river systems within the Kelang River Basin. The study area, namely Taman Tun Dr Ismail (TTDI) (E area = 107 hectares) was selected due to severe flash flood that occurred in 26 February 2006. This resident area, situated at the confluence of two rivers (Air Kuning and Damansara) has undergone rapid and drastic development over the last 20 years (Fig. 1). Other areas that vulnerable to flash floods are Subang Jaya and Shah Alam. Damansara River catchment is now estimated to have a population of about 245,000 in the year 2007. The area contains important industries and areas of commercial and economic significance to the state. The lengths and corresponding sub-catchment areas are shown in Table 1.

In term of hydrological region, the study area is located at L_5W_2 which categorized as region with loose clayey and sandy deposits with runoff is between 2300mm to 2600mm year^{-1}. The L_5 has yields varying from more than 200 m^3/day/well from Shah Alam to between 50-200m^3/day/well at Petaling Jaya. The average annual rainfall depth at the study area is approximately 2,400 mm ranging from 1,800 to 3,000 mm (Petaling Jaya Meteorological Station-lat. 3º8'; long. 101º44'E). A trend of gradual increase in rainfall from the coast towards the hilly areas prevails. The highest rainfall occurs in the month of

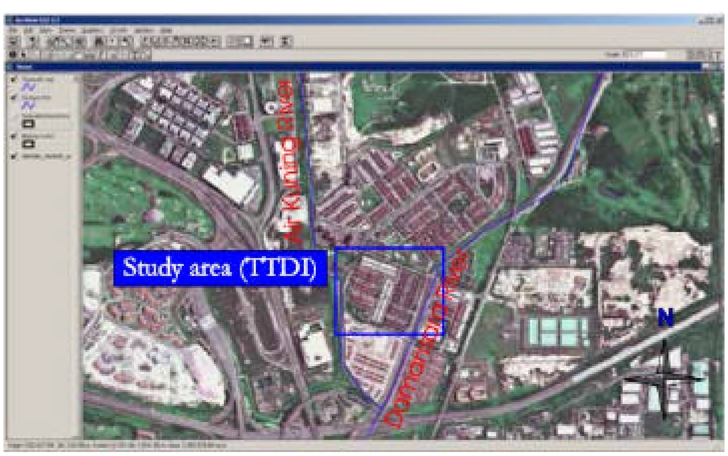

Fig. 1: Location of the study area (TTDI), Damansara River and Air Kuning River

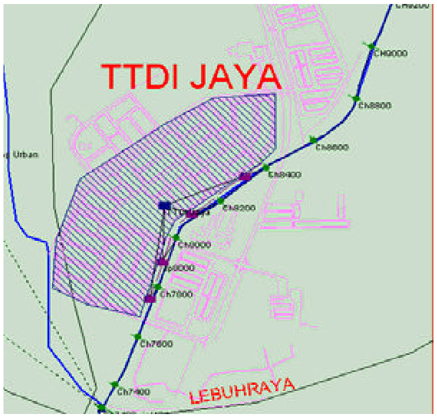

Fig. 2: Sample of hydrographic survey at Damansara River

April and November with a mean of 280 mm. The lowest rainfall was recorded in the month of June with a mean of 115 mm. The wet seasons occur in the transitional periods the monsoons, from March to April and from October to November. [10] showed that about 40 percent of all heavy rainfalls exceeding 50 mm/day at most stations in Selangor occurred during the intermonsoon months. The thunderstorm rainfall although is of short duration, its intensity can be surprisingly high over a small area giving rise to flash flood events [11].

Experimental Design

Hydrographic Survey: The main input for the hydraulic model is the river cross section. The cross section survey was carried out on 04-20th November 2007 at 50-100m interval which extent up to 50m each side of the river bank (Fig. 2). All together, about five cross sections (or nodes) were surveyed involving the coordinate longitude latitude and the ground value. For the purpose of the study, only downstream part of the river system was used to develop the flood extends.

River Hydrodynamic Model Development: The hydraulic model was developed using XP-SWMM software. It is a 1-D hydrodynamic model which is able to simulate steady and unsteady flow [12]. The main input to the model is rainfall, river cross section, spill level and flood plain information. For the proposed of this study, the simulation is focus on the rate of water travel from the upper catchment before overtop and filling the TTDI area. The hydraulic model for Damansara River is shown in Fig. 3. Calibration was carried out using the flash flood event of 26th February 2006. This event is considered as the worth flood over the last 20 years [13]. A heavy rain occurs in Damansara Catchment from 3.00 am until 6.00 am causing an increased on water level as shown in Fig. 4.Total rain exceeds 100mm which caused water level in Damansara River increased rapidly and overtop the wall along TTDI Jaya. The flood water caught the resident by surprise and within 1 hour, about 80 percent of the housing estate was flooded up to 1m.

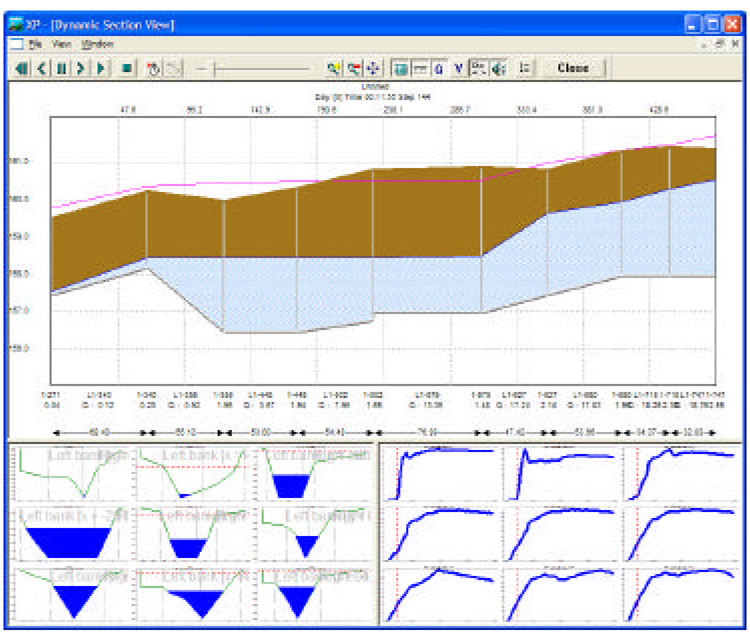

Fig. 3: Hydraulic Model for Damansara River along TTDI Jaya

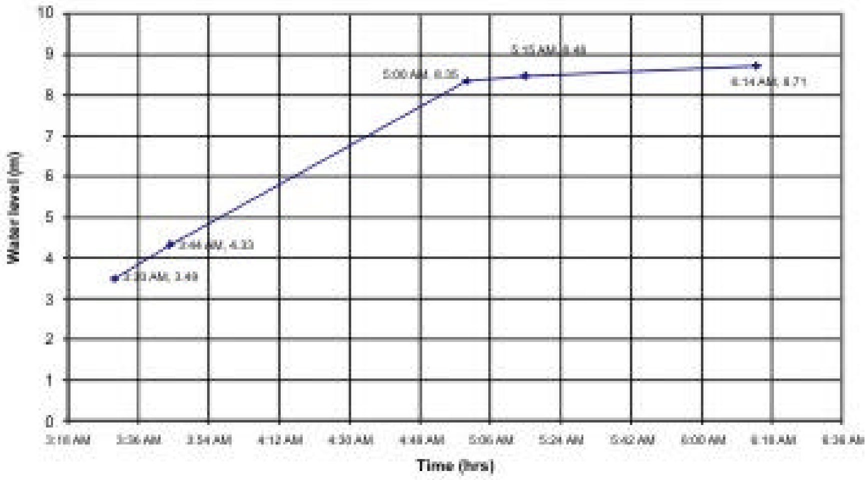

Fig. 4: Rise of water level in Damansara River recorded on 26 February 2006

Flood Hazard Map Development: In this study, the flood hazard map based on 26th February 2006 flood scenario was created to provide general view of inundation area during flash flood. This non-structural measures also useful to prevent loss of people's lives and help the local resident to take a right direction during evacuation process [14]. For the flood delineation, XP-SWMM combined water levels from the hydraulic computation were exported into ArcView GIS 3.1 to produce the extent of flooding. In this study, the contour layer, available from Drainage and Irrigation Department was used to develop the flood hazard map. Using overlay process between flood hazard map and hydraulic results, flood for different water level can be produce. As most of the historical flood levels were recorded between 1 to 2 meters, the inundation map produced here was scaled as less than 1 meter and above than 1 meter.

RESULTS AND DISCUSSIONS

FHMUA for flood preparedness and emergency response is one of the main non-structural methods introduced in Malaysia. For this study, FHMUA is a map geographically provides information on inundation area and depth for TTDI area. Combining with GIS knowledge and XP-SWMM for hydrodynamic simulation, the results sound promising for government agency and public to enhance their flood forecasting and flood warning system in TTDI. In case of Damansara River catchment, massive development at upstream sites is one of a major factor contributing to flash flood. Presently, only two green lungs are untouched namely Taman Pertanian Bukit Cerakah and Taman Botani near Sungai Buloh.

Hydraulic Simulation: The observed water level (m) in Damansara River at TTDI has already shown in Fig. 4, while the simulation is presented in Fig. 5. It clearly shows that the rate of water rising is similar as observed. Waters was started ascending at 6 am and reached the crest level of 1.23 m at 8.15 am. That means that, it only takes 1 hour and 30 minutes to achieve a maximum level. At this point, almost 60 percent of TTDI areas were submerged.

From the analysis estimated discharge (m^3/s) from the river to TTDI over the wall is about 100. This value, expressed in hydrograph was derived from the different of flow between upstream and downstream of TTDI (Fig. 6). As showing in the figure, the maximum flood level of 364.6 m^3/s was recorded at 7.10 am while along the TTDI, the volume of water recorded at peak discharge is 270.3 m^3/s at a same time, a different of approximately 100 m^3/s was spelled out to flooding areas. Along TTDI, the flood water was travel to rising limb and achieved 280 m^3/s within less an hour. From the simulation, various characteristics of the flood can be observed. Short duration and high intensity rainfall is a major cause of flooding in Damansara River. The flood discharge was started ascending at 4.30 am and continuous rising for about 30 minutes. As demonstrated in the hydrograph, the flood water travel and rise very fast. It took only 30 minutes for the area to be flooded.

Flood Hazard Mapping for Urban Area: During the 26th February, the flood waters inundated low laying areas comprising residential, commercial and institutional areas. Two hours of heavy rain of around 118 mm had resulted in Damansara River overflowing its banks and inundated about 3,000 houses and forced about 11,000 people to

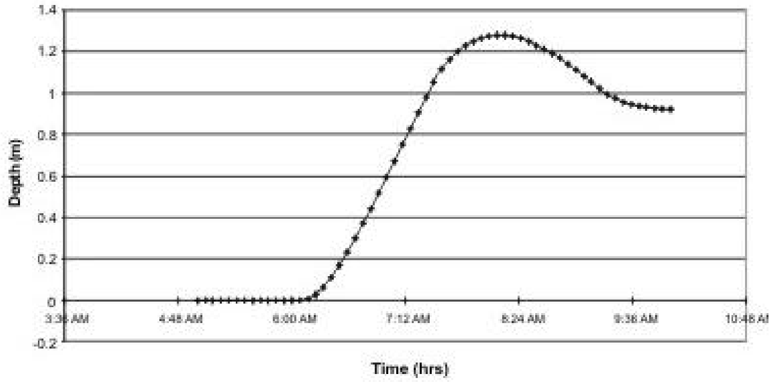

Fig. 5: Simulation showing rise of water level in TTDI

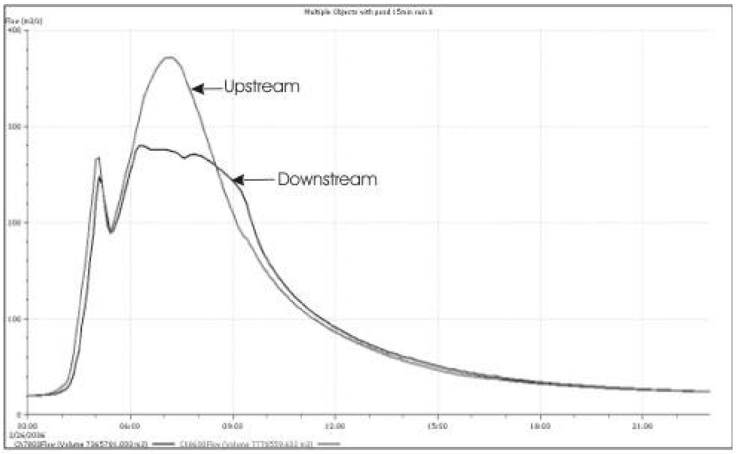

Fig. 6: Flow characteristics at upstream and downstream of TDDI area

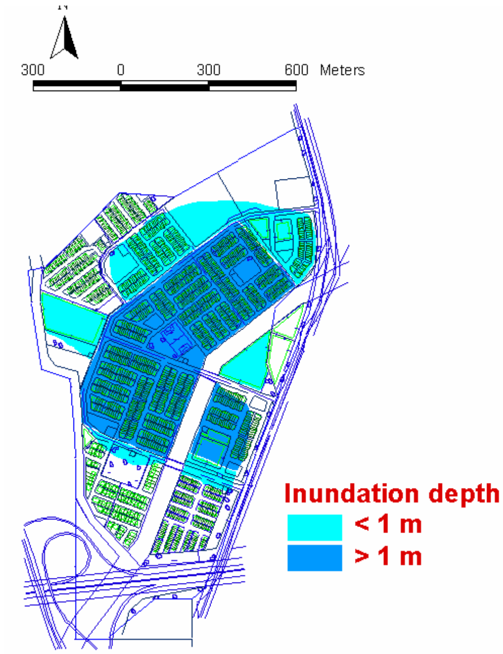

Fig. 7: FHMUA for Damasara River at TTDI

vacate the flooded areas. This scenario on inundation depth is illustrated in Fig. 7. It clearly shows that the areas of more than 1 m inundation depth or 67.3 hectares were recorded on the right bank of Damansara River and a small portion of residential area at the left bank. Meanwhile, the other 39.7 hectares of residential and commercial areas were inundated with less than 1 m.

CONCLUSION

The study has successfully demonstrated the integration of GIS, hydrology and hydraulic simulations to model the FHMUA in the study area. There are many different types of GIS data layers that can be used for flood hazard map. However, for this study the main data layers for flood hazard map are consists of property parcel data, roads and rivers. For more informative data, a raster data such as digital images can be incorporated for permitting better flood management analysis.

Based on the hydrology and hydraulic simulations, it can be concluded that the 26th February 2006 flooding incident at Damansara River is merely happened due to heavy storm occurred on that day. The hydrograph clearly shows that the flood is categorized as flash flood with time travel to rise is only 30 minutes. With advance information of time and inundation area at different depth, FHMUA provides better spatial and temporal evaluations particularly on flood forecasting and warning system in the study area.

ACKNOWLEDGEMENT

This study was conducted and supported by the GUP fund (UKM-GUP-ASPL-07-06-002). The authors are also thankful to the Centre for Research and Innovation Management (CRIM), Universiti Kebangsaan malaysia for funding the research. Special thank also due to the Wallingford Software (M) and Drainage and Irrigation Malaysia, Majlis Perbandaran Shah Alam for general assistant.

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