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GIS-BASED RIVER BASIN FLOOD MODELLING USING HEC-HMS AND MIKE11 - KAYU ARA RIVER BASIN, MALAYSIA

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River flood modelling comprises three main components as follows: hydrological modelling, hydraulic modelling and river flood visualization in a geographic information system (GIS). In this research, HEC-HMS and MIKE11 were utilized as hydrological and hydraulic models which were linked to a GIS environment using HEC-GeoHMS and MIKE11GIS extensions. In this procedure, firstly, the rainfall-runoff simulation is conducted to generate the design flood hydrographs which are used as input for the hydraulic model with boundary or initial conditions. Then, according to design hydrographs, hydraulic modelling is performed for defined scenarios. GIS is used to visualize the results of the hydraulic model. The primary results visualized consist of flood extent and flood depth maps. These maps are the basic requirement for preparing the river flood hazard and river flood risk maps.

INTRODUCTION

Floods are the most damaging phenomena that effect to the social and economic of the population (Smith and Ward 1998). River flood is defined as a high flow that exceeds or overtops the capacity either the natural or the artificial banks of a stream (Hoyt and Langbein 1958, Knight and Shiono 1996, Omen et al. 1997, Smith and Ward 1998, Walesh 1989). Flooding results from excessive rain on the land, streams overflowing channels or unusual high tides or waves in coastal areas. Some of the most important factors that determine the features of floods are rainfall event characteristics, depth of the flood, the velocity of the flow, and duration of the rainfall event (Smith 1996). River flood extent mapping is the process of determining inundation extents and depth by comparing river water levels with ground surface elevation. The process requires the understanding of flow dynamics over the flood plain, topographic relationships and the sound judgments of the modeller (Noman et al. 2001, Sinnakaudan et al. 2003). Flood hazard maps produced may include water depth, flood extent, flow velocity and flood duration. This is a basic and important indicator for the flood plain land use development planning and regulations (Walesh 1989).

Essentially all flood mapping methods use the same procedure to delineate flood plain boundaries by determining the flood elevation at each river cross section. The boundaries are then interpolated between the cross section. The three methods differ only in their way of determining the water surface profile. The analytical method determines a T-years surface profile by obtaining solutions to the dynamic equation to a T-year flood. The historical method involves the adjustment of water surface profiles according to historic flood. This method requires detailed historical flooding information. Predicted flood hazard zones are largely based on mathematical or statistical theory and use the historical record of the past events to estimate the future probability or recurrence of similar events.

Historical and physiographic approaches which are similar to DID´s modified method, may be used to get the basic idea about the river flood hazard for planning purposes, but are inadequate for detailed design and floodplain mapping for insurance rating. However there is no evidence on the provision of flood insurance schemes in Malaysia although it is considered as a possible alternative or complementary components of the overall flood proofing designs (DID 2000). Only the analytical approach can meet the requirement of the Urban Storm-water Management Manual for Malaysia (USMM), as specified in Volume 4, Chapter 11 which requires that any new development proposals should include base flood elevation (BFE) information. These three methods are labour-intensive, involving the manual interpretation of aerial photos and contour maps and full of uncertainties during the entire mapping process. Because of the high cost incurred, flood plain maps are very difficult to update using these traditional manual methods (Sinnakaudan et al. 2003).

Computer models for the determination of river flood generally consists of four parts (Snead 2000), including:

i. The hydrologic model which develops rainfall-runoff from a design rainfall or historic rainfall event.

ii. The hydraulic model which routes the runoff through stream channels to determine water surface profiles (including depth and velocity) at specific locations along the stream network.

iii. The extraction of geospatial data for use in the hydrological and hydraulic models

iv. A tool for floodplain mapping and visualization.

The GIS technology has the ability to capture, store, manipulate, analyze, and visualize the diverse sets of geo-referenced data (Aronoff 1989, Burrough 1986, Goodchild 1993). On the other hand, hydraulic is inherently spatial and hydraulic models have large spatially distributed data requirements (Graf 1998, Horritt and Bates 2002, Jones et al. 1998, Noman et al. 2001). It is shown that the integrated modelling approach coupled through a GIS environment with a Digital Elevation Model (DEM) of the study plan shows quite constructive tool for the analysis, control and effective management of low-lying coastal areas (Gambolati et al. 2002).

The integration of hydraulic model and GIS is therefore quite natural. The GIS allows modulation and simulation of different scenarios and the graphic representation of the different alternatives. Nowadays the integration between GIS software and hydrological modelling software has been developed for various purposes. One of them is HEC-GeoHMS, which is an ArcGIS extension specially designed to process geospatial data for use with the Hydrological Engineering Center- Hydrological Modelling System (HEC-HMS). The other one is MIKE11GIS which is the linking extension between ArcGIS and MIKE11 hydraulic model. Note that other computational techniques such as artificial neural network (ANN) and Fuzzy probability method are integrated with GIS for river flood studies in recent years (Huang and Inoue 2007, Ni and Xue 2003).

MATERIALS AND METHODS

Sungai Kayu Ara river basin was the case study in this research which is located in Kuala Lumpur, Malaysia. Sungai Kayu Ara river basin is geographically surrounded within N 3° 6´ to N 3° 11´ and E 101° 35´ to E 101° 39´. Figure 1 illustrates the location and base map of the Sungai Kayu Ara river basin in Malaysia, respectively. Sungai Kayu Ara river basin covers an area of 23.22 km^2. The main river of this river basin originates from the reserved highland area of Penchala and Segambut. The Sungai Kayu Ara river basin can be a suitable study river basin for this research because of some reasons such as follows: primarily, a large part of this river basin area is well developed urban area with different land-use and also high population density that shows the importance of this river basin. Secondly, the availability of high density rainfall station network, whereby 10 rainfall stations and one water level station are available and also according to the area of Sungai Kayu Ara river basin, 23.22 $km^{2,}$ the rainfall station network density is equal to 2.3 km^2 /station, which justifies the minimum requirement of one station per 25 km^2 recommended by Linsley et al. (1975) in case of precipitation over small mountainous river basins. The third reason is the availability of stage discharge curve which has been developed by the DID, Malaysia. Finally, the availability of river basin digital topographic information which can be used in Geography Information System (GIS) is one of the reasons to select this river basin for this research. This data has been produced by the Department of Survey and Mapping, Malaysia.

HEC-HMS is a hydrological model developed by the Hydrologic Engineering Center of the United States Army Corps of Engineers which was utilized as in this research. HEC-HMS3.1.0 is used as hydrological model which was widely applied in many water resources studies (He et al. 2007, García et al. 2008, Lin et al. 2009, Chen et al. 2009, Kousari et al.). The program simulates a rainfall-runoff response of a river basin system to a precipitation input by representing the entire river basin as an interconnected system of hydrologic and hydraulic components, which include river basins, streams and reservoirs. The results from HEC-HMS3.1.0 model can be used as an input for hydraulic models. Beside this, Geospatial Hydrologic Modeling Extension (HEC-

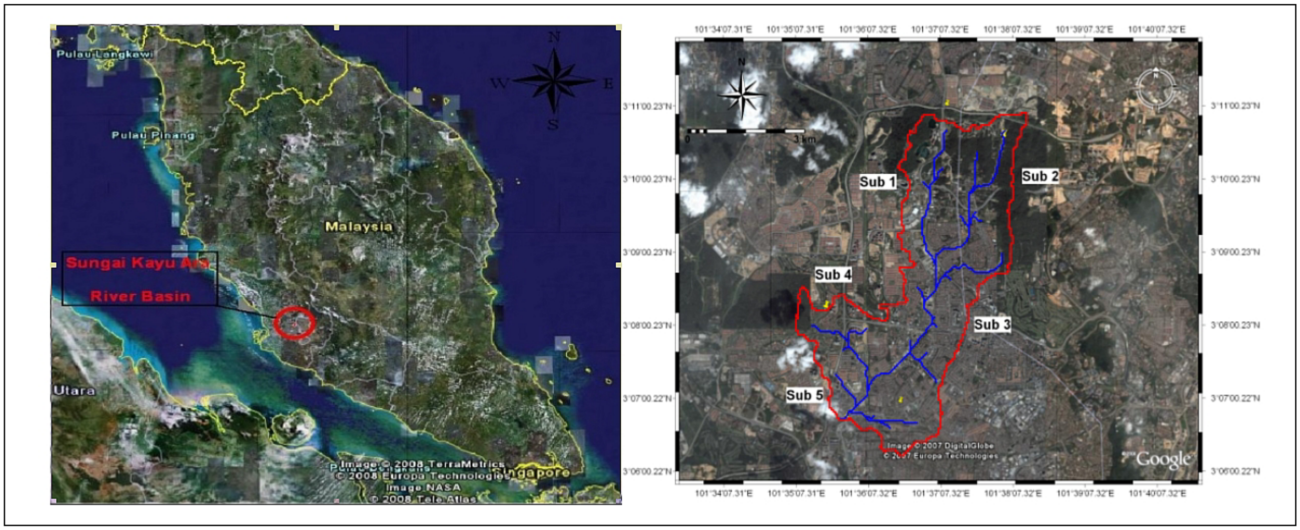


Figure 1. Location and Base Map of Sungai Kayu Ara in Malaysia.

GeoHMS) is a software package which can be used as an extension of the ArcGIS (HEC-GeoHMS 2003). Past studies have shown HEC-GeoHMS to provide accurate and useful results in river basin hydrological studies (Knebl et al. 2005, Bonnet et al. 2008, Chen et al. 2009, Jang et al. 2010, Koutroulis and Tsanis 2010). ArcGIS uses HEC-GeoHMS and Spatial Analyst to develop a number of hydrological model inputs. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. Additional interactive capabilities allow users to construct a hydrologic schematic of the watershed at stream gages, hydraulic structures, and other control points. The results generated from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS3.1.0, where simulation is performed. HEC-GeoHMS1.1 was used as a preprocessor for hydrologic model which means that, some significant inputs which are needed for hydrological modeling is prepared by this extension. These inputs are as follows: drainage network, river basin boundary, sub-river basin boundary, river basin and sub-river basin centroid points (as the location of the object of sub-river basin in the HEC-HMS), longest flow path and flow direction (Figure 2).

HYDROLOGICAL MODELING

The model was calibrated based on three factors of simulated hydrograph which consists of, peak value, runoff volume and time to peak. 18 rainfall events which were occurred between the year 1996 and 2001 are selected for calibration process and 18 rainfall events between the years 2002 and 2004 are used for validation. The basin mean areal rainfall depth for the 18 calibration and 18 validation rainfall events which are calculated with Thiessen method ranges between 7.14 mm and 58.93 mm, respectively. The maximum runoff peak discharge and runoff volume were observed on 10th February 1999 which are 220 m^3/s and 1190000 m^3, respectively. The minimum and maximum validation events were observed on the 20th February 2003 and 5th April 2004. Figure 3 represents the values of observed runoff peak discharge and runoff volume, respectively, of selected rainfall events for validation of HEC-HMS.

In the calibration procedure three calibrated parameters which include imperviousness, lag time and peak flow coefficient, are adjusted. The results of the calibration process for Sungai Kayu Ara river basin are evaluated using, the coefficient of determination (R^2) which exhibits higher than 0.9 that shows acceptable correlation between simulated and observed data. The coefficient of

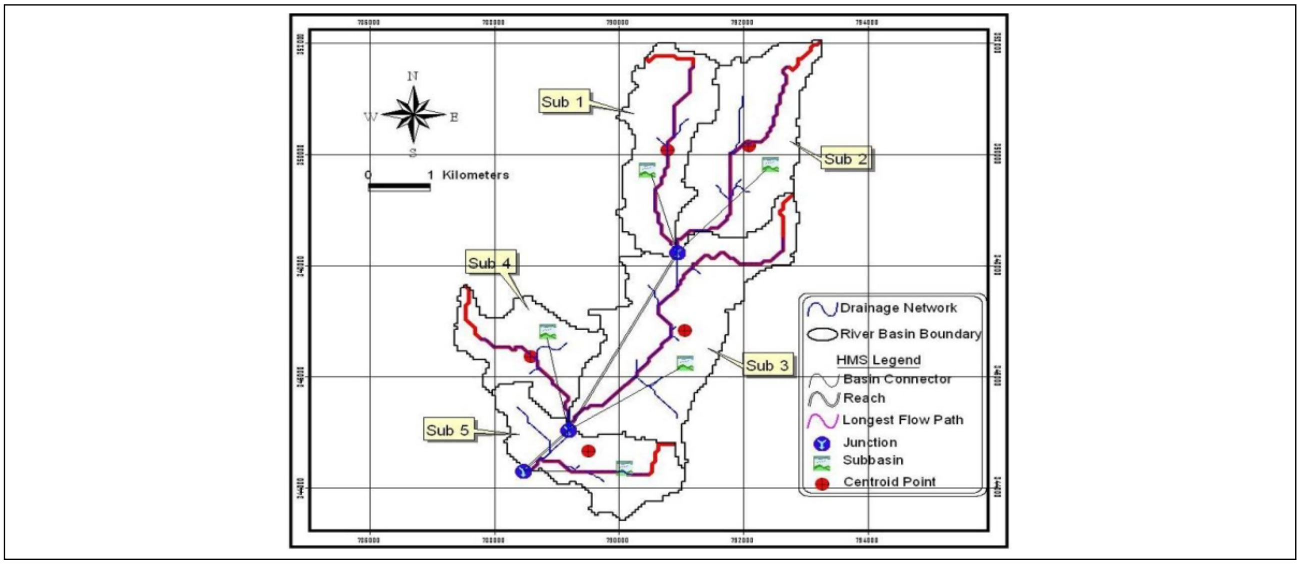


Figure 2. Characteristics for Sungai Kayu Ara River Basin Extracted using HEC-GeoHMS.

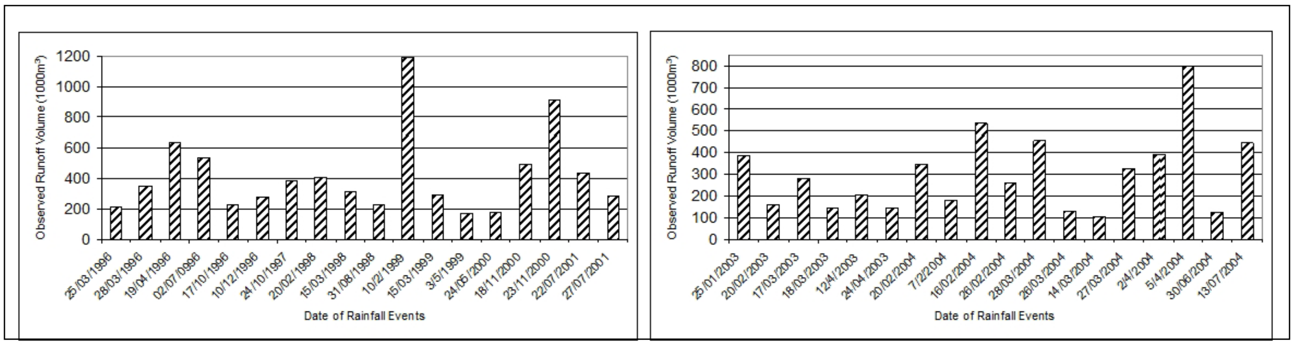


Figure 3. Observed runoff volume for hydrologic model calibration and validation.

determination (R^2) and the correlation between observed calibration events and simulated values for calibration events are calculated by REGRESS1.0 software. Figure 4 shows two of the results of the HEC-HMS3.1.0 calibration process for Sungai Kayu Ara river basin.

By consideration to Figure 4 it appears that there is a satisfactory correlation between observed and simulated data in calibration process. It was intended to reduce the difference of observed and simulated values by adjusting the calibration parameters. These results show that the values selected for three calibrated parameter were adequately adjusted with the Sungai Kayu Ara river basin.

After calibration process, a total of 18 rainfall events were simulated for validation of HEC-HMS hydrological model for Sungai Kayu Ara river basin. In validation process all values were kept

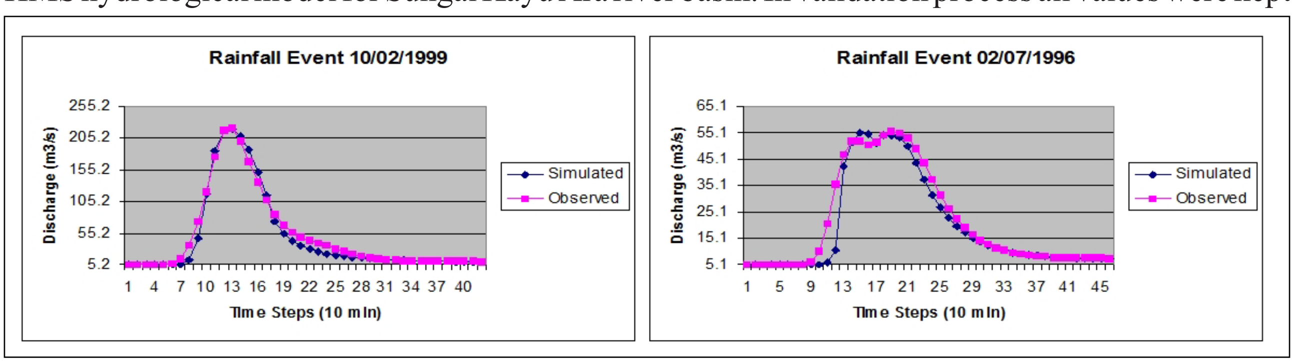
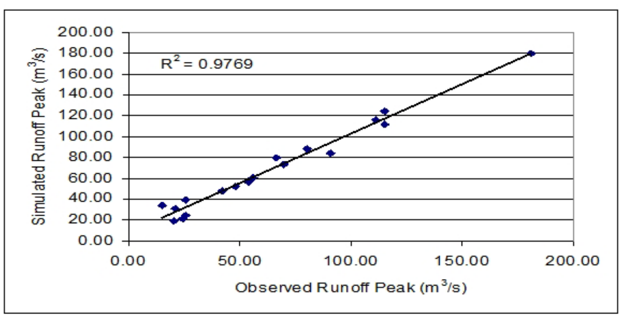


Figure 4. Results of the HEC-HMS3.1.0 calibration process for Sungai Kayu Ara river basin for 10/02/1999 (R^2: 0.99) and 02/07/1996 (R^2: 0.97) rainfall events.

constant and output values for runoff volume and runoff peak discharge are evaluated and compared with observed runoff volume and runoff peak discharges. In fact, during validation process the reliability and credibility of the calibrated values were clarified. The results of the validation process for 18 rainfall events are illustrated in Figure 5. The runoff peak discharge and runoff volume exhibit satisfactory R^2 values for the validation simulation. This shows that the parameter values for HEC-HMS model have been adequately identified to represent Sungai Kayu Ara river basin.

After establishment of the hydrological model, design hyetographs are required as the input for the hydrological model. The IDF polynomial equation derived by DID (2000) were used for three different ARI (20 years, 50 years and 100 years), to derive the design rainfall as an input to HEC-HMS hydrological model. Duration of rainfall events were selected according to two criteria, first the time of concentration of the river basin which is equal to 2 hours, secondly with consideration to the availability of spatial temporal pattern in Storm Water Management Manual for Malaysia which is used as a reference in this research (rainfall temporal patterns are available only for 10, 15, 30, 60, 120, 180 and 360 min). Therefore, the durations selected were 60 minutes (1/2 t_c), 120 minutes (t_c) and 360 minutes (3 t_c). Table 1 shows the calculated rainfall densities and depth values for Sungai Kayu Ara river basin for two different ARI and three different durations.

Finally, by having the design hyetographs the hydrological model is ready to simulate the runoff hydrographs for defined scenarios. Hydrological models such as HEC-HMS simulate the hydrograph of generated runoff caused by rainfall event. According to this definition of hydrological modeling, the main input for hydrological model is rainfall event hyetograph. In order to obtain the best results different rainfall durations and ARI in different river basin land-use development conditions were defined. In this research, 30%, 60% and 90% imperviousness were defined as existing, intermediate and ultimate river basin development conditions, respectively. The results of the HEC-HMS3.1.0 simulation for three ARI (20 years, 50 years and 100 years) and three durations (60 minutes, 120 minutes and 360 minutes) in three development conditions (existing, intermediate and ultimate), a total of 27 scenarios are illustrated in Figures 6, 7 and 8.



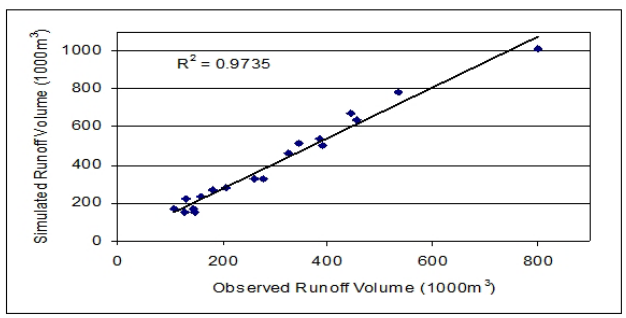


Figure 5. Correlation of observed and simulated runoff peak and volume discharge in validation process for Sungai Kayu Ara River Basin.

Table 1. Design rainfall intensity and depth for Sungai Kayu Ara River Basin.

Event Duration	20 year		50 year		100 year	
	Intensity (mm/hr)	Depth (mm)	Intensity (mm/hr)	Depth (mm)	Intensity (mm/hr)	Depth (mm)
60min	91.34	91.34	100.54	100.54	110.21	110.21
120min	54.47	108.93	59.77	119.53	65.39	130.78
360min	22.43	134.56	24.66	147.98	26.83	160.95

According to Figures 6, 7 and 8, it can be concluded that, in each specific ARI with increasing development (from existing to ultimate development condition), the runoff peak discharge and runoff volume are increased which can be attributed to the increasing of the impervious area in the river basin. This pattern is similar for each specific development condition; it means that in a similar development condition, the runoff peak discharge and runoff volume of the 100 year ARI is higher than, the runoff peak discharge and runoff volume of the 20 year ARI, respectively. Furthermore, the results of the HEC-HMS simulation demonstrate that, effect of development condition in river basin response is more pronounce than the ARI, it means that, with increase development condition the changes in runoff peak discharge and runoff volume is higher in comparison with increase of the ARI. For example, the comparison between runoff peak discharges and runoff volumes of 20 year ARI and 100 year ARI in existing development condition shows 19% and 33% increase, respectively, while increase of the development from existing condition to ultimate condition, gives an increase of 91% and 45%, respectively. This proves that, runoff peak discharge is more sensitive to development condition changes, but runoff volume is more sensitive to ARI changes.

HYDRAULIC MODELING

Hydraulic model which was used in this research was MIKE11 which is developed by Danish Hydraulic Institute (DHI) in 1987 and it became a widely applied 1D dynamic modelling tool for

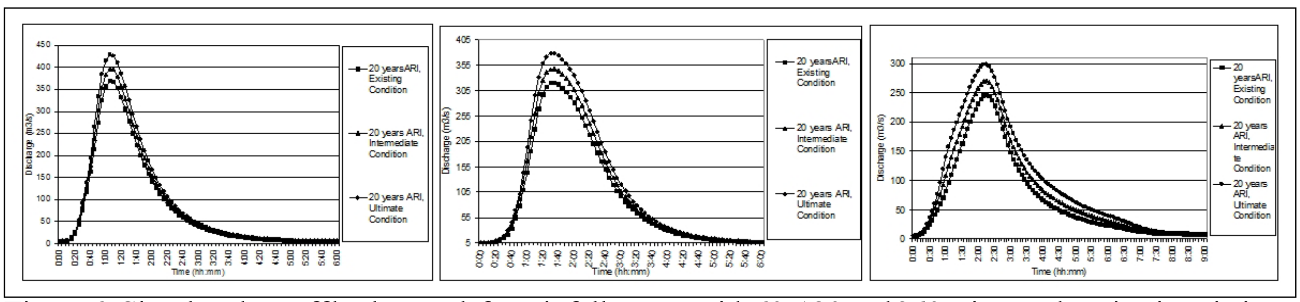


Figure 6. Simulated runoff hydrograph for rainfall events with 60, 120 and 360 minutes duration in existing,

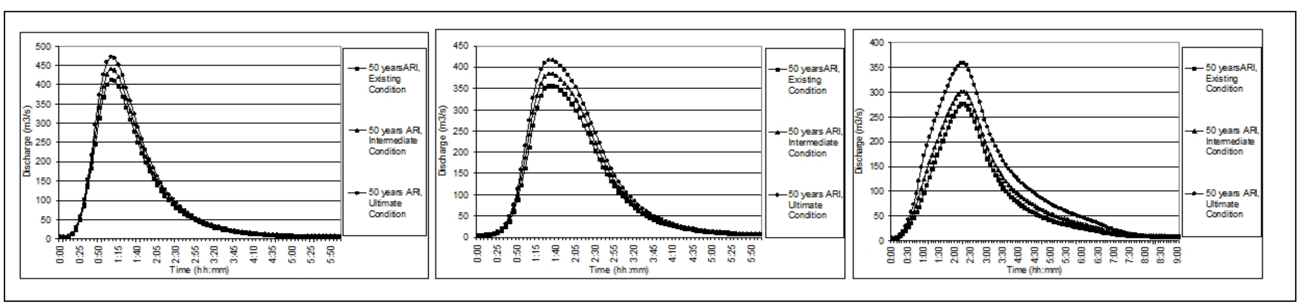


Figure 7. Simulated runoff hydrograph for rainfall events with 60, 120 and 360 minutes duration in

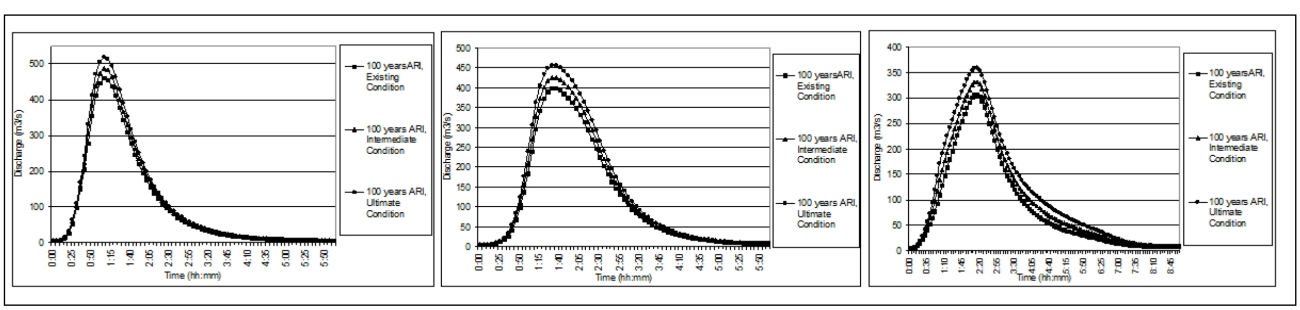


Figure 8. Simulated runoff hydrograph for rainfall events with 60, 120 and 360 minutes duration in existing,

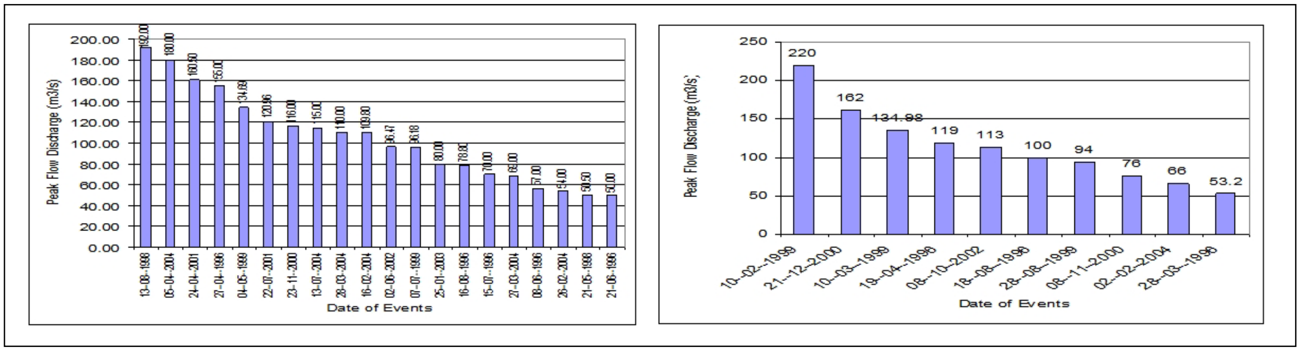


Figure 9. Flood events for calibration and validation of hydraulic model in Sungai Kayu Ara.

rivers and channels (Hashemi et al. 2008, Liu and Sun 2010, Luu et al. 2010, Makungo et al. 2010, Kusre et al. 2010). The hydrodynamic module (HD) is the core of MIKE11. The MIKE11GIS extension integrates the MIKE11 model with ArcGIS. In fact, it acts as a bidirectional exchange between MIKE11 and ArcGIS. By running the model, MIKE11GIS is able to generate three types of flood maps for display and analysis in ArcGIS: depth/area inundation, duration, and comparison/impact (DHI 2004). In addition, MIKE11GIS can produce output graphs of water level time series data, terrain and water level profiles, and flood zone statistics. When using the MIKE11GIS extension for ArcGIS, time-series results from a MIKE11 simulation can be imported into a GIS-based digital terrain model for flood visualization. The surveyed data of DID which has been prepared in the year 1996 were used as raw cross section data for this research. These data include 25 cross sections along 5.1 km of study reach, which equivalent to 200 m interval between each cross section.

The calibration process of hydraulic modelling using MIKE11 for Sungai Kayu Ara river basin includes a total of 20 flood events. The lowest and highest discharges used in calibration process of MIKE11 for Sungai Kayu Ara river basin were 50 m^3/s and 192 m^3/s, respectively. The flood events for calibration were selected from the historical data between the years 1996 to 2004 for the water level station which is located at the outlet of the Sungai Kayu Ara river basin. Figure 9 demonstrates the flow discharge of the selected calibration rainfall events. Then, the generated water levels of calibration data set rainfall events were compared with observed water levels to evaluate the accuracy of the calibrated parameter. The calibration result of MIKE11 has a good correlation between simulated and observed data with coefficient of determination R^2 values of 0.9. It shows that selected value for Manning's n value for main channel and floodplain reflect the condition of the bed resistance of the Sungai Kayu Ara. Finally, for validation of the MIKE11 for Sungai Kayu Ara river basin a total of 10 events which are shown in Figure 10. According to Figure 10 the maximum and minimum runoff peak discharge of validation rainfall events are 220m^3/s and 53.2 m3/s, respectively. These ten events were simulated with calibrated Manning's n value. The generated water level by validation data set rainfall events were expected to be comparable to observed water levels. Results of validation process for MIKE11 in Sungai Kayu Ara river basin approve the credibility of the MIKE11 model. Figure 11 represent the results of the validation process of MIKE11 for Sungai Kayu Ara river basin.

After preparation of preprocessing requirement of MIKE11, such as: network file, cross section file and boundary conditions, the hydraulic simulation was performed for 27 scenarios. Recall that input geometric data such as network file and cross section file were extracted using

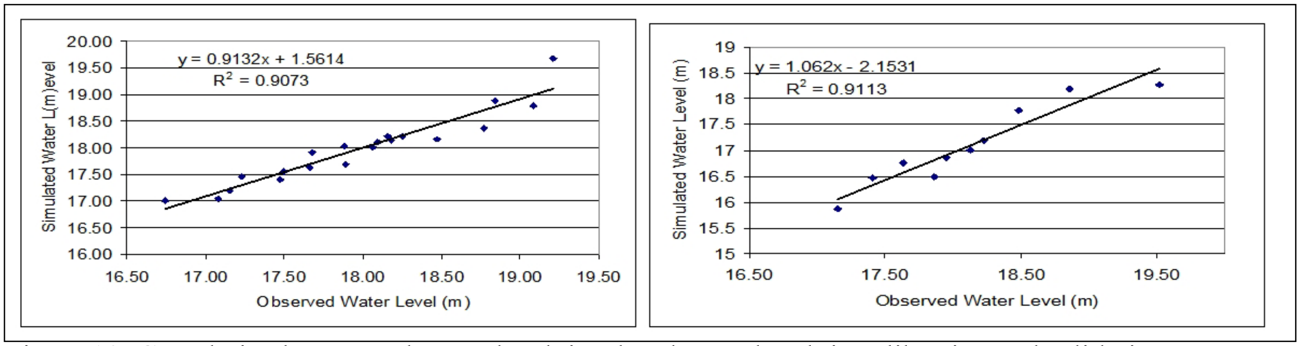
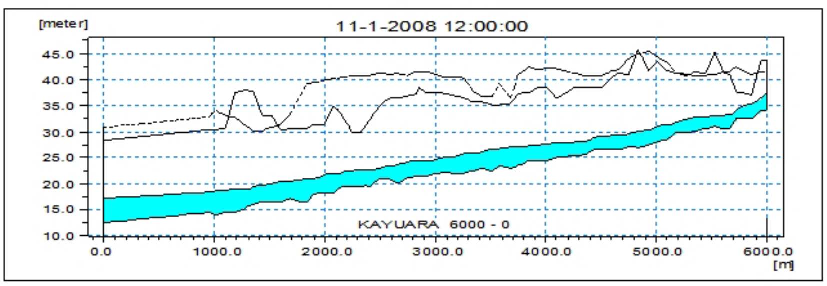
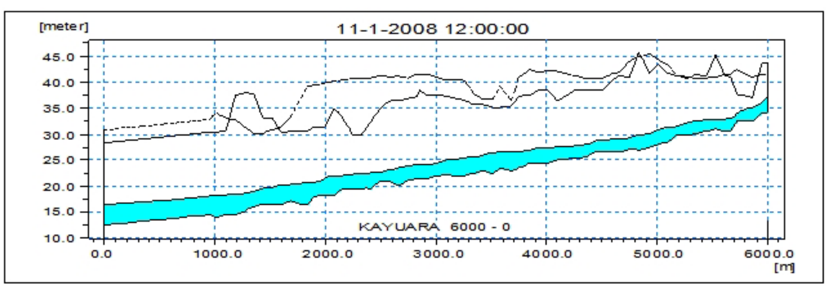


Figure 10. Correlation between observed and simulated water levels in calibration and validation processes of MIKE11 in Sungai Kayu Ara River.

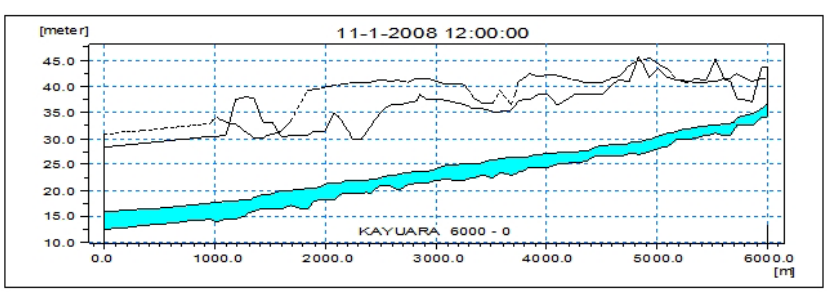
MIKE11GIS. In addition, boundary condition which includes design hydrographs was generated by HEC-HMS hydrological model. Hydraulic simulation in MIKE11 was conducted for 6 km of Sungai Kayu Ara. The control point for calibration, validation and assessment of the hydraulic modelling was location of the water level station which is located in chainage 5.1 km (outlet of the Sungai Kayu Ara river basin). Figures 11 represent three of the longitudinal profile generated from MIKE11 for 3 of 27 defined scenarios for Sungai Kayu Ara river basin.



60 minutes rainfall



120 minutes rainfall



360 minutes rainfall

Figure 11. Longitudinal profile for events with 20 years ARI in existing development Condition in Sungai Kayu Ara River Basin.

River Flood Visualization

MIKE11GIS can process and visualize the hydraulic model results of MIKE11 in ArcGIS environment which include the river flood extent map, river flood depth distribution map, comparison map and river flood duration map. These maps were created based on exchange file between MIKE11 and ArcGIS which can be read by using MIKE11GIS extension. In fact, after hydraulic simulation in MIKE11 model the results were exported to exchange file and then imported by ArcGIS to further process which includes river flood visualization. Among these four types of map, river flood depth distribution map and river flood extent map are visualized and represented here.

The visualization of the results was obtained through the MIKE11GIS. The Q- and h-points were imported into the ArcGIS interface from the MIKE11 network file data. The Q-points were average flows at the midpoint of each finite segment within the model (half the distance between successive cross-sections). The h-points were stage heights at upstream and downstream finite segment boundaries (cross-section locations). The simulation data was spatially imported to each corresponding Q- or h-points along the stream network, using the Chainage values for geo-referencing. Using Q- and H-points data which are developed in MIKE11 and exported to ArcGIS environment, flood extents maps and flood depth maps are developed in MIKE11GIS. A water level surface grid is interpolated using inverse distance-weighted interpolation of the nearest h-points. The difference between the water level surface grid and the terrain model grid creates the flood maps. MIKE11GIS is able to develop four types of river flood maps; river flood extent map, river water depth map, comparison map and duration map. Among these river flood maps only river flood extent and depth maps are available for this research. Figures 12 to 14 demonstrate river flood extent and water depth distribution generated by MIKE11 for events with 20 year, 50 year and 100 year ARI with 60 minutes, 120 minutes and 360 minutes durations in existing, intermediate and ultimate river basin land-use development conditions in Sungai Kayu Ara river basin.

Figures 12 to 14 illustrate the generated river flood extent and water depth distribution maps for different rainfall events durations in MIKE11GIS environment for Sungai Kayu Ara river basin. The calculated flood extents are shown in different development conditions and with different ARI and also different rainfall event durations. In order to discuss about the roles of development condition and rainfall event ARI and duration on the river flood extents, the inundated area is a prime parameter to be considered. Table 2 shows the computed area of river flood extents for Sungai Kayu Ara river basin.

By considering to Table 2 it appears that, increase of rainfall event ARI from 20 year to 100 year causes 29% increase in the river flood inundated area. This approves that increase of rainfall event ARI significantly increases the magnitude of the river flood. On the other hand, the calculated inundated area for rainfall event with 20 year ARI in existing development condition is 26.99 hectares while it is 33.60 hectares for ultimate development condition. This means that, the increase of the Sungai Kayu Ara river basin land-use development condition from existing to ultimate condition leads to 19% increase on the flood inundated area. Moreover, results depicted in Table 2 show that rainfall event duration affects on the river flood inundated area. Since, the increase of rainfall event duration, the intensity and consequently runoff peak discharge is decreased which leads to reduction in generated river flood magnitude (water level and river extent). Hence, development condition of the river basin, rainfall event ARI and duration play an important and significant role in the river flood extents. Meanwhile, rainfall event ARI and development condition have affected significantly the river flood extent.

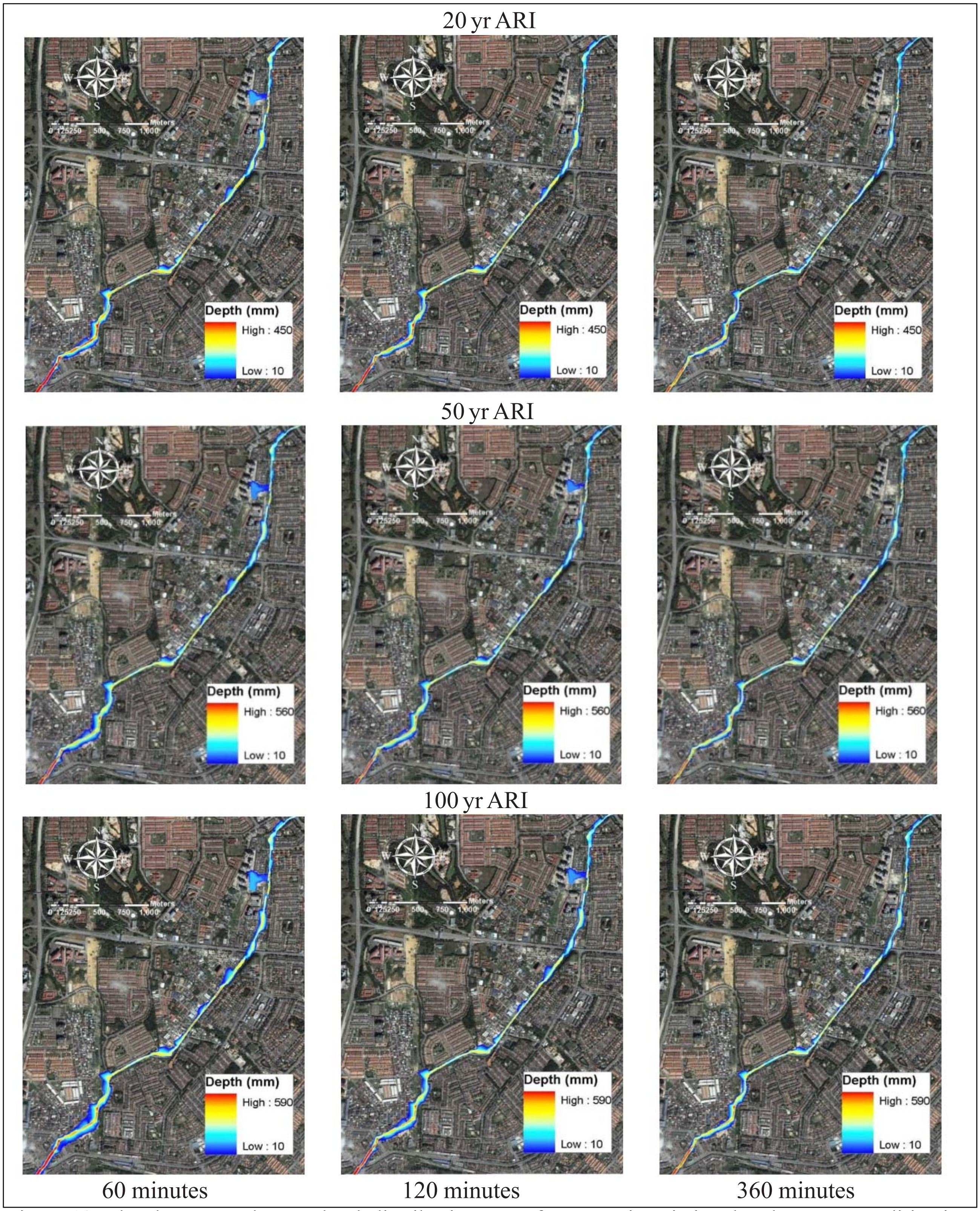


Figure 12. Flood extent and water depth distribution maps for events in existing development condition in Sungai Kayu Ara River Basin.

Figures 12 to 14 show the generated river flood water depth distribution maps by MIKE11GIS for Sungai Kayu Ara river basin in different development conditions and different rainfall event ARI for different rainfall events durations. In order to assess the effect of the river basin land-use development condition and rainfall event ARI on the generated river flood depth distribution map,

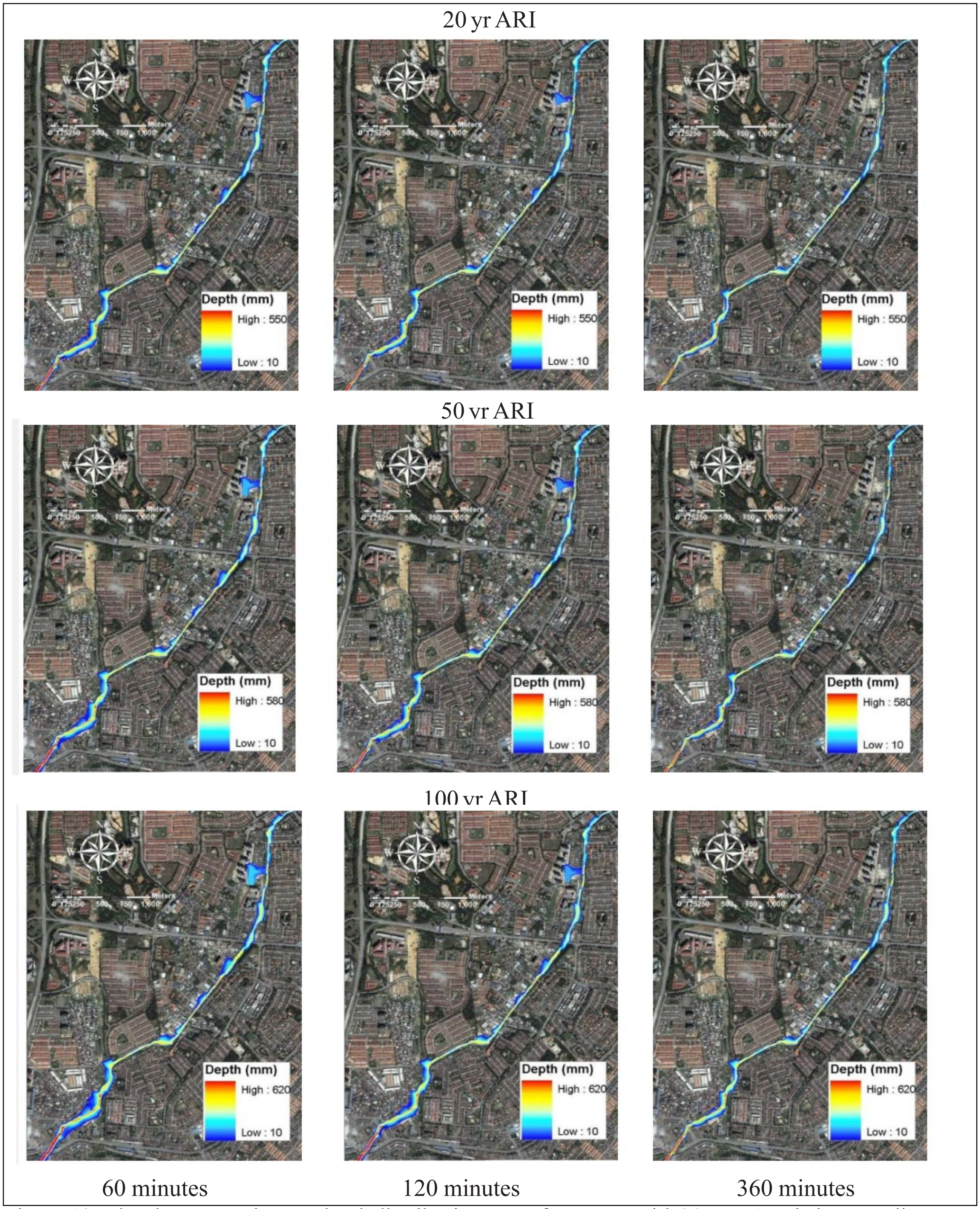


Figure 13. Flood extent and water depth distribution maps for events with 20 year ARI in intermediate development condition in Sungai Kayu Ara River Basin.

the inundated area for 60 minutes rainfall events with inundation depth between 0 cm and 100 cm can be calculated and compared, since most of the inundated area which exceeds the river banks (on the floodplain) are between 0 cm and 100 cm depth. Table 3 denotes the calculated inundated area with depth between 0 cm and 100 cm.

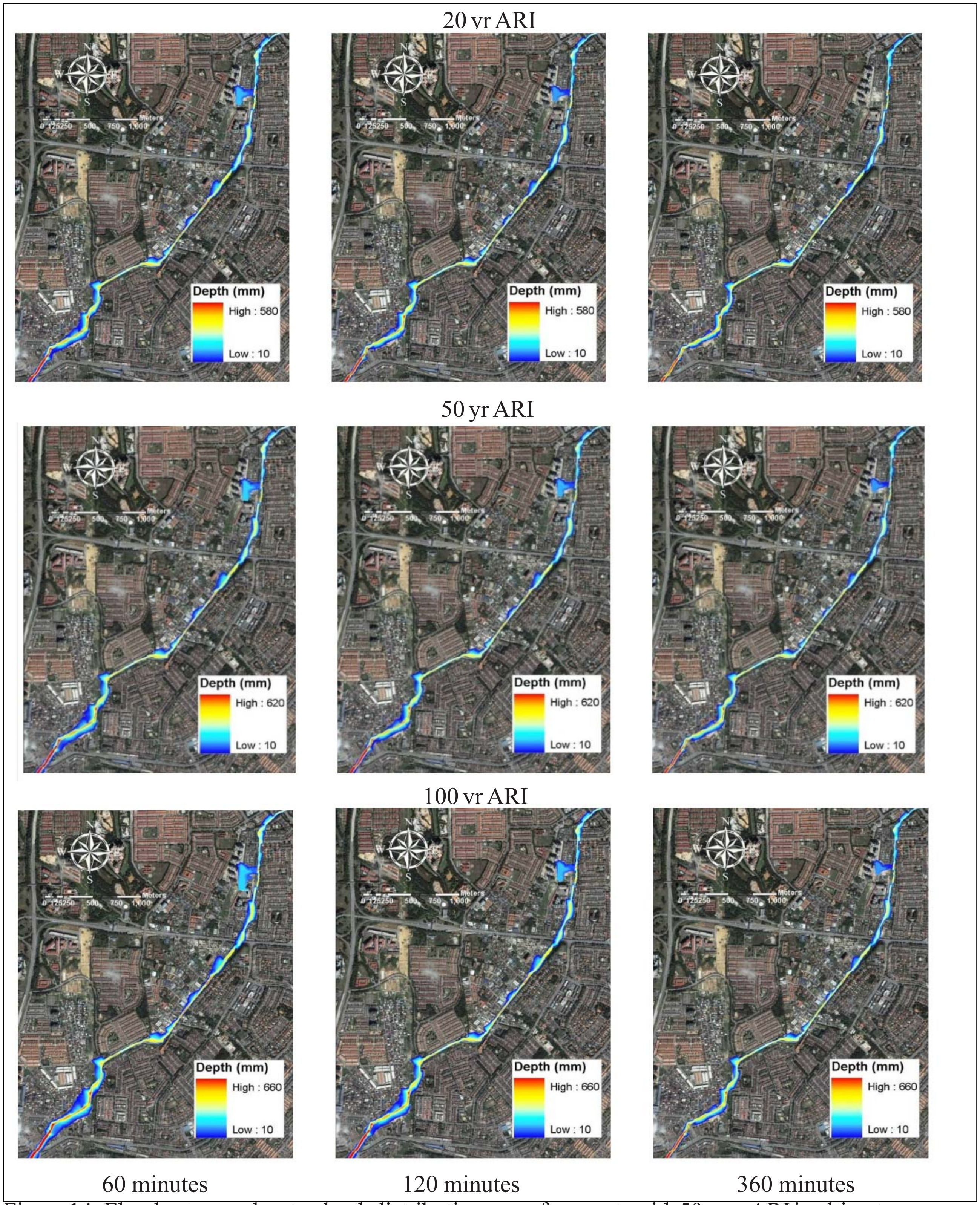


Figure 14. Flood extent and water depth distribution maps for events with 50 year ARI in ultimate development condition in Sungai Kayu Ara River Basin.

According to Table 3 it can be seen that river basin land-use development condition and rainfall event ARI have identical effect on the inundated area on floodplain. For instance, for increase of rainfall event ARI from 20 year to 100 year, inundated area with 0 cm to 100 cm depth is increased from 10.36 hectares to 14.40 hectares. Alternatively, inundated area with 0 cm to 100 cm depth

Table 2. River flood extents area for Sungai Kayu Ara River Basin.

Development Condition	Rainfall Duration (min)	20 years ARI (hectares)	50 years ARI (hectares)	100 years ARI (hectares)
Existing	60	26.99	29.13	35.31
	120	22.22	22.61	28.6
	360	18.64	20.08	21.39
Intermediate	60	29.27	33.46	39.01
	120	25.21	27.86	31.78
	360	19.86	21.33	22.94
Ultimate	60	33.6	38.84	45.45
	120	28.51	31.66	36.04
	360	21.85	22.42	26.71

Table 3. Calculated inundated areas with depth 0-100 cm for Sungai Kayu Ara River Basin.

Development Condition	20 year ARI	50 year ARI	100 year ARI
Existing	10.36	11.48	14.4
Intermediate	11.65	14.24	16.6
Ultimate	14.32	16.49	19.77

in existing development condition for ARI 20 year is 13.36 hectares while in ultimate development condition this increases to 14.32 hectares. To conclude, the inundated area on floodplain is increased up to 39% by river basin development condition in Sungai Kayu Ara river basin from existing to ultimate and with the changes of rainfall event ARI from 20 year to 100 year.

CONCLUSIONS

This research consists of three components; hydrological modelling, hydraulic modelling and flood visualization were performed in GIS environment. Findings of this research prove that HEC-GeoHMS can be readily employed as a reliable and accurate tool for extraction of input geometric data for HEC-HMS hydrological model. In hydrological modelling it is shown that river basin land-use development condition, magnitude and duration of rainfall reflect significant effects on the generated runoff hydrograph. As increase of river basin land-use development condition leads to increase of imperviousness of the river basin and an increase of the volume and peak discharge of the generated runoff hydrograph. On the other hand, increase of magnitude of rainfall event, the volume and peak discharge of the generated runoff hydrograph increase significantly. Increase of rainfall event duration leads to increase of runoff hydrograph volume and decrease peak discharge. In hydraulic modelling it can be concluded that, MIKE11GIS can be utilized for preparation of input geometric data for MIKE11 hydraulic model, and also for visualization of the hydraulic model results. Finally, The generated water level by hydraulic model is significantly sensitive to river basin land-use development condition, magnitude and duration of rainfall event.

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