IMPACT OF LAND USE CHANGE ON FLOODING IN AN URBANIZED TROPICAL CATCHMENT

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ABSTRACT

Malaysia has experienced rapid transformation of forested catchments to urbanized ones since mid-1980s. The present study depicts the impact of land use changes on flooding potential of an urbanized tropical catchment located in Sungai Dua Besar, Klang Valley, Malaysia. For this, the available land use maps from years 1966, 1984, 2002, and 2010 were used to predict the flooding potential in 2020. The study was piloted into three phases including land use change study, rainfall-runoff model development, and hydraulic model development to assess the flooding potential for estimated land use change. The transformation of land use in the study area was remarkable from year 1984 to 2010 for which the percentage of forest area has reduced from 55% in 1984 to 7% in 2010. A land use prediction model was developed based on historical data and was compared with the future development plans. In the next stage, a rainfall-runoff (R-R) model was developed using Storm Water Management Model (SWMM) for which selected R-R events of year 2000 and 2004 were used for model calibration. The calibrated model was then validated using selected events of year 2010. Several evaluation statistics including R^2, Coefficient of Efficiency (CE), RMSE, MAE, and Relative Peak Error (RPE) were used to assess the model performance. Since the land use map for 2015 was not available, the validated SWMM model was used to estimate the imperviousness in the catchment for year 2015. After re-adjustment of the land use prediction model, imperviousness percentage was estimated for the year 2020. Finally, a hydraulic model was developed using same historical data to estimate water level in the waterway. Using Digital Elevation Model (DEM) data and the results of the hydraulic model, the potential flood prone areas were identified for different Average Recurrence Interval (ARI) for year 2020.

Keywords: Flood, hydraulic model, land use change, rainfall-runoff model.

INTRODUCTION

Asia has experienced rapid industrialization and urbanization in the past decades [1]. Malaysia as one of the Asian countries has not been an exception as it has gone through a rapid development and increase in its urban population started from mid-1980s. The impact of urbanization and urban growth in Malaysia is evident as its economy has changed from an agricultural base to a manufacturing base since 1987 [2]. This change has led to a significant influx of rural people and migrants to urban centres which has increased urban population from 35.8% in 1980 to 61.8% in 2000 [3]. This change has brought pressure on the local and state governments to provide land for the required infrastructures for the growing urban populations [4]. A study [5] concluded that rapid urbanization and other land use changes due to population growth alter the hydrological regime by increasing the peak flow and runoff volume while decreasing infiltration. Same finding has been aslo reported by several other studies [6,7,8]. In another study [9] it was identified that activities associated with land use and land cover changes can induce local impacts such as changes in ecosystem and atmospheric composition of water and energy balance.

Land use change has been viewed as a continuous process for a long time while in fact it is a disjointed process with periods of rapid/slow growth or even stasis [10]. To date several studies have been made to predict future land use change for better forecasting of flooding potentials in urban areas. Wooldridge et al. [11] attempted to use a simple model for forest/non-forest land use classification for different climate regions to predict the impact of land use change on the hydrological respond of a catchment. A different approach is to use rainfall-runoff model which is less demanding in data requirement. In this approach, model parameters will be estimated a priori based on field data or modeling results. There could be some parameters still need to be adjusted through processes of calibration and validation. Therefore, one can use this approach in predicting the effect of changes in land use associated with the model parameters. Application of such approach to assess the impact of land use change has been reported by a few researchers [12-14]. Although this topic is well-studied, still there is a need for developing more accurate and reliable models that can capture the land use change and predict the potential flooded areas specifically in urban catchments. Therefore, this study aims to understand the trend of land use change in an urban tropical catchment, Sungai Dua Besar, located in Klang District, Malaysia. This study aims to estimate the impact of predicted urbanization on flood peak and inundated areas of the study catchment for year 2020.

STUDY AREA AND DATA COLLECTION

Sungai Dua Besar catchment is located in Klang Valley which is one of the most urbanized catchments in Malaysia. The Klang Town is a highly urbanized district which covers a total land area of 573.8 square kilometres (km^2) with a population well above 800,000. Sungai Dua Besar catchment is at the west side of North Port. The total catchment area is approximately 1765ha where river flows into Sungai Dua Besar before it goes into Sungai Che Awang (See Figure 1). The catchment is relatively flat where the terrain ranges from +3.5m to -1.5m AMSL. The required data in this study including rainfall, water level, land use, river cross-sections survey and LIDAR data were provided from Department of Irrigation and Drainage (DID). The land use changes were assessed using five land use maps obtained from various government agencies including Ministry of Agriculture and Lands Malaysia, Federal Department of Town and Country Planning Peninsular Malaysia and Klang Municipal Council between year 1966 and year 2020. Twelve land use types were considered for land use classification including water body, forest, industrial, infrastructure and utility, institutional, residential, commercial, vacant land, open space and recreational, agricultural, transportation, and others.

Figure 1. Scematic map of Sungai Dua Besar Catchment, Klang, Malaysia

METHODOLOGY

LAND USE CHANGE PREDICTION

The land use change is assessed using four land use maps for years 1966, 1984, 2002, and 2010. A map based on the national development plans for the study region was also available for year 2020. Two different scenarios have been identified to assess the land use change. In scenario 1, twelve available land use types were grouped into two major types namely non-urbanized and urbanized. Water bodies, forest, vacant lands, open spaces and recreational areas, and agricultural lands were considered as non-urbanized while the remaining ones were considered as urbanized. In scenario 2, only the main key players of urbanization including industrial, residential, and transportation were considered and individual change trend for them is being assessed. Simple regression-based models were used to identify the trends and predict future land use status.

HYDROLOGICAL AND HYDRAULIC MODEL DEVELOPMENT

To develop a rainfall-runoff model, XP-SWMM was used. Total 20 major R-R events of years 2000 and 2004 (10 from each) were selected for model calibration while model validation was carried out in three stages using 5 events from year 2010 and 5 events of year 2015. In the first stage of validation process, 5 events from year 2010 were simulated using the actual percentage of imperviousness (from land use map) while all other calibrated parameters (e.g. catchment width, catchment slope etc.) were kept fixed. In the second stage of validation, 5 events of 2015 were simulated while imperviousness parameter was adopted from the the two proposed land use prediction scenarios of this study. This was due to the fact that no land use map was available for 2015. In the third stage, an analysis was conducted in which a search was done to find a specific value for imperviousness parameter that can result the best fit between simulated and observed runoff. This analysis aimed to estimate the most accurate impreviousness percentage for year 2015 and to re-adjust the land use prediction model. In each of the three stages of validation, model performance was evaluated using different criteria such as R^2, CE, RMSE, MAE, and RPE. The calibrated and validated rainfall-runoff model based on historical data was then used to develop a hydraulic model to predict river water level for the study river stretch. XP-SWMM model was again used for hydraulic model development and same calibration and validation events were used. As there were no middle point station in the river and all hydraulic model development was based on single station in the outlet, it was decided to have a temporary river stage measurement for a middle point for further validation of the developed model. The river stage measurement was collected at two points in Sungai Dua Besar; upstream part and downstream part of the river for one month. Then the calibrated model validated for this middle point as well.

RESULTS AND DISCUSSION

LAND USE PREDICTION

In scenario 1, the twelve available land use types were grouped into two major types namely non-urbanized and urbanized. Water bodies, forest, vacant lands, open spaces and recreational areas, and agricultural lands were considered as non-urbanized while the remaining ones were considered as urbanized. However, in scenario 2, only main contributors to imperviousness including industrial, residential, and transportation land uses were considered as urbanized. Considering urbanization trends by adopting scenarios 1 and 2, prediction was made for urbanized area year 2015 as shown in Table 1.

Table 1. Urbanized area and its percentage in study catchment for year 2015

Land Use	2015 Area (ha)	2015 Area (%)
Scenario 1	1412	80
Scenario 2	1442	82

R-R MODEL CALIBRATION

To calibrate the rainfall-runoff model, a total of 20 rainfall-runoff events were selected for model calibration from which 10 events were from year 2000 and another 10 from year 2004. The performance of the model for individual events was assessed in terms of R^2, CE, RMSE, and MAE values. After tunning the parameters of the model, in general model was able to simulate hydrograph for the 20 calibration events with average values of CE=0.814, R^2=0.866, RMSE=0.771, and MAE=0.556. Model performance on calibration events was considered as good since all the R^2 and CE values were above 0.8 which is an indication of acceptable goodness of fitness. Finally the model parameters were fixed based on calibration events to be used for the validation stage.

R-R MODEL VALIDATION

Following the observed urbanization percentage in 2010, the imperviousness of validation events (from year 2010) was taken as 72%. The results of the Phase-1 of the validation are shown in Table 2. As can be seen, the performance of the model in phase 1 of the validation is good in terms of all assessment parameters. For phase 2 of validation, imperviousness percentage was predicted for year 2015 using two land use change scenarios. Scenario 1 and 2 predicted imperviousness value as 80% and 82%, respectively. The performances of the calibrated model under two scenarios for this phase of validation are presented in Tables 3 and 4. In phase 3 of validation a sensitivity analysis was conducted to identify the value of imperviousness in model that can produce the best fitted discharge compared to observed ones for validation events of year 2015. The results showed that 70% imperviousness produced the best match between simulated and observed discharge for these events. Therefore, scenario 1 model was revised accordingly to accommodate the estimated imperviousness for year 2015 where no real land use map was available. A regression-based fitted line was used to show the trend of land use change from 1966 to 2015 which are illustrated for urbanized and non-urbanized areas separately in Figures 2 and 3, respectively. These prediction trend-lines were used to estimate urbanized and non-urbanized areas in year 2020. It was predicted that urbanized and non-urbanized areas in year 2020 would be 1470ha (83%) and 295ha (17%), respectively.

Table 2. CE, R^2, RMSE, MAE and RPE values resulted for 5 validation events of year 2010

Event	CE	R^2	RMSE (m^3/s)	MAE (m^3/s)	RPE
2010-1	0.721	0.888	0.197	0.158	0.103
2010-2	0.854	0.885	0.061	0.037	0.037
2010-3	0.882	0.896	0.165	0.095	0.015
2010-4	0.747	0.890	0.235	0.179	0.191
2010-5	0.829	0.888	1.373	0.692	0.253
Average	0.806	0.889	0.406	0.232	0.120

Table 3. CE, R^2, RMSE, MAE and RPE values resulted for 5 validation events of year 2015 based on scenario 1

Event	CE	R^2	RMSE (m^3/s)	MAE (m^3/s)	RPE
2015-1	0.687	0.908	0.344	0.257	0.004
2015-2	0.656	0.869	0.461	0.398	0.190
2015-3	0.833	0.933	0.392	0.305	0.014
2015-4	0.871	0.887	0.581	0.380	0.025
2015-5	0.916	0.921	1.413	0.806	0.045
Average	0.793	0.904	0.638	0.429	0.056

Table 4. CE, R^2, RMSE, MAE and RPE values resulted for 5 validation events of year 2015 based on scenario 2.

Event	CE	R^2	RMSE (m^3/s)	MAE (m^3/s)	RPE
2015-1	0.728	0.895	0.320	0.237	0.008
2015-2	0.783	0.898	0.366	0.317	0.014
2015-3	0.868	0.900	0.349	0.280	0.017
2015-4	0.857	0.877	0.611	0.391	0.048
2015-5	0.663	0.865	2.838	1.909	0.048
Average	0.780	0.887	0.897	0.627	0.027

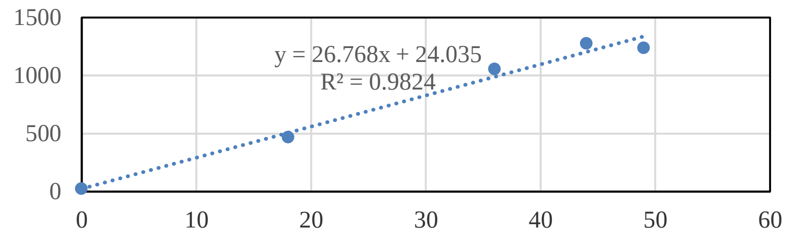

Figure 2. Trend-line of change in urbanized area for years 1966, 1984, 2002, 2010, and 2015

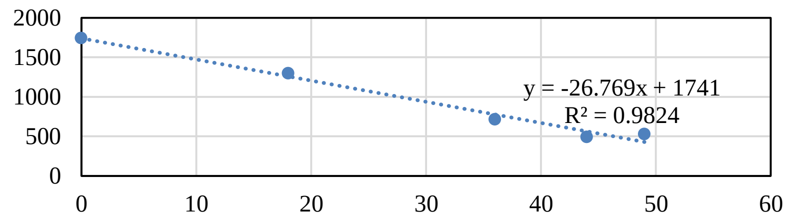

Figure 3. Trend-line of change in non-urbanized area for years 1966, 1984, 2002, 2010, and 2015

CALIBRATION OF HYDRAULIC MODEL

To develop the hydraulic model, XP-SWMM model was calibrated by the same 20 events (10 events from year 2000 and 10 from year 2004) used to calibrate the R-R model. Calibration performance was assessed in terms of evaluation measures CE, R^2, RMSE, MAE, and RPE. The average values for the 20 calibration events were found as CE=0.861, R^2=0.911, RMSE=0.064, MAE=0.497, and RPE=0.342 which were an indication of a successful calibration process.

VALIDATION of HYDRAULIC MODEL

A total of 10 rainfall events (5 from 2010 and 5 from 2015) were employed to validate the calibrated hydraulic model in estimating water level. The results of validation stage is presented in Table 5. As can be seen, the performance of the model in predicting water level in the outlet is reasonably good as average CE value of 0.870 and R^2 value of 0.928 are indications of a very good level of goodness-of-fittness. However, the performance of a hydraulic model cannot be judged based on the outlet results. As there was no mid-point water measurement in the catchment, it was decided to consider an on-site water level data collection in a point further upstream of the catchment outlet during the monsoon period of November-December 2016. These data were used for further validation of the hydraulic model in simulating water level in the study catchment. The result of hydraulic model validation is provided in Table 6. As can be seen, the performance of the model for an on-site measurement of water level in river mid-point is quite promising for the 3 major events.

Table 5. Average, minimum, maximum and standard deviation values of CE, R^2, RMSE, MAE and RPE obtained from 10 validation events

	CE	R^2	RMSE (m^3/s)	MAE (m^3/s)	RPE
Average	0.870	0.9284	0.076	0.057	0.025
Min	0.800	0.827	0.034	0.028	0.007
Max	0.942	0.982	0.131	0.093	0.065
STDEV	0.054	0.049	0.033	0.022	0.015

Table 6. Results of On-Site Validation of Hydraulic Model for a mid-point in Sungai Dua Besar

No	**Events**	**Observed Discharge (m^3/s)**	**Peak Water Level at mid-point (m)**		**Error (%)**
			Observed	**Simulated**	
1	2016-1	16.650	1.535	1.489	3.00
2	2016-2	15.920	1.469	1.425	3.00
3	2016-3	15.401	1.420	1.388	2.25
4	2016-4	0.811	0.744	0.711	4.44
5	2016-5	0.012	0.025	0.022	12.00

FLOOD PREDICTION

The IDF curves for 20, 50, and 100 years ARI were adopted to be used as design rainfall in XP-SWMM R-R model. Considering catchment time of concentration and availability of spatial-temporal rainfall patterns in Storm Water Management Manual for Malaysia, rainfall durations of 15, 30, 60, 120, 180, and 360 minutes were chosen in this study. Maximum resulted peak discharges for 2010 (urbanization=72%) and 2020 (urbanization=83%) were obtained from the R-R model. Results showed that the critical peak for 20, 50, and 100 years ARI happen when rainfall duration is 120 minutes. Comparison between critical peak values for 100-years ARI showed that it has changed from 198.98 m^3/s in 2010 to 204.78 m^3/s in 2020 which is equivalent of 2.9% increase in peak flood. Same investigation was also made for water level for which a 4.9% increase from 2.026m (in 2010) to 2.125m (in 2020) was found. Using topographical data of the catchment the flooding potential of the catchment was assessed and is provided in Table 7. As can be seen, for 20, 50, and 100 years ARI, flooded area has increased for 6.6%, 4.7%, and 3.0%, respectively from 2010 to 2020 for critical rainfall duration of 120 minutes. This shows the impact of urbanization on the flooding potential of the study area.

Table 7. Flooded area at Sungai Dua Besar river basin for rainfall duration of 120minutes

Year	Average Recurrence Interval (ARI)		
	20 years	50 years	100 years
		Flooded Area (km^2)	
2010	1.06	1.29	1.67
2020	1.13	1.35	1.72

CONCLUSIONS

(i) The land use change in the study catchment was studied and two predicting scenarios deveoped on it based on historical land use data from 1966 to 2010.
(ii) XP-SWMM was employed to calibrate a rainfall-runoff and a hydraulic model in study catchment using R-R events of years 2000 and 2004 for calibration and 2010 and 2015 fore validation. Land use predictor was then readjusted based on validation results of year 2015.
(iii) The on-site water level measurement was made in a mid-point of the river for further validation of hydraulic model for which the model parameters were fine-tunned.
(iv) The developed model was able to predict the potential critical peak discharge and water level and estimate the flooded area for year 2020.
(v) This study can be used by various Government agencies (DID, town council etc.), consultants and town planners in helping of tackling flood issues and future land use planning. Proper future planning will help to reduce the significant rise of impervious surface area which can lead to flash floods. It is also possible to implement a controlled development condition based on the urbanized trend by using a network of laws to reduce the flood hazard.

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