Variation in Hydrological Responses Estimation Simulations due to Land Use Changes

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***Abstract*—** The Sungai Kelantan has become prone to flood disasters, and this is potentially due to meteorological factors (i.e. climate change), rapid changes in land use, and weaknesses in development planning and monitoring. Increases in population, coupled with urbanization, may contribute to residential and industrial development in the floodplain. Such changes have caused disturbance of the natural water flow as well as the hydrological response particularly, in the study area of the Sungai Kelantan catchment. The objectives of the study were to quantify *current* land use condition effects to peak discharge and runoff volume through utilization of a geospatially semi-distributed hydrological modelling of the Sungai Kelantan catchment and to quantify which land use types have the greatest effect on the peak discharge and runoff volume using hypothetical land uses simulations. A hypothetical scenario for land use was adopted using an arbitrary land use change scenario or also known as *the land use sensitivity scenario*. This analysis was carried out to provide plausible causes and effects if such developments were observed in the future in the study area. Six land use change scenarios were used which are named low, medium, high, extreme 1 (equal proportion i.e. 50% each changes to agricultural and built-up lands), extreme 2 (all i.e. 100% forest area is converted to agricultural land), and extreme 3 (i.e. 100% forest area is converted to built-up land). The result showed that the conversion of forest to built-up land had the most significant effect on peak discharge and runoff volume, followed by conversion of forest to built-up land and agricultural land jointly. Although the results in this study are not meant to represent actual floods in the future, the results may be appropriate to be used as useful guidelines for any studies of the implications on society and adaptive requirements for water management practices and land use planning.

***Keywords*—** GIS, hydrological modelling, land use change, peak discharge, runoff volume

I. Introduction

THE Sungai Kelantan has become prone to flood disasters, and this is potentially due to several factors such as meteorological factors (i.e. climate change), rapid changes in land use, and weaknesses in development planning and monitoring. Increases in population, coupled with urbanization, may contribute to residential and industrial development in the floodplain. Furthermore, human activities such as unplanned rapid settlement development, uncontrolled construction of buildings and problems in relation to drainage management are factors, which may cause increases in runoff. These changes may lead to higher peak flow and runoff volume when coupled with heavy rainfall in the monsoon season (October to March) as normally experienced in the Southeast Asian countries particularly, Malaysia.

Land use change due to human activities may influence hydrological processes such as evapotranspiration and infiltration [1]. Deforestation may cause increases in overland and river flow due to lower evapotranspiration capacity [2]. In contrast, urbanization may lead to a greater impervious surface area (e.g., pavements, roads, car parks and buildings) and may cause infiltration excess to occur when poor infiltration conditions are coupled with high rainfall intensities [3]. Several studies have found that changes of land use from forest to other land uses (e.g., built-up, agricultural or bare land) may cause increases in runoff volume, frequency of flooding and peak discharge [4],[5],[6].

Therefore, this study tries to quantify the extent to which changes in hydrological response (i.e. peak discharge and runoff volume) is due to land use changes. The objectives of the study were to quantify *current* land use condition effects to peak discharge and runoff volume through utilization of a geospatially semi-distributed hydrological modelling of the Sungai Kelantan catchment and to quantify which land use types have the greatest effect on the peak discharge and runoff volume using hypothetical land uses simulations. The answer will hopefully determine future land use planning policy in the area, as well as flood management policy and decisions making.

II. Methodology

The study will involve three different methods known as land use classification from remotely-sensed imagery (i.e. Landsat TM) of *current* land use for the year 2004, hydrological modelling to quantify hydrological response changes and simulation of hypothetical land use changes effect to hydrological response changes.

Firstly, image classification needs to be performed using a remotely-sensed image to make use of its multispectral and multitemporal information and convert it to meaningful information such as the type of land use in the study area. The maximum likelihood algorithm of supervised classification was used because the algorithm takes variability of the classes into account using the variance-covariance matrix. The land

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use and land cover (LULC) classification system for remote sensor data was used [7]. Accuracy assessment also was performed using stratified random samples of reference data to measure the agreement between a standard assumed to be correct and a classified image of known quality. Later, land use classification was converted to curve number (CN). The CN was used because it is a method to estimate precipitation excess and antecedent moisture as a function of cumulative precipitation, soil types, antecedent moisture and land use [8].

Secondly, the Hydrological Modeling System (HMS), developed by the Hydrological Engineering Center (HEC) of th4e United States Army Corps of Engineering (USACE), is a lumped, semi-distributed software package used to model rainfall-runoff processes in a watershed or region. The model is suitable for small and larger catchment hydrologic applications in addition to lumped and distributed rainfall-runoff modeling. The HEC HMS events model is associated with short period of rainfall event was used in this study. Finally, simulation of *current* (i.e. year 2004) land uses and hypothetical land use effect to hydrological response were performed using calibrated-validated HEC HMS model.

A. Study Area and Data

Kelantan is one of the largest states in Malaysia and is affected annually by monsoon flooding, especially in the months of October to March. The Sungai Kelantan was chosen to perform the analysis because it is subject to the most severe monsoon flooding in Malaysia [9]. The River Kelantan has two tributary rivers: River Galas and River Lebir. River Galas has two other tributaries known as the River Nenggiri and River Pergau which contributed about 8,000 km2 or 54% from the total Kelantan's catchment (i.e. 13,100 km2). Meanwhile, River Lebir has one tributary known as River Relai which contributed about 2,500 km2 or 17% from the total catchment (Fig.1 (a)).

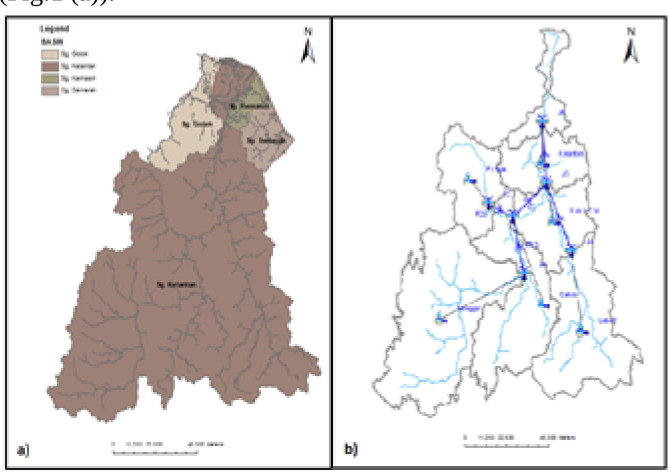

Fig. 1 a) River Kelantan catchment map and b) The six sub-basins (i.e. Nenggiri, Galas, Pergau, Lebir, Kuala Krai and Guillemard Bridge) as derived from the HEC-GeoHMS tool processing.

A multi-temporal satellite sensor images was used. Landsat Thematic Mapper (TM) imagery of 28 May 2000 were supplied by the Malaysian Remote Sensing Agency (Remote Sensing Malaysia) with 30 m spatial resolution, 8-bit radiometric resolution and six spectral channels. These dates were chosen because the temporal difference was relevant to the study and sufficient to perform land use change analysis in the area. The TM3, TM4 and TM5 bands were used to discriminate land use in the study area. Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) data were provided by the Consultative Group for International Agriculture Research–Consortium for Spatial Information (CGIAR-CSI) (http://srtm.csi.cgiar.org/). The data have a horizontal resolution of 30 m and vertical resolution of 90 m. The data were used to delineate sub-basins in the study area. The data were subjected to error correction by filling in sinks using the Arc Hydro tool in the ARCGIS software. Additionally, other GIS layers representing the Kelantan catchment were obtained from DID, Malaysia. The layers comprise of a grid data structure of digital elevation model (DEM) with 30 m spatial resolution, river network, soil type data, rainfall gauge stations and streamflow gauge stations. Further datasets of land use data were provided by the Department of Town and Country Planning Malaysia (TCPD). The catchment processing using HEC GeoHMS derived six sub-basin of the Sungai Kelantan catchment as shown in Fig. 1 (b).

III. Result and Discussion

The land use classification result using maximum likelihood showed in Table 1. The model calibrated to the 2004 runoff event was used to provide a baseline scenario. The baseline rainfall-runoff model for the calibrated peak discharge and runoff volume result showed the values of 863.7 m3s-1 to 12586.2 m3s-1 and 145.3 mm to 3420.7 mm respectively. To simulate runoff change due to land use hypothetical changes attention was given to differences in peak discharge and runoff volume resulting from the replacement of land use.

TABLE 1
LAND USE CHANGE RESULT FOR RIVER GALAS (UPSTREAM) SUB-CATCHMENT STREAMFLOW. CLASSIFICATION WAS UNDERTAKEN FOR BOTH YEARS USING MAXIMUM LIKELIHOOD CLASSIFICATION.

River Galas (Upstream)			River Kelantan (Downstream)	
Land use class	Pixels count	%	Pixels count	%
Forest	4347143	65.52	2760395	62.77
Built-up	73009	1.1	71004	1.61
Bare soil	282016	4.25	192869	4.39
Paddy	40850	0.62	46438	1.06
Mangrove	26624	0.4	18805	0.43
Oil palm	599055	9.03	432812	9.84
Rubber	786903	11.86	726177	16.51
Mixed-agriculture	463156	6.98	134571	3.06
Water	16560	0.25	14267	0.32
Total	**6635316**	**100**	**4397338**	**100**

The hypothetical scenarios for land use were adopted using an arbitrary land use change scenario was simulated. The hypothetical scenarios were performed to study what types of land use change significantly affect peak discharge and runoff volume. This analysis was carried out to provide plausible causes and effects if such developments were observed in the future in the study area. The key factor of land use change involved in the hypothetical scenario was degradation of forest area since it is observed to be happening in the study area.

Decreases in forest area are assumed to cause increases in agricultural and built-up land with possible proportions as portrayed in Table 2. Six land use change scenarios were used which are named low, medium, high, extreme 1 (equal proportion i.e. 50% each changes to agricultural and built-up lands), extreme 2 (all i.e. 100% forest area is converted to agricultural land), and extreme 3 (i.e. 100% forest area is converted to built-up land). These changes in land use were applied to study the effect of increases in each type and in combinations land use types (i.e. agricultural and built-up land) on hydrological response in the River Kelantan catchment. The difference from the baseline runoff model was calculated and the results were presented.

Based on the land use classification as presented in Table 1 the SCS CN was calculated. The 2004 land use was used as a baseline and all the land use types were kept constant except for three land use types which are forest, agricultural (i.e. rubber, oil palm and mixed-agriculture) and built-up land The new SCS CN resulted from the what-if land use changes presented in Fig. 2.

The SCS CN of the what-if land use scenarios showed that for all sub-basins the CN was higher for the extreme 1 scenario than extreme 2. This suggests that conversion of forest to a combination of agricultural and built-up lands resulted in a higher CN as compared to only forest conversion to agricultural land. The extreme 3 scenario showed the largest CN for all sub-basins. This suggests that built-up land gives the largest CN as compared to agricultural land and the combination of agricultural and built-up lands.

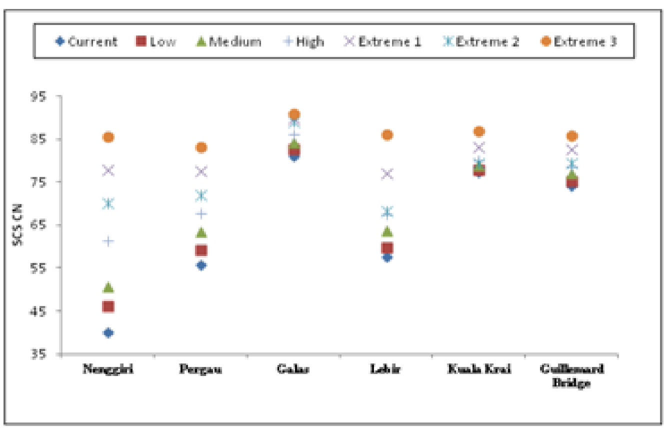

Fig. 2 SCS CN of baseline and what-if land use scenarios.

Using the new calculated CN as presented in Fig. 2 differences in peak discharge and runoff volume were calculated from the observed baseline. The result showed that what-if land use scenario extreme 3 has the highest increases in peak discharge absolute difference compared to the others scenarios (Figure 3 (a)). This suggests that conversion from forest to built-up land (i.e. 100%) was the largest contribution to increases in peak discharge for all streamflow gauges in the River Kelantan catchment. More interestingly, the extreme 1 land use scenario leads to greater increases (i.e. in peak discharge and runoff volume) compared to the extreme 2 scenario. The extreme 1 scenario models a decrease in 100% of forest to 50% increase in agricultural and 50% increase in built-up land. Meanwhile, the extreme2 scenario represents decreases of 100% in forest to agricultural land.

The result suggests that built-up land plays a significant role in increasing peak discharge [12], [13]. The combination of agricultural and built-up land was the second greatest contributor to differences in peak discharge. Agricultural land was the third highest contribution to increases in hydrologic change in the study area. Amongst the individual flow gauges stations the Nenggiri station which is located in the most upstream part of the study area exhibited the largest increases in peak discharge compared to the other five flow gauges (i.e. 12.8% to 149.2%). The result may imply that deforestation that happened in the upstream area as well as in the Lebir sub-basin may contribute to increases in peak discharge.

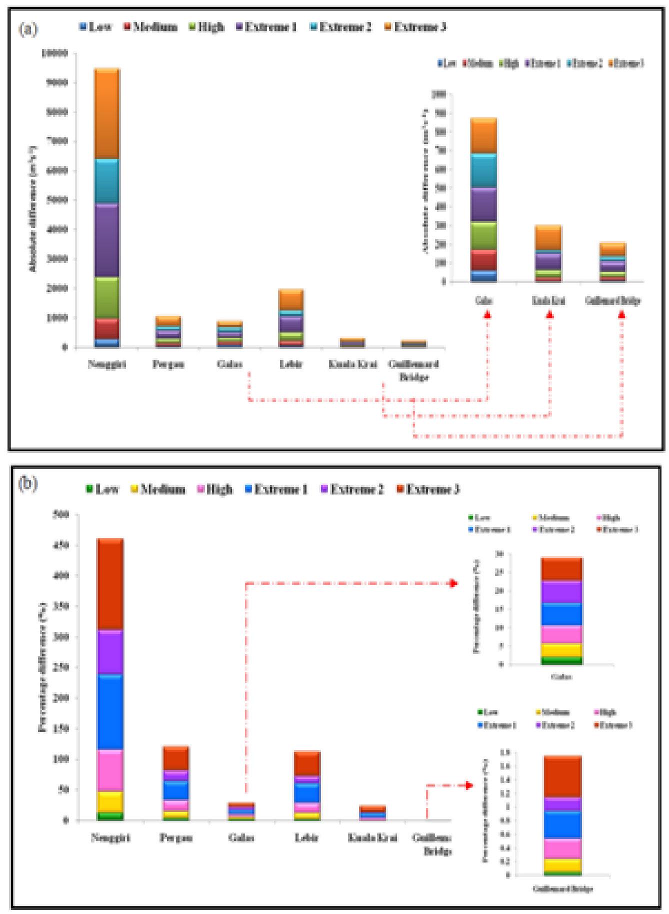

Fig. 3 Peak discharge (a) absolute difference (b) percentage difference using what-if land use scenarios medium, high, extreme 1, extreme 2 and extreme 3.

The percentage difference in peak discharge is also presented in Fig. 3 (b). The results showed a similar pattern to absolute difference in peak discharge. The extreme 3 scenario showed the largest increases followed by the extreme 1 and extreme 2 scenarios. Again, the Nenggiri exhibited the largest increases in peak discharge and runoff volume compared to the other five gauges in the River Kelantan catchment. However, the results showed that runoff volume was less sensitive compared to the peak discharge with increases in peak discharge being higher than the increases in runoff volume.

The hypothetical land use scenario was used to quantify which land use types have the greatest effect on the hydrological response in the River Kelantan catchment. The conversion of forest to built-up land had the most significant effect on peak discharge and runoff volume, followed by conversion of forest to built-up land and agricultural land jointly. The forest is important to reduce runoff since it provides of greater rainfall interception and transpiration due to broader leaves compared to crop vegetation [10], and deeper rooting which enables more precipitation water to be absorbed into the deeper soil layer [11]. In contrast, built-up land which is associated with highly impervious areas may cause less water to be absorbed into the soil layer, hence causing high runoff to occur.

IV. Conclusion

Land use change analysis for the hypothetical scenario led to interesting findings. The main findings demonstrated that forest plays an important role in controlling water flow and subsequently minimizing the flood magnitude in the downstream area. If forest were replaced by different land use types such as agricultural and built-up land, less infiltration would be expected to occur and hence a higher peak discharge and runoff volume would be predicted. The what-if land use change scenario simulated that if forest was converted to built-up and agricultural lands, greater peak discharge and runoff volume were derived. However, if forest was fully converted to urbanization or to agricultural land only, smaller peak discharge and runoff volume were observed. The knowledge gathered from this analysis can lead to improve management policies, especially to mitigate changes in hydrological response and their consequences. Based on such information, suitable strategies can be implemented by decision makers, including land use planners, such as controlling rapid urban development, particularly along the river and in floodplain areas.

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