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Land use Changes Impact on extreme flood events in the Hulu Kelang River Basin, Malaysia

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Abstract:
Hulu Kelang is a flood prone area near to Kuala Lumpur. Urban development has caused numerous landslides and mudflow events in this region. The current research tried to study the area inundated by a rainfall period of a hazard to be determined in relation to the land use. The assessment of land use impact in the Hulu Kelang basin focused on the runoff contributions from different land cover classes and the potential impact of land use changes on runoff generation. To minimize losses incurred by mudflow events, A hydrological regional modeling of rainfall induced runoff event were employed in this study. Five approaches were considered in this research, i.e: (1) Drainage Basins Delineation; (2) Calculation the rate of Loss/ Infiltration; (3) Assessment of basins in term of flood potential; (4) Land Cover Change analysis, and (5) Change to runoff volume due to land cover change. In this regard, the results showed that the transient rainfall infiltration and grid based regional modeling (TRIGRS) provides important information about the flood intensity and significantly improves our ability to model future flood scenarios through other area. On the other hands, impact of land cover on runoff volume was computed with TRIGRS model based on the transient infiltration changes, and attendant changes in the runoff, due to rainfall period. Computation for the effects of rainfall infiltration on the land cover showed that the direct runoff from development area, agricultural area, and grass lands are dominant for a flood event compared with runoff from other land covered areas in the study area. The urban areas or lower planting density areas tend to increase for runoff and for the monsoon season floods, whereas the inter flow from forested and secondary jungle areas contributes to the normal flow.

Keywords: TRIGRS model, Flood volume, Land use impact, Hulu Kelang

1. Introduction

Floods are one of the major natural disasters that have been causing loss of human life and influence on social and economic development. Flood hazard is among the most severe risks on human lives and properties, and has become more frequent and severe along with local economic development. Land use change triggered by population increase and economic growth in recent decades is considered the dominant cause of increased flood occurrence (Boyle et al. 1997; Weng 2001). Human settlements and activities have always tended to use floodplains. Their use has frequently interfered with the natural floodplain processes, causing inconvenience and catastrophe to humans (Mays 2005). Undoubtedly, the greatest dilemma that humanity faces today is a consequence of deterioration of the existing balance of rainfall-runoff in the river basins in favour of flow owing to various reasons, i.e. deforestation, unstable land forms, etc., which make the flood prone areas more vulnerable for floods. As a result, the risk of flooding may change over time due to changing development conditions within the river basin.

Flood damage may exceed what would have occurred if the option had not been implemented. Therefore, an integrated approach is increasingly endorsed as a crucial support for proactive mitigation efforts, which is far more cost-effective than paying to clean up and rebuild after a flood occurs. In practice, detailed assessments are conducted to quantify the effectiveness of a promising alternative and estimate the associated costs, through a comprehensive hydrological and hydraulic analysis across the entire river basin. Consequently, an optimal set of mitigation measures will provide a more robust solution to deal with the increasing development pressure inside flood prone areas and the uncertainties created by changes in land use.

Several rainfall-runoff models are widely used, in order to provide a hydrographic showing the variation of volume flow rate (Q) of direct runoff over time at a particular point of interest, usually taken as the river basin outlet, i.e., HEC-HMS (US Army Corps of Engineers 2000), TOPKAPI (Liu and Todini 2002), TACD (Uhlenbrook et al. 2004), PRMS (Yeung 2005), SWAT (Neitsch et al. 2005), MIKE11 Rainfall Runoff (RR) module (DHI Water and Environment 2007), (TRIGRS) (Baum et al. 2008), etc. These hydrological and hydraulic models provide information on the dynamics and the behavior of the river basin. In this regards, The Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability Model (TRIGRS) as a hydraulic approach computes transient infiltration changes, and attendant changes in the runoff, due to rainfall period. The program models rainfall infiltration using analytical solutions for partial differential equations that represent one-dimensional, vertical flow in isotropic, homogeneous materials for either saturated or unsaturated conditions. Use of step-function series allows the program to represent variable rainfall input, and a simple runoff routing model allows the user to divert excess water from impervious areas onto more permeable downslope areas.

During recent years in "risk mitigation and emergency preparedness in the event of natural disasters" the areas which have accumulation lakes or other discharge control structures and the lower courses of rivers in Malaysia were reinforced or rebuilt to strengthen the flood protection infrastructure. But most mountain areas still have flooding problems due to little or no maintenance of flood protection infrastructure in these areas. Besides these problems, Malaysia was also affected by uncontrolled deforestation without the removal of vegetation leftovers from the deforested areas. The massive deforestation in the last decades raised the runoff coefficients and reduced the infiltration and retention, so a higher volume of rainfall becomes runoff which concentrates as flash floods in these areas. Therefore, a high percent of mountain settlements are affected by torrents and flash floods.

Flood event as one of the worst natural disasters can be affected by Land Use and Land Cover (LULC) changes among other factors. LULC are changing year by year due to the ever-growing population and economy. The various types of land cover and land use have significant roles and impacts on runoff and flood; but how and to what extent is not clear and highly uncertain. The overarching objective of this paper is to develop an integrated modelling framework with certain tools and techniques for flood management in light of land use and its changes in the study river basin.

2. Materials and method

2.1 Background of the study area

The Hulu Kelang region in Malaysia is very susceptible to landslides and mudflows (Mukhlisin et al. 2010). Hulu Kelang is located in the northeast of Kuala Lumpur, the capital city of Malaysia between 3° 09' 25" and 3° 13' 45" North latitude and 101° 44' 13" and 101° 47' 51" East longitude (Fig. 1). From 1990 to 2011, a total of 28 major landslide and mudflows incidents had been reported in this area.

Hulu Kelang has a typical equatorial climate characteristic with constantly high annual temperatures and heavy rainfall. While the temperature range is practically the same all over throughout the year, it is governed by the height of the land above sea level. Based on Malaysian Meteorological Department (MMD), the temperature of the Hulu Kelang area represents usually between 29 and 32° C with a mean relative humidity of 65-70%. The average annual temperature is about 25°C. April and June represent as the highest temperature months, while the relative humidity is lower in June, July and September.

Figure 1. Location of Hulu Kelang area, Malaysia

The precipitation amount varies between 58 and 420 mm per month in the study area (MMD). There are two pronounced wet seasons from February to May and from September to December each year (Lee et al. 2014). The peak of precipitation represents between March and May and also from November to December in the study area. The single-day precipitation high that had been recorded ranged from 87 to 100 mm.

2.2 Overview of modeling framework

The development of an integrated modelling framework with certain tools and techniques for flood management in light of land use and its changes in the study river basin was the main objective of the current study. The existing deterministic Grid-Based models are mostly physical and temporal dynamic hydrological models that can be used for predicting rainfall-induced runoff events. The distributed models represent watersheds as raster cells with parameters that are fully distributed in space. SHETRAN, CASC2D (CASCade 2Dimensional model), GSSHA (Gridded Surface/Subsurface Hydrologic Analysis), TREX (Two Dimensional Runoff Erosion and Export), and The improved TRIGRS (Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability Model) are the examples of the distributed model. The improved TRIGRS method was performed using Microsoft Excel® and GIS framework system for additional land cover equations. Fig. 2 represents the flow diagram of the improved TRIGRS model in order to perform runoff analysis on a regional scale. The improved model was applicable based on three major components; rainfall interception loss model, water infiltration analysis model, and the water surface calculation model. The input data was converted into a grid based framework with information for each cell assigned (e.g. terrain data, slope geometry data, soil mechanical properties, rainfall data, and land cover characteristics). All input layers were acquired by the GIS data-base system. For each parameter used in the model, a map was generated at the same Grid based (30 m×30 m) and raster format.

2.3 Rainfall interception loss based on Leaf Area Index (LAI)

Interception loss refers to rainfall that does not reach the ground, but is instead intercepted by the leaves and branches of land cover and the forest floor. It occurs in the canopy, and in the forest floor or litter layer (Gerrits et al. 2010). Leaf Area Index (LAI) plays an essential role in theoretical production ecology. An inverse exponential relation between LAI and light interception, which is linearly proportional to the interception rate, has been established:

$$Incep=P(1-e^{-C.LAI}) \quad (1)$$

Where P is the precipitation and c is a crop-specific growth coefficient.

Several models have been developed to apply empirical equation based on relationships between LAI and leave to ground gaps typically expressed in the form of vegetation indices (Sellers et al. 1986; Kergoat 1998; Lawrence and Chase 2007). Canopy interception method was based on Lawrence and Chase (2007) and is currently determined as the precipitation arriving at the vegetation top which is either intercepted by foliage, or falls directly through the leaf gaps to the ground. The water intercepted by the canopy in a model time step (mm) is:

$$Incep=P(0.25(1-e^{-LAI/2}) \quad (2)$$

Where 0.25 is implemented to scale the parameterization of interception from point to grid cells (Lawrence and Chase 2007). The scaling factor reflects the total fractional area of a leaf that collects water. Lawrence and Chase (2007) reduced canopy interception, and therefore canopy evaporation, by reducing the tuning parameter from 1.0 to 0.25, a value that more realistically reflects that only one side of a leaf can collect water and that rainwater tends to bead on the leaf and does not typically wet the entire exposed leaf surface. Land cover maps of Hulu Kelang (Fig. 3 and Table 1) have been used as major data to determine LAI properties for each land class. The Land cover distribution in this study area was classified by the Department of Survey and Mapping Malaysia (JUPEM). Under the classification system, nine types of land use were identified, i.e. primary forest, secondary jungle, rubber, tree cultivation, grass, cleared land, urban area, recreation area and lake.

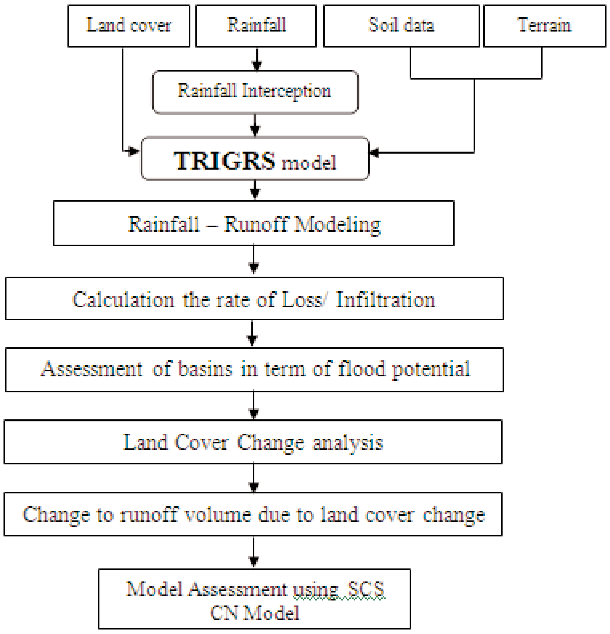

Figure 2. The general framework of this proposal research

2.4 Transient vertical infiltration model

TRIGRS model developed by Baum et al. (2008) was adopted in this study to simulate water infiltration. The transient infiltration models assumed the infiltration process typically relies on one-dimensional, vertical flow (Srivastava and Yeh 1991; Savage et al. 2004; Salciarini et al. 2006; Godt et al. 2008), with a time-varying specified flux boundary condition and

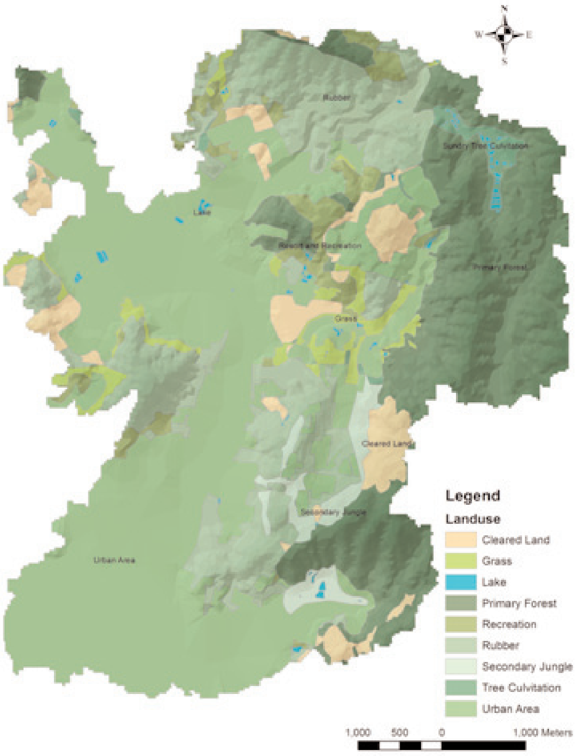

Figure 3. Land cover of Hulu Kelang area

varying duration based on intensity and duration of rainfall events at the ground surface. This condition treats the soil as a two-layer system consisting of an unsaturated layer that extends to the ground surface above a saturated layer with a capillary fringe above the water table. The water passes through the unsaturated zone and accumulates at the top of the saturated zone above the initial groundwater.

The Richards equation is used to describe unsaturated vertical flow in response to infiltration water at the ground surface (Fig. 4).

$$\frac{\partial \psi}{\partial t} C(\psi) = \frac{\partial}{\partial z}\left[K(\psi)\left(\frac{\partial \psi}{\partial z} - \sin\beta\right)\right] \quad (3)$$

Where t (s) is the time; Z (m) is the depth in vertical direction; ψ (m) is the pore-water pressure head; C (ψ) is the specific moisture capacity, and it is obtained by aθ/aψ, θ is the volumetric water content; K(ψ) (m/s) is the pore pressure head dependent hydraulic conductivity and saturated permeability in the Z direction; β (°) is the slope angle.

In TRIGRS model, Eq. (3) is linearized and solved at discrete time steps and in the vertical direction. The linearization procedure relies on the identification of two different time scales (Iverson 2000). For each grid cell, H is depth, A is the catchment area that potentially affects groundwater pressure and D0 is the maximum hydraulic diffusivity of the soil and equal to K_S/S, where Ks is the saturated soil hydraulic conductivity and S is the specific water storage and approximately equal to (H2/4D_0 where g is the magnitude of gravitational acceleration. The first time scale can be identified with A/D_0 as the longest pertinent timescale. The second time scale is defined as shorter timescale H^2/D_0 associated with transient pore pressure transmission during and following storms (Iverson 2000). One can then build the length scale ratio that plays a key role in analyzing pressure head responses to rainfall on slopes:

$$\varepsilon = \sqrt{\frac{H^2/D_0}{A/D_0}} = \frac{H}{\sqrt{A}} \quad (4)$$

Under the condition of ≤ 1, Eq. (3) can be simplified to identify long-term and short-term response terms (Iverson 2000) used in the numerical implementation of Baum et al. (2008). Eq. (4) is also used to identify the approximate limits of applicability of the model implemented by TRIGRS model. When rainfall intensity exceeds the local infiltration capacity, the excess water in each grid cell is routed downslope to the nearest cells (Baum et al. 2008). TRIGRS model accepts inputs of complex rainfall histories (i.e., spatially and temporally varying), and permits a realistic modeling of the runoff and slope stability/instability conditions driven by real rainfall events (Saadatkhah et al. 2014, 2015).

2.5 Runoff modeling

The program, Improved TRIGRS, uses a method for routing of surface runoff from cells that have excess surface water to adjacent downslope cells where it can either infiltrate or flow farther down slope. So, this model is used for storage and movement of water vertically within the soil layer. It is assumed that runoff occurs when the precipitation and runoff supplied to a cell exceed its infiltrability. The saturated hydraulic conductivity, Ks, generally equals the infiltrability, i, for saturated and tension-saturated soils (Iverson 2000). The purpose of routing the surface runoff is to prevent the loss of excess precipitation that cannot infiltrate at the cell of origin and to improve the performance of the model in urbanized or other areas where pavement or other impervious surfaces exist.

It is computed the infiltration, I, at each cell as the sum of the precipitation, P, plus any runoff from upslope cells, R_u, with the limitation that infiltration cannot exceed the saturated hydraulic conductivity, K_S:

$$I=P+R_u, if\ \ P+R_u \leq K_S \quad (5)$$

Or

$$I=K_S,\ \ if\ P+R_u > k_s \quad (6)$$

At each cell where $P+R_u$ exceeds K_s the excess is considered runoff, R_d, and is diverted to adjacent downslope cells.

$$R_d = P+R_u - K_s, if\ \ P+R_u - K_s > 0 \quad (7)$$

Or

$$R_d = 0, if\ \ P+R_u - K_s < 0 \quad (8)$$

Overland flow between adjacent cells is assumed to occur instantaneously. Consequently, individual storm periods should be long enough to allow surface water to flow to adjacent cells.

2.6 Data acquisition and parameterization procedure

The contour data for TRIGRS model and the improved methods were generated from standard 1:10000 scale topographic Ampang and Kampung Kelang Gates Baharu maps. A 30×30 m cell digital elevation map (DEM) was constructed for terrain analysis using ArcGIS 10 (ESRI, Inc.). In addition, according to the reports and historical bore log data from the Jabatan Mineral dan Geosains Malaysia (JMG), Ampang Jaya Municipal Council (MPAJ) and the Slope Engineering Branch of Public Works Department Malaysia (PWD), the relationship between bedrock depth (t) and topographic elevation (y) was identified as: y = 103.31 t - 1789.9

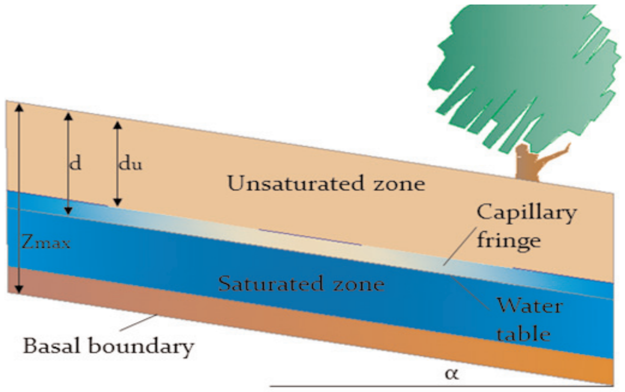

Figure 4. Shallow ground-water conditions in hillside soils. The unsaturated zone above the water table has depth. The capillary fringe is between the unsaturated zone and the water table at depth, u. The lower boundary, which is treated as impervious in this model, is at depth Z

(Saadatkhah et al. 2015). The thickest soil depth appears at the western part of the study area with a thickness of 32 m.

The hydraulic and mechanical data sources were obtained from the Ministry of Agriculture and Agro-Based Industry of Malaysia (MOA), Geological department of Malaysia (JMG), Ampang Jaya Municipal Council (MPAJ) and the Slope Engineering Branch of Public Works Department Malaysia (PWD), as well as data compilation from the previous reported studies and geotechnical boreholes. The properties of the soils are tabulated in Table 2. The mechanical and hydraulic properties were assigned to each cell of the grid map for both the existing and improved models, as created by the ASCI grid files (Fig. 5).

The rainfall interception loss was calculated based on the land cover maps, and relationships between leaf area index (LAI) and gaps of leaves to ground. Land cover maps of Hulu Kelang (see Fig. 3, Table 1) have been used as major data to determine LAI properties for each land class. In particular, Canopy interception method (Lawrence and Chase (2007) was employed in the present study to determine the precipitation arriving at the vegetation top and LAI characteristic (Table 1). The leaf area index (LAI) of the study area was defined as ranging from 1.49 to 3.99 based on LAI-2000 (LI-COR 1991) and linear regression equation from NDVI (Wang et al. 2006) (Table 1).

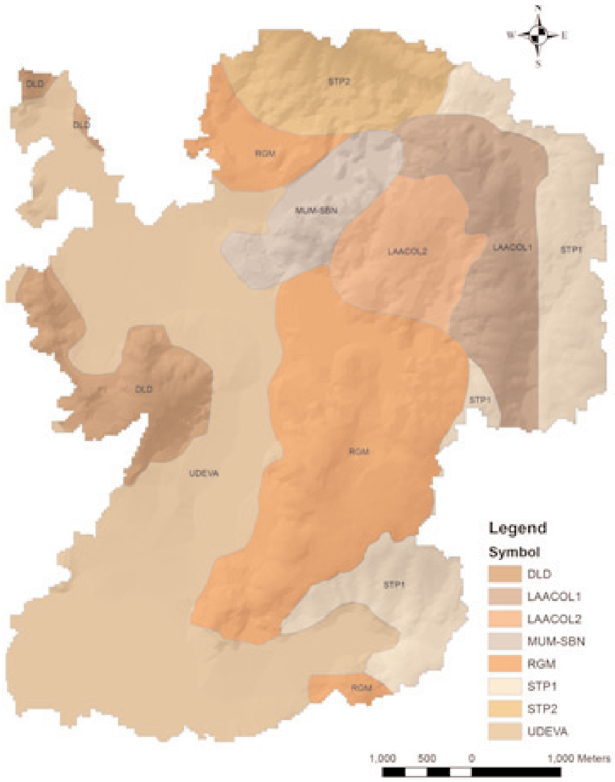

Figure 5. Soil property map of Hulu Kelang

Table 1. Land cover characteristics of Hulu Kelang area

Class	% of total area	LAI	Interception loss (%)
Primary forest	31.61	3.99	24
Secondary forest	1.88	3.35	23
Rubber	14.29	2.29	19
Sundry tree cultivation	1	3.5	23
Grassland	2.87	1.49	17
Cleared land	4.64	0	0
Urban area	43.25	0	0
Lake	0.47	0	0

3. Result and discussions

3.1 Catchment overview

The Hulu Kelang area covers the entire streams catchment from its source above to Ampang area. To obtain the basins, the 30 m × 30 m resolution DEM was exploited, and the Arc Hydro extension of ArcGIS 10 was employed to extract of basin regions in the study area (Fig. 6). A drainage basin or watershed is an extent or an area of land where surface water from rain, melting snow, or ice converges to a single point at a lower elevation, usually the exit of the basin, where the waters join another waterbody. Upslope area (counted in terms of the number of grid cells) is calculated using a recursive procedure that is an extension of the very efficient recursive algorithm for single directions (Mark, 1988). The upslope area of each grid cell is taken as its own area (one) plus the area from upslope neighbors that have some fraction draining to it.

The flow from each cell either all drains to one neighbor, if the angle falls along a cardinal ($0, \pi/2, \pi, 3\pi/2$) or diagonal ($\pi/4, 3\pi/4, 5\pi/4, 7\pi/4$) direction, or is on an angle falling between the direct angle to two adjacent neighbors. In the latter case the flow is proportioned between these two neighbor pixels according to how close the flow direction angle is to the direct angle to those pixels.

3.2 Rate of loss/ infiltration

Fig. 7 showed the total amounts of precipitation along with the total infiltration losses that resulted in the presented hydrographs. Considering the 10 days of the modeled rainfall events along with the extreme rainfall intensities of more than 44 mm/hour in the most intense 1 hour of the 10 day storm, the model predicted moderate losses of less than 22% of the total rainfall. The main reason for the low losses is the fact that the residual soils with low permeability characteristics have already been covered most of the study area. The absolute loss of a certain event is only a function of the land cover, soil characteristics, and the absolute rainfall depth regardless of the intensity distribution. Nevertheless, a time component is introduced in the model when it is applied for the estimation of runoff from successive intervals in a rainfall period as done in this study. In this regard, TRIGRS model first calculated the accumulated infiltration I from the accumulated precipitation P of each time step and then derived the runoff for each time step as the difference between the accumulated I at the beginning and end of each time interval. The relation between rainfall and runoff used in the TRIGRS model as shown in Figure 7 allows for an approximate description of the loss processes during a rainfall event.

According to Maidment (1993), this relationship for the determination of the effective rainfall Pe from the total accumulated rainfall P is well established by both theory and observation. After the beginning of the rainfall event, no runoff begins until the accumulated precipitation P equals the initial hydraulic conductivity of soil K. After the accumulated rainfall exceeds the initial K, runoff is calculated by subtracting R (water retained in the watershed) from the accumulated rainfall.

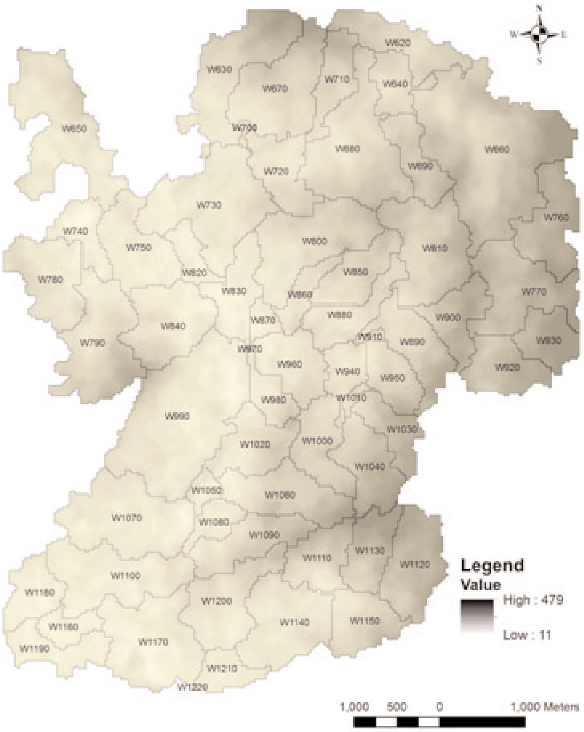

Figure 6. Catchment areas of Hulu Kelang

3.3 Land cover change analysis

Land cover is an important extrinsic factor controlling the hydrological and mechanical responses of an area to rainfall. It is believed that dense vegetation / canopies covering tropical mountains could act as a buffer to limit rainwater infiltration into soil slopes by evapotranspiration from the canopies (Interception loss) and, to a lesser extent, absorbed by plants (Rutter et al. 1971, 1975). Major changes in land cover that affect hydrology are deforestation, intensification of agriculture, drainage of wetlands, and urbanization. The most obvious influence of land cover on the water balance of a catchment is on the evapotranspiration process (Cadler 1993).

In terms of hydrological circulation, rainfall interception is the part of rainfall that is intercepted by the earth's surface and which subsequently evaporates. How much of the precipitation evaporates depends on land cover characteristics, rainfall characteristics, and on the evaporative demand. In the study area, the canopy interception has a clear local trend ranging from 17% of monthly average rainfall to 24%. The land cover classes that participate in runoff event include agricultural area (Rubber, tree cultivation), development area (Urban area, recreation region, and cleared land), grass, lake, forest, and secondary jungle (Fig. 8). In this regards, the amount of rainfall interception loss depends on kinds of plants and land

Table 2. Characteristics of soils in Hulu Kelang area

Soil Name	Group Sym.	ys	C '	φ '	K_s	K_r	θ_r	θ_s
STP1	CL	15.4	7	29	9.47E-07	5.79E-07	0.079	0.442
STP2	CL	14.1	3	31.5	9.47E-07	5.79E-07	0.079	0.442
LAACOL1	SC	16.8	4	33	1.52E-06	8.02E-07	0.063	0.384
LAACOL2	SC	16.3	11	31	1.52E-06	8.02E-07	0.063	0.384
MUM-SBN	CH	13.7	2	23	1.71E-07	3.43E-07	0.098	0.459
DLD	SC	15.7	5	32	1.40E-06	1.66E-06	0.093	0.263
RGM	SM	18.7	2	35	4.43E-06	1.79E-06	0.039	0.387
UDEVA	CL	14.8	6	28	1.11E-06	3.67E-07	0.111	0.481

STP granite residual soil, LAACOL phyllite residual soil, MUM-SBN Munchong Seremban association, DLD reformed area, RGM Rengam series, UDEVA Urban development area.

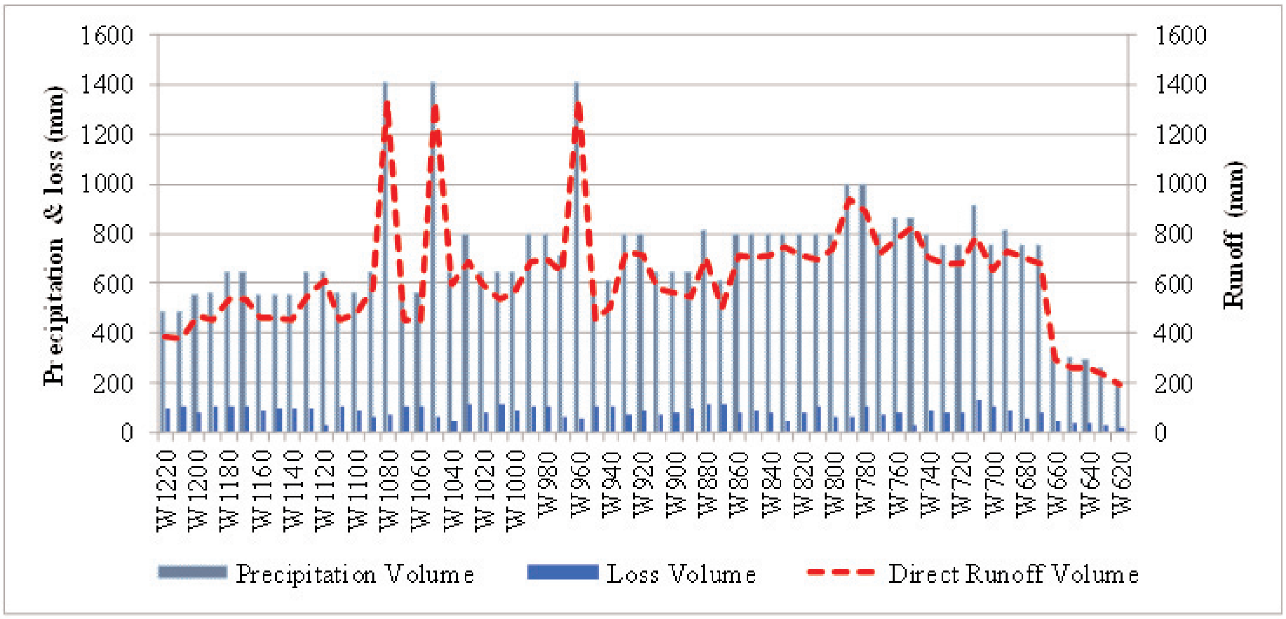

Figure 7. The total amounts of precipitation along with the total infiltration losses that resulted in the presented hydrographs

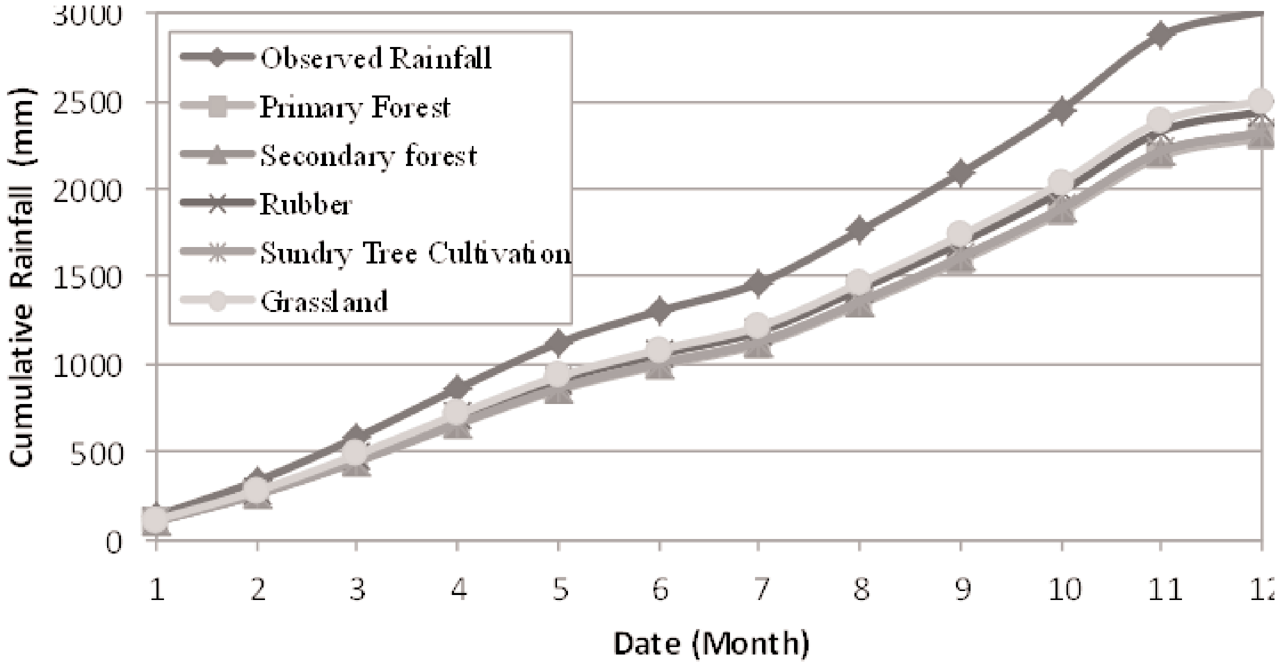

Figure8. Temporal average distributions of observed rainfall and infiltration rainfall based on rainfall interception loss

covers in this study, i.e., primary forest (24%), secondary forest (23%), rubber (19%), sundry tree cultivation (23%), and grassland (17%) (Mall et al. 1974; Clough et al. 1997; Giardina et al. 2003).

The results of using the improved TRIGRS model showed that critical runoff events were mainly scattered on the agricultural regions and the areas under development. Forest conversion to the less canopy coverage, i.e., urban areas, agricultural areas is responsible for a higher level of runoff events in the study area (Fig. 9). Tang (1991) found that fatal debris flows and runoff were caused by a combination of extreme rainfall, destruction of natural forest cover (human-caused), grassland, and conversion to agricultural plantations in thin, granitic soils.

3.4 Change to runoff volume due to land cover change

The percentage participation of land covers in the runoff volume for 1994 and 2013 is shown in Figures

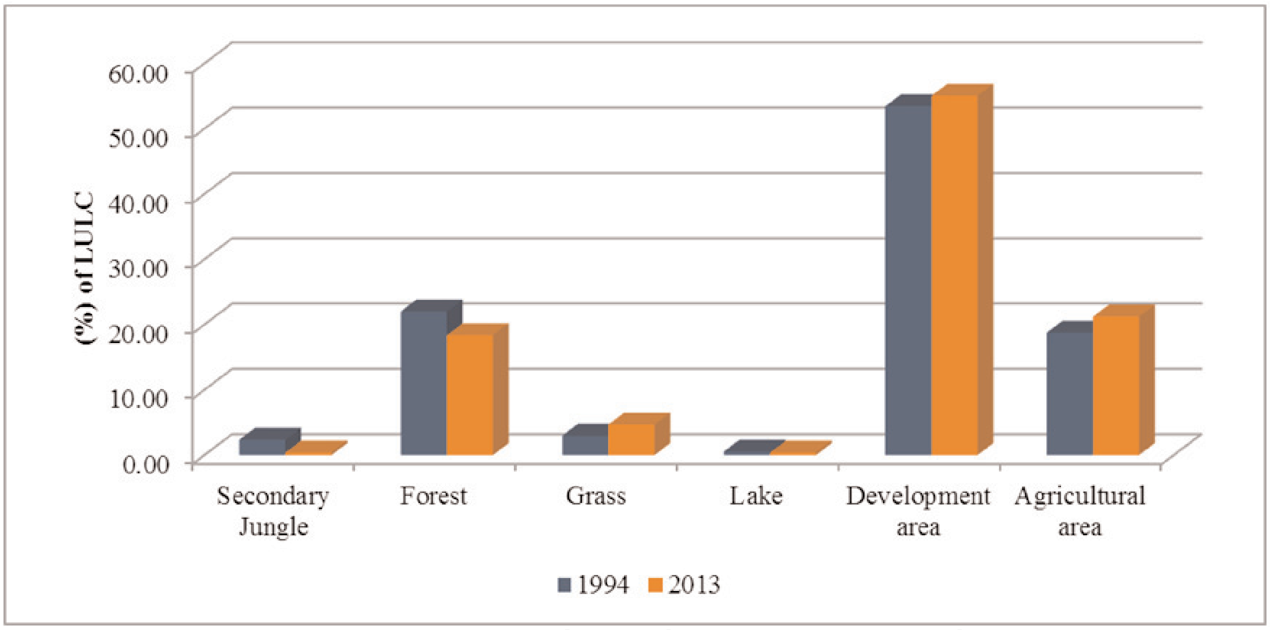

Figure 9. Detecting Land Cover Change over a 20 Year Period

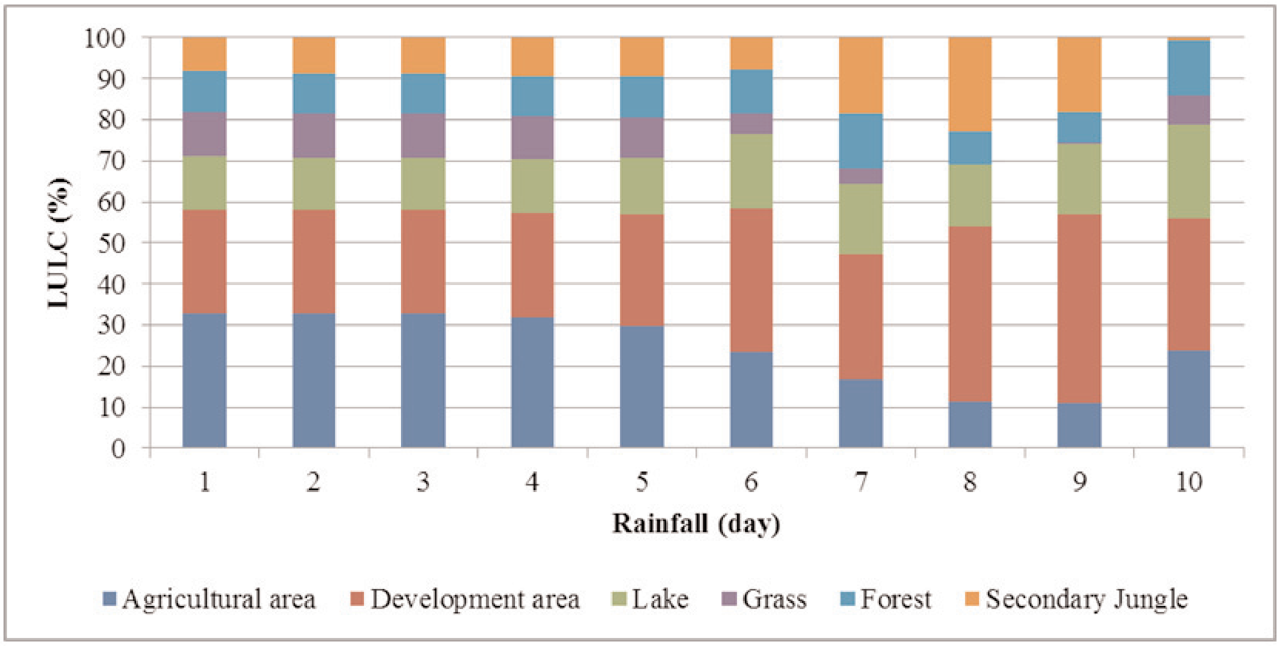

Figure 10. The percentage participation of land covers in the runoff volume for 1994

10 and 11. Different runoff volume values were observed by different land cover classes. The result predicts that the runoff volume increased between 1994 and 2013 as a function of land use changes. The largest differences between Figures 10 and 11 were observed for the agricultural and development areas with differences runoff volume of more than 50% for 1994 to more than 60% for 2013. The smallest predicted difference in runoff due to land use change was observed for the forest and secondary jungle with differences runoff volume of 20% for 1994 to 15% for 2013, respectively (Fig. 10 and 11).

The analysis managed to provide a framework into which to differentiate and quantify the effect of land use change factors in understanding the behaviour of the hydrological system in catchment areas. Figure 12 presented the increasing of runoff volume as a function of deforestation, agricultural conversion and urbanization for the study area. In this regard, the land use change analysis from 1994 to 2013 revealed a large percentage of total agricultural conversion and increase in development area. The change analy-

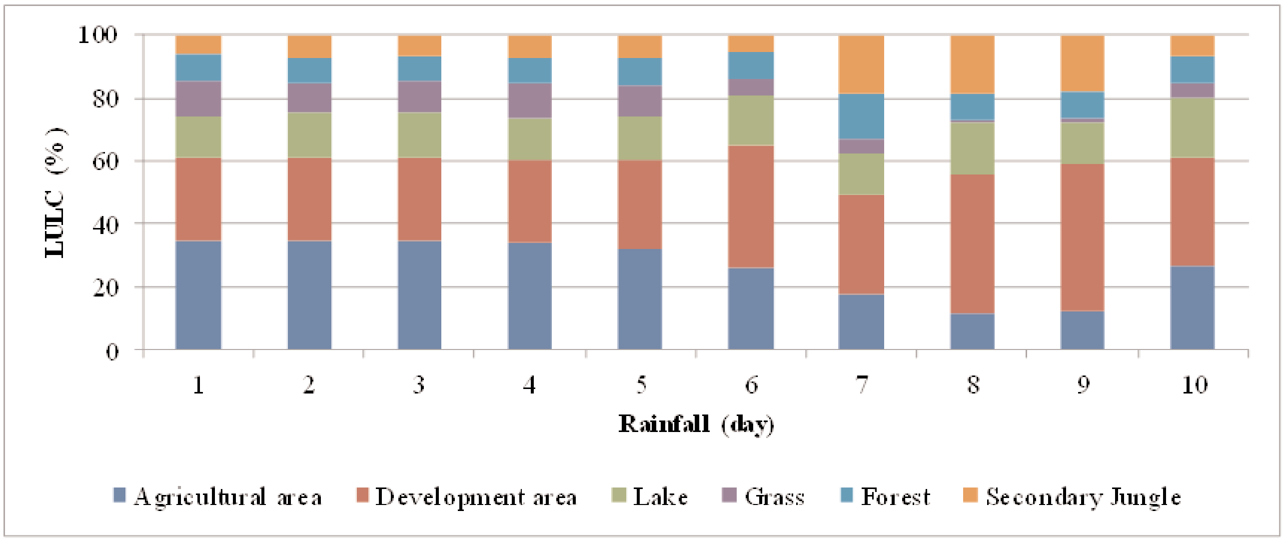

Figure 11. The percentage participation of land covers in the runoff volume for 2013

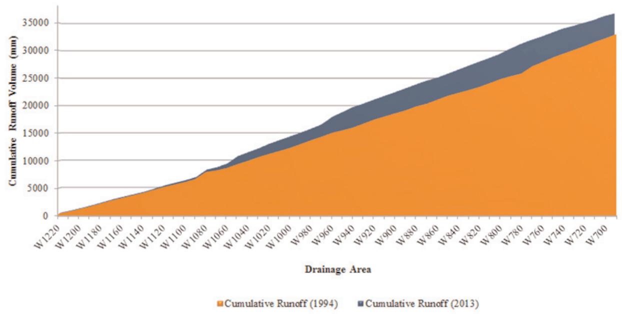

Figure 12. Detecting Change of Cumulative Runoff Volume over a 20 Year Period

sis presented here implies that these land use changes may be significant contributors to increases in runoff volume in the upstream area.

The effect of land use on runoff volume varied between the different catchment areas. In the agricultural and development area, the land use change from 1994 to 2013 resulted in an increase in runoff volume. Such increases in runoff volume are probably due to deforestation and conversion to agricultural land (i.e. rubber and mixed-agriculture). Hence, plantation development may cause excess runoff as a result of the formation of a surface crust with low moisture storage capacity and hydraulic conductivity.

3.5 Assessment of TRIGRS model using SCS CN calculation

Using the SCS loss model in HEC-GeoHMS, land use changes were represented by the CN and percentage of impervious surface. Determination of CN depends on the watershed's soil, antecedent moisture content (AMC) and land use/cover conditions. In the study area, nine land use types were derived consisting of primary forest, secondary jungle, rubber, tree cultivation, grass, cleared land, urban area, recreation area and lake. The AMC type two (AMC II) was used, which represents average soil wetness, and most of the Hulu Kelang's soil falls in hydrologic soil group D and C.

The CN values published in Technical Report 55 (TR 55) by USDA (1986) were used as a reference to infer the CN values. The CN values of all sub-basins for 1994 and 2013 is shown in Figures 13 and 14, respectively. In this regard, sensitivity analysis demonstrated that land use change, modelled through changes in the SCS CN, can have an important impact on runoff volume (Hernandez et al. 2000). Land use conversion from forest to agricultural land and urbanization may have important effects on runoff volume. Nearing et al. (2005) suggested that changes in land use and surface cover such as deforestation due to slash and burn activities or alterations in surface slope due to farming may have large impacts on runoff susceptibility.

Figures 13 and 14 showed that the curve number value have increased from 1994 to 2004 as a function of land use changes by a distinctive linear increasing. Upstream catchment area exhibited an increase in the runoff volume as a function of land use changes. Similarity TRIGRS model, the CN analysis from

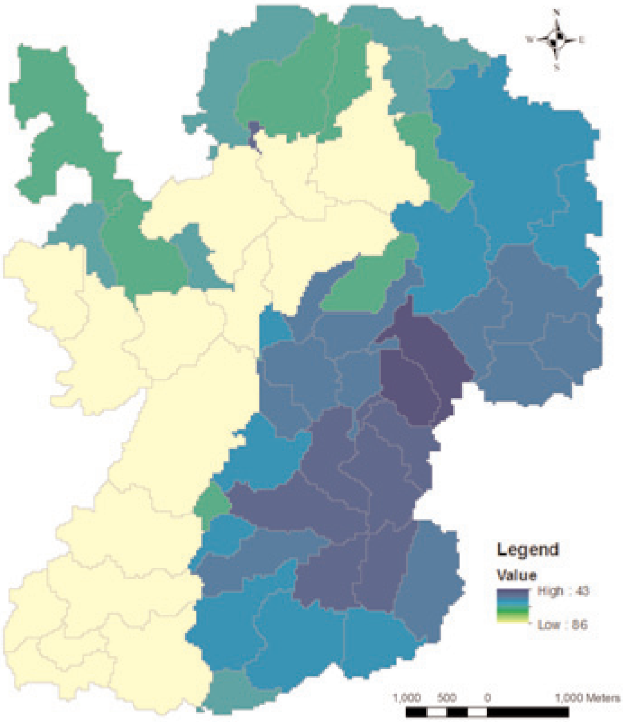

Figure 13. CN values of all sub-basins for 1994

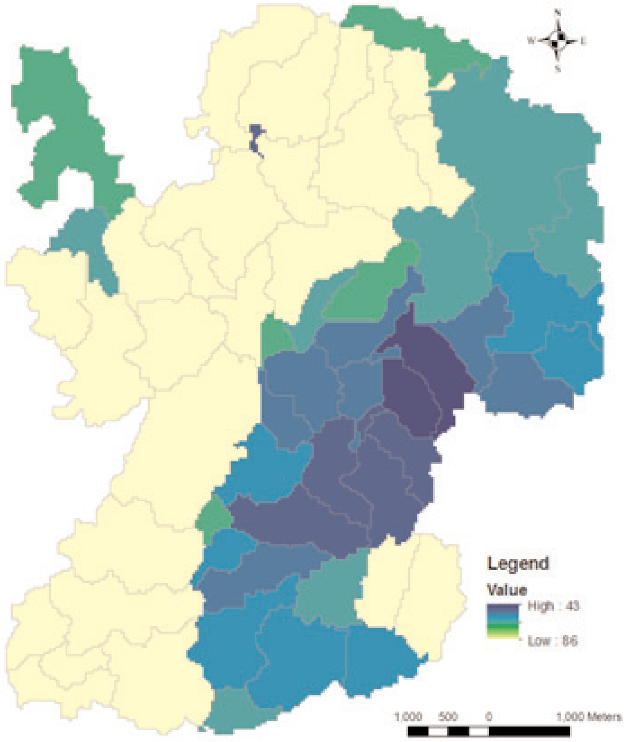

Figure 14. CN values of all sub-basins for 2013

1994 to 2013 revealed a large percentage of runoff volume through agricultural conversion and development area.

4. Conclusion

This paper provides the assessment of land cover impact on runoff processing using spatial temporal regional modelling under local rainfall pattern in Hulu Kelang area, Kuala Lumpur, Malaysia. The following conclusions and key findings can be summarized:

- The TRIGRS model used the infiltration model for unsaturated initial conditions to calculate rainfall losses for pervious surfaces and the transform model to calculate direct runoff transformation for impervious surfaces.
- Assessment analysis demonstrated that land use caused significant differences in hydrological response to surface water. This parameter caused larger differences in runoff volume, total direct runoff, and total loss.
- The main findings demonstrated that forest plays an important role in controlling water flow and subsequently minimizing the flood magnitude in the study area. If forest were replaced by different land use types such as agricultural and development land, less infiltration would be incurred and hence a higher runoff volume would be predicted.
- The analysis managed to provide a framework into which to differentiate and quantify the effect of land use change factors in understanding the behaviour of the hydrological system in catchment areas.

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