

Impact assessment of land cover changes on the runoff changes on the extreme flood events in the Kelantan River basin

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Abstract In the current years, changing the land cover/land use had serious hydrological impacts affecting the flood events in the Kelantan River basin. The flood events at the east coast of the peninsular Malaysia got highly affected in the recent decades due to several factors like urbanisation, rapid changes in the utilisation of land and lack of meteorological (i.e. change in climate) and developmental monitoring and planning. The Kelantan River basin has been highly influenced due to a rapid change in land use during 1984 to 2013, which occurred in the form of transformation of agricultural area and deforestation (logging activities). In order to evaluate the influence of the modifications in land cover on the flood events, two hydrological regional models of rainfall-induced runoff event, the Hydrologic Engineering Center (HEC)-Hydrologic Modeling System (HMS) model and improved transient rainfall infiltration and grid-based regional model (Improved TRIGRS), were employed in this study. The responses of land cover changes on the peak flow and runoff volume were investigated using 10 days of hourly rainfall events from 20 December to the end of December 2014 at

the study area. The usage of two hydrological models defined that the changes in land use/land cover caused momentous changes in hydrological response towards water flow. The outcomes also revealed that the increase of severe water flow at the study area is a function of urbanisation and deforestation, particularly in the conversion of the forest area to the less canopy coverage, for example, oil palm, mixed agriculture and rubber. The monsoon season floods and runoff escalate in the cleared land or low-density vegetation area, while the normal flow gets the contribution from interflow generated from secondary jungle and forested areas.

Keywords HEC-HMS model · Improved TRIGRS model · Kelantan River basin · Land cover changes · Flood event

Introduction

Land cover change is an important external factor controlling the stream hydrology responses of a basin area to precipitation. It is believed that the thick vegetation/canopies layering the tropical mountains might prevent rainwater from reaching to surface water by evapotranspiration from the canopies (interception loss) by acting as a buffer, whereas the plants absorb it to a very less extent (Rutter et al. 1975). In the recent decades, the growth of population and needs to produce agricultural crops have further forced societies to change natural areas to low-density vegetation areas.

Land cover changes (i.e. deforestation, human activities, development of the agricultural area) during the last three decades are actually affected on the severe water flow in Malaysia. The estimated disaster area to runoff event is approximately 29,800 km² or 9 % of the total Malaysia area and is affecting almost 4.82 million people which are around the floodplain. Due to the most serious flooding,

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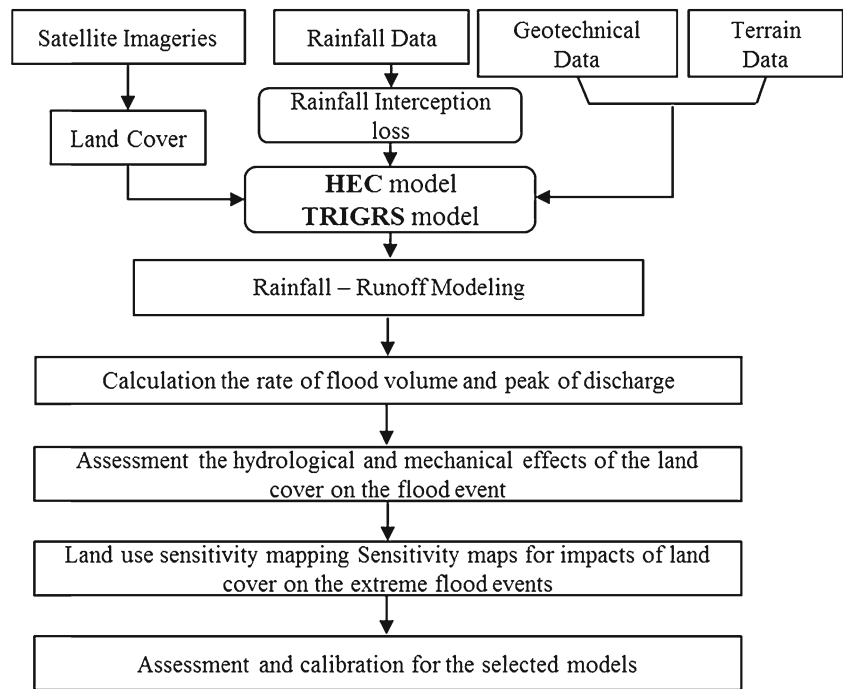
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Fig. 1 The overall research flow

the Kelantan River is significant in Malaysia (DID 2004). Rapid changes in land use, urbanisation and limitations in the planning and monitoring of development and meteorological factors (such as climate change) are affected due to the increasing flood events at Kelantan River basin during the last three decades. Frequent modifications in land cover from the year 1970 until 2000, specifically in relation to the alteration to agricultural land (oil palm and rubber) as well as deforestation (because of logging activities), have occurred in more areas close to Kelantan River (Wan 1996; Jamaliah 2007).

A substantial amount of research studies was conducted in the past, quantifying the modelling of the rainfall-induced runoff event, to deliver a hydrographic presenting the variation of water flow rate or water volume (Q) of direct flood event over the particular period of time at a specific site, typically measured at the river basin outlet, i.e. The Hydrologic Engineering Center (HEC)-Hydrologic Modeling System (HMS) (US Army Corps of Engineers 2000), TOPographic Kinematic APproximation and Integration (TOPKAPI) (Liu and Todini 2002), Tracer Aided Catchment model, Distributed (TACD) (Uhlenbrook et al. 2004), Precipitation-Runoff Modeling System (PRMS) (Yeung 2005), Soil and Water Assessment Tool (SWAT) (Neitsch et al. 2005), MIKE 11 Rainfall Runoff (RR) module (DHI Water and Environment 2007), improved transient rainfall infiltration and grid-based regional model (Improved TRIGRS) (Baum et al. 2008) and so on, though inadequate research has been conducted related to the quantitative evaluation of the effect of land cover changes on the rate of flood volume in terms of the land cover sensitivity maps (Bathurst et al. 2010).

Two spatial temporal models of precipitation-induced flood event, HEC-HMS model and Improved TRIGRS, were developed in this research study to compute the rate of infiltration and the additional impact of land cover changed equations of the runoff volume in terms of the land cover sensitivity maps. The following sections explain the detail of modelling processes. The impacts of land cover variations on severe water flow and peak discharge were examined using the frequency of extreme rainfall events throughout December 2014. Consideration was focused on the alterations in runoff volume and peak flood generated from the land cover/land use type data for 2014. The results showed that the land cover changes are due to higher runoff volume and peak flow in the study area.

Materials and models

Overview of modelling framework

In this study, the HMS (HEC-HMS) using curve number (Soil Conservation Service curve number (SCS-CN)) model and geotechnical Improved TRIGRS model were used to study the significant impact of land use/land cover (LULC) changes on severe water flow events in the Kelantan basin during the end of December 2014 (US Army Corps of Engineers 2000). HEC-HMS tools were executed in conjunction with the HEC-Geospatial Hydrologic Modeling Extension (GeoHMS)) for ArcGIS 10.3. Flood estimation was executed in view of hourly rainfall scale. Each type of model in the process flow possessed separate input data sets. The input data of the HEC-

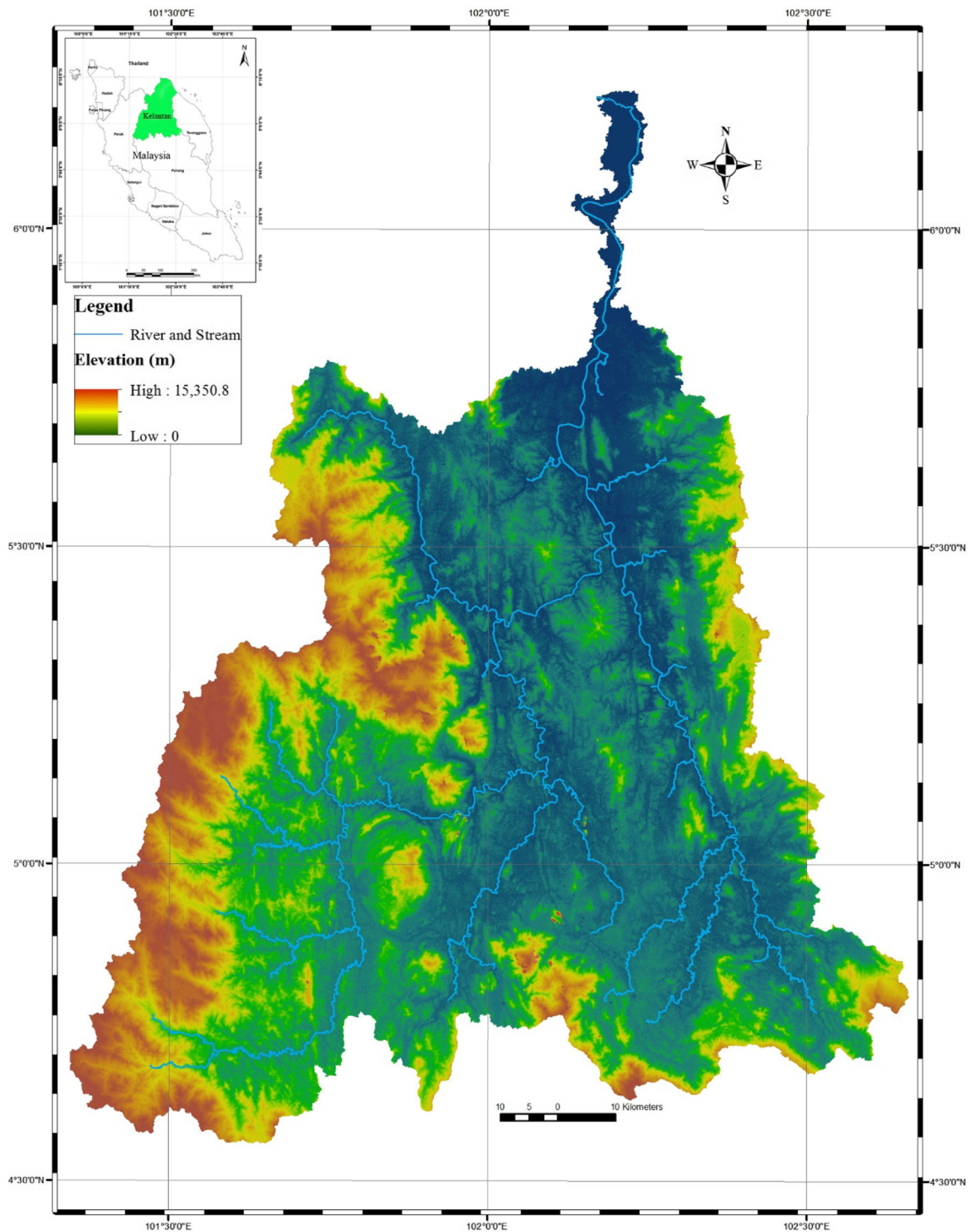


Fig. 2 Location of Kelantan River basin, Malaysia

HMS model include digital data sets of LULC, soil and digital elevation map (DEM) using curve number (SCS-CN) values, while the Improved TRIGRS model includes mechanical and hydrological soil properties, hourly precipitation data, land cover/land use maps and DEM. Figure 1 depicts the overall flow diagram of the methodology.

The first part of the current study focused on the preparation of raster data (grid based) to simulate severe water flow at the study area. A grid-based framework was established by the conversion of the input data including terrain data (slope inclination, slope aspect, land cover), geological information (lithology weathering), geotechnical

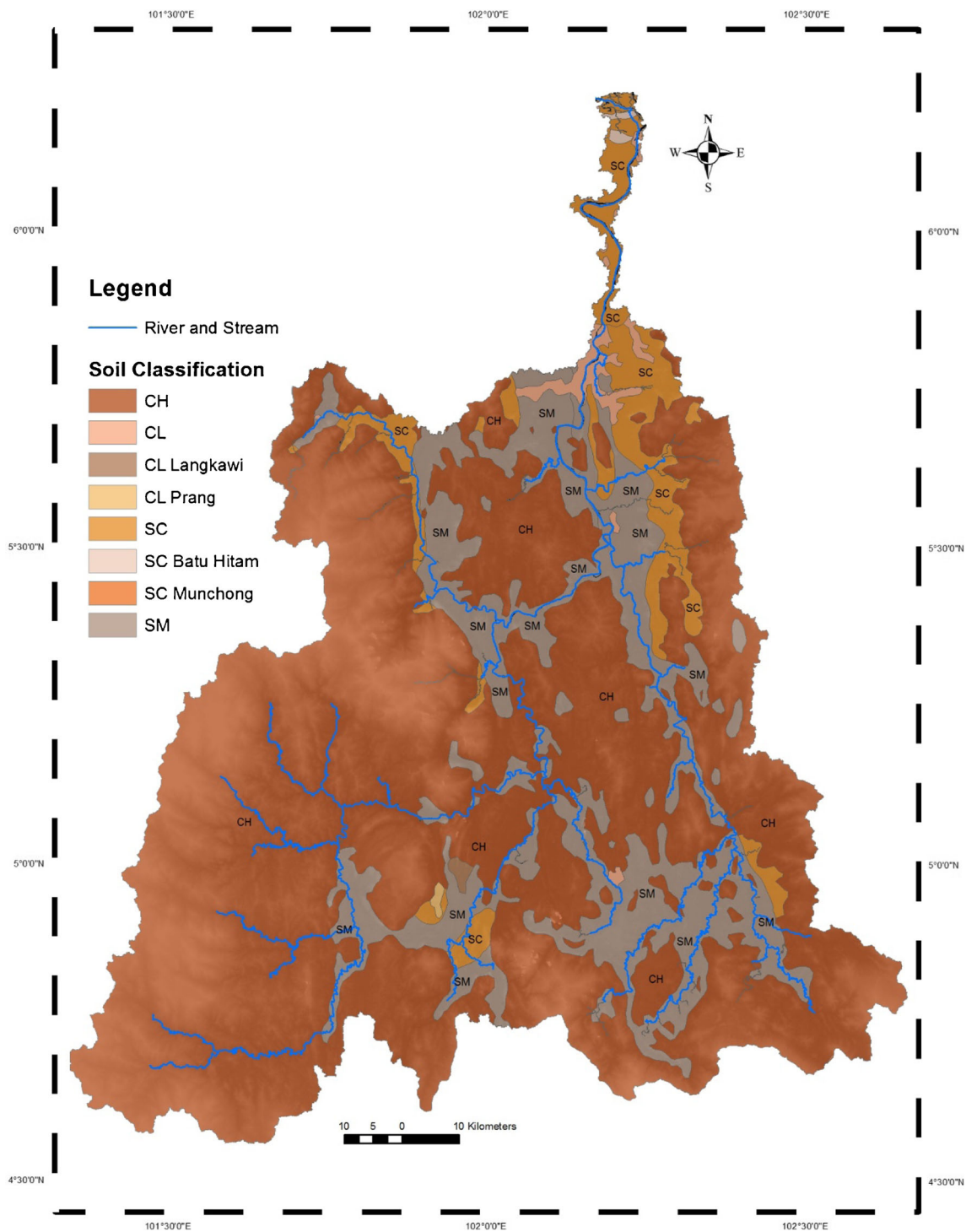


Fig. 3 Soil classification of Kelantan River basin

properties (hydraulic and mechanical characteristics), geomorphological data (DEM) and precipitation data (real-time and patterns) in the study area. The Geographic Information System (GIS) database system based on raster format and same grid-based (10 m × 10 m) system were used to attain all input layers using ArcGIS 10.3.

The second part of the current study was dedicated to assess the impact of land cover/land use changes on the severe water flows in the study area. LULC changes as one of the most effective factors in the rate of water infiltration/loss and, consequently, the severe water flows were conducted based on the HEC-HMS model and Improved TRIGRS model. The

Table 1 Characteristics of soils at Kelantan River basin

Soil name	Group sym.	γ_s	C'	φ'	K_s	K_r	θ_r	θ_s
Batu Hitam	SC	15.7	5	32	1.40E-06	1.66E-06	0.043	0.263
Munchong	SC	16.8	4	33	1.52E-06	8.02E-07	0.063	0.384
Rengam	SC	16.3	11	31	1.52E-06	8.02E-07	0.063	0.384
STP	CH	13.7	26	23	1.71E-07	3.43E-07	0.098	0.459
Prang	CL	14.1	23	31.5	9.4E-07	5.79E-07	0.079	0.442
ULD	CL	14.8	22	28	1.11E-06	3.6E-07	0.111	0.48
Langkawi	CL	15.4	21	29	9.47E-07	5.79E-07	0.079	0.442
Batang/Durian Munchong	SM	18.7	2	35	4.43E-06	1.79E-06	0.039	0.387

canopy interception loss model, soil water infiltration and water losses using the study by Lawrence and Chase (2007) and the Richard equation were used for computing the rate of rainfall deposited at the vegetation and top and ground surface, whereas the Improved TRIGRS model was used to measure the rate of precipitation infiltrated in the ground.

HEC-HMS model

The HEC-HMS is one of the open-source software (OSS) for the assessment of the impacts of flooding caused by extreme rainfall events (US Army Corps of Engineers 2000). HEC-HMS software comprises a graphical user interface for the simulating and modelling of the input data. It is adequate to model a flood hydrograph after a storm. This basic water cycle was additionally split into four components for modelling purposes that were modelled independently.

Loss method The loss method refers to a model that was used to calculate the runoff volume considering losses that take place during a rainfall event due to evapotranspiration and infiltration. The loss method helped to compute the rate of water flow that adds to the flood event in the basin, in the form of effective rainfall.

Transform method The transform method is for the models of direct runoff, as they transform the effective precipitation over a basin into a hydrograph at the basin outlet. The geometry of the watershed and surface roughness were also included in these models.

Base flow method The base flow models were employed to simulate and model the fraction of the water flow added by groundwater.

Routing method The water flow at the outlet of a particular upstream basin is bound to be directed across the stream channel in the downstream basin in the case when the analysed

basin is divided into sub-basins. In order to simulate this directing process, models were developed through the method known as the routing method in which the roughness and geometry of the appropriate river channel were also included.

Curve number (SCS-CN) values

The curve number method is used to approximate the event runoff depth with the help of annual maximum runoff events and corresponding daily rainfalls. This method was developed in 1954 by the US Department of Agriculture Soil Conservation Service. In the start of 1950, the necessity for this method was understood for the use in the design of structures for soil protection by routing and storing water and land appraisal. For the very first time, this method was employed in the design of structures for agricultural purposes. In the development of this method, rainfall-runoff data, principally from agricultural lands in the Midwestern USA, were analysed. Subsequently, by the inspection and analysis of data, the basic relationship between the rainfall and runoff depths was developed.

The curve number method is an effort to compute the amount of water that adds to direct the runoff. The primary concept of this method was to account for the amount of rainfall that is accumulated on top and within the soil and plants before the appearance of any runoff. This accumulated rainfall is considered as a storage after the start of runoff as it is measured with the help of soil parameters, for example, infiltration capacity and maximum soil storage capacity.

The existing Improved TRIGRS model

The Improved TRIGRS model was performed using the GIS framework system and Microsoft Excel® and additional LULC equations. The Improved TRIGRS model was implemented on the basis of three major components: modelling water interception loss by leaves and branches

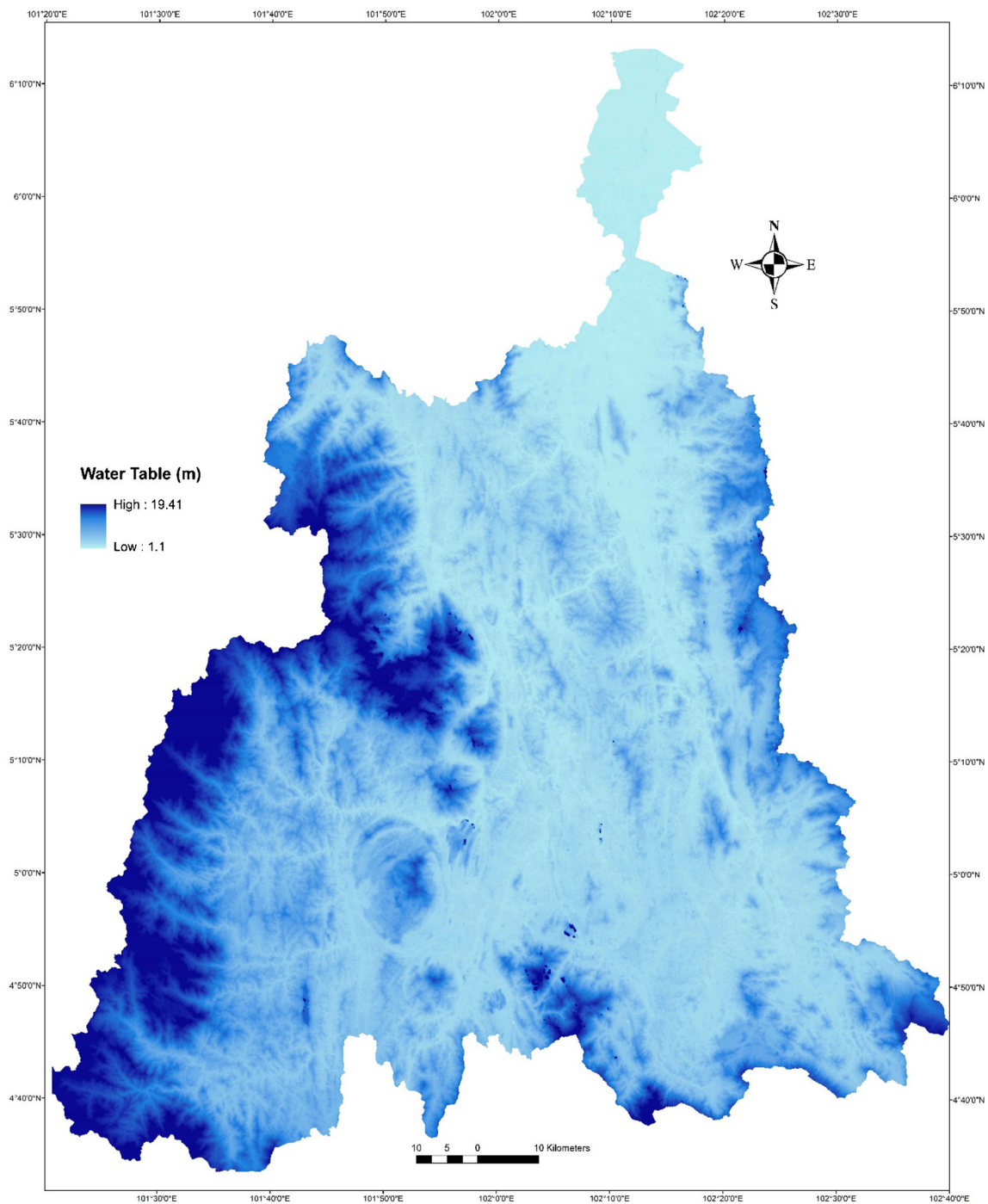


Fig. 4 Groundwater table

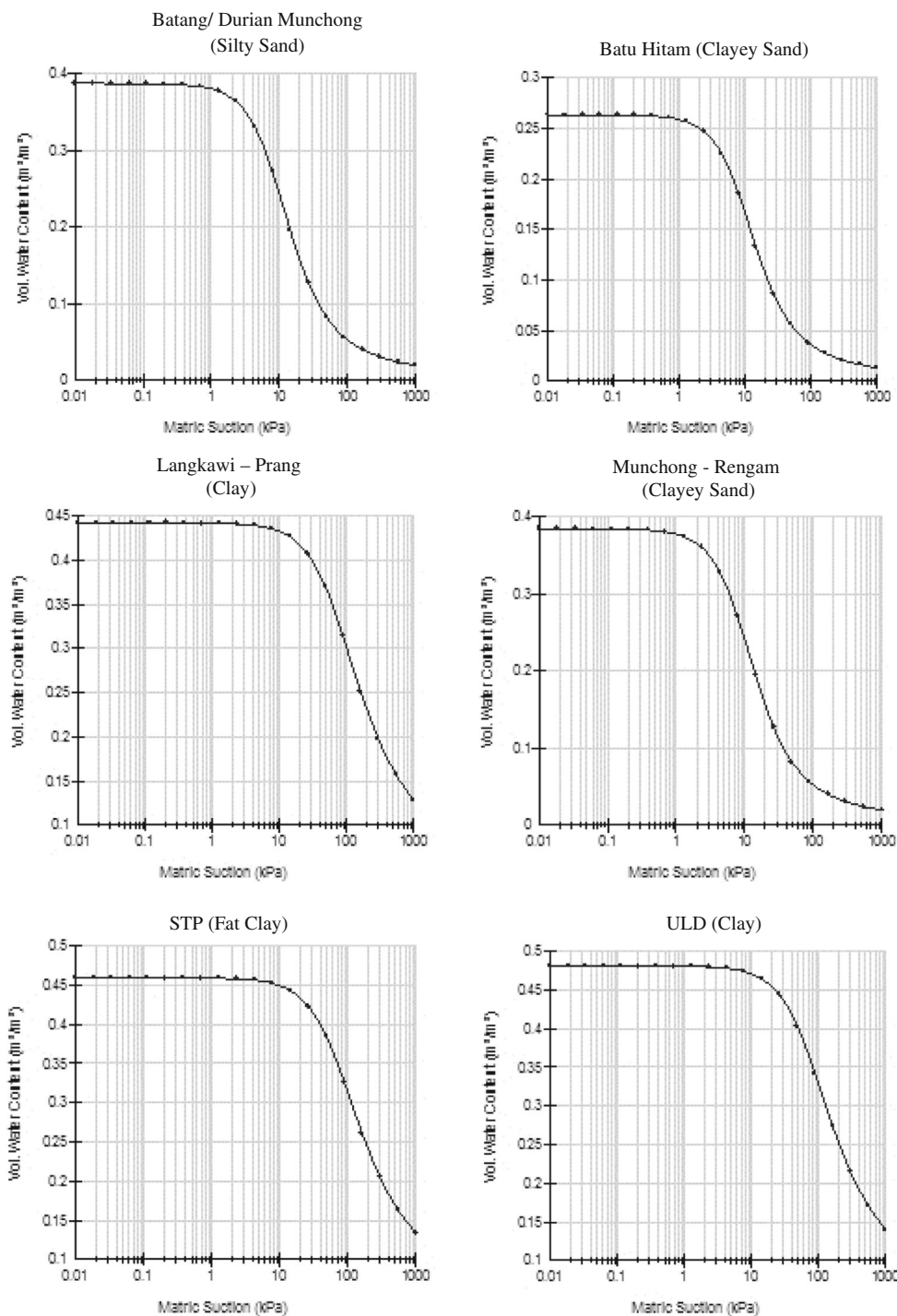
of canopies, transient vertical water infiltration into the soil and the water surface calculation model.

Water interception loss by canopy

The rainfall that is interrupted by the leaves and branches of LULC and the forest floor and does not reach the ground is categorised as an interception loss. Leaf area index (LAI) is

defined as a dimensionless quantity that recognises the water interception loss by canopies. This quantity plays an important role in intercepting precipitation. In order to practice empirical equation based on relationships between the arrival rate of precipitation at the ground and LAI, numerous models have been established in the past (Sellers et al. 1986; Kergoat 1998; Lawrence and Chase 2007). In this study, the water interception loss by the canopy was

Fig. 5 Matric suction versus volumetric water content based on the soil zonation



calculated using the study by Lawrence and Chase (2007), as given below:

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

where *Incep* is the water interception loss (mm), *P* is the precipitation (mm), and 0.25 is implemented to scale the parameterization of interception from point to grid cells (Lawrence and Chase 2007).

Transient vertical infiltration model

The mechanism of water infiltration to soil using the Improved TRIGRS model assumed that the infiltration process usually depends on vertical and one-dimensional flow, as reported by Savage et al. (2004), Salciarini et al. (2006) and Godt et al. (2008). The water infiltration model is defined with a time-varying specified flux boundary condition at the ground surface. The vertical water flow in response to water infiltration at the

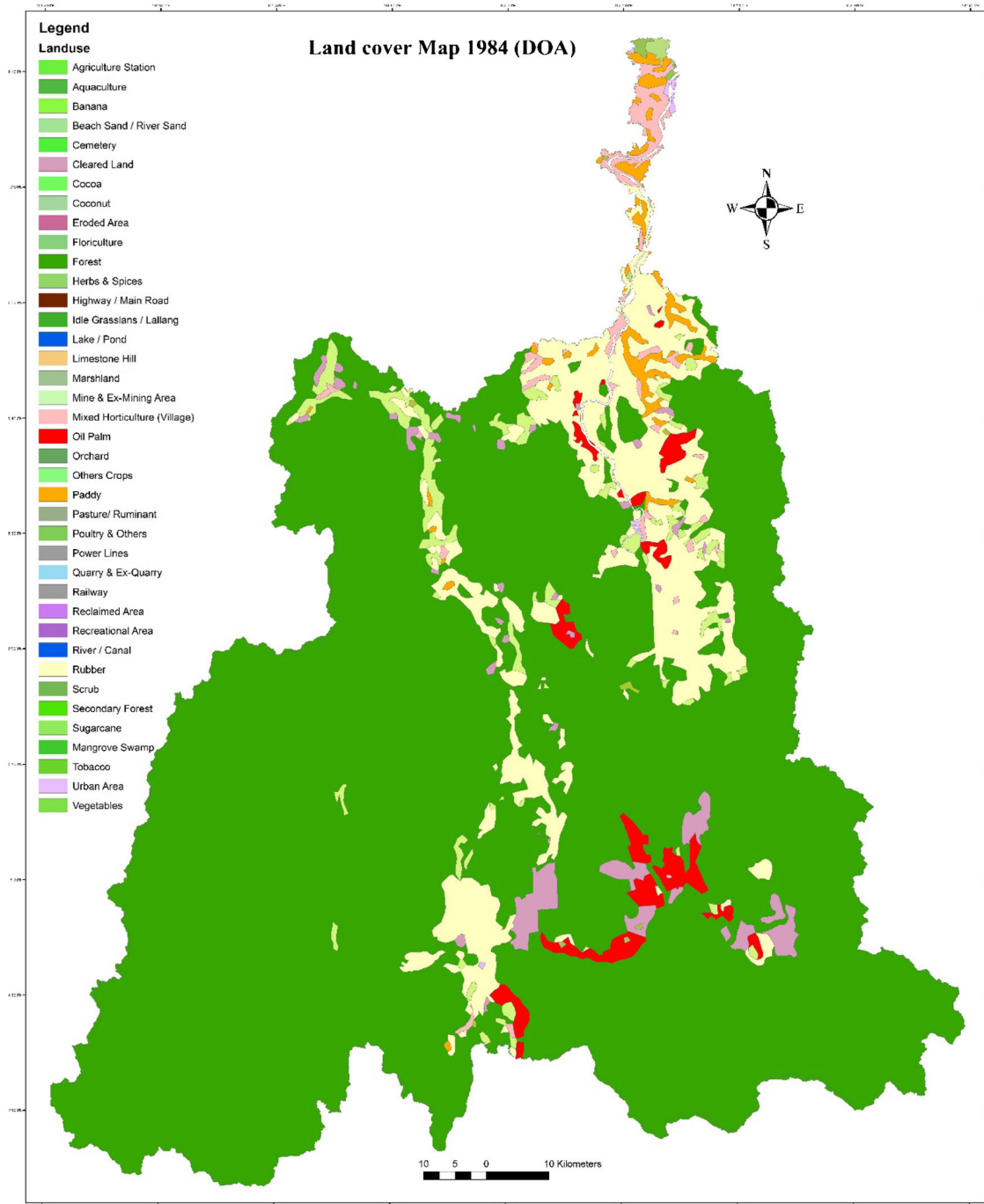


Fig. 6 Kelantan land cover/land use map (1984)

ground surface was defined by the application of Richard’s equation as given below:

$$\frac{\partial \psi}{\partial t} C(\psi) = \frac{\partial}{\partial z} \left[K(\psi) \left(\frac{\partial \psi}{\partial z} - \sin \beta \right) \right] \tag{2}$$

where t (s) is the time, ψ (m) is the pore-water pressure head, Z (m) is the depth in vertical direction, $K(\psi)$ (m/s) is the pore pressure head dependent on hydraulic conductivity, $C(\psi)$ is the specific moisture capacity, θ is the volumetric water

content and hydraulic conductivity in the Z direction and, β ($^\circ$) is the angle of slope.

Runoff modelling

Improved TRIGRS involves a model for surface water flow from upslope cells that have surplus surface water to adjacent cells in downslope, flowing either beyond downslope or infiltrate. It was assumed that flood occurred due to the excess

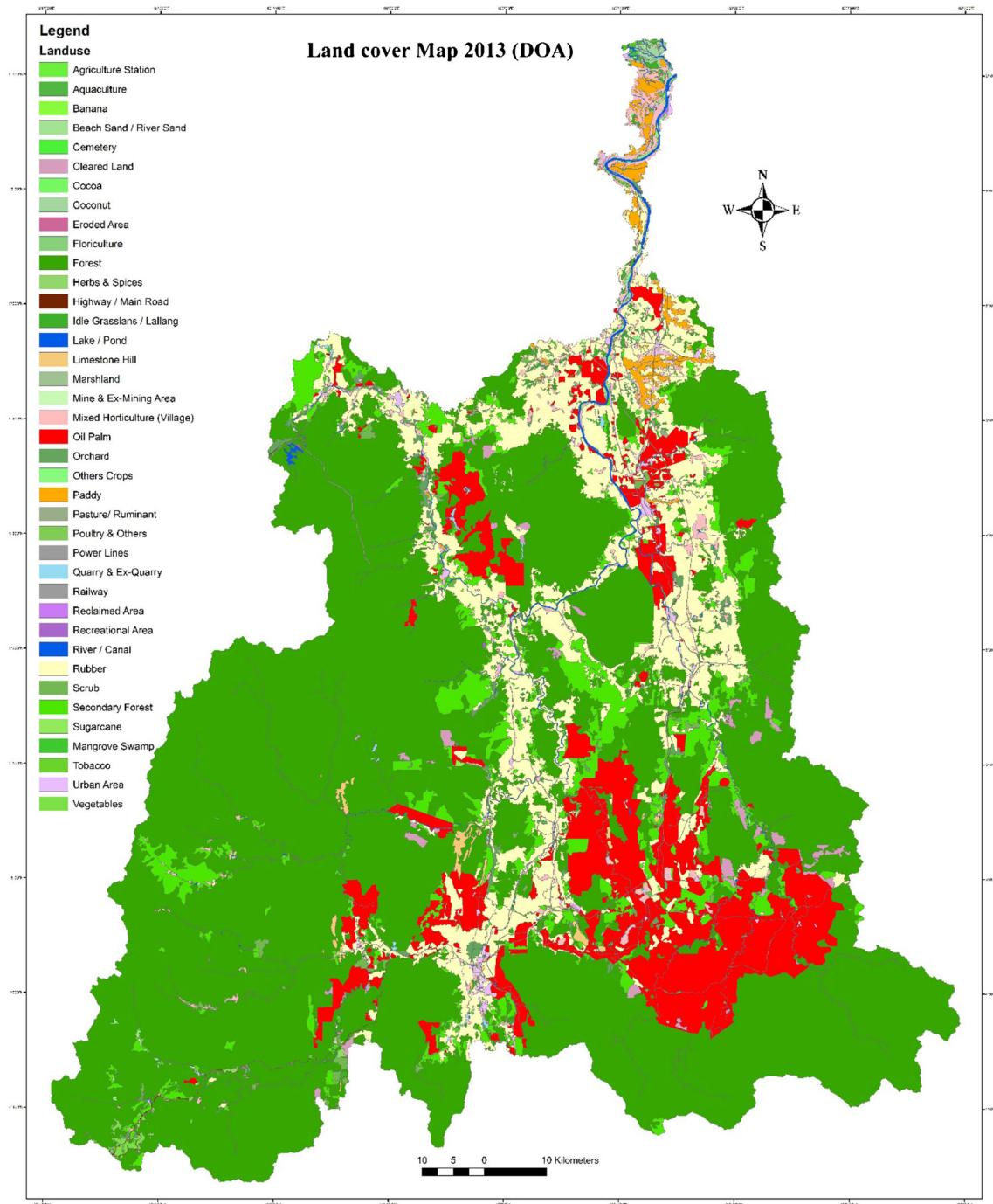


Fig. 7 Kelantan land cover/land use map (2013)

infiltrability of the runoff and precipitation provided to a cell (Iverson 2000).

The infiltration, I , at each cell was computed as the sum of the rainfall event, P , plus any water flow from upslope cells, R_u , with the limitation that water infiltration cannot surpass the saturated hydraulic conductivity, K_s :

$$I = R_u + P \text{ if } R_u + P \leq K_s \tag{4}$$

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

$$R_d = R_u + P - K_s \text{ if } R_u + P - K_s \geq 0 \tag{5}$$

The overland flow between adjacent cells was supposed to happen rapidly. Thus, in order to let surface water flow towards adjacent cells, individual storm periods should be sufficiently long.

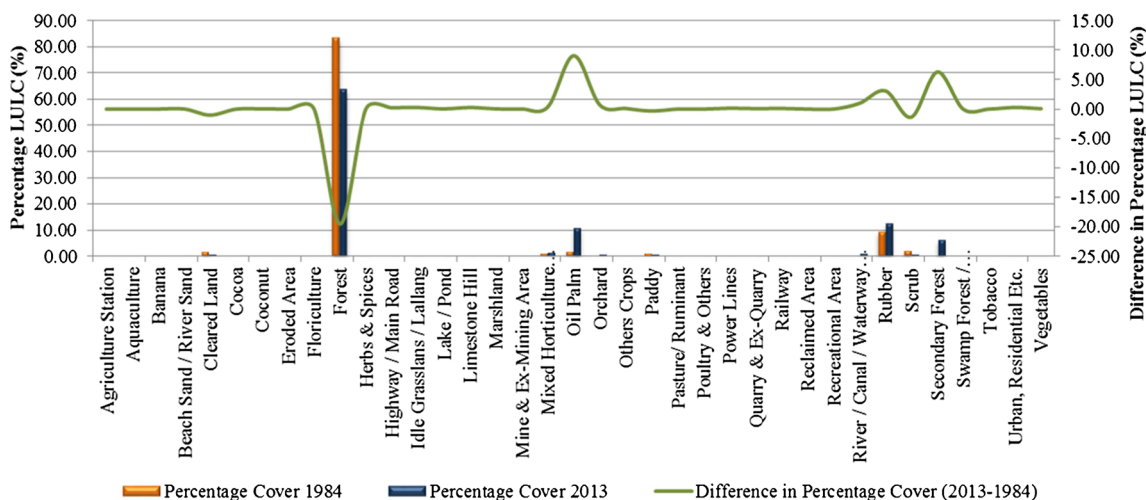


Fig. 8 Increase in secondary forest and areas under oil palm and rubber and decreases in the forest areas and scrub

Background information on the study area

Kelantan area is one of the largest states having a huge river and very hilly lands, as shown in Fig. 2. The Kelantan River basin is located between the longitudes 101° 20' and 102° 20' east and latitudes 4° 40' and 6° 12' north with 13,100 km² (Satyanarayana et al. 2011). The Kelantan River is among the most frequent flood event affecting the major water flows in Malaysia (Chan 2002; DID 2004; Satyanarayana et al. 2011). The main branches of the Kelantan River are the Galas River, which adds around 8000 km² or 54 % of the total basin. Meanwhile, as reported in the Department of Irrigation and Drainage (DID) (1995), River Lebir is known as a second branch, which adds around 2500 km² or 17 % of the total Kelantan River basin.

Climate

Southwest (SW) and northeast (NE) monsoons hit Peninsular Malaysia each year (Tangang et al. 2007). The northeastern monsoon produced heavy rains and thunderstorms between

November and March. From May to September, another monsoon comes from the SW and hits places like Kelantan directly, bringing the most rainfall to the study area. Nonetheless, the maximum rainfall usually takes place through the transition period between the Monsoon seasons, termed as the inter-Monsoon season. According to the findings of the Department of Irrigation and Drainage, Malaysia (DID 2004), in the month of April and May, as well as in October and November, usually, the highest rainfall is recorded. However, January is reported as the driest month during a year.

Hydrological and mechanical characteristics of Kelantan soil

The mechanical and hydrological data were obtained from numerical data compiled from geotechnical boreholes and the previous reported studies reported by DID, Ampang Jaya Municipal Council (MPAJ) and the Slope Engineering Branch of Public Works Department (PWD) Malaysia. The soil properties and distribution in this study area were defined under eight different types of soil classes based on a 1:100,000-scale

Fig. 9 Percentage of the total area in the Kelantan River basin changed in land cover from forest to oil palm, forest to secondary forest, forest to rubber, forest to scrub, forest to orchard, scrub to oil palm, forest to horticultural (village), forest to paddy, forest to urban area and forest to grassland from 1984 to 2013

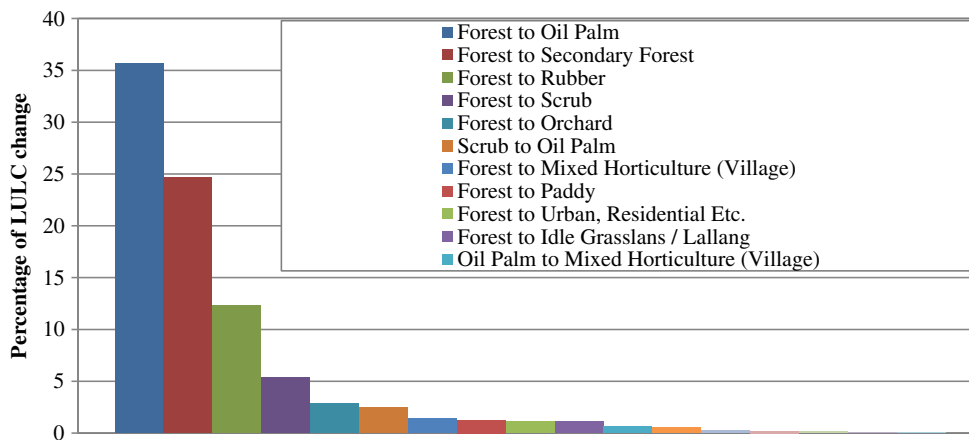


Table 2 The major percentage of the land cover changes in Kelantan River basin

Land cover changes	Rate (%)
Forest to oil palm	35.65
Forest to secondary forest	24.70
Forest to rubber	12.29
Forest to scrub	5.39
Forest to orchard	2.84
Scrub to oil palm	2.50
Forest to mixed horticulture (village)	1.37
Forest to paddy	1.26
Forest to urban, residential, etc.	1.11
Forest to idle grasslands/lallang	1.08

Selangor soil map, as shown in Fig. 3. It contained respective information about friction angle, soil cohesion, total unit weight of soil, unit weight of water, soil saturated water content θ_s , soil residual water content θ_r , residual hydraulic conductivity of soil K_r and vertical saturation hydraulic conductivity K_s , as tabulated in Table 1.

The groundwater table of the Kelantan River basin (Fig. 4) was mapped with the Geoscience Department of Malaysia (JMG 2009). On the other hand, volumetric water content versus matric suction was assigned to each zone using the van Genuchten equation, as shown in Fig. 5. According to Wang et al. (2006), the LAI is calculated using LAI-2000 (LI-COR 1991), ranging from 1.49 to 3.99, and linear regression equation from NDVI.

The December 2014 flood event

The study area confronted the intense floods by the end of December 2014. During this time, heavy rainfall events were recorded between 17 December and 3rd January due to which the people residing at the river basin in Kelantan escaped their homes to safety. In fact, in December 2014, the Kelantan basin

exhibited total rainfall amount greater than 1200 mm per month (DID 2015; Nurul Fatyhan 2016). Seemingly, the water flow events presented good agreements with the rate of precipitation in this area (DID 2015). In this study, 10 days of hourly precipitation data using 15 rainfall measurement stations at the end of December 2014 were collected for the evaluation of the impact of rapid change in land use on the runoff event at the study area.

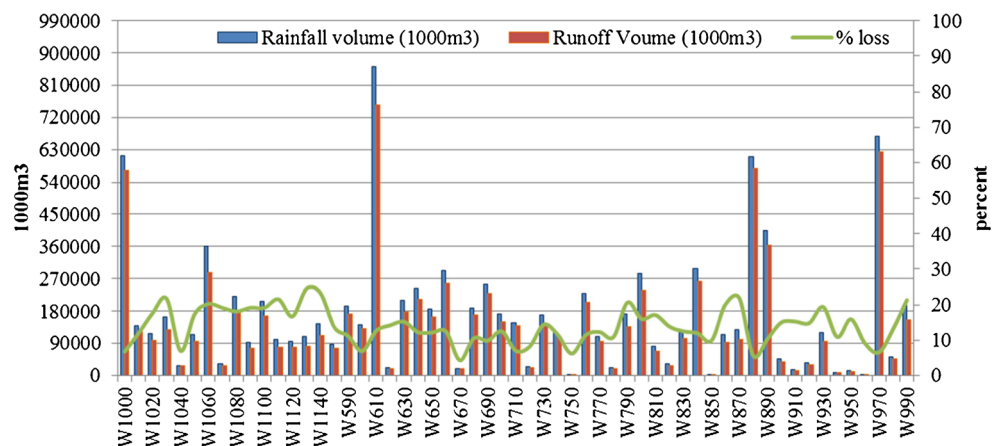
Results and discussion

Mapping and analysis of land use and land cover

According to a belief, the thick vegetation/canopies layering tropical mountains might prevent rainwater from reaching to surface water by acting as a buffer, whereas the plants absorb it to a very less extent (Rutter et al. 1975). The land cover distribution for this study area was classified based on satellite imageries. Based on a system of classification, there are 32 types of land covers, i.e. lake/pond, highway/main road, railway, power lines, recreational area, mine and ex-mining area, urban/residential, quarry and ex-quarry, cemetery, agriculture station, floriculture, mixed horticulture (village), vegetables, herbs and spices, cocoa, coconut, rubber, oil palm, orchard, banana, paddy, tobacco, other crops, aquaculture, poultry and others, pasture/ruminant, idle grassland/lallang, scrub, forest, secondary forest, swamp forest/mangrove swamp, marshland, beach sand/river sand, cleared land, eroded area, a limestone hill and reclaimed areas.

The Kelantan state area has been specified by jungle and forest reserves, which is 63.66 % of the total area (956,139.9 ha) (Satyanarayana et al. 2011). The agricultural area is mainly located in the upstream of the Kelantan basin, which covers an area of 26.32 % of Kelantan area (395,156.8 ha); i.e. oil palm and rubber cover 23.27 % (349,365.4 ha), while the development area and urban area cover only 0.92 % (14,616.5 ha) (Satyanarayana et al. 2011). The conversion of forests to the less

Fig. 10 The total amounts of precipitation along with the total infiltration/losses (2013)



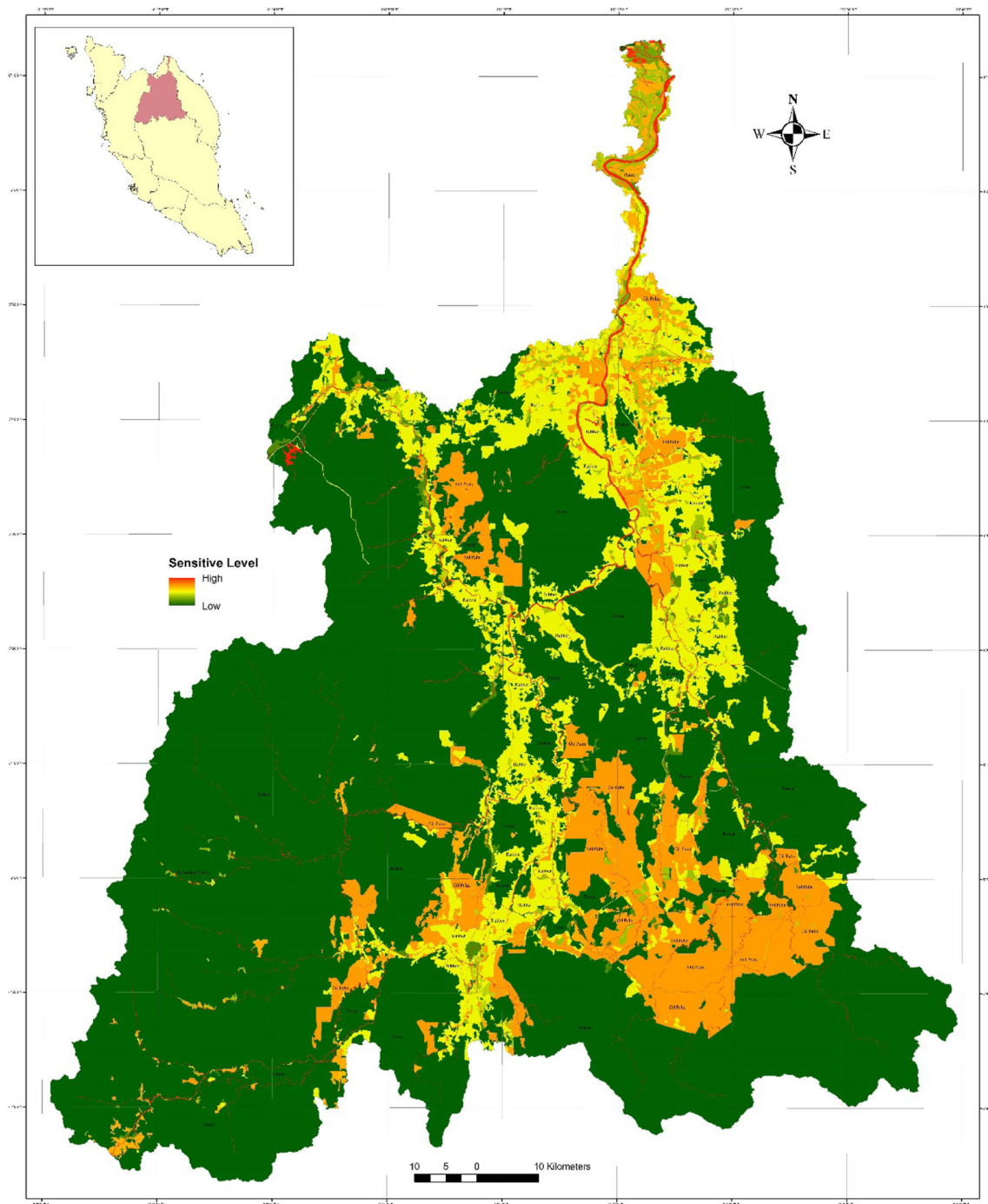


Fig. 11 Land use sensitivity map using the TRIGRS model

canopy coverage has been defined with a considerable pace from 1984 to 2002, which became slower from 2002 to 2013 (Figs. 6 and 7). The land cover changes during the last 30 decades show a considerable increase in secondary forest and areas covered with rubber and oil palm and a decrease in the scrub and forest areas, as shown in Figs. 8 and 9. In the other words, a substantial percentage of the total area at the basin area is modified in plant cover from forest to the less canopy coverage, as shown in Fig. 9 and Table 2.

Impact of land cover changes on the flood volume

The LULC values gathered from the location were used in the initial run of the hydrological models, which were created for the end of December 2014. Many processes are disturbed by the land cover alterations in any catchment, for instance, evapotranspiration, water interception loss or resistance to surface runoff. Through the simulated and observed values from the last 30 years, the land cover

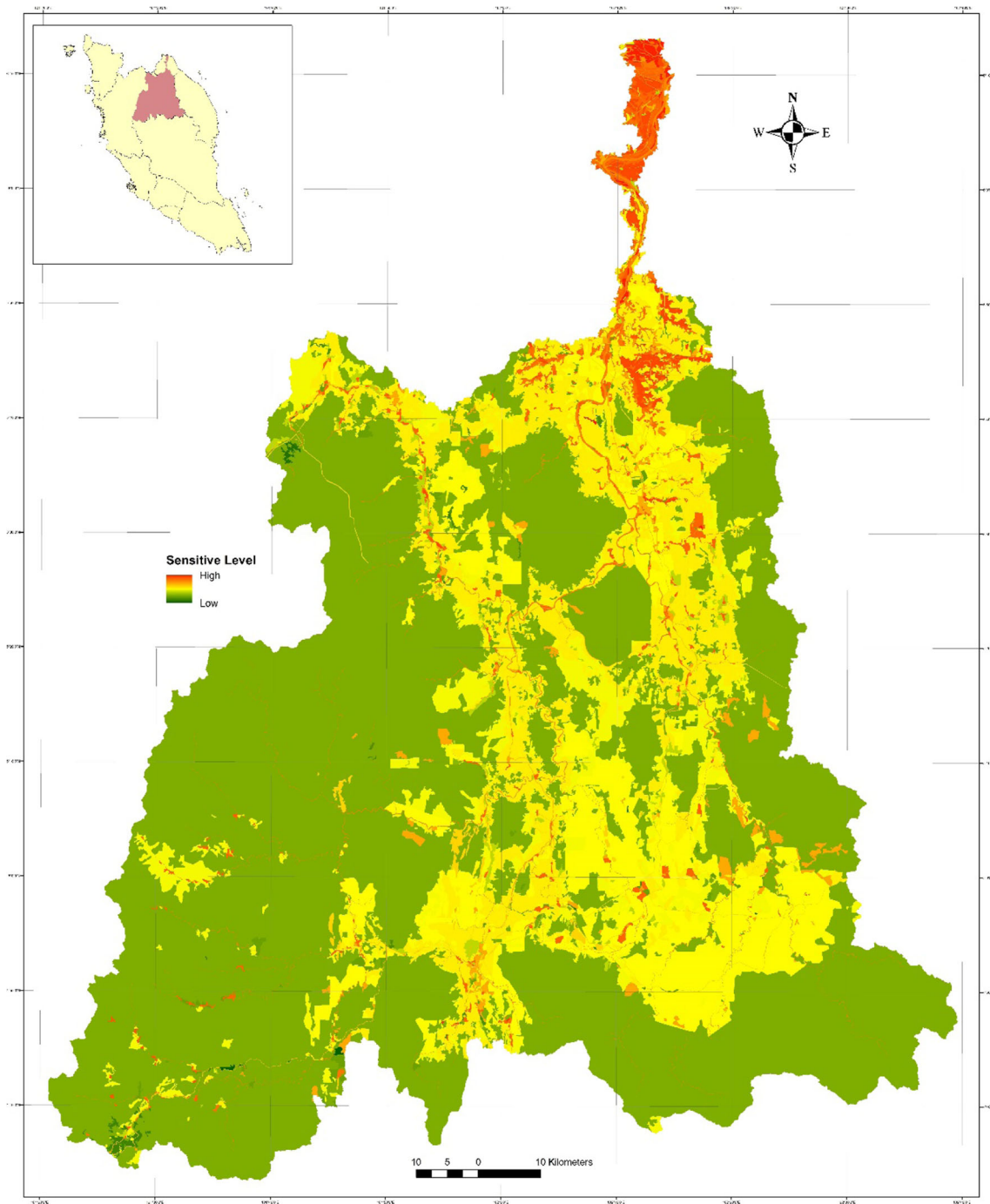


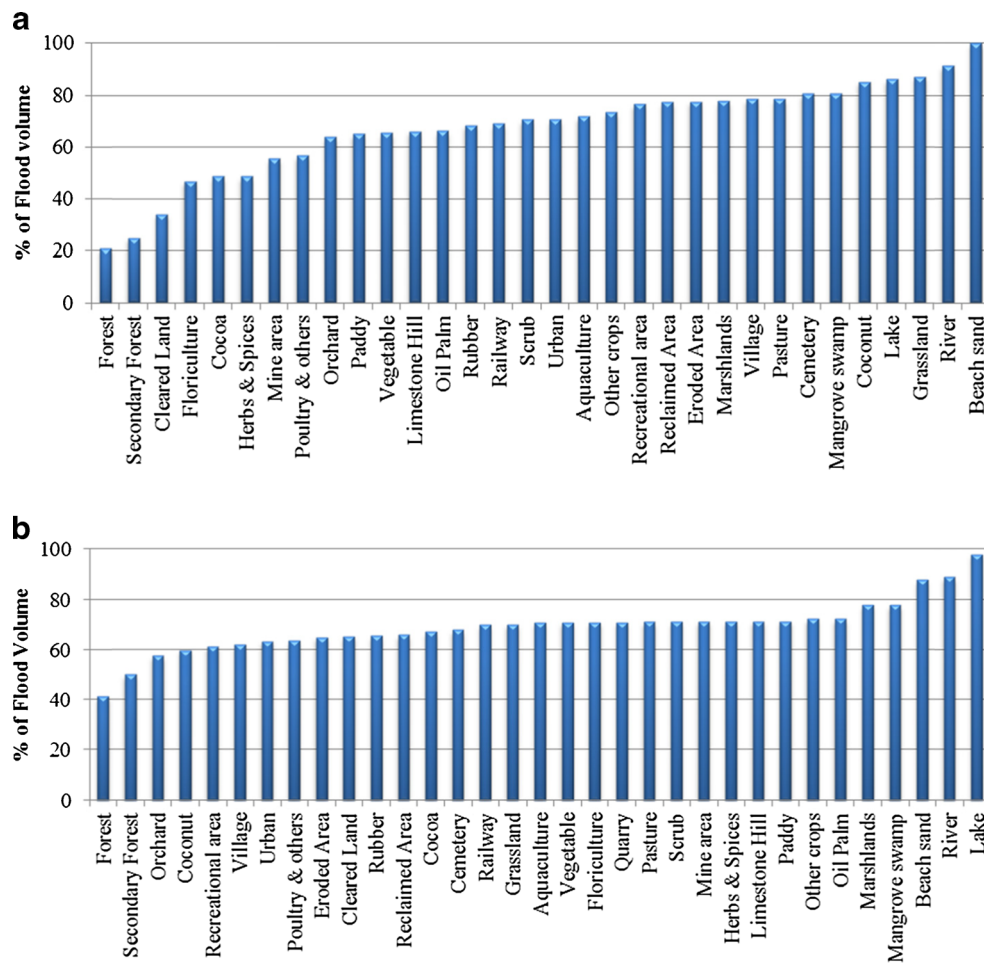
Fig. 12 Land use sensitivity map using the HEC model

modifications to the less canopy coverage led to the enhancement in flood volume. Figure 10 displays the hydrographs in catchment areas of Kelantan River basin using the HEC-HMS model showing the total amounts of rainfall events accompanied by the total water infiltration/losses. Ten days of the modelled rainfall events, the most powerful 1 h of the 10-day storm were measured together with the severe rainfall intensities (>44 mm/h). The absolute water interception loss is only a function of the

absolute precipitation volume, the land cover and the soil characteristics irrespective of the intensity distribution.

The outcome of land cover changes on the rate of flood volume from 1984 to 2013 led to the enhancement of flood volume. This increase in flood volume is possibly owing to the alteration to urbanisation, agricultural area (i.e. rubber, oil palm and mixed agriculture) and deforestation. Figures 11 and 12 depict an increase in severe water flow as a function of urbanisation and deforestation for the Kelantan River basin.

Fig. 13 The rate of contribution land use types in flood event. **a** Using TRIGRS model. **b** Using HEC model



The outcome of land cover/land use changes disclosed a moderate percentage of the forest area alteration to the agricultural areas and upsurge in the urban area.

The LULC sensitivity evaluations based on the HEC-HMS model and Improved TRIGRS model indicated that the critical runoff events were mostly distributed in the underdevelopment areas as well as the agricultural regions (Figs. 11 and 12). Forest conversion to the low-density vegetation, i.e. development areas and agricultural regions, was accountable for an advanced level of water flow. Subsequently, the runoff and water flow were produced by a blend of factors including natural forest destruction (manmade), severe rainfall and alteration to the less canopy coverage.

A comparison of total flood volume from diverse land cover classes

In the flood contributions, the coverage area of every land cover class behaves as a scaling factor. Figure 13 depicts a summary of the total flood volume from diverse land cover classes. The outcomes disclosed that agricultural area added to 60 and 50 % more of water flow using the Improved TRIGRS model and HEC-HMS model, respectively. The rates of

contribution of forest and secondary forest regions at flood events were defined by 40 and 25 % using the Improved TRIGRS model and HEC-HMS model, respectively. Thus, the forest clearing leads to less interception loss of water and less infiltration/loss owing to the *reduction* in porosity. On the contrary, the huge contribution to the flood events was from grasslands, i.e. 84 % and 70 % using HEC model and TRIGRS model, respectively. Total values of discharge and higher peak flows are achieved by the increase of temperate grassland permitting less water infiltration attributable to the crusting of soil.

The key results demonstrated that the forest area significantly controls the water flow. The high-density vegetation effect minimises the runoff volume, while different land cover classes such as urban area and development area replacing jungle area, less water loss or infiltration would be incurred, and hence, a higher water flow would be predicted.

Numerically and graphically assessment and calibration of models

To derive a satisfactory match between the simulated and the observed hydrographs, model calibration is a fundamental

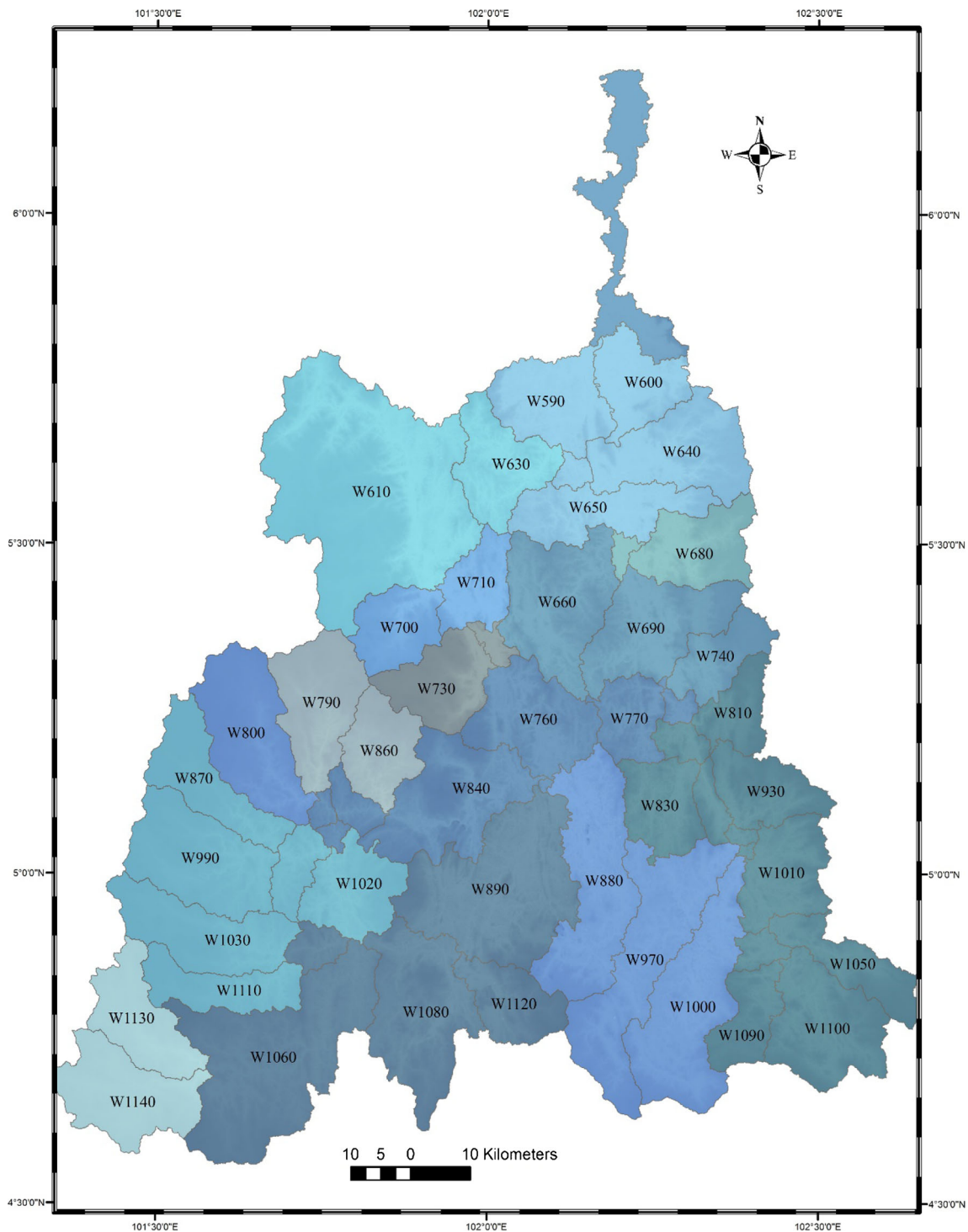


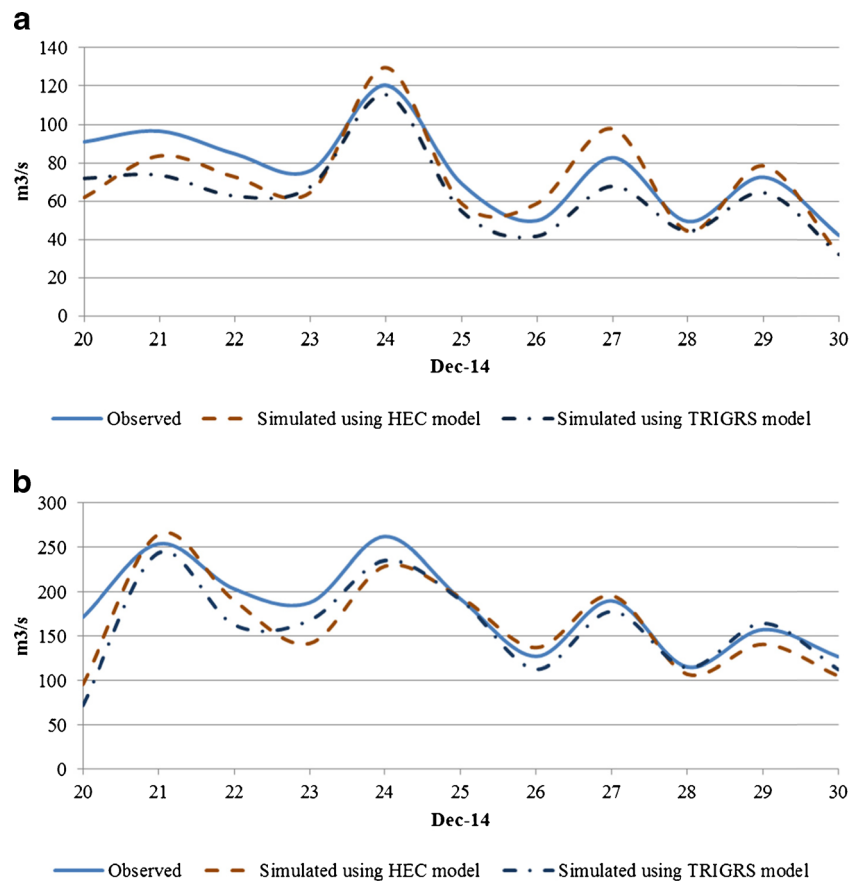
Fig. 14 Sub-catchment areas of Kelantan River basin

method for regulating model parameter values. The peak discharge and flood volume are employed quantitatively to compare the different degrees between simulated and observed floods (O'Donnell et al. 2011). The method attempted to locate the optimum values for parameters, which were difficult to be assessed merely through the measurement. The calibration and assessment of the HEC and Improved TRIGRS

models were carried out to evaluate whether the hydrological models can produce the outputs with reasonable accuracy. Then, they were set depending on the best fit of observed ranges and output data.

Two flood measurement stations close to w580 and w670 sub-basin areas were considered for the calibration and assessment of the simulated values (Fig. 14). Subsequently, the rates

Fig. 15 Calibration and assessment of two models on the **a** w670 and **b** w580



of increasing flood volume for the two observed and simulated values were collected. The comparison was carried out numerically (comparison of observed and simulated values) or graphically (visual comparison). From the comparison results, the curve line showed acceptable agreement between the observed and simulated values (Fig. 15), although the simulated results using the TRIGRS model showed a better fit with observation data.

Conclusions

This study provides the assessment of the influence of land cover/land use modifications on the severe water flow processing using the spatial temporal regional HEC modelling and Improved TRIGRS modelling under the rainfall events during 30 years ago at the Kelantan basin. The following conclusions and key findings can be summarised:

- The land cover changes during the last 30 decades show a considerable increase in areas covered with oil palm and rubber and secondary forest and decrease in scrub and forest areas. In the other words, a substantial percentage of the Kelantan River basin changed in land cover from forest to the less canopy coverage.
- The highest surface flow was observed in the sub-basin areas covered with the low-density vegetation and cleared lands, while the lowest surface flow was observed in the sub-basin areas covered with high-density vegetation (i.e. forest and secondary jungle).
- The usage of the HEC model and Improved TRIGRS model revealed that the modifications in land cover led to substantial changes in water infiltration/loss response to rainfall events. The upsurge in severe water flow at the study area is a function of urbanisation and deforestation and, most importantly, the conversion of the forest and secondary forest area to the less canopy coverage such as oil palm lands, rubber areas and mixed agriculture regions.
- Deforestation and conversion to the less canopy coverage triggered increases in the flood volume and peak of discharge due to evapotranspiration capacity and lower interception loss. On the contrary, urban development area led to excess runoff volume and a superior impervious ground surface when less infiltration happened.
- After the calibration and verification process for the reliable frameworks (HEC-HMS model and Improved TRIGRS model) to identify the influence of LULC modifications in understanding the behaviour of the mechanical and hydrological processes in the basin area, it could be clearly demonstrated that the results of the Improved

TRIGRS model were closer to reality, although both of the models are capable of generating water-level forecasting at Kelantan River basin.

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References

- Bathurst JC, Bovolo CI, Cisneros F (2010) Modelling the effect of forest cover on shallow landslides at the river basin scale. *Ecol Eng* 36: 317–327
- Baum R, Savage W, Godt JW (2008) TRIGRS—a Fortran program for 560 transient rainfall infiltration and grid-based regional slope-stability analysis, 561 version 2.0. US Geological Survey 75 1159
- Chan NW (2002) Reducing flood hazards exposure and vulnerability in Peninsular Malaysia floods (Edited by Dennis J. Parker). Taylor & Francis Publisher, London
- DHI Water and Environment (2007) MIKE 11: a modelling system for rivers and channels: reference manual. DHI Water and Environment 516 p
- Drainage and Irrigation Department (DID) (1995) Annual flood report of DID for Peninsular Malaysia. Unpublished report. Kuala Lumpur DID
- Drainage and Irrigation Department (DID) (2004) Annual flood report of DID for Peninsular Malaysia. Unpublished report. Kuala Lumpur DID
- Drainage and Irrigation Department (DID) (2015) Annual flood report of DID for Peninsular Malaysia. Unpublished report. Kuala Lumpur DID
- Godt JW, Schulz WH, Baum RL, Savage WZ (2008) Modeling rainfall conditions for shallow landsliding in Seattle, Washington. In: Baum RL, Godt JW, Highland Groundwater Colloquium 2009 “Groundwater management in Malaysia—status and challenges” (2009) A Report of the Proceedings of the Colloquium held in Putrajaya, Malaysia from 25 to 26 March
- Iverson RM (2000) Landslide triggering by rain infiltration. *Water Resour Res* 36(7):1897–1910
- Jamaliah J (2007) Emerging trends of urbanization in Malaysia [online]. Accessed from http://www.statistics.gov.my/eng/images/stories/files/journalDOSM/V104_Article_Jamaliah.pdf Accessed 20 January 2009]
- Kergoat L (1998) A model for hydrological equilibrium of leaf area index on a global scale. *J Hydrol* 212–213:268–286
- Lawrence PJ, Chase TN (2007) Representing a new MODIS consistent land surface in the community land model (CLM3.0). *J Geophys Res* 112. doi:10.1029/2006JG000168
- LI-COR (1991) LAI-2000 plant canopy analyzer operating manual. LI-COR Inc, Lincoln, NE
- Liu Z, Todini E (2002) Towards a comprehensive physically-based rainfall-runoff model. *Hydrol Earth Syst Sci* 6(5):859–881
- Mineral and Geoscience Department Malaysia (JMG) (2009) Hydrogeological map of the Kelantan River basin. Scale 1:250,000
- Neitsch SL, Arnold JG, Kiniry JR, Williams JR (2005) Soil and water assessment tool: theoretical documentation version 2005. Soil and Water Research Laboratory and Blackland Research Center, Temple, Texas
- Nurul Fatyhan B (2016) Analysis of lag time for December 2014 flood incident in Kelantan river basin, Malaysia. Bachelor thesis, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang
- O’Donnell G, Ewen J, O’Connell PE (2011) Sensitivity maps for impacts of land management on an extreme flood in the Hodder catchment. *UK Phys Chem Earth* 36:630–637
- Rutter AJ, Morton AJ, Robins PC (1975) A predictive model of rainfall interception in forests. II. Generalization of the model and comparison with observations in some coniferous and hardwood stands. *J Appl Ecol* 12(1):367–380
- Salciarini D, Godt JW, Savage WZ, Conversini P, Baum RL, Michael JA (2006) Modeling regional initiation of rainfall-induced shallow landslides in the eastern Umbria region of Central Italy. *Landslides* 3:181–194
- Satyanarayana B, Mohamad KA, Idris IF, Husain ML, Dahdouh-Guebas F (2011) Assessment of mangrove vegetation based on remote sensing and ground-truth measurements at Tumpat, Kelantan delta, east coast of Peninsular Malaysia. *Int J Remote Sens* 32:1635–1650
- Savage WZ, Godt JW, Baum RL (2004) Modeling time-dependent areal slope stability. In: Lacerda WA, Ehrlich M, Fontoura SAB, Sayao ASF (eds) *Landslides*. Taylor and Francis Group, London, pp. 23–36
- Sellers PJ, Mintz Y, Sud YC, Dalcher A (1986) A simple biosphere model (SiB) for use within general circulation models. *J Atmos Sci* 43: 505–531
- Tangang FT, Juneng L, Ahmad S (2007) Trend and interannual variability of temperature in Malaysia: 1961–2002. *Theor Appl Climatol* 89: 127–141
- Uhlenbrook S, Roser S, Tilch N (2004) Hydrological process representation at the meso-scale: the potential of a distributed, conceptual catchment model. *J Hydrol* 291(3–4):278–296
- US Army Corps of Engineers (2000) Hydrologic Modeling System (HEC-HMS): technical reference manual. Hydrologic Engineering Center, Davis, CA, p 149
- Wan I (1996) Urban growth determinants for the state of Kelantan of the state’s policy makers, Penerbitan Akademik Fakulti Kejuruteraan dan Sains Geoinformasi. *Buletin Ukur* 7:176–189
- Wang K, Li Z, Cribb M (2006) Estimation of evaporative fraction from a combination of day and night land surface temperatures and NDVI: a new method to determine the Priestley-Taylor parameter. *Remote Sens Environ* 102:293–305
- Yeung CW (2005) Rainfall-runoff and water-balance models for management of the Fena Valley Reservoir, Guam: scientific investigations report 2004-5287, U.S. Geological Survey Scientific Investigations Report 2004-5287, p 52