UNIVERSITI PUTRA MALAYSIA

HYDROLOGICAL RESPONSES TO CLIMATE AND LAND USE CHANGE IN UPPER LANGAT BASIN, PENINSULAR MALAYSIA

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By

MAHBOUBEH EBRAHIMIAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

HYDROLOGICAL RESPONSES TO CLIMATE AND LAND USE CHANGE IN UPPER LANGAT BASIN, PENINSULAR MALAYSIA

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September 2016

Chairman : Professor Ahmad Ainuddin Nuruddin, PhD
Faculty : Forestry

It is undeniable that climate and land use changes affect the major components of hydrological cycle such as streamflow and water availability in river basins. However, the magnitude and contributions of their effects are still uncertain. It is highly required to study the individual and combined impacts of changes in climate and land use on streamflow and consequently flood vulnerability in tropical river basins particularly those basins which experience rapid changes in land use. Langat River basin which experiences flooding as a response to both climate variability and rapid urbanization and industrialization was chosen to investigate the hydrological responses of the basin to both factors. This research aimed to evaluate past and probable future environmental changes and their effects on the hydrological response of the Hulu Langat river basin. More specifically the study provides a framework to analyze the historic trends of major hydro-climatic variables as secondary data including rainfall, temperature and streamflow (1984-2010) and land cover changes (land use maps of 1984-2006-2008) and also to quantify their individual and combined impacts on streamflow through designed scenarios of different combinations of land use and climate conditions. The trends of historical time series of temperature, rainfall and streamflow were determined with the Mann-Kendall method. The study applied the semi-distributed hydrological model, SWAT, and calibrated and validated against observed streamflow using SWAT-CUP (SUFI-2). The land use/land cover changes were examined using LCM model and future land use change scenarios were developed using the combination of Markov chain and Multi-Layer Perceptron (MLP_Markov) model. The climate change scenarios were based on the combination of one RCM (PRECIS) and stochastic weather generator (LARS-WG). To this end, the daily temperature and precipitation projection of A1B emission scenario by the PRECIS model and A2, B1 emission scenarios by LARS-WG for 2020s, 2050s and 2080s were superimposed in the calibrated SWAT model. Annual streamflow in three stations (F1, F2, and F4) out of four exhibited significant increasing trend at $\alpha = 0.01$ significance level. The annual streamflow had been significantly increasing at the rate of 0.036, 0.023 and 0.001 $\times 10^3$ m^3/year in those stations, respectively, from 1980 to 2010. Seasonal streamflow showed significant increasing trend in the upper part of basin in all seasons. Significant increasing trend for monthly streamflow was detected for January and August, but insignificant trends were found in May, September and November in all hydrological stations. Streamflow was primarily correlated to rainfall ($P<0.05$). Land use change analysis indicated that forest cover, short-term crops and permanent crops were notably decreased from 1984 to 2006. The area of permanent crop and forest area in 2006 was 48.5 % and 3.1% lower than that in 1984, respectively, but the built-up and residential areas were increased distinctly. The simulation results of the hydrological model under land use change scenarios showed that the magnitude of streamflow was impacted by land use change in all scenarios. Streamflow was highest due to expansion of urban area and contraction of forest and croplands. Future land use change would account for increase in streamflow about 20%, 61% and 71% for the 2020s, 2050s and 2080s land use scenario maps, respectively. Under only climate change scenarios, streamflow was predicted to increase 8.7% in 2020s, 54.7 % in 2050s and 21% in 2080s under A2 scenario, 14.7%, 21.4% and 75.7% for the 2020s, 2050s and 2080s under B1 scenario, respectively. Streamflow was also projected to decrease about 3.1% and 10.4% under A1B scenario for the 2020s and 2050s, but it showed an increase of about 28% in the 2080s. The intensification of streamflow is in maximum percent (92%) in 2080s under B1 scenario. The combined scenarios of land use and climate indicated that climate variables change coupled with land use change have resulted significant increase in streamflow about 9%, 20.1%, 9% for the 2020s, 2050s and 2080s under A2 scenario, and 14.9%, 24.4% and 19.7% for the 2020s, 2050s and 2080s under B1 scenario. Under A1B scenario, 19% decrease in streamflow in the 2020s was predicted, but the streamflow increases 25.6% and 65.4% for the 2050s and 2080s, respectively. This study concludes that under different designated scenarios, streamflow is expected to experience significant increase in the future decades as a consequence of land use and climate changes, but changes in land use have led to greater streamflow changes against climate change. Consequently, there is an urgent need to reverse land use change trends such as afforestation, conservation on natural habitat and control on urban expansion for future development programs and land use planning to mitigate probability of possible flooding which is a major problem in this region.

Keywords: climate change, hydrological processes, hydroclimatic variables, land use conversion, trend analysis, streamflow

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

TINDAK BALAS HIDROLOGI KEPADA PERUBAHAN IKLIM DAN PENGGUNAAN TANAH DIKAWASAN HULU LEMBANGAN SUNGAI LANGAT SEMENANJUNG MALAYSIA

Oleh

MAHBOUBEH EBRAHIMIAN

September 2016

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Adalah tidak boleh dinafikan bahawa iklim dan penggunaan tanah akan mengubah komponen hidrologi seperti aliran sungai dan ketersediaan air di lembangan sungai. Walau bagaimanapun, magnitud dan sumbangan kesannya tidak begitu jelas. Adalah penting untuk mengkaji kesan individu dan gabungan perubahan iklim dan tanah digunakan pada aliran sungai dan seterusnya kemungkinan banjir di lembangan sungai topikal terutamanya lembangan yang mengalami perubahan pantas dalam penggunaan tanah. Oleh itu, lembangan Sungai Langat yang mengalami banjir sebagai tindak balas kepada kedua-dua iklim kepelbagaian, pembandaran dan perindustrian telah dipilih untuk menyiasat responsi hidrologi lembangan untuk kedua-dua factor ini. Kajian ini bertujuan untuk menilai perubahan persekitaran masa sebelum dan kemungkinan pada masa hadapan serta kesannya terhadap hidrologi lembangan sungai Langat. Lebih khusus lagi kajian ini menyediakan rangka kerja untuk menganalisis trend bersejarah pembolehubah hidro iklim yang ketara termasuk hujan, suhu dan aliran sungai (1984-2010) dan perubahan persekitaran tanah (1984-2006-2008) juga untuk mengukur individu mereka dan kesan kombinasi pada aliran sungai melalui senario yang direka kombinasi yang berbeza penggunaan tanah dan keadaan iklim. Trend suhu, hujan dan aliran sungai ditentukan dengan kaedah Mann-Kendall. Kajian ini menggunakan model hidrologi, SWAT, ditentukur dan disahkan terhadap aliran sungai yang diperhatikan menggunakan SWAT-CUP (SUFI-2). Perubahan penutup penggunaan tanah / tanah telah diperiksa menggunakan model LCM dan senario perubahan penggunaan tanah masa depan telah dibuat dengan menggunakan kombinasi rantaian Markov dan model Multi-Layer Perceptron (MLP_Markov). Senario perubahan iklim adalah berdasarkan kombinasi satu RCM (PRECIS) dan penjana cuaca stokastik (LARS-WG). Untuk tujuan ini, suhu dan hujan unjuran harian menjadi senario pelepasan A1B oleh model PRECIS dan A2, senario pelepasan B1 oleh LARS-WG untuk 2020-an, 2050s dan 2080s telah ditekankan dalam model SWAT yang telah ditentukur. Aliran sungai tahunan tiga stesen (F1, F2 dan F4) daripada empat mempamerkan trend yang ketara meningkat pada tahap $\alpha = 0.01$ kepentingan. The aliran sungai tahunan telah meningkat dengan ketara pada kadar 0,036, 0,023 dan 0,001 × 103 m3 / tahun dalam stesen masing-masing, dari tahun 1980 hingga 2010. Aliran sungai bermusim menunjukkan trend yang ketara meningkat di bahagian atas lembangan dalam semua musim. Trend yang ketara semakin meningkat bagi aliran sungai bulanan telah dikesan bagi Januari dan Ogos, tetapi trend yang tidak ketara ditemui pada bulan Mei, September dan November di semua stesen hidrologi. Aliran sungai terutamanya dikaitkan dengan hujan ($P < 0.05$). Analisis penggunaan tanah menunjukkan bahawa hutan, tanaman jangka pendek dan tanaman jangka panjang telah turun dari tahun 1984 hingga 2006. Kawasan tanaman jangka panjang dan kawasan hutan pada tahun 2006 adalah 48.5% dan 3.1% lebih rendah berbanding pada tahun 1984 masing-masing, tetapi binaan dan kawasan perumahan telah meningkat dengan amat jelas. Keputusan simulasi model hidrologi di bawah senario perubahan penggunaan tanah menunjukkan bahawa magnitud aliran sungai terjejas kerana perubahan penggunaan tanah dalam semua senario. Aliran sungai adalah paling tinggi disebabkan oleh pengembangan kawasan bandar dan pengecutan hutan dan tanah pertanian. Masa depan perubahan penggunaan tanah akan mengambil kira peningkatan dalam aliran sungai kira-kira 20%, 61% dan 71% bagi tahun 2020-an, 2050s dan 2080s penggunaan tanah masing-masing. Di bawah hanya senario perubahan iklim, aliran sungai telah diramalkan meningkat 8.7% pada 2020-an, 54.7% pada tahun 2050s dan 21% pada tahun 2080s di bawah senario A2, 14.7%, 21.4% dan 75.7% bagi tahun 2020-an, 2050s dan 2080s di bawah senario B1 masing-masing. Aliran sungai juga dijangka berkurangan kira-kira 3.1% dan 10.4% di bawah senario A1B bagi 2020-an dan 2050s, tetapi ia dijangka meningkat sebanyak kira-kira 28% dalam 2080s. Peningkatan aliran sungai adalah dalam peratus maksimum (92%) dalam 2080s di bawah senario B1. Senario kombinasi penggunaan tanah dan iklim menunjukkan bahawa pembolehubah iklim dengan tambahan perubahan penggunaan tanah akan menyebabkan peningkatan yang ketara dalam aliran sungai kira-kira 9%, 20.1%, 9% bagi tahun 2020-an, 2050s dan 2080s di bawah senario A2, dan 14.9%, 24.4% dan 19.7% bagi tahun 2020-an, 2050s dan 2080s di bawah senario B1. Di bawah senario A1B, pengurangan sebanyak 19% dalam aliran sungai dalam tahun 2020-an telah diramalkan, tetapi aliran sungai meningkatkan 25.6% dan 65.4% bagi 2050s dan 2080s masing-masing. Kesimpulan kajian ini adalah senario yang ditetapkan yang berbeza, aliran sungai dijangka mengalami peningkatan yang ketara dalam dekad yang akan datang akibat daripada penggunaan tanah dan perubahan iklim, tetapi perubahan penggunaan tanah yang telah membawa kepada perubahan aliran sungai yang lebih besar terhadap perubahan iklim. Oleh itu, terdapat keperluan mendesak untuk mengubah trend penggunaan tanah untuk program-program pembangunan masa depan dan penggunaan tanah yang merancang untuk mengurangkan kebarangkalian kemungkinan banjir yang merupakan masalah utama di rantau ini.

Kata kunci: perubahan iklim, proses hidrologi, pembolehubah hydroclimatic, penggunaan tanah penukaran, analisis trend, aliran sungai

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I certify that a Thesis Examination Committee has met on 22 September 2016 to conduct the final examination of Mahboubeh Ebrahimian on her thesis entitled "Hydrological Responses to Climate and Land Use Change in Upper Langat Basin, Peninsular Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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Signature: ______________________
Name of Member of Supervisory Committee: Associate Professor Dr. Liew Ju Neng

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95PPU	95% prediction of uncertainty
AD	Anderson-Darling
ADB	Asian Development Bank
AGCM	Atmosphere Global Circulation Model
AGNPS	Agricultural Non- Point Source Pollution
ALPHA_BF	Base Flow Alpha Factor
ANN	Artificial Neural Network
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
AOGCMs	Atmospheric-ocean general circulation models
AR4	Fourth Assessment Report
AVHRR	Advanced Very High Resolution Radiometer
BMP	Best Management Practices
CANMX	Maximum Canopy Storage
CCA&SVD	The canonical correlation analysis and singular value decomposition
CCC	Canadian Climate Centre
CCIRG	Climate Change Impacts Review Group
CCSM3	The Community Climate System Model version 3
CCSR	Japanese Research Center of Climate Systems model
CDF	Correction for systematic bias correction
CGCM	Canadian General Circulation Model
CGIAR-CSI	Consultative Group for International Agriculture Research–Consortium for Spatial Information
CH4	Methane

CLUE	Conversion of Land Use Change and its Effects
CN2	Curve Number
CO2	Carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital elevation model
DHSVM	Distributed Hydrology-Soil-Vegetation Model
DID	Department of Irrigation and Drainage, Malaysia
ECHAM5	Max Planck Institute for Meteorology
ESCO	Soil evaporation compensation factor
ET	Evapotranspiration
FRIM	Forest Research Institute Malaysia
GCM	General circulation model
GHG	Greenhouse gases
GIS	Geographical information system
GLUE	generalized likelihood uncertainty estimation
GW_DELAY	Groundwater delay time
GWQMN	Threshold depth of water
HadAM3P	Hadley Centre's global atmosphere- only model
HadCM	Hadley Centre coupled model
HBV	Hydrologiska Byråns Vattenbalansavdelning
HEC-HMS	Hydrologic Engineering Centre – Hydrologic Modelling System
HRUs	Hydrologic Response Units
Hydro-BEAM	Hydrological River Basin Environmental Assessment Tool

IPCC	Intergovermental Panel on Climate Change
IRSHAM	Integrated Regional Scale Hydrologic-Atmospheric Model
KIA	Kappa Index of Agreement
KINEROS	kinematic runoff and erosion model
LARS-WG	Long Ashton Research Station Weather Generator
LCM	Land Change Modeler
LH-OAT	Latin Hypercube-One Factor at a Time
LULC	Land use and land cover
MCMC	Markov chain Monte Carlo
MLP	Multi-Layer Perceptron (MLP)
MM5	Mesoscale Meteorological Model
MMD	Malaysia Meteorological Department
MPI	Max-Planck Institute for Meteorology
MRI	Meteorological Research Institute of Japan
N2O	Nitrous Oxide
NAHRIM	National Hydraulics Research Institute of Malaysia
NAM	Nedbor-Afstromings Model
NAP3	Third National Agricultural Policy
NC2	Malaysian Second National Communication
NDVI	Normalized Difference Vegetation Index
NE	North-east
NHMM	Nonhomogeneous Hidden Markov Model
NRCS	Natural Resources Conservation Service
NSE	Nash and Sutcliffe
OV_N	Manning's "n" value for overland flow

ParaSol	Parameter Solution
PBIAS	Percent Bias
PCM	Parallel Climate Model
PET	Potential Evapotranspiration
PFE	Permanent Forest Estate
PM	Peninsular Malaysia
PRECIS	Providing Regional Climates for Impact Studies
PRMS	Precipitation-Runoff Modeling System
R^2	Coefficient of Determination
RCM	Regional Climate Model
RegHCM-PM	Regional Hydro-Climate Model of Peninsular Malaysia
RegHCM-SS	Regional Hydro-Climate Model of Sabah and Sarawak
RMSE	Root Mean Square Error
SD	Standard Deviation
SDSM	Statistical Downscaling Model
SEA	Southeast Asian
SLR	Sea Level Rise
SLSUBBSN	Average slope length
SLURP	Semi-distributed Land Use-based Runoff Processes
SOL_AWC	Available water capacity of the soil layer
SRES	Special Report on Emissions Scenarios
SUFI-2	Sequential Uncertainty FItting
SW	South West
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration Uncertainty program

TFPW	Trend-Free Pre-Whitening
TOPMODEL	TOPographic MODEL
UBC	University of British Columbia
UKM	Universiti Kebangsaan Malaysia
UKMOH	United Kingdom Meteorological Office high resolution
UNFCCC	United Nations Framework Convention on Climate Change
US NCAR	U.S National Centre for Atmospheric Research
USDA	U.S. Department of Agriculture
USGS	United State Geological Survey
UTM	Universal Transverse Mercator
VIC	Variable Infiltration Capacity
WaSiM	Water Flow and Balance Simulation Model
WatBall	Water Balance model
WECAM	Water and Energy Consumer Association of Malaysia
WEPP	Water and Erosion Prediction Project
WMO	World Meteorological Organization

CHAPTER 1

INTRODUCTION

1.1 Background

Climate change refers to changes in the mean and/or the variability of climate's characteristics due to anthropogenic activities or natural factors that persists for decades or longer (IPCC 2007; Zulkarnain *et al*., 2014). Anthropogenic factors (e.g., urbanization and deforestation) are believed to increase the concentration of greenhouse gases (carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)) that induce tremendous changes in the global climate system (IPCC 2007; Wu *et al*., 2012a). Elevated atmospheric gases not only can raise global mean temperatures but also can change the spatial and temporal distribution of precipitation. Consequently, increased concentration of atmospheric gases and global warming are expected to affect terrestrial hydrological cycle as well as watershed hydrological conditions significantly (Liu *et al*., 2011; Wu *et al*., 2012b). Increased or decreased of river discharge and streamflow, more frequent and severe drought and flood events are some hydrological consequences of global warming (Wu *et al*., 2012b).

Besides climate, land use is an important factor influencing hydrological conditions of watersheds (Li *et al*., 2010). Understanding the hydrological response of a watershed to land use change due to human activities and climatic changes is a significant component of water resource management. Therefore, the potential effects of these two interrelated issues on water resources need to be addressed in an integrated way in management practices (Mango *et al*., 2011). In addition, disasters (such as flood, drought and land slide) due to human activities (such as urbanization, deforestation, inappropriate land use system and poor agricultural practices) and natural phenomena related to climate such as, floods, drought and landslides, among others, can affect ecosystem service functioning of watersheds, such as water availability and erosion rate (Serpa *et al*., 2015), sustainable development and socio-economic activities.

In Malaysia, there are more than 150 river systems with 100 of them in the Peninsular Malaysia and 50 in Sabah and Sarawak (Ayub *et al*., 2009). These river systems consist of 1800 rivers with a total length of 38000 km which cover a total land mass of 329,760 km^2. Langat Basin is one of the important river systems providing raw water supply and other amenities to approximately 1.2 million people within the basin (Juahir, 2011). Rapid development and urbanization and subsequently deforestation can change the natural hydrological conditions and infiltration rate of river systems in Malaysia (Ayub *et al*., 2009). The prolonged and intensive rain in dense network of rivers and streams can increase the occurrence of flash flooding and monsoon flooding (Shafiee *et al*., 2004). From the above standpoint, water resource managers under the climate and land use/land cover change condition in Malaysia like to know whether an adjustment in water resources management is needed, and if so, what change should be applied to protect ecosystems. In order to deal with this issue and to minimize adverse environmental impacts, reliable hydrological modelling is one of the most urgent tasks to quantify the magnitude of changes, the way they affect hydrological variables along with the magnitude and frequency of them. Therefore, modelling categories include hydrological models; climate change models, land use models integrated with a geographical information system (GIS), are potentially powerful tools for assessing and representing the interaction effects of climate and land use changes in hydrological response.

Langat River basin has sensitive response to the South-West monsoon that blows across the Straits of Malacca. Furthermore, the Langat basin is lately subjected to the high rate of land use change (e.g., rapid urbanization and deforestation). Therefore, by understanding grow of these features, i.e. rapid land use change and sensitive responses to the South-West monsoon, make the Langat watershed a suitable basin to evaluate and understand the response of streamflow to land use and climate changes (Adnan, 2010). For that reason, it is possible to assess combination impacts of land use change with climate change on water resources in the Langat River watershed.

1.2 Statement of the problem

The impacts of land use change on river basin hydrology are interlinked with impacts of climate change. Determination of the watershed response to climate change and rapid urbanization and deforestation is the most serious problem facing local water resource managers. In Malaysia, flooding is the most common hydroclimatic and natural disaster. Compared to other disasters, great numbers of people have been affected by floods over the last century (Tan and Pereira, 2013). Around 9% of the total land area (30,000 km^2) and greater than 22% of total population (4.82 million people) in Malaysia are affected by flooding every year (Taliair, 2003). Figure 1.1 shows the frequency of flood events for the past 50 years in Malaysia. Major flood events and their associated damages are also listed in Table 1.1 It is clear that the frequency of flood events have been increased over decades, besides the great number of people affected, that showing problem in managing policies. Therefore, additional costs on management of water resources and future flood mitigating plans needed (WECAM, 2013).

Langat River basin is one of the most important areas for economic growth especially in developing manufacturing zones in the Selangor state. Furthermore, the basin provides raw water to two-third of the state of Selangor (Juahir *et al*., 2010). Land use change through rapid urbanization and industrialization and conversion of forest land to other land uses e.g. oil palm, rubber plantations, orchards, and other land uses within Langat River basin, which mainly is due to the changes in economic policies of Malaysian Government, will increase the area of pervious and impervious surfaces, which is identified as main factor in rises of streamflow and river discharge (Memarian *et al.,* 2012; Juahir *et al*., 2010). In addition, deforestation and landscape changes can make the basin area more vulnerable to climate change issues such as heavy rainfall. These changes in land use/land cover have affected the hydrological variables (e.g., surface and groundwater, discharge and evapotranspiration) in the Langat watershed, switching the hydrological cycle and flood vulnerability of the watershed (Juhair *et al*., 2011; Guo *et al*., 2008).

On the other hand, flood happens in the Langat River basin frequently. However, the frequency and severity of floods have increased during the last decades (DID, 2007). Therefore, occurrence of frequent and severe floods have raised the concerns of how changes in climate and land use in regional and local scales can impact the hydrological conditions (Guo *et al*., 2008). It has been suggested that increased frequency and severity of floods in the Langat basin is due to increased variation of seasonal rainfall due to climate change and, also, the rise possibly has been influenced by land use/land cover changes. Variation in climate variables and the subsequent increase of global temperature can cause an intensification of the hydrological cycle. It can lead rainy season more wet and dry seasons more dry and consequently the risks of more severe and frequent floods will be increased.

Consequently, it is essential to quantify streamflow response to changes of climate and land use in the watershed by way of hydrological modelling to understand the impacts of those changes on river discharge and streamflow (Azlinda & Mohd, 2011; Guo *et al*., 2008). To improve and optimise water supply and demand, both water and land use decision makers should use the estimations made by hydrological modelling to support for best management practices and compensate the adverse effects of the land use activities for sustainable environmental development. Finding the response of the Langat River watershed to climate and land use changes is the most serious problem facing local water resources managers.

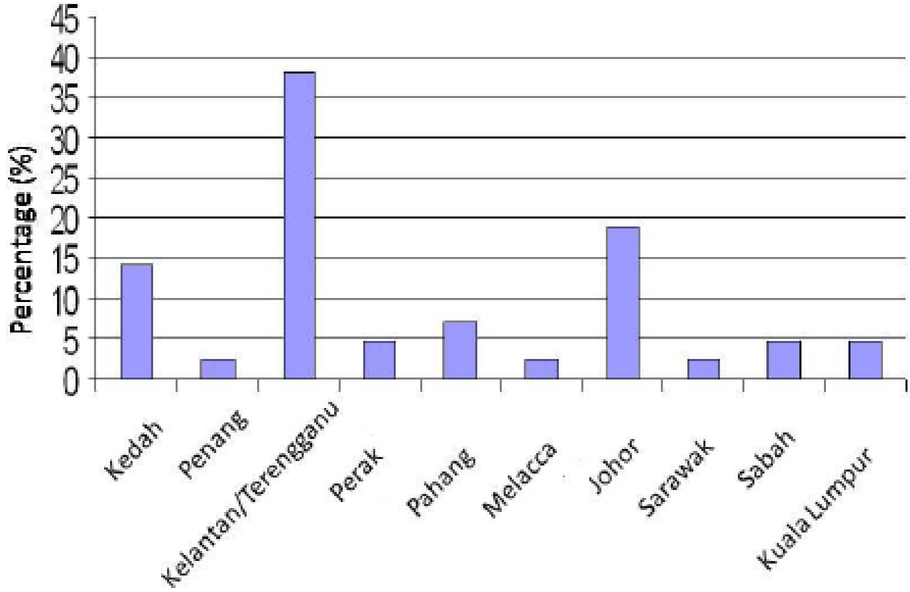

Figure 1.1 : Frequency of flood events, past 50 years in Malaysia (1960-2010) (Source: WECAM, 2013)

Table 1.1 : Major flood events in Malaysia and associated damages

Flood Event (Year)	(Place)	Damage (USD million at 1996 prices)	Deaths	No.of Victims Evacuated
1886	Kelantan & Besut Rivers ("Storm Forest Flood")	Several hundred square kilometers of forest destroyed	NA	NA
1926	Most of Peninsular Malaysia	Damage to natural environment	NA	NA
1954	Johor, Terengganu	Hundreds of acres of padi	2	Thousands
1965/66	Besut, Kelantan-Terengganu	>30,000 acres of padi destroyed	NA	Thousands
1966	Perlis	NA	1	NA
1967	Kelantan River Basin	72.31	38	320,000
1967	Perak River Basin	56.04	0	280,000
1967	Terengganu River Basin	14.57	17	78,000
1971(December)	Kuala Lumpur	30.71	24	NA
1971(December)	Pahang River Basin	33.77	24	153,000
1979	Peninsular Malaysia	NA	7	23,898
1981	Kelantan State	NA	8	2,740
1982	Peninsular Malaysia	NA	8	9,893
1983	Penang State	0.20	0	NA
1983	Other Peninsular Malaysia	NA	14	60,807
1984	Batu Pahat River Basin	7.37	0	8,400
1984	Kelantan dan Terengganu States	NA	0	Thousands
1986	Peninsular Malaysia	11,96	0	40,698
1988	Kelantan River Basin	NA	19	36,800
1988	Other Peninsular Malaysia	NA	37	100,755
1989	Johor State	NA	1	Thousands
1989	Kuala Lumpur/Petaling Jaya	0.03	0	220
1991	Other Peninsular Malaysia	NA	11	NA
1992	Peninsular Malaysia	NA*	12	NA
1993	Peninsular	NA	22	17,000
1993	Sabah State	72.57	5	5,000
1995	Shah Alam/Kelang Valley	1.76	1	8,970
1995	Klang Selangor	NA	3	0
1995	Other Peninsular Malaysia	NA	4	14,900
1996	Sabah (June)	>100 houses destroyed	1	9,000
29.8.1996	Pos Dipang, Perak	97.8**	44	Hundreds
1996	Sabah (December)	NA	241***	23,000
30.12.98	Kuala Lumpur	NA	5	0
5-9.1.99	Penampang, Sabah	NA	6	4,481
11.1.99	Sandakan Sabah	NA	3	0
23.11.2000	Kg. La	NA	6	0
Dec. 2001	Kelantan, Pahang, Terengganu	Crop loss & property damage in millions USD; USD 0.65 million tents destroyed	6	>10,000
27.12.2001	Gunung Pulai, Johor	Mudslide swept away 4 houses	5	4 families
31.12.2001	Benut Marang, Terengganu	Crop loss & property damage	4	Thousands
Dec 2006 – Jan	Johor State	USD 489 million Property Damage	18	110,000
2007	Kelantan State	USD 17.28 Damage to Infrastructures		
2008	Johor State	65 (Relief Costs)	28	34,000
November 2010	Kedah & Perlis States	Alor Setar Airport closed, railway line flooded, USD 8.48 million padi crop damage	4	50,000

(Source: Drainage and Irrigation Department Malaysia, 2010)
Note: NA= Not Available; * = In the state of Kelantan; ** = Damage to infrastructure and public utilities estimated at USD 42.38 million. Destruction of properties (more than 4,553 houses were destroyed), crops and livestock loss estimated at USD 55.42 million. *** = Another 108 people are still missing more than a month after the even.

1.3 Objectives

The goal of the current research is to assess the potential impacts of changes in climate and land use/land cover on the streamflow of the Langat River basin in Selangor, Malaysia.

The objectives of the study are:

i) To analyse the trends of major hydroclimatic variables including rainfall, temperature and streamflow in past decades and to explore the probable causes of the changes;
ii) To simulate and quantify the impact of potential climate change on streamflow of the Langat River under different climate change scenarios;
iii) To simulate and quantify the impacts of land use/land cover changes on streamflow characteristics through designed scenarios for future;
iv) To model the impacts of individual and combined land use and climate changes on streamflow attributes through designed scenarios of different combinations of land use and climate conditions;

1.4 Hypothesis

Changes in climate and land use affect hydrological variables in the watershed. Climate change might lead to increase or decrease in rainfall and flood generation. Deforestation due to rapid urbanization and oil palm plantation establishment might cause increase in streamflow rate in the Langat basin.

Specifically, the hypotheses to be tested in this study are:

1. Climate change affects hydrological regime of the Langat River through increase in rainfall and streamflow rate.
2. Changes in land use increase the streamflow and flood events regime in the Langat watershed.
3. There is a strong relationship between land use change and streamflow variability in the Langat watershed.

1.5 Justification of the study

The hydrological effects of climate variation and land use conversion can occur at various spatial scales, but the most important sources of these changes are at the regional or watershed scale (Raneesh and Santosh, 2011). In addition, the managerial and technical measures are primarily implemented at local and watershed scales in order to mitigate adverse impacts of human activities on the renewable resources of the watershed. Therefore, quantitative estimation of the possible hydrological consequences of potential land use and climate changes on hydrological regime at watershed scale is of tremendous importance. These studies are important to facilitate the application of results to real environment (Praskievicz and Chang, 2009). Consequently, the watershed-scale studies are essential to measure the extent of influences made to the hydrological conditions and understanding of causes and effects of climate variation and land use conversion on hydrological cycle and water resources.

Results of this study on the hydrological response of watershed to land use and climate changes is valuable for making better planning decisions and management of land use in long-term, for effective management of water resources, and for formulating the decision and adaptive strategies for the proper management of water resources and floods under future variations. Moreover, the outcomes of the current research can address the questions raised on how the future land use and climate changes will influence the water resources and flood potential of the watershed. Proper responses to these questions and related subjects will increase the predictability of hydrological reaction to climate and land use changes.

1.6 Gap of knowledge

Despite many studies on the assessment of the land use and climate changes impacts on hydrological processes, quantitative information on possible changes of regional patterns of climate and land use and their implications for the hydrologic cycle and water resources are still scarce in humid tropical regions like southeast Asia and yet poorly understood. Quantitative assessment of the sensitivity, vulnerability and adaptive capacity to climate change especially for humid tropical regions are rare at watershed scale where the most important sources and drivers are located. Studies that relate both land use and climate changes with hydrological processes and streamflow of the watershed are one of the urgent issues and high priorities of today's water management needs to narrow the gaps between current knowledge and policymaking needs in tropical regions.

Langat River basin is one of the most urbanized river basins in peninsular Malaysia that warrant focused attention. Flooding is a common phenomenon in the Langat Basin during wet monsoon period particularly when it coincides with localized rainfall. In addition, 1.8 million inhabitants were affected by the severe drought in 1998, in southern part of Kuala Lumpur City, Bangi and Kajang, where the source of their water supply is from the upper Langat river basin. These issues indicate that sustainable water resources management in the Langat basin requires knowledge of how hydrological processes respond to changes of various aspects of climate particularly in watersheds with high land use conversion. Unfortunately, no modeling studies have addressed the combined effects of climatic and land use conditions for the Langat River basin.

1.7 Thesis outlines

This thesis is divided into five chapters. Chapter 1 includes introduction of thesis. The chapter begins with general discussion to the research topic followed by problem statement, research objectives, significance of the study and gap of the knowledge.

In the second chapter, the impacts of land use and climate changes on streamflow and their relationships explained by discussing the various aspects cited in existing literature. The purpose of this chapter is to review relevant published documents such as journal articles, books and online documents on the responses of hydrological variables to climate and land use changes and to identify the gaps in knowledge by scrutinizing the strengths and weaknesses of existing literature.

Brief descriptions of study area were explained in the third chapter. Third chapter also discusses trend analysis of major hydroclimatic variables and examined the data for any trends between them in order to understand hydrological responses of climate change. Three types of time series data are analysed in this chapter which are rainfall, temperature and stream flow to investigate the possible trend and relationship between hydro climatological variables of Langat River basin. In order to increase confidence on existence of trend four widely nonparametric test of Mann-Kendall method, Pettitt test, Sen's slope method and Pearson correlation test were used. The procedures were performed using XLSTAT and R statistical packages.

In the fourth analyses of land use changes between various classes performed over time and different transition matrices were created for prediction of future land use scenarios. Reclassification of land use subcategories into broad categories and conversion of shape files to raster format was performed in ArcGIS 10.1. In this chpter Land Change Modeler (LCM) and Markov Chain modules in IDRISI Selva 17.0 software were used to analyze land use changes between various classes over time and to create transition matrices for prediction of future land use scenarios. Reclassification of land use subcategories into broad categories and conversion of shape files to raster format was performed in ArcGIS 10.1. Then, land use maps with raster format were imported into IDRISI for further analysis.

Then in the fifth chapter, the hydrological model set up, calibration and validation of the model were explained. ArcSWAT as an ArcGIS extension and graphical user input interface for SWAT was used in for hydrological modelling and the model input files were created by ArcSWAT (ArcGIS –SWAT) interface. The SUFI-2 program in SWAT-CUP software was used as an optimization algorithm for calibration of SWAT and estimation of parameter and uncertainty analysis.

In chapter sixth the individual and combined impacts of land use and climate changes on the streamflow of the Langat River basin were explained. First analysis of the impacts of land use/land cover change on streamflow were clarified then climate change impacts on streamflow were analyzed based on the future scenario derived from RCM (PRECIS) and SDSM (LARS-WG) climate models and finally combined impacts of land use change and climate change were investigated to assess the sensitivity of land use change, rainfall and air temperature variation on the streamflow for past and future. Results are discussed after presenting of the outcomes for each objective. This discussion is based on existing literature including citation indexed and peer reviewed journal articles, books, internet documents and circumstantial evidences in the area under study. The study is concluded in Chapter 7. This final part of the thesis summarizes the major outcomes of the study in compressed manner according to research objectives. At the end, some recommendations for future researches in relation to the topic of this research and in accordance with the limitations of the present study were presented. Briefly, according to the objectives of this work, a hydrological modelling framework was applied in the Langat River basin to investigate the possible impacts of changes in land use and climate conditions on watershed hydrological components, particularly streamflow, in the Langat River. First (I) major hydroclimatic variables examined for any trends between time series data. Then in second step (II) land use changes were analysed and different scenarios developed and based on designed scenarios, future land use changes were projected. At the third stage (III) the hydrological model, set up and the model calibrated and validated. The fourth (IV) was extracting of future climatic variables from future scenario derived from RCM (PRECIS) and SDSM (LARS-WG) climate models. Lastly in the fifth step (V) in order to understand hydrological responses of climate change to simulate streamflow under the different climate and land use/land cover conditions observed in last decades (reference), and also for a set of climate and land use scenarios developed for the future (simulated). Then, the impacts of simulations under different scenarios were analysed. General flowchart of thesis methodology is shown in figure 1.2.

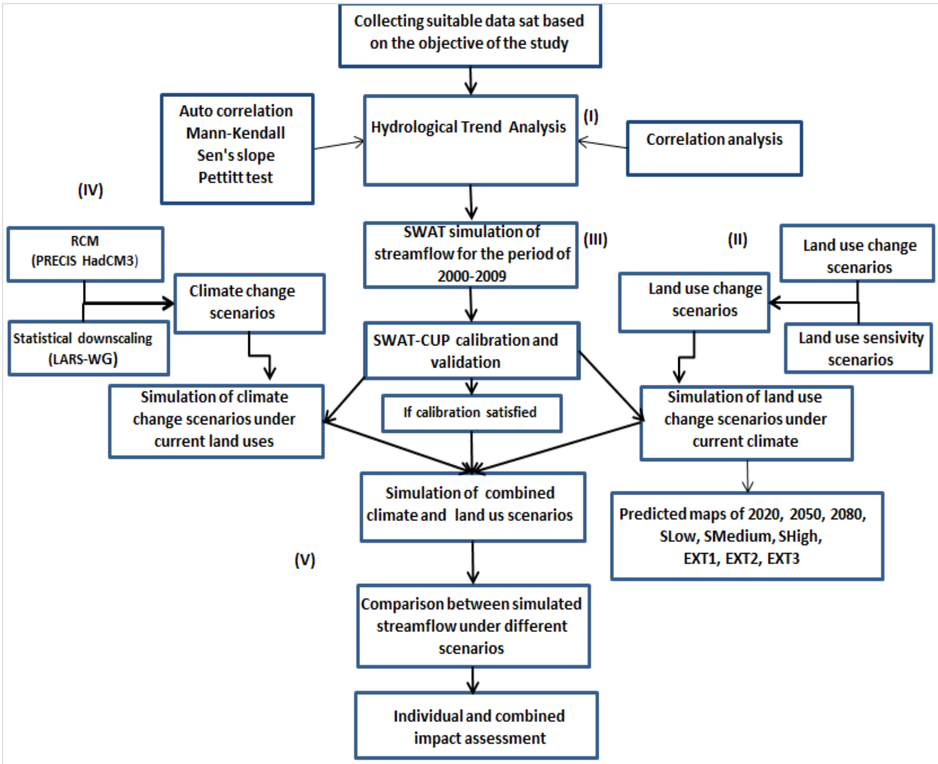

Figure 1.2 : General flowchart of research methodology

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