



Hydrological Responses to Climate and Land Use Change at Watershed Scale_ Malaysia

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Abstract – 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. 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. This paper focuses on the impacts of climate change as well as land use change on the hydrological processes of river basin based on pertinent published literature which were precisely scrutinized. The various causes, forms, and consequences of such impacts were discussed to synthesize the key findings of literature in reputable sources and to identify gaps in the knowledge where further research is required. Results indicate that the watershed-scale studies were found as a gap in tropical regions. Also, these studies are important to facilitate the application of results to real environment. 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.

Keywords: Climate change, land use conversion, hydrological response, watershed scale.

Introduction

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 (CO₂), methane (CH₄), and nitrous oxide (N₂O)) 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 km². 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 (Shafie *et al.*, 2013). 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 km²) and greater than 22% of total population (4.82 million people) in Malaysia are affected by flooding every year (Taliar, 2003). Figure 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. 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).

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 Malaysia 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. 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 a watershed, switching the hydrological cycle and flood vulnerability of the basin (Juahir *et al.*, 2011; Guo *et al.*, 2008). 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.

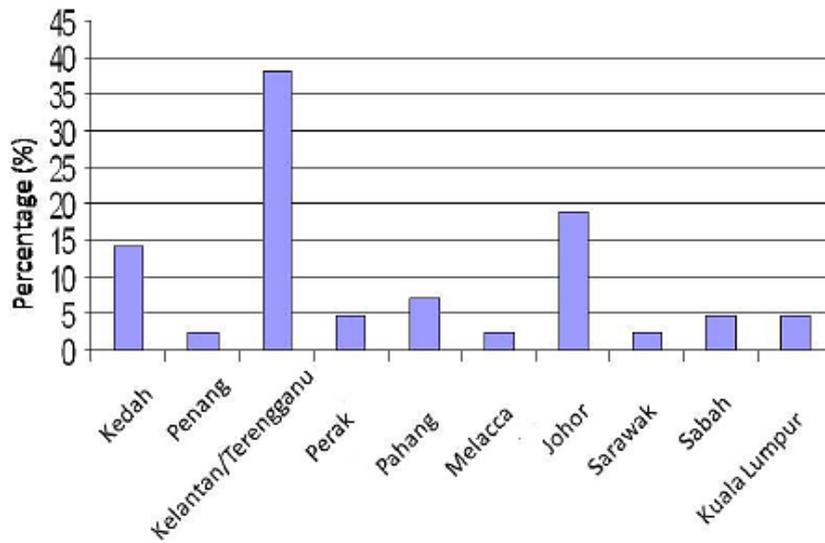


Figure 1: Frequency of flood events for past 50 years in Malaysia (1960-2010)
Source: (WECAM, 2013)

Table 1: Major flood events in Malaysia and associated damages (Source: Drainage and Irrigation Department Malaysia, 2010 and WECAM, 2013)

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	Sahab (June)	>100 houses destroyed	1	9,000
29.8.1996	Pos Dipang, Perak	97.8**	44	Hundreds
1996	Sahab (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 texts destroyed	6	>10,000
27.12.2001	Gumung 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 2007	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

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.

Impacts of Climate Change on Hydrological Processes

Understanding the hydrological processes of the watershed is an essential requirement to assess the impact of climate change on streamflow and it differs from one region to another (Leemhuis, 2005). The hydrological processes of the watershed include surface runoff, soil water content, percolation, groundwater flow, lateral flow, streamflow, water yield evaporation and transpiration and so on.

Climate variability could affect the hydrological processes of the watershed through changes in air temperature, precipitation and CO₂ concentration. These climatic variables have been selected as major predictands in almost all climate impact assessment studies (Nie *et al.*, 2012; Li *et al.*, 2010). Potential changes of evapotranspiration rates and precipitation will subsequently affect runoff and discharge regime of rivers (Middelkoop *et al.* 2001). Labat *et al.* (2004) concluded that the rise of 1 °C in temperature will increase runoff by 4% globally as a consequence of increased oceanic evaporation. Climate change may also have major impacts on water availability for agriculture, industry, and domestic uses. It is also projected that the amount of runoff can increase due to decrease in plant transpiration and improves water use efficiency; therefore, more water would be available for runoff (Middelkoop *et al.* 2001; Praskievicz and Chang, 2009). These hydro-climatological variations will increase risk of flood during rainy season, whilst low flow during dry season will adversely affect water availability for agriculture and industry (Middelkoop *et al.* 2001).

In recent years, numerous research have documented the impacts of climate change on hydrological processes throughout the world (Bae *et al.*, 2000; Middelkoop, *et al.*, 2001, Andreason, 2004; Leemhuis, 2005; Merritt *et al.*, 2006; Schulla and Jasper, 2007; Guo *et al.*, 2008; Ficklin *et al.*, 2009; Xu *et al.*, 2009; Li *et al.*, 2010). However, the Intergovernmental Panel on Climate Change (IPCC) reported the first comprehensive assessment of climate change and its related impacts on runoff and flooding in 1996. The IPCC reported that the frequency of heavy rainfall events is likely to increase. This may cause higher runoff and risk of flooding due to increased sea level especially in South East Asian countries. In the US, Fontaine *et al.* (2001) studied the potential response of water yield in catchment to variation in air temperature, precipitation and atmospheric CO₂ in Black Hills, South Dakota. The results showed that increase in air temperature can decrease streamflow, whereas increased precipitation will increase streamflow rate. On the other hand, largest increase in water yield will happen when both CO₂ concentration and precipitation increase. In China, Li *et al.* (2010) evaluated the impacts of climate change on hydrological variables in the Heihe watershed to find adaptive measure to mitigate the adverse effects of changes. The outputs of four General Circulation Models (GCMs) with three emission scenarios were used to estimate future changes in temperature and precipitation. Results showed that due to changes in annual precipitation from -2.3% to 7.8%, increase in maximum temperature from 0.7 to 2.2°C, and increase in minimum temperature from 1.2 to 2.8°C, the runoff will change from -19.8% to 37.0%. Evapotranspiration and soil water content will also change from and 0.1% to 5.9% and -5.5% to 17.2% respectively during 2010–2039. Yu and wang (2009) investigated the impacts of climate variability on evapotranspiration, precipitation and streamflow in northern Taiwan. Six scenarios of GCM projections of monthly precipitation and temperature data were used to generate the daily temperature and precipitation time series data using a weather generator model. They found that during rainy season (May to October) future precipitation and runoff would be higher and the projected precipitation and temperature would be lower during dry season (November to April). Increased in evapotranspiration amount was expected in the entire year, except in November and December. In South Korea, Bae *et al.* (2008) investigated the potential impact of climate change on runoff in 139 drainage basins. They used two GCMs scenarios output to drive the hydrological model, i.e. Precipitation Runoff Modelling System (PRMS), and did downscaling using a stochastic weather generator. Their findings indicated that runoff will change

seasonally and regionally within the selected basins. Thus the basins which are located in north parts of the country will experience increase in runoff whereas runoff will be decreased in the southern basins. In the USA, Jha (2005) used downscaled GCM output to drive the Soil and Water Assessment Tool (SWAT) in order to project impacts of climate change through the 2040s on the hydrology of the Upper Mississippi River Basin. The study reported a 51% increase in annual stream flow, a 43% increase in groundwater recharge, and a 50% increase in total water yield. Again in the USA, Liew *et al.* (2012) assessed the potential impacts of climate change on streamflow, water quality and best management practices (BMPs) based on different scenarios in two watersheds (Shell Creek and Logan Creek) of Nebraska. The study found that under the three future climate change scenarios, the amount of sediment load are projected to be 2 to 2.5 times higher than the baseline condition for Logan Creek and 1.2 to 1.5 times higher for the Shell Creek. The study also showed that streamflow projected to be increased due to future projected increase in CO₂ concentration and precipitation in both watershed but in different way. In Denmark, the impact of climate change on runoff was investigated by Thodsen (2007) in five Danish basins. The study used a lumped conceptual hydrological model NAM, driven by an RCM, to simulate impacts of climate change on runoff. The result of the simulation presented that runoff will increase by 12% due to an increase in projected precipitation by the end of the twenty-first century.

It can be concluded that although studies reported that the changes of hydrological components are very uncertain, their findings are in general agreement and consensus. Almost all studies indicated that sensitivity of hydrological responses and streamflow to climate change is very obvious to any changes in temperature, precipitation and increased atmospheric CO₂ concentrations, but in different ways in each basin.

Climate Change in Malaysia

Past and current records of climate change trends are obvious in Malaysia and show similar trends that have been encountered globally. It is projected that Malaysia may become warmer by the middle of the last century when the average temperature has been increasing (Tan & Pereira 2013). Most of the impacts of climate variability are expected to be associated to water in Malaysia (Malaysian Second National Communication, 2012). The potential influences of climate change that have been seen in the country are: sea level rise, increased flood risk, increased coastal erosion and extensive coastal flooding, decreased surface and groundwater quality, impacts on agriculture and aquaculture through decrease in soil and water quality (Abdul Kader, *et al.* 2012; Al-Amin *et al.*, 2013). In Malaysia, various researches have been carried out to simulate the potential impacts of climate change in future with both Global Climate Models (GCM) and Regional Climate Models (RCM). Ensemble of nine coupled Atmosphere Ocean General Circulation Models (AOGCMs) developed by USA, Canada, Japan, UK, France, Germany and China were applied by the Malaysian Meteorological Department to study the projection of variations in temperature and rainfall based upon A1B scenario for future period of 2020-2099. The result of the ensemble GCMs indicated that temperature will be increased amongst all nine AOGCMs in peninsular Malaysia as well as Sabah and Sarawak. Whereas, projected rainfall showed that it will increase over the west coasts of peninsular Malaysia and will decrease over the east coastal and increase significantly in western Sarawak (MMD, 2009). In 2006,

the impact of climate change on water resources and hydrologic regime of Peninsular Malaysia was studied. The output of coarse spatial resolution of GCM was downscaled. First, a coupled hydro-atmospheric model for peninsular Malaysia for future period of 2025 to 2050 (2025-2034 and 2041-2050) was developed which is called Regional Hydro-climate Model of Peninsular Malaysia RegHCM-PM. The RegHCM-PM model was coupled with regional hydrologic model component of IRSHAM (Integrated Regional Scale Hydrologic-Atmospheric Model) and MM5 regional atmospheric model of US NCAR (National Centre for Atmospheric Research). The regional model then validated and used to downscale the coarse spatial resolution of Canadian General Circulation Model (CGCM1) simulation output. The model runs from four main scenarios B1, A1B, A2 and A1FI from 3 GCMs. The resolution of GCM is about 410 km which is downscaled to fine grid resolution of 9 km in RegHCM-PM model (Kavvas *et al.* 2006; Jamalluddin, 2013). The projected and observed climatic changes are shown in Table 2. Projected annual precipitation for past (1984-1994) and future (2025-2034 and 2041-2050) periods of different sub-regions in Peninsular Malaysia is shown in Figure 2. The projections are established upon the medium range emission scenario (Second National Communication to the UNFCCC, 2012; NAHRIM, 2006).

Table 2: Observed and projected climate change

Climatic variables	Observed	Projected (by 2050)
Temperature	0.6-1.2 °C increased per 50 years (1969-2009)	Increased 1.5-2 °C
Rainfall amount	No significant difference Projected	Within Peninsula Malaysia: (-) 5% to (+) 9% variation Within Sabah and Sarawak: (-) 6% to (+) 11% variation
Rainfall Intensity	1 hour duration: 17% increased 3 hour duration: 29% increased (2000-2007 compared to 1971-1980)	Extremes increased in wet cycle and increase in frequency of them
Sea Level Rise (SLR)	1.3 mm/yr rise in Tanjung Piai, Johor (1986-2006)	0.5m rise (Global high worst case at 10mm/y)

In addition, the impact of climate change on the hydrologic regime and water resources for east Malaysia was studied in 2010 (NAHRIM, 2006). A similar regional downscaling model as RegHCM-PM for Sabah and Sarawak region was developed. The hydrologic-atmospheric model is called Regional Hydro-climate Model of Sabah and Sarawak (RegHCM-SS). The model then validated by the historical hydroclimatic data and run to downscale the coarse grid resolution of GCM simulated output on data of Sabah & Sarawak from about 208/310 km to 9 km. The regional model projected from A1B scenarios from 2 GCMs (ECHAM5 GCM and MRI GCM2.3.2) for the period of 2010 to 2100 (Kavvas *et al.*, 2006; Jamalluddin, 2013).

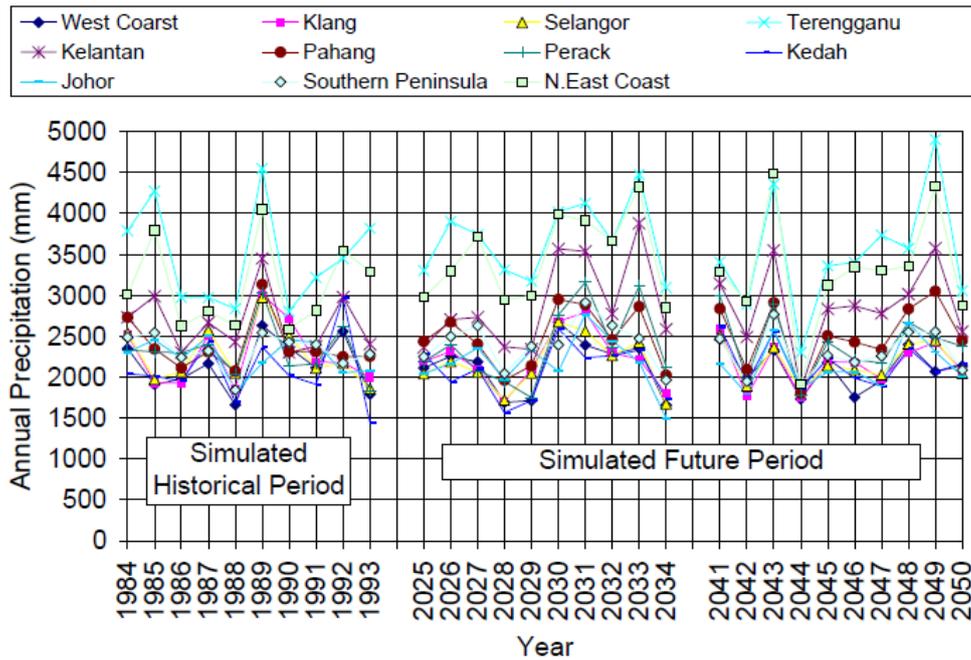


Figure 2: Projected annual precipitation for past (1984-1994) and future (2025-2034 and 2041-2050) periods of Peninsular Malaysia (MMD, 2009).

To face climate change impacts and issues in relation to sea level rise (SLR), a study has been done by NAHRIM (2006) to project SLR in the Malaysian coastline for the 21 century (2010 to 2100). To obtain SLR rate for Malaysian coastline, a linear trend analysis was performed with 25 years data from 30 gauging stations and 17 years (1993-2010) satellite altimetry data along Malaysian coastline with GCM projections. The result of the analysis assimilated with the output of 49 simulations of 7 Coupled Atmospheric-Oceanic General Circulation Model (AOCGM) to project SLR for Malaysian coastline (NAHRIM, 2006). The results showed that the projected SLR rate is expected to increase. SLR rate for the year 2100 is increasing 0.25 – 0.5 m with the maximum value occurring in the northeast and west coast of the peninsular Malaysia i.e. Kelantan and Kedah (NAHRIM, 2006; Awang and Radzi, 2013).

Another projection model that has been used by Malaysian Meteorological Department to study the climate change impact on hydrological processes is PRECIS (Providing Regional Climates for Impacts Studies). The model was developed by the Hadley Centre, UK Meteorological Office for long term climate projection and modelling. Meteorological lateral boundary conditions which used to run the RCM PRECIS derived from the coupled Hadley Centre HadCM3 AOGCM. The HadCM3 is established upon the SRES A1B scenario for initial baseline period of 1961-1990 and simulation was done for period of 2001-2099. Lateral boundary conditions for A2 and B2 scenarios were derived from HadAM3P AGCM and simulated using PRECIS for period of 2070-2100 (MMD, 2009). Horizontal resolution of PRECIS is 50 km that can be further downscaled to 25 km resolution and the model output is derived on daily time-step which is the most appropriate time-step used for climate change impact studies (MMD, 2009). The PRECIS outcome of future projection showed increasing temperature for Peninsular Malaysia around 2028, 2048, 2061 and 2079 with strong variability and significant increase recorded in 2028. The PRECIS result on future temperature for three decades (i.e.

2020 – 2029, 2050 – 2059 and 2090 – 2099) for end of the century, relative to 1990-1999 historical time period which is driven by the HadCM3 AOGCM, are displayed in Table 3 (MMD, 2009).

Table 3: Annual mean temperature changes (°C) relative to 1990-1999 periods (MMD, 2009)

Region	2020-2029	2050-2059	2090-2099
North-West PM	1.3	1.9	3.1
North-East PM	1.1	1.7	2.9
Central PM	1.5	2.0	3.2
Southern PM	1.4	1.9	3.2
East Sabah	1.0	1.7	2.8
West Sabah	1.2	1.9	3.0
East Sarawak	1.4	2.0	3.8
West Sarawak	1.2	2.0	3.4

The simulation result of PRECIS for rainfall showed an increase in peninsular Malaysia by the end of century. By looking at the simulated temperature, it demonstrated that major increase in projected annual temperature for 2028, 2048, 2061 and 2079 is related to major decrease in annual rainfall simulated for the same years. Decrease in maximum rainfall was projected for 2028, which associated to the maximum temperature increase in the same year during El-Nino events (MMD, 2009). Simulated annual rainfall has major periods of increase during 2030-2031, 2055-2058 and 2084-2091 which is significantly increased between 2030-2031 during La-Nino events. Projected result showed that annual rainfall will vary by -18.7% for 2020-2029 period, -6% for 2050-2059 and 4.1% for the period of 2090-2099 which is in good agreement with the result of ensemble of nine AOGCMs (NAHRIM, 2006). PRECIS results of simulated rainfall driven by the HadCM3 AOGCM are displayed in Table 4.

Table 4: Future annual rainfall changes (%) relative to 1990-1999 (MMD, 2009)

Region	2020-2029	2050-2059	2090-2099
North-West PM	-11.3	6.4	11.9
North-East PM	-18.7	-6.0	4.1
Central PM	-10.2	2.3	14.1
Southern PM	-14.6	-0.2	15.2
East Sabah	-17.5	-12.8	-3.6
West Sabah	-8.9	-1.2	0.3
East Sarawak	-9.1	-1.3	6.2
West Sarawak	-8.8	3.8	14.6

The above studies on the impact of climate change on water resources in Malaysia showed that there are significant highlights for more quantification of climate change impacts on various natural processes. It is also important to assess the vulnerability of a certain area or watershed for development and choosing suitable adaptation decisions. In this regard, according to a review by

Adnan (2010) demonstrated that the impact of climate change on extreme hydro-climatological phenomena such as droughts, floods and tropical cyclones in Southeast Asian countries have become more frequent and intense which can cause extensive loss and damages to human life. Extreme weather events such as cyclones, lightning and heavy precipitation are expected to change in intensity and pattern (Shamsudin and Neo 2011). There would be a substantial increase in monthly rainfall over the north east coastal region of Peninsular Malaysia, and a decrease in monthly rainfall on the west coast may also be expected (Tan and Pereira, 2013). In regions such as Kelantan, Terengganu and Pahang, the annual rainfall will be higher by 10% (Shamsudin and Neo 2011). On the other hand, other regions such as Selangor and Johor, the annual rainfall are expected to be lower by 5% (Shamsudin and Neo 2011). Higher rainfall will increase the risks of floods.

Jamalluddin (2013) stated that on climate change impacts in Malaysia, surface temperature increased 0.6°C to 1.2°C during the period 1969-2009 (MMD, 2009), 1-hour rainfall intensity increased 17% between 2000 and 2007 compared to 1970s (NAHRIM, 2006). Furthermore, according to satellite imagery data, sea level rise observed from 4.6 cm to 11.9 cm between the years 1993 to 2010 and massive floods occur in Johor Baru, Batu Pahat, Segamat, Kota Tinggi, Murar, Mersing and Kluang. It is also predicted that Malaysia will experience extreme weather conditions such as cyclones, lightning and unevenly distribution of rainfall which are probable to change in pattern and intensity in future (Shamsudin and Neo, 2011). Tan & Pereira, (2013) demonstrated that north east coastal region of Peninsular Malaysia will experience a significant increase in monthly rainfall and a decrease on the west coast may be expected by the end of the century. Meanwhile, western regions of the Sabah and Sarawak will experience more significant change in the annual rainfall (Tan & Pereira, (2013); Malaysian Second National Communication, 2012). Shamsudin and Neo (2011) indicated that in regions such as Terengganu, Pahang and Kelantan which are the main food-producing areas in Malaysia, 10% increase in annual rainfall simulated and consequently river flows estimated to rise 11%. The annual rainfall and streamflow are expected to decrease by 5% and 31%, respectively, in other regions such as Johor and Selangor which are the more populated states in the country. Increases in hydrological extreme events have been shown by simulated future streamflow of several catchments on the east coast of the peninsula when compared with their historical levels (Tan & Pereira, 2013). Additional costs would be incurred due to increase in flood frequency and severity to adjust future flood mitigation plans (Low & Jamaluddin, 2001; Tan & Pereira, 2013). Localised climate modelling projected that Malaysia may become warmer and the average temperature in the country will be rising by the middle and end of the twenty-first century (NAHRIM, 2006; Tan & Pereira, 2013). Variation of temperature has been projected for Malaysia up to 2099 (MMD, 2009). In Peninsular Malaysia, the maximum simulated increase of seasonal mean temperature will be in December, January and February (3.7 °C) and the minimum simulated increase will be in September, October and November (3.3 °C) by the end of the century (MMD, 2009). On the basis of three emission scenarios i.e. A2, A1B and B2 selected by Malaysian Metrological Department (MMD), the simulated range of the maximum temperature rise for Peninsular Malaysia is between 2.3 and 3.6 °C and for East Malaysia is between 2.4–3.7 °C (MMD, 2009; Al-Amin *et al.*, 2013). An increase of every 1°C temperature may result a 10% reduction in rice yields and rice ecosystem may be affected by prolonged drought conditions, which lead to high risk of national food security. On the other hand,

the oil palm plantation may be negatively influenced in two possible scenarios: rising temperatures that cause droughts, or increased rainfall that leads to flooding (Tan & Pereira 2013). On another study by conducted by Tayebiyani *et al.* (2016) on potential impacts of climate change on precipitation and temperature at Jor Dam lake in Malaysia. A statistical weather generator (LARS-WG) model was used to simulate future climate data for 50 years in the future. The data included of daily precipitation and maximum and minimum temperature based on SRES A1B, A2, and B1 scenarios simulated by the General Circulation Model's (GCMs). According to their results, it was expected that precipitation will be lower in most months. Moreover minimum and maximum temperatures will increase around 0.3-0.7 °C, which will greatly intensify reservoir surface evaporation. The simulated parameters significantly influenced water availability and elevation in the reservoir. Therefore, Malaysia must be prepared to adapt and mitigate the adverse impact of changing climate which varies spatially. Specifically, the local level (states and cities) needs appropriate actions because of the direct impact of climate change in this area therefore adaptation measures such as basic elements for reduction of disaster risk need to be developed accordingly used for nation sustainability (Tan & Pereira, 2013).

Impacts of Land Use and Land Cover Changes on Hydrological Processes

Land use/land cover changes represent another anthropogenic disturbance which can directly or indirectly influence hydrological behavior of watershed (Lahmer *et al.*, 2001). The hydrologic effects of land use change on water cycle have been controversial among researchers, but most of them focused on how hydrologic regime of a watershed will be affected by land use/land cover changes. For example, Guo *et al.* (2008) indicated that streamflow is a helpful index of hydrologic responses to land use/land cover and vulnerability to flood has been further elevated by deforestation. The impact of deforestation on the water balance was studied by Kleinhans (2004) in a small tropical catchment in Central Sulawesi, Indonesia. He concluded that an increase of the low water discharge and significant increase of the peak flow could be expected by deforestation. He suggested that in addition to drying condition, the wetting condition must be considered for a comprehensive analysis of the impact of land use change on water resources. Li *et al* (2009) stated that the runoff would be decreased when grassland converted to woodland, and conversion of woodland into urban land would increase runoff. Impacts of land use change on hydrologic responses were studied by Mao and Cherkauer (2009) in the Great Lakes region, USA. They found that simulated changes of land use varied spatially and seasonally. Conversion of deciduous forest to agriculture crop land in the central areas can result a decrease of 5–15% in evapotranspiration (ET) and 10–30% increase in total runoff. The northern areas experienced conversion of evergreen forest to deciduous forest, which caused decreases of 5–10% in ET and increase of 20–40% in total runoff. By conversion from grasslands to agriculture, ET increased 10–15% and total runoff decrease 20–30% in the southern and western parts of the study domain. In the Loess Plateau of China, Liu *et al* (2010) showed that in forested basin, water yields were 1.7–3 times higher and surface runoff was 40–60% lower in this area. Rainforests are the main land cover in tropical regions and high amount of intense rainfall is the key climatic characteristic of such regions. If tropical rainforest is converted to pasture or other land uses water balance of the watershed will be significantly affected. Bruijnzeel (2004) stated that when the forest land use is converted to agricultural land surface runoff and streamflow significantly increase. The

impact of reforestation on streamflow was studied by Trimble and Weirich (1987) in the southern United State. The result of their study indicated that by an increase of 10–28% of forest cover the annual streamflow reduced 4–21%. The same studies by Chen and Pei (2000) in the Changjiang River basin showed that reforestation would decrease annual streamflow and the water yield would be 21.8–32.8% greater in forested catchments rather than non-forested catchments. Plant growth that inherently is associated with hydrological cycle would be affected directly by elevated atmospheric CO₂ concentration through increase in leaf area and decrease in stomatal conductance (Eckhardt and Ulbrich, 2003; Ficklin *et al.*, 2009). Evapotranspiration (ET) would be reduced by any decrease in stomatal conductance, whereas ET will be increased by increased leaf area (Kergoat *et al.*, 2002). Many studies have pointed out that combined effects from elevated CO₂ concentrations may lessen ET, resulting in increased runoff (Gedney *et al.*, 2006; Leipprand and Gerten, 2006; Betts *et al.*, 2007; Wu *et al.*, 2012).

Land Use Change in Malaysia

In tropical region where rainforest is the natural land cover, land use planner's decisions play pivotal role in mitigating the adverse effects of climate change. It is important that land use decision makers have some knowledge about the strong links between land cover change and climate change (Abdul Kader, *et al.*, 2012). Although flood is a natural phenomenon, but there is no doubt that human activities particularly through land use conversion have great impacts on flooding conditions. In other words, climate change impacts can be intensified by environmental changes. But, because of the complex interaction of the processes involved in hydrological cycle, the magnitude and intensity of environmental changes impacts on runoff generation and flood is still highly uncertain (Niehoff, 2002). It has been found that forest can reduce up to 50% of flood by way of controlling overland flow. Any changes of land use from forest cover to other land uses can increase flood occurrence, flash flood frequency and runoff volume (Bronstert *et al.*, 2002; Xiaoming *et al.*, 2007; Wang *et al.*, 2008).

Agriculture is the main land use in Southeast Asia (ADB, 2009). It is projected that agriculture land area will be increased through decrease in natural forest land in future. The conversion of non-agricultural land to agricultural land especially forest cover to rubber, oil palm, coffee plantations and paddy fields led to decrease of natural forest land use about 27% from 1990 to 2005 in Southeast Asia. It is also reported that about 75% of the world's total natural rubber plantation is planted by Thailand, Indonesia and Malaysia. According to the Forest Research Institute Malaysia (FRIM), the forest cover in Malaysia has been decreasing since 1990 and most of the primary forest cut down for logging purposes and transformed into agricultural land including oil palm, rubber, rice and etc. The trend has been increasing by the year 2020, towards the direction of a developed country which is the target time for Malaysia to be fully developed (WECAM, 2013). Moreover, Malaysian Second National Communication in 2012 reported that 56% of total land area of Malaysia was forest in 2000, but the percent of forest land decreased to 55% in 2007. In that regard, total population was increased from 23.5 million in 2000 to 27.2 million in 2007. Urbanisation rate is growing and varies from state to state. It increased from 62% in 2000 to 63% in 2005 and increase to 63.8% in 2010 (Malaysian Second National Communication (NC2), 2012). It should be noted that Malaysia experiencing rapid

development. Land use/land cover has undergone major changes in recent decades in large parts of Malaysia (WECAM, 2013). Mustafa (2000) showed that due to rapid development in Malaysia, land use/land cover experienced a lot of changes through urbanization, deforestation and other land use activities. All these activities make change in the soil physical properties such as infiltration rate and moisture content by changing the soil surface from pervious to impervious surface. Consequently, seasonal and annual distribution of streamflow in the basins will alter.

In Malaysia, Othman *et al.* (2009) analysed and modelled land use change and deforestation in Klang Valley river basins for the period of 1990 -2001 and projected land use change up to 2020. Results showed that multiple spatial and temporal variations occurred in the study area. The total area of the agriculture and forest lands decreased by 17.3% (11,598 ha) and 9.5% (4,303 ha), respectively. Urban area increased about 18,860 ha. Matrix of land use conversion showed that the increase of urban area, were at the exchange of agriculture and forest lands. Projection for the year 2020 under scenario of “if the Permanent Forest Reserve is strictly protected” showed that forest conversion will be decreased to 22%; otherwise, the land will be heavily deforested at 50%. Balamurugan (1999) in Kinabatangan River basin found that while there has been no significant change in rainfall patterns and the frequency of floods, the magnitude of floods has been changed. He demonstrated that the major reasons for this issue are the impacts of logging and land clearing for oil palm cultivation in this basin. This transformation reduced infiltration rate, more compaction, and subsequently extensive surface flow. Gasim *et al.* (2009) studied the impacts of land use change on variations in climatic variables in Cameron Highlands. They analyzed changes of velocity and discharge of catchment in two sampling period (dry season and rainy season). Their results showed that hydrologic responses of catchment has influenced by climate pattern. Velocity and discharge range from 0.33 m/s and 0.079 m³/s to 0.90 m/s and 2.619 m³/s, during dry season and from 0.38 m/s and 0.096 m³/s to 1.44 m/s and 2.709 m³/s during the rainy season. Also it was found that the flow data of river Bertam and Lemoi increase synchronizely by increase of rainfall pattern from 1970 to 2005 and from 1985 to 1995. Memarian *et al.* (2012) conducted a study in Langat river basin as one of the developed basins in Malaysia. The impacts of land use/cover changes on runoff and sediment load were evaluated. The result of LUCC impacts analysis showed that direct runoff and sediment discharge increased as consequences of unmanaged agricultural activities and expansion of urban area. The outcomes also were supported by hydrological trend analyses, the NDVI and landscape metrics. In another study in the Tekam River Experimental Basin, it was showed that during the land clearing activities, the sediment load into the river was 4 times greater in crop establishment phase. It was much greater than natural forest cover (WECAM, 2013). It should be highlighted that in the study of the impacts of a changed land use on the regional and local hydrological cycle, analysis and development of extreme scenarios is an important step, as it cover the possible variety of hydrologic response in the watershed and determine the sensitivity limits of the model used. The outcome of these sensitivity studies demonstrate that the methodology is appropriate even the impacts of land use changes limited to small fractional areas. In addition, the integration of GIS and land use maps derived from remote sensing data with different land use change analysis model, to simulate the spatial and temporal changes of land use effectively, is highly recommended in different literatures (Li *et al.*, 2010; Wang *et al.*, 2008; Yang *et al.*, 2014; Memarian *et al.*, 2012).

Combined Impacts of Climate and Land Use Changes

Interaction of climate and land surface variables is important in the functioning of the hydrological processes. Climate and land use are two main driving forces directly influencing the hydrology and water availability at global, regional, and local scales (Li *et al.*, 2009; Praskievicz and Chang, 2009). Vitousek (1994) indicated that ‘three of the well-documented global changes are increasing concentrations of carbon dioxide in the atmosphere; alterations in the biochemistry of the global nitrogen cycle; and on-going land-use/land-cover change’. The impacts of land use on hydrological variables are interlinked with impacts of climate change (Mango *et al.*, 2011). Unsustainable land use conversion can worsen the negative impact of climate change as consequences of natural resources loss and increased pollution (WECAM, 2013). For example, land use change can change flood severity, frequency, base flow, and annual mean discharge, whereas climate variability can change the flow volume, routing time, and peak flow (Prowse *et al.*, 2006; Li *et al.*, 2009). Analysis of the combining effects of both climate and land use/land cover change can generate more results for water resources management in a specific region or watershed. On the other hand, various factors affect the relationships of hydrological variability and lack of understanding of involved mechanism reduces our ability to differentiate the effects of climate and land use change (Li *et al.*, 2009). In that regards, the separation of their effects is of highest priority for water resources management. Several researches have been conducted to distinguish and quantify the impacts of combination of climate and land use changes on runoff generation (Lahmer, 2001; Crooks and Davies, 2001; Prudhomme *et al.*, 2002; Bronstert, 2003; Chen and Pei, 2000; Ficklin *et al.*, 2009; Githui, *et al.*, 2012; Zhang, *et al.*, 2012). There is a general consensus in results of these studies that the effects of land use/land cover on streamflow vary due to complexity of such impacts in different climatic conditions. Praskievicz and Chang (2009) stated that in modelling the combined impacts of land use and climate changes, whether change in each driving force is more significant or not depends on scenario assumptions and watershed characteristics, each type of change may amplify or ameliorate the effects of the other. In China, Zhang *et al.* (2012) studied the impacts of climate change and human activities on runoff in Huifa River basin. The results indicated that both combined changes of climate and human actions are responsible for the decrease of observed runoff depending on temperature, precipitation and land cover changes. Wilk and Hughes (2002) applied a hydrological rainfall-runoff model to assess the land use and climate change impacts on water resource availability in the Upper Bhavani catchment, India. They tested a set of climate and land use change scenarios along with hydrological model. The simulated result showed that by converting savanna and forest to agriculture land, the mean annual runoff increased by 19%. The mean annual runoff decreased 35% and 6% after conversion of forest to commercial forest and tea plantation, respectively. Combined effects of land use change and climate change on hydrological responses of Wolf Bay watershed were analysed by Wang *et al.* (2013). Land use and climate change effect were considered simultaneously. Results indicate that if future loadings are expected to increase/decrease under either climate or land use change scenarios, combined change scenario intensify that trend synergistically. On the other hand, if their effects are in opposite directions, then the combined change has an offsetting effect. Legesse *et al.* (2003) indicated that in regions with humid climate condition even some extreme land use conversion only may lead in comparatively small impacts on regional water balance. This statement is supported by Lahmer *et al.* (2001). In China, Li *et al.* (2012) demonstrated that hydrological regime of the Heihe catchment

varied significantly under the integrated effects of climate variability and land use change. They concluded that different factors had different influences on the hydrological condition of a geographic region. In affecting surface hydrology, climate variation played a more significant role than land use change in this river basin. The study reported that both factors (land use change and climate variability) decreased runoff and soil water contents. According to Tollan (2002) and Fohrer *et al.* (2001), land use and climate affect the hydrological conditions in different ways at different spatial and temporal scales, depending on prevailing variable and the quantity of it. For instance in the arid climate, the effect of land use change is more apparent on river flow where the low flow is more sensitive to land use changes. In spatial manner, land use and climate variations play important role on peak flows in small scales such as hillslope or fields, nevertheless annual water balance would be affected relatively small at large scales. In a temporal manner, climate and land use changes impact the peak flow in short period of time while mean annual flow could be affected in long period of time. To sum up, the impact of climate change should be separated while the hydrological impact of land use/land cover changes is assessed. The point is that climate change affects hydrological regime of a region through increase or decrease in rainfall and temperature. Changes in climate parameters affect hydrological variables in the watershed. It might lead to increase or decrease in rainfall and subsequently flood generation. In the case of tropical regions such as Langat river basin, 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. On the other hand, the hydrology of a catchment varies slightly when the amount of the land use change is relatively small. Therefore, evaluating the impacts of changes on hydrological processes and ecosystems deserves more attention when the extent of changes in land use patterns is relatively significant and large (Li *et al.*, 2012). It could be noted that in comparison with climate change, land use has very large impact on the functioning of environmental and hydrological variables such as streamflow rate and severity and frequency of flood. Land use conversion can influence many other hydrological processes including infiltration, groundwater recharge processes, base flow, runoff and annual mean discharge plus location of watershed, scale of it, vegetation types and species should be considered. It means that land use patterns have diverse effects on hydrological processes (He *et al.*, 2008). Since spatial scale of climate change is inherently large, land cover change can have substantially larger impacts at smaller scales. Therefore, the magnitude of the impact of climate and land use on the hydrological components changes may vary spatially in a region (Cuo *et al.*, 2011).

Hydrological Modelling

The effects of changing in climatic variables and land surface components and their interactions are often dynamic, nonlinear, and complex. To study and assess such complex integrated systems, hydrological modelling through appropriate hydrological model is essentially needed to simulate

phenomena and processes involved in impact studies (Li *et al.*, 2010). Hydrological models are powerful tool to simulate and quantify the potential impacts of atmospheric and land surface changes with hypothetical sensitivity scenarios or future projections derived from models in a specific region. They use projected future climatic variables and evaluate variables in hydrological and environmental interactions such as runoff, ground water, soil moisture and evapotranspiration (He *et al.*, 2008; Wu *et al.*, 2012). To calculate the impact of climate change on hydrological behaviour of a watershed, two steps need to be taken. First, the simulation of the changes of climatic variables such as precipitation and temperature which are due to alterations in the atmosphere; second step is the estimation of potential stream flow variation using projected climate variables as inputs for the hydrological model (Liu *et al.*, 2011).

Many hydrological models have been developed such as SWAT (Soil and Water Assessment Tool), WaSiM (Water Flow and Balance Simulation Model), HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System), HBV (Hydrologiska Byråns Vattenbalansavdelning), kinematic runoff and erosion model (KINEROS), Distributed Hydrology-Soil-Vegetation Model (DHSVM), TOPMODEL, ANSWERS, MIKE BASIN, MIKE-SHE, MIKE 11, AGNPS, NAM and WEPPMIKE SHE and a lot more. These models are used to simulate the responses of watersheds to different land use and climate changes scenarios. Ficklin *et al.* (2009) noted that hydrological models simulate hydrological process by providing a link between climatic variables and streamflow. Combination of hydrologic models with climate change scenarios which is produced by GCMs generates likely scenarios of climate change impacts on water resources. They emphasized on confidence of the model result that varies highly depending on the structure and technique of the climate scenario and the hydrologic model. Schellekens (2000) pointed out that the accuracy of a model output strongly depends on the good understanding of the processes involved in hydrological aspects within a catchment. He indicated that despite of uncertainties in hydrological models, there is no other option to simulate the spatial variability of the water balance for better understanding of hydrological responses to climate and land use change (Leemhuis, 2005). In other words, distributed hydrological models are powerful tools for understanding such complex issues that they connect parameters of the models directly to physically observable land surface physical processes. But they need extensive quality data and hard to configure and also time consuming in accordance with simulation and calibration. While semi-distributed models, are easy to setup and require shorter time relatively. That is the reason why climate change scenarios are wildly used along with integrating hydrological models. Table 5 shows comparison between some of these models that is used in climate studies.

Table 5: comparison between hydrological models

Model	WaSiM-ETH	HSPF	MIKE11/SHE	SWAT	DHSVM	HEC-HMS
Spatial representation	Distributed	Lumped	Distributed	Semi distributed	Distributed	Semi distributed
Advantages	Can handle glacial melt, groundwater, lakes, and reservoirs	Simple or complex setup Flexible time scale Combined upland and channel processes	Long term and single event simulation Detailed prediction Interaction between units Simple or complex setup Flexible time scale Easy to link with other mike models	User friendly Continue developments Wide range of application Computationally efficient Suitable for large, complex watersheds Combined upland and channel processes	Powerful for a wide range of watershed hydrology applications	User friendly Less demanding on input data Compatible with other HEC-programs Allows for discharge output values as well as all internal state variables at user defined grid locations
Disadvantages	Complex model; no testing to date in forest management context	Lumped Extensive calibration No single event predictions	Data intensive Computationally intensive Numerical instabilities High computational time,	Numerous parameters Subunits not linked No single event predictions	Difficult to use; functionality may be limited to mountainous watersheds; high model parameterization requirements	Cannot model branching or looping stream networks Cannot model backwater in the stream network

Muttiah and Wurbs (2002) studied the climate change impacts on water supply capabilities in the San Jacinto River Basin, Texas. Output of a general circulation model (GCM) was used with SWAT hydrological model along with a river/reservoir system management model (WRAP). The result showed that streamflow had great seasonal and random variations. Seasonal differences of streamflow were greater under future climate change scenarios. Long-term average flow will also increase and a wide range of variations is expected in extremes for future. Lorup *et al.* (1998) applied a combination of statistical tests and hydrological modelling in order to analyze the effects of land use changes and climate variations on runoff. The methodology of the study divided into three categories i.e. paired catchments approach, time series analysis (statistical method) and hydrological modelling. The study concluded that the hydrological model was in general capable to simulate the process occurred in the catchment very well. Additionally, the hydrological model in combination with the power of the statistical tests provides a way to account for the climate change effects.

Sennikovs and Bethers (2009) studied the impact of climate change on the future flow regime of the rivers in Latvia. They used two-way ensemble of seven RCMs and three hydrological models

including MIKE SHE, MIKE BASIN and FIBASIN for prediction and calculating time series in climatic data. The results indicated a decrease in annual streamflow and snowmelt flood with increase of winter runoff which varies spatially. The study concluded that uncertainty in climate change impacts studies can be reduced significantly by choosing best climate and hydrological models. Viney *et al.* (2009) assessed the hydrological impacts of land use change by hydrological ensemble modelling in the Dill catchment, Germany. The study used ensemble of 10 hydrological models to improve prediction accuracy of several projected land use changes and to reduce the uncertainty in model prediction. Results showed that the presentation of the models is acceptable during calibration and validation periods. They concluded that calibration method was different from one model to another model, but the semi-distributed models such as SWAT perform best during both calibration and validation periods. Hosseini *et al.* (2011) used SUFI-2, which is linked with SWAT and is known as SWAT-CUP, for calibration and validation of SWAT in Taleghan catchment, Iran. They concluded that SWAT model coupled with SUFI-2 program is one of the best fitted models that can be used by water resources managers for making best decision in sustainable planning of future land and water development. Li *et al.* (2009) studied the impacts of land use and climate change on the hydrological components of agricultural watershed using SWAT model in the Loess Plateau, China. The study reported that SWAT is a powerful tool to simulate and show the hydrological responses of the catchment to any environmental changes. This finding is in consistent with the results of Li *et al.* (2012) in the Loess Plateau of China. Neitsch *et al.* (2005) demonstrated that the SWAT model is designed to simulate long term impacts of climate change, land use conversion and land management practices on water resources and more significantly it is suitable for ungauged river basins with limited data.

It could be concluded that hydrological models are the best tools to show the interactions between climate, environment, human activities and water resources. They provide basis and detail information for decision makers and managers to quantify and conceptualize the process involved. Among the all hydrological models, the important and essential applications of distributed and semi-distributed hydrological models seem to be the best models because they link parameters involved in the models directly to physically observable land surface characteristics (Schellekens, 2000; Jothityangkoon *et al.*, 2001; Legesse *et al.*, 2003; Li *et al.*, 2012).

Conclusion

During the past decades, a great number of works on environmental changes due to anthropogenic factors have been carried out from different viewpoints. Various investigators have studied the impacts of climate and land use changes on water resources and hydrological processes in North America and Northern Europe. However, up-to-date 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 and yet poorly understood.

Furthermore, studies in the vast majority of tropical catchments have been conducted at the micro spatial (< 10 km²) and time (< 5 years) scale and not in watershed scale. Considering the increasing stress on water resources in tropical developing countries and 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. Therefore 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 such as Malaysia. 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 coupled with other sources of data such as remotely sensed data (e.g. for rainfall), high spatial and temporal streamflow data and ground water data can be used to simulate more proper results. In the end, although it is well known that climate and land use changes interact, but both factors were usually studied independently. Consequently, it can be recommended that combined effects of climatic and land use conditions on hydrological processes to be studied on different part of Malaysia rather than their individual impacts in future studies.

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