International Journal of the Physical Sciences Vol. 6(32), pp. 7390 - 7409, 2 December, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.1036
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Analysis of hydrological processes of Langat River sub basins at Lui and Dengkil

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Accepted 14 October, 2011

Land use changes have seriously impacted the hydrological regimes. This study considered both the upstream and downstream areas of Langat River namely the Lui and Dengkil sub basins, respectively. The important parameters selected for the study were river flowrate, precipitation distribution, and the baseflow (BF) estimation. For the Lui sub basin, the daily flowrate data obtained from 1972 to 2009 (35 years) were used, while for Dengkil sub basin, the data obtained from 1965 to 2009 (44 years) were used. The overall result showed that the monthly mean flowrate of April and November was higher as compared to other months, while the lowest mean flowrate occurred in February and August. Both sub basins showed upward trends in yearly mean flowrate throughout the study period. To obtain a clearer picture on the annual mean flowrate distribution of the two basins, Boxplot variables were plotted. The estimation of the BF was based on the separation method of the United Kingdom Institute of Hydrology (UKIH) smooth minima. Subsequently, BF indexes (BFI) for various years were determined. The Lui sub-basin showed almost constant annual BFI, while Dengkil sub basin exhibited downward trend. This indicated that the contribution of the BF on total flow of the Dengkil sub basin reduced over the years. The land disturbances and the increase in the size of imperviousness has certainly reduced the opportunity for infiltration of rainwater into the ground and has most probably decreased the quantum of ground water to recharge the river system during intervening periods between rainfall events. Analysis on the trend of the annual 7-day low flow, however, seems to show increasing trend for both sub basins. This seems to contradict with the decreasing trend of BF, in particular those of Dengkil sub-basin. Finally, this study also included analysis of rainfall based on the 20 to 54 years of available data of the fourteen rain gauging stations within the study areas. The result indicated that the contribution of the total monsoon rainfall in both Lui and Dengkil sub-basins was above 77% of total rainfall received, which is similar to the average monsoon rainfall (81%) of Peninsular Malaysia. The rainfall was classified based on 5 classes as follows: 0 mm/day (no rainfall), 1 to 10 mm/day (light), 11 to 30 mm/day (moderate), 31 to 60 mm/day (heavy) and >60mm/day (very heavy).

Key words: Lui and Dengkil sub-basin, landuse change, daily flowrate, rainfall classification, BF separation, UKIH; BF index, annual 7-day lowflow.

INTRODUCTION

Modification of land surfaces during urbanization typically will increase the impervious surfaces such as roofs and roads, construction of hydraulically efficient drainage systems, compaction of soils, and modifications to vegetation. The term urbanization once conveyed an image of a city’s radial expansion into its rural surroundings. Natural waterways end up being used as drainage channels, and are frequently lined with rocks or concrete to move water more quickly and prevent erosion. With natural ground-cover, 25% of rain infiltrates into the aquifer and only 10% ends up as runoff (UNEP, 1994). As impervious coverage increases, the volume and velocity of surface

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runoff increase with a corresponding decrease in infiltration. In addition, these land modification affects the environment in terms of biodiversity (Löfvenhaft et al., 2002), habitat suitability, water balance and water regulation, microclimate or photosynthesis (Hirzel et al., 2002). The land cover changes brought by human activities tend to occur incrementally; however, communities often do not realize the extent of their development and the potential changes in their environment.

Researches on possible effects of urban areas on enhancement of rainfall are done less if compared on the study of urban impacts on surface runoff and stream flow. Sorman (1977) has indicated that the frequency of storm occurrences from the year of urbanization and the areal depth of rainfall on the urban area increases with increase of storm depth. Another study by Jauregui and Romales (1996) has shown that the land use has some effects on the precipitation pattern. The results indicate that the frequency of intense (> 20 mm h^{-1}) rain showers has significantly increased in recent decades observed at Tacubaya (urban) station from July-September 1939-1989. In respect of the rainfall pattern, more frequent now in the afternoon and in the evening during recent years when the capital city initiated its rapid development. This seems to be linked to the accelerated increase in the urban sprawl of the capital city which in turn has induced an intensification of the heat island effect. Using rainfall-measuring satellite, NASA (2002) has for the first time confirmed that urban heat-islands (UHI) create more summer rain over downwind of major cities, including Atlanta, Dallas, San Antonio and Nashville. On average, maximum rainfall rates in downwind regions often exceeded the maximum values in upwind regions by 48 - 116%.

An UHI is a climatic phenomenon in which urban areas have higher air temperature than their rural surroundings as a result of anthropogenic modifications of land surfaces, significant energy use and its consequent generation of waste heat (Shahmohamadi et al., 2010). To further understand the origins of the UHI, it is instructive to examine a surface heat budget equation (Shepherd, 2005):

$$Q_{SW} + Q_{LW} + Q_{SH} + Q_{LE} + Q_G + Q_A = 0 \tag{1}$$

In Equation (1), the terms are Q_{SW} (net shortwave irradiance) - Shortwave radiance from the sun is absorbed only during the daytime, Q_{LW} (net longwave irradiance) - Longwave radiance emitted by the Earth system is lost all the time, Q_{SH} (surface sensible heat flux), Q_{LE} (latent turbulent heat flux), Q_A (anthropogenic heat input), and Q_G (ground heat conduction). The difference in surface properties of urban and rural areas leads to the differences in the thermal fluxes in (1). Major causes of the heat-island effect include: evaporation (or latent heat cooling) by plants is a major cooling process for the land surface and the atmosphere, replacing the forest by buildings and roads reduces this cooling effect in urban areas (Lin et al., 2008) As sensible heat is transferred to the air, the temperature of the air in urban areas tends to be 2–10°C higher than surrounding nonurban areas (Shepherd, 2005). In addition, preferential heating in the city compared to the surrounding area increases convection over the city that traps heat as well as pollutants inside the urban area (Oke, 1982; Arnfield, 2003).

Takahashi (2003) states that contribution of large daily rainfall classes (high-order classes) to total rainfall amount increased from 1880's to 1940's, and then decreases except around 1960. Contribution of high-order classes, however, changed to an increase in around 1980. The possibility of urban influence is suggested since the recent increasing tendency of rainfall amount of high-order classes is more obvious in the densely populated urban areas, Tokyo. Likewise, in Taiwan, sensitivity investigations show that the effects are the surrounding areas and were more pronounced not only the precipitation over downstream along with the urban size increase. The sensible heat flux is nearly 500 Wm^{-2} around noon-time. It is about a factor of 3 more than the non-urban case (Lin et al., 2008).

On the other hand, the urbanization has greatly affected the hydrology of an area by changing groundwater recharge and discharge. Under normal hydrologic regime, the groundwater discharges sustain flows in stream over extended periods between rainfall [baseflow (BF)] and minimum flow in river during dry periods. Zhang and Schilling (2006) indicates that conversion of perennial vegetation to seasonal row crops and accompanying agricultural activities that occurred in the Mississippi River (MR) basin since 1940s decreased evapotranspiration and surface runoff, and increased groundwater recharge, BF, and thus streamflow. Gebert and Krug (1996) mentioned that improved agricultural land management practices are likely important factors responsible for increased BFs and decreased storm flows (SW). These occur due to the practices such as terraces, conservation tillage, and contour cropping that decrease soil erosion during storm events and at the same time it serves to increase water infiltration on row croplands since runoff is slowed or captured by the conservation practices. In turn, greater infiltration would increase groundwater levels and contribute to higher BF in streams.

For the catchment that has changed into urban, low flows have the tendency to decrease due to the effects of urban impervious surfaces upon direct runoff, infiltration and evapotranspiration (Ferguson and Suckling, 1990). In facts, the study of (Simmons and Reynolds, 1982) has shown that urbanization has greatly affected the BF of the study area in Long Island, New York. Before urbanization, roughly 95% of total annual stream flow on Long

Island was BF while after urbanization the increase of impervious surface area and off site discharge of domestic wastewater have reduced BF to 20% of total stream flow. In an adjacent urbanized but unsewered area in southeastern Nassau County, base flow has decreased to 84% of total annual stream flow. Gilbert and Krug (1996) examined annual flood peak and the annual seven-day low flow records at 12 Wisconsin stream gauging stations and found that annual low flows increased and annual flood peaks decreased in many agriculture-dominated watersheds between about 1930 and 1991.

In this context, a motivation for the hydrologists to study the hydrological components is raised (Othman and Naseri, 2011; Solaimani, 2011). Several researches have been developed for rainfall forecasting (El-Shafie et al., 2011a), rainfall-runoff modeling (El-Shafie et al., 2011b, c). On the other hand, base-flow is considered as one of the important hydrological component, several studies have been performed to estimate the values of this component (Citiroglu and Baysa, 2011).

For the Land-use and Land-cover (LULC) in Malaysia, particularly in Klang-Langat basin, urban expansion is recorded up to 150% from 1989 – 1999 periods. In 1989, urban landuse occupied 380.5 km^2. However, the area was almost double in 1996 with a total coverage of 631.9 km^2 (APN, 2002). Langat River basin is one of the most important watersheds which supply water to a third of the state of Selangor and Federal Territory including Kuala Lumpur, Petaling Jaya, Shah Alam, Klang as well as domestic and industries usage in the Langat River basin itself. The Langat basin is chosen as one of the major areas for economic growth in Selangor as Kuala Lumpur International Airport, West Port at Klang, the Multimedia Super Corridor (MSC) and Putrajaya, all of which are situated in the basin (Juahir et al., 2010). In describing the dynamic of landuse changes within the Langat River catchments, APN (2002) reported a steady decline on the agricultural landuse especially rubber, coconut and horticulture. The decline of rubber landuse of up to 27% was experienced from 1989-1999, while oil palm underwent a slight decrease in coverage but continued showing dominance in this region. Oil palm landuse reached its peak in 1995 and showed trend of stability at 1995 with the area of 760 km^2 by the conversion of rubber land.

In facts, the study of UNDP-ICBP-HDP (2001) in Othman Jaafar 2008, the landuse changes in Klang River and Langat River basin from the year of 1985, 1990 and 1994 has depicted the changes of the trends of landcover especially decreasing the forest area and the increase in both agricultural and urbanization of the area. The study also shows that the process of development is quite rapid in Klang River and Langan River basin where 28% of the forest area has cut-off for development where 21% of the total is used for the agricultural purpose. Unfortunately, the landuse change has greatly impacted the hydrological regimes particularly for the upstream area-Lui River sub-basin and downstream area-Langat-Dengkil River sub-basin. One of the factor that always relates to the incidence of disturbance on water supply is the decrease of water resources that may result from the changes of land cover within water catchment, especially when it involves the exploitation of forest into agricultural purposes as well as the urbanization (Othman, 2008).

The problem statement of the research is LULC changes as aforementioned above has greatly impacted on the hydrological regimes upstream area-Lui River sub-basin and downstream area-Langat-Dengkil River sub-basin in terms of river flowrate precipitation distribution, and groundwater recharge rate where groundwater has been identified as an important source for domestic and industrial usage. Therefore, it is significant to understand the landuse changes and population growth on groundwater availability and stability in recharging the river at Langat River basin especially during drought. Objectives of this study include: (i) to examine the trends of rainfall and the flowrate in the study area of Langat sub-basin; (ii) to evaluate the extent of BF regimes changes that affect BF index (BFI) and annual 7-day average low flow as a result of land cover change in both Lui and Dengkil sub-basin; (iii) to study and establish the long-term hydrological trend responses of the water catchments (Lui and Dengkil sub-basin) particularly the LULC changes via river discharge rate analysis, precipitation distribution study and yearly BFI time series.

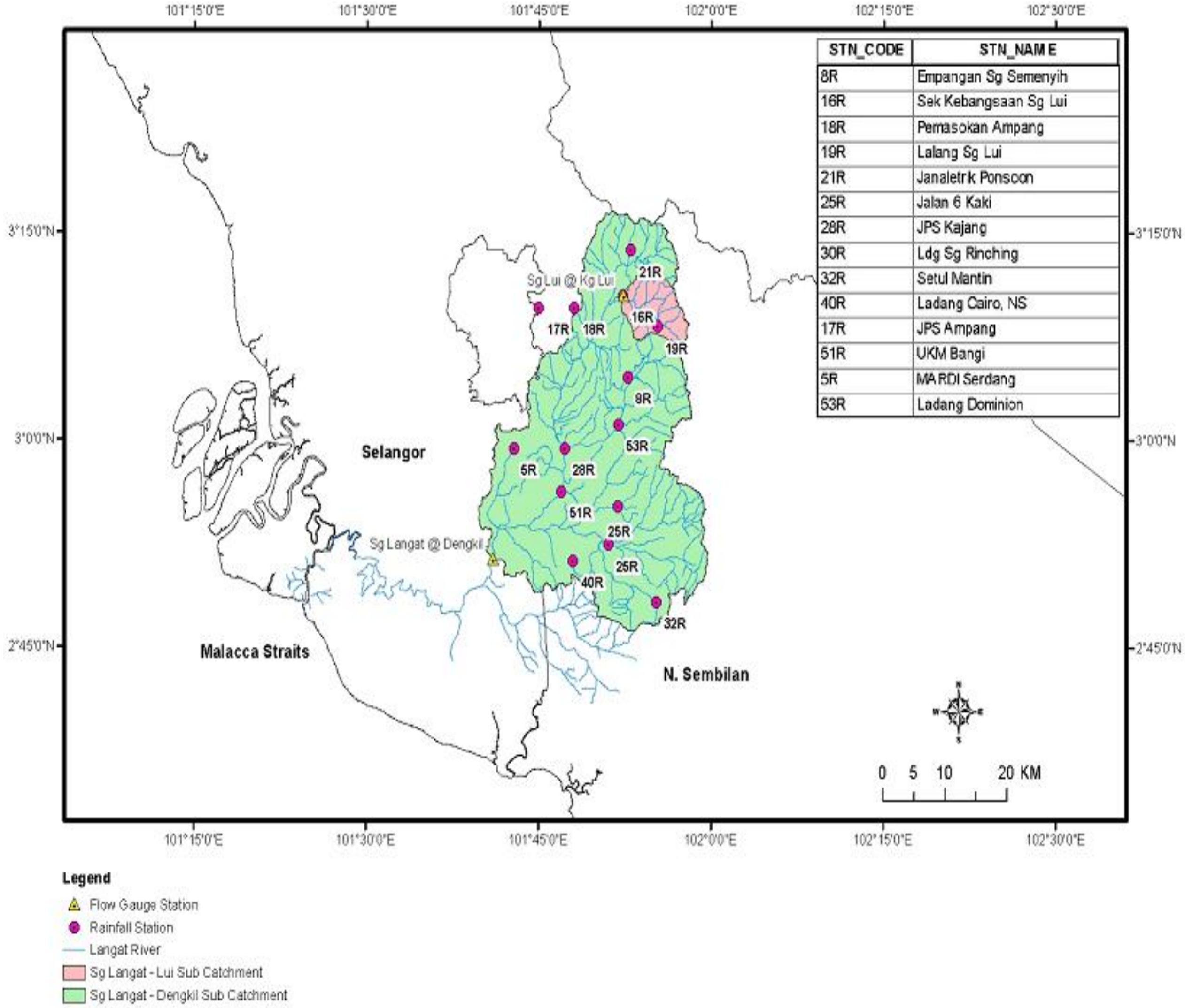
METHODOLOGY

Monthly mean and yearly mean trend analysis were used for the rainfall and flowrate data. In addition, simple regression and descriptive analysis were also used in both data. Prior to the determination of BFI, the BF of the sub basins were established using separation technique developed by UKIH that separate BF from the total streamflow hydrograph. The details of the method are described in the following study.

Study area

Langat basin is lies within the longitude of 101°17′E to 101°55′E and latitudes of 2°40′N to 3°17′N. Langat River starts its flows from the main range (Banjaran Titiwangsa), east of Selangor State through four districts in Selangor State consisting: Hulu Langat District, Kuala Langat District, part of Sepang and Petaling District as well as some part of the western region of Seremban in state of Negeri Sembilan. The main tributary of Langat River flows about 182 km from the main range (Banjaran Titiwangsa), in the northeast of Hulu Langat District, in south-southwesterly direction before draining into the Straits of Malacca.

Figure 1 shows the flowrate and rainfall gauging stations within the study area. There are four flowrate gauging stations in the Langat River basin located at Kg Lui, Kajang, Rinching and Dengkil. For the purpose of the research, only two out of four major sub-basins of Langat River were chosen, namely Lui and Dengkil sub-basin respectively. The Lui gauging station which is located at



STN_CODE	STN_NAME
8R	Empangan Sg Semenyih
16R	Sek Kebangsaan Sg Lui
18R	Pemasokan Ampang
19R	Lalang Sg Lui
21R	Janaletrik Ponsoon
25R	Jalan 6 Kaki
28R	JPS Kajang
30R	Ldg Sg Rinching
32R	Setul Mantin
40R	Ladang Cairo, NS
17R	JPS Ampang
51R	UKM Bangi
5R	MARDI Serdang
53R	Ladang Dominion

Figure 1. Rainfall and flow gauging station in the study area.

Table 1. Gauging stations in Langat River sub-basin.

Gauging stations	Location coordinate		Area (km^2)	Observed data
Station 3118445: Kg Lui	03°10′25″N	101°52′20″E	68.4	1972-2009
Station 2816441: Dengkil	02°51′20″N	101°40′55″E	1,251.4	1965-2009

latitude 03°10′25″N and longitude 101°52′20″E represent the upstream of Langat River. The Dengkil gauging station representing the lower reaches of Langat River is located at latitude 02°51′20″N and longitude 101°40′55″E. Table 1 showed the details of the gauging stations of the study area.

Both gauging stations are managed by Department of Irrigation and Drainage (DID); since 1960 for Dengkil and 1965 for Lui. The flows are continuously measured and are recorded as daily mean flowrate in the unit of (m^3/s). The two type of analysis carried out in this study were:

Monthly mean flowrate

Monthly mean flowrate in m^3/s for existing data is analysed. The graph of minimum, mean and maximum flowrate from January to December of Lui River and Langat-Dengkil River were plotted and compared. The overall monthly trend of the Lui and Langat-Dengkil

Table 2. Rainfall stations in the study area.

Number	Sub-basin	Rainfall station		Location		Source	Period of data availability
		Station number	Station name	Latitude	Longitude		
1	Lui River	3118102	Sek Keb Sg Lui	3°10′25 ″ N	101°52′20 ″ E	DID	1972-2009
2		3119002	Lalang Sg Lui	3°08′10 ″ N	101°55′20 ″ E	DID	1997-2009
3		3218101	Janalektrik Ponsoon	3°13′40 ″ N	101°53′00 ″ E	DID	1955-2009
4	Semenyih River	MMD RG1	Empangan Sg Semenyih	2°56′00 ″ N	101°52′00 ″ E	MMD	1989-2003
5		DID 11	Ladang Dominion	3°01′05 ″ N	101°51′55 ″ E	DID	1970-2009
6	Langat-Kajang River	3117070	JPS Ampang	3°09′20 ″ N	101°47′00 ″ E	DID	1955-2009
7		3118069	Pemasokan Ampang	3°09′25 ″ N	101°48′05 ″ E	DID	1955-2009
8		2917001	JPS Kajang	2°59′30 ″ N	101°47′50 ″ E	DID	1998-2009
9	Langat-Dengkil River	MMD RG2	MARDI Serdang	2°59′15 ″N	101°40′00 ″ E	MMD	1975-2003
10		2818110	Jalan 6-Kaki	2°52′55 ″N	101°33′15 ″E	DID	1965-2009
11		2918109	Ldg. Sg. Rinching	2°55′10 ″N	101°51′55 ″E	DID	1965-1996
12		2819002	Setul, Mantin	2°48′15 ″N	101°55′15 ″E	DID	1960-2009
13		2818003	Ldg. Cairo	2°51′45 ″N	101°48′00 ″E	DID	1965-1996
14		UKM	UKM Bangi	2°56′00 ″N	101°46′45 ″E	UKM	1980-2009

River flowrate can be observed.

Yearly mean flowrate

Yearly mean flowrate in m^3/s for existing data is analysed. The analyses of linear regression were done for both Lui and Dengkil sub basin, whereby the value of coefficient of determination (R^2) and significance value (δ) were also determined. In addition, the overall yearly trend of the Lui and Dengkil sub basin flowrate can also be identified as either increasing or decreasing.

In contrast, daily rainfall series data for this study have been obtained from various sources, that is, DID, Malaysian Meteorological Department (MMD) and the Universiti Kebangsaan Malaysia (UKM) rain gauging station. Fourteen rain gauge stations were chosen within the Langat River basin as shown in Figure 1. Details regarding the stations code, name, location (latitude and longitude) and period of data availability are shown in Table 2. Two types of mathematical analysis, that is, monthly mean and yearly mean were carried out to represent the sub-basins daily rainfall data as it is the same analysis method used in flowrate analysis. As noted, the rainfall data of Dengkil sub-basin are the combination of the fourteen rainfall station which includes the rainfall stations in Lui sub-basin. Apart from analysis of monthly mean and yearly mean, the additional analysis of the monsoons rainfall contributions in the study area as well as the classification of rainfall into five different classes: no rain, light (1-10 mm/day), moderate (11-30 mm/day), heavy (31-60 mm/day) and very heavy (>60 mm/day) were also carried out.

BF index (BFI) derivations

Streamflow (Q) composed of SW and BF. The former is mainly surface runoff and the latter is groundwater discharge into a stream. SW is the major portion of Q that occurs right after a rainfall event and during a raining season whereas BF is the main source of stream water during dry periods long after a rain has ended (Zhang and Schilling, 2006). BF is an important component of Q, which comes from groundwater storage or other delayed sources such as the shallow subsurface storage, lakes, melting glaciers and others.

BF is the comparatively slowly varying component of streamflow and is frequently the result of the discharge of groundwater to wetlands, lakes and rivers. In some settings, BF is also the result of natural processes such as delayed flow through wetlands and lakes, and anthropogenic processes such as flow regulation and wastewater discharge (Piggott et al., 2005). So, BF is critical to the health of streams where continuous flowing of water is maintained.

Smakthin (2001) defined BFI as a non-dimensional ratio where the volume of BF divided by the volume of total stream flow:

$$BFI = \frac{V_B}{V_A} \tag{2}$$

Where BFI - BF Index; V_B–volume of BF; V_A–volume of streamflow (total flow).

The volume of BF (V_B) can be estimated first by the utilization UKIH smoothed minima BF separation method. This method is based on the identification and interpolation of turning points within an input time series of streamflow monitoring information collected from DID Malaysia. In facts, the method is applied to daily average data only. The turning points identified indicate the days and corresponding values of streamflow where the observed flow is assumed to be entirely BF. This process results in an irregular sequence of turning points (Piggott et al., 2005). The complete UKIH process as described in Mazvimavi et al. (2004) and Aksoy et al. (2009) use in this study is summarized below:

Daily flowrate data from Lui sub-basin was partitioned into non-overlapping blocks of five days.

For each block or segment, the minimum daily flow in Lui sub-basin Q data was identified, and these form the Q_1, Q_2, Q_3... Q_t series of minima as the candidate turning points. If n is not a multiple of 5, then the final Q_t can be ignored in the BF separation calculation.

Turning points among the Q_t can be identified in Lui sub-basin Q data in such a way that when the flow value was multiplied by 0.9, it is smaller than both neighbours, that is, Q_t is a turning point if $0.9Q_t < Q_{t-1}$ and $0.9Q_t < Q_{t+1}$ or overall defined where the condition of Equation 3 is satisfied

$$0.9Q_t < \min (Q_{t-1}, Q_{t+1}) \quad (3)$$

The turning points become BF ordinates for Lui sub-basin, and BF values between turning points were linearly interpolated in time under the condition that the BF cannot exceed the total daily flow, since BF is part of the daily flow.

The steps from i to iv were repeated for the calculation of BF ordinates in Langat-Dengkil sub-basin.

In this application, there are four important highlighted points regarding the UKIH method. Firstly, the multiplication factor, 0.9 has no physical meaning and obtained after manual BF separation in the UK (Institute of Hydrology, 1980). Secondly, the segments that contain less than five days of data are not used in the identification of turning points. In the other words, Q_t, Q_{t-1} and Q_{t+1} in Equation 3 are required to be the minima of five observations in daily flowrate data. Thirdly, BF is not calculated outside of the sequence of turning points as the BF separation cannot start on the first day of the record, similarly cannot finish on the last day and therefore there is a gap in the calculated results at the beginning and end of the output time series. Lastly, Piggott et al. (2005) stated that BF is not calculated if fewer than two turning points are defined.

Once the method of UKIH BF separation was done on the each hydrograph throughout each year long data for Lui sub-basin over 35 years from year 1972 to 2009 (exclude 1996 and 1997 as it is identified as outlier) and for Dengkil sub-basin over 44 years from year 1965 to 2009 based on above procedure, then, the volume of BF, V_B can be estimated and approximated by calculating area under the graph via the trapezium area formula shown below:

$$V_B = \text{Trapezium} = \tfrac{1}{2} (a+b) \times h \quad (4)$$

Where a is turning point 1, Q_1 (m^3/s); b is turning point 2, Q_2 (m^3/s); and h is the time in day between the two turning point.

The volume of total streamflow, V_A can be simply calculated from the data collected from DID. BFI can be determined by a non-dimensional ratio whereby the volume of BF divided by the volume of total stream flow as Equation 2 above. The BF index is used in this paper as a quantitative measure for BF by mathematical approximation.

RESULTS AND DISCUSSION

Discussion of result will begin with the hydrology analysis of the discharge rate for upstream and downstream in Langat River sub-basin. Time series graphs for the monthly mean and yearly mean of the flowrate will be analysed. The trends of the flowrate for the long-term condition can also be observed by constructing the graph to discern hydrological patterns and to evaluate the effect of LULC change on flow in the lower and upper reaches of the Langat River. Next, rainfall trend analysis of 5 rainfall gauging stations around Lui sub basin that represent upper catchment of Langat River and the 14 stations around Dengkil sub basin representing downstream areas were carried out. In addition, the rainfall contributed by South-West monsoon (SWM), North-East monsoon (NEM) and Inter monsoon experienced in Malaysia as well as study area is evaluated and compared. The classification of rainfall of the Langat River sub-basin was done by SPSS software.

The BFI in the study area of both upstream (Lui sub-basin) and downstream (Langat-Dengkil sub-basin) was determined following the procedure explain earlier. Long-term BF responses of the sub-basins (Lui and Dengkil) particularly in LULC changes was studied via graph plotting of yearly BFI time series. The relationship between LULC and BFI can later be established from the analysis. In the last section, the analysis of the lowflow regimes by the annual 7-day (7Q1) will be discussed of the both Lui and Dengkil sub-basin. The 7Q1 help to provide information on the trend of lowflow in Lui and Dengkil sub-basins that occurs once a year throughout the study period.

Flowrate analysis

Langat River basin is one of the most important water sources in Selangor and Kuala Lumpur. In facts, before water resources of Selangor River (another major water source) was developed, the Langat River basin is the primary source of water supply for Kuala Lumpur, Petaling Jaya, Shah Alam, Klang as well as domestic and industries usage in the Langat River basin itself (Othman, 2008). The chronology of raw water abstraction for Langat River water treatment plant is shown in Table 3. Therefore, in evaluating the flowrate at Dengkil flow gauging station (station 2816441) the amount of daily abstraction by the water treatment plant above has to be taken into account.

Monthly mean flowrate

In this section, the monthly mean flowrate at both Lui and Dengkil flow gauging station were plotted (Figure 2). The

Table 3. Chronology of raw water abstraction at Langat River (Batu 9, Jalan Hulu Langat) for water supply treatment plant.

Phase	Year	Capacity (MLD)	Abstraction (MLD)	Outflow form Dengkil Sub-basin	
				MLD	m^3/s
1	1971	102.3	102.3	92	1.06
2	1975	204.5	204.5	174.0	2.01
3	1979	386.4	386.4	227.3	2.63

Source: Perbadanan Urus Air Selangor (PUAS) (Kajang, 2004).

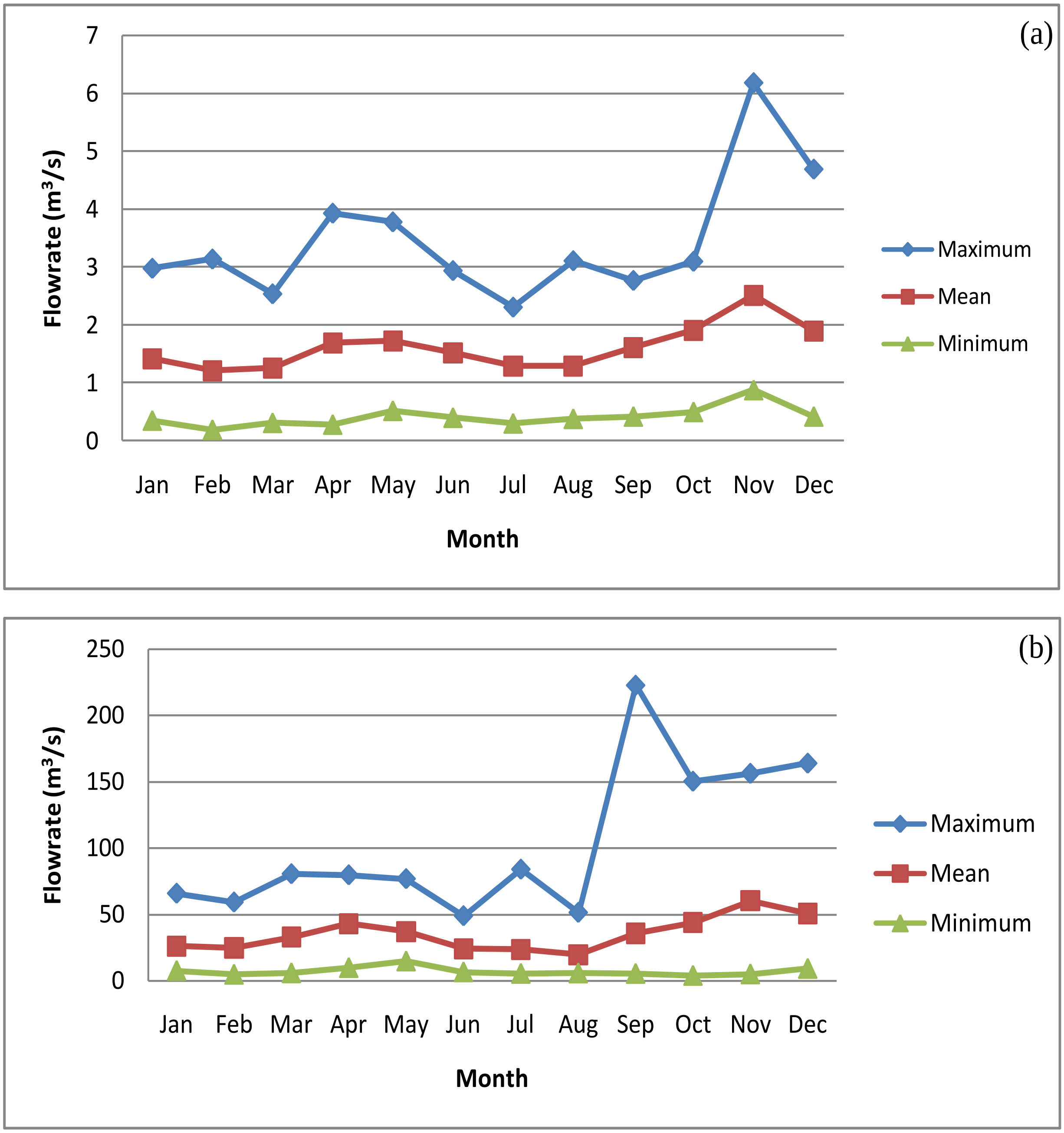


Figure 2. Monthly mean flowrate (a) Lui sub-basin and (b) Dengkil sub-basin.

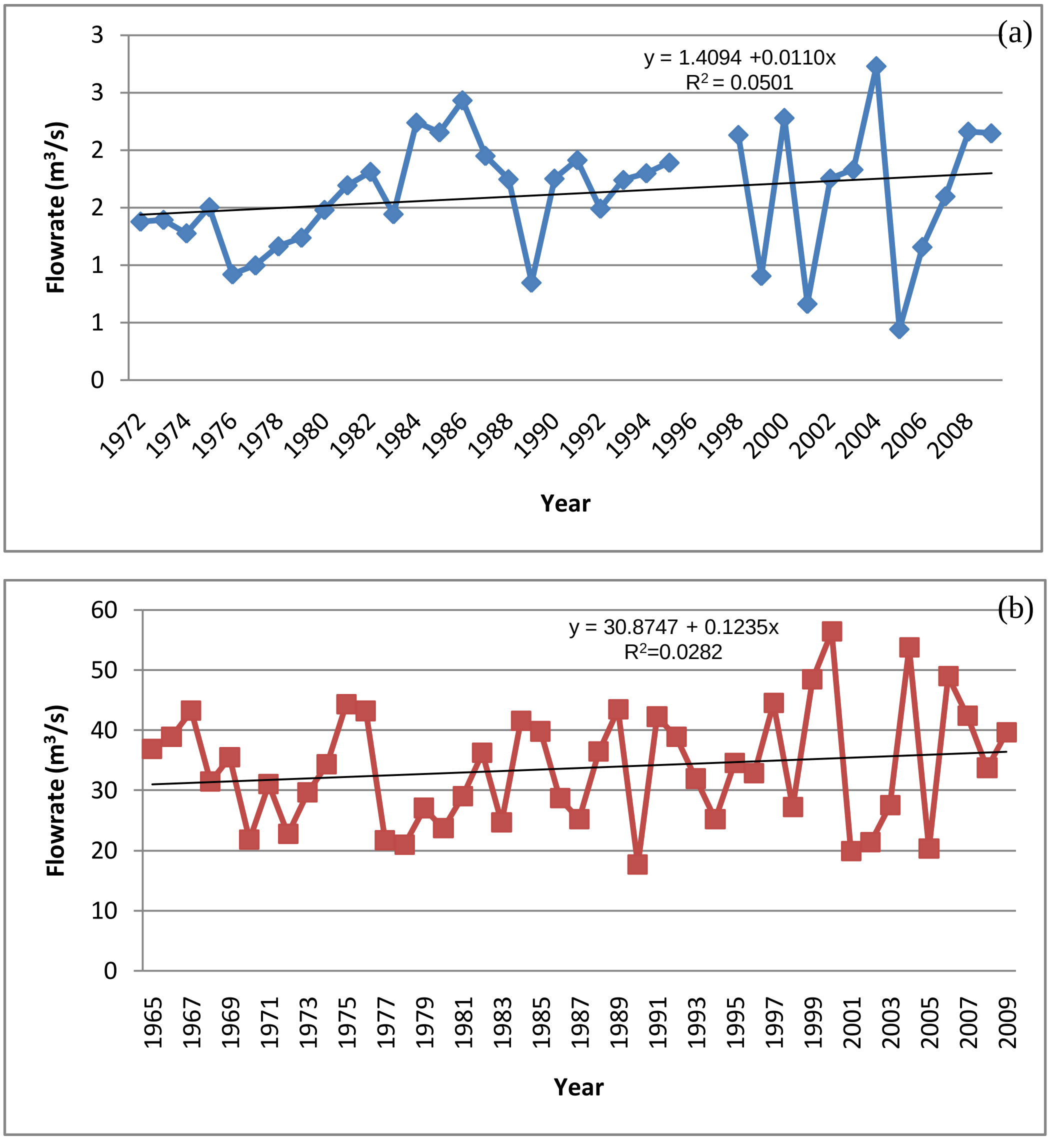


Figure 3. Yearly mean flowrate trend for (a) Lui sub-basin and (b) Dengkil sub-basin.

value of maximum, mean and minimum is illustrated in a single graph for both sub basins. Based on available data, the flowrate is observed from 1972 to 2009 for Lui River while 1965 to 2009 for Dengkil.

From the graphs above, it can generally conclude that the overall monthly mean flowrate value is higher in April and November relatively to the other months and are lower in the months of February and August. The trends are the same at both Lui and Dengkil flow gauging stations. For minimum flowrate, the Rui gauging station has shown flowrate of less than 1m^3/s with the value ranging from 0.19-0.88m^3/s while Dengkil flow gauging station has higher minimum value for every month compared to Lui due to the fact its catchment is much bigger being located in the downstream part of Langat River. The maximum monthly mean values for Lui flow gauging station is fluctuating in a smaller range and quite stable based on the 35 years data ranges between 2.31-6.18 m^3/s. In contrast, the Dengkil flow gauging station has shown higher inconsistency of flowrate with more rigorous fluctuation.

Yearly mean flowrate

Likewise, the yearly mean flowrate for both Lui and Dengkil sub-basins are plotted as shown in Figure 3. Yearly mean flowrate for both Lui and Dengkil sub-basins

Table 4. Summary statistic of yearly mean flowrate trend of Lui and Dengkil sub-basins.

Sub-basin	Duration	Observations	Coefficient of determination (R^2)	Trend and significance
Lui	1972-2009	36	0.0501	↑, Not Significance (δ=0.1896)
Dengkil	1965-2009	45	0.0656	↑, Not Significance (δ=0.0895)

Table 5. Descriptive statistics for discharge at Lui (1972-2009) and Dengkil stations (1965-2009).

Statistics	Station	
	Lui	Dengkil
Minimum	0.444	20.250
Maximum	2.730	58.990
Range	2.290	38.740
Mean	1.613	35.664
Variance	0.270	93.406
Standard deviation	0.519	9.665
Skewness	-0.199	0.405
Kurtosis	-0.237	-0.437

have shown a increasing trend througout the year of study. In addition, the analysis of linear regression was also carried out for the both of the study areas as depicted in Table 4. In general, the results indicated the the yearly trends is not sigificant for both of the Lui and Dengkil sub-basin. Lui flow gauging station has lower mean discharge with smaller annual fluctuation compared to Dengkil, which is located further downstream.

To get important facts of the study area, a descriptive analysis was done by SPSS software programme. A summary of descriptive statistics for discharge at Lui and Dengkil stations is shown in Table 5. A higher discharge value was observed at Dengkil station (2816441) with the discharge value of 58.99 m^3/s in the year 2000 while lower discharge value of 20.25 m^3/s in year 1990. Lui station (3118445) overall, gave a lower discharge at 2.73 m^3/s in the year 2004 and 0.44 m^3/s for year 2005. The mean flowrate of the year 1996 and 1997 at Lui stations is ignored as they are suspected as outlier.

The skewness is the measure of the symmetry of the distribution. In most instances the comparison is made to a normal distribution. For both Lui and Dengkil station, the value of skewness fall within -1 and +1 where Lui station has negative skewness while Dengkil station illustrated positive skew. Another important statistical analysis is the evaluation of the Kurtosis. Kurtosis is the measurement of peakedness and flatness of a normal distribution. Both Lui River and Dengkil River stations shows a Kurtosis value of -0.237 and - 0.437 which implies the flatter peak around its mean in the distribution of existing data or relatively flat distribution. Before excluding the year 1996 and 1997 data, Lui station showed a Kurtosis value of 12.04.

The box plot of annual mean for both Lui and Dengkil sub-basins were also plotted to represent the distribution of variables (Figure 4). The box plot analysis was done using SPSS software program to show the shape of the distribution, its central value, and spread. The central box covers the middle 50% of the data; the lower and upper box represent the first quartile (25%) and upper quartiles (75%) and the horizontal line drawn through the box is the median (Lui 1.72 m^3/s; Dengkil 35.42 m^3/s). The first quartile is the number below which lies the 25% of the bottom data (Lui 1.44 m^3/s; Dengkil 32.76 m^3/s). The third quartile has 75% of the data below it and the top 25% of the data above it (Lui 1.79 m^3/s; Dengkil 38.57 m^3/s). Box plots in Figure 5 show that Lui station, which is located at the upper part of Langat River, had lower annual mean and annual fluctuations in its discharge compared to the Dengkil station. The whiskers or the extension is the end points of the lines attached to the box extend out the minimum and maximum value of the data series. These plots are also a graphical summary of the outliers present in the data (individual points beyond the whiskers).

Outliers are observations that are numerically distant from the rest of the observations. Outliners can be arising from procedural error such as a data entry error or a mistake in coding. But these types of outliers should be identified in the data cleaning stage. Outliers can also occur as the result of an extraordinary event. In these cases an explanation of its uniqueness is necessary. If the outliers represent the valid observation, it should be retained or else it should be omitted and deleted from the analysis. Based on the statistical analysis done by SPSS, Lui River discharge station has two outliers respectively in the 25th and 26th data as it is recorded in the year of 1996 and 1997 where value of discharge of the outliner for 25th and 26th data are 6.5233 and 4.2825 m^3/s, respectively. Therefore, to maintain the preciseness of analysis, the flowrate data in the year of 1996 and 1997 were omitted.

Rainfall data analysis

As mentioned earlier, 14 rain gauge stations within the Langat River basin were chosen from DID, MMD and UKM. The available rainfall data of respective gauging station ranges for the duration of 20 to 54 years. There

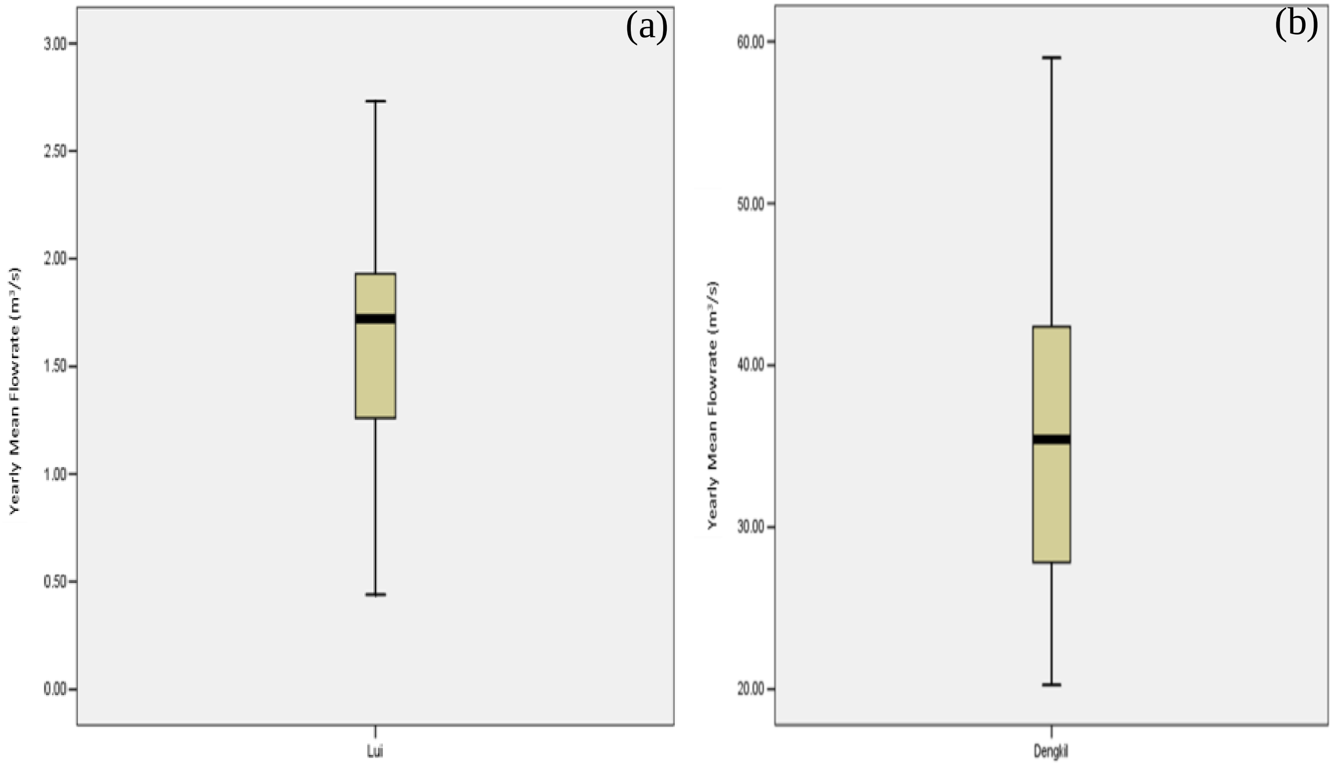


Figure 4. Box plot of yearly mean flowrate for (a) Lui and (b) Dengkil sub-basin.

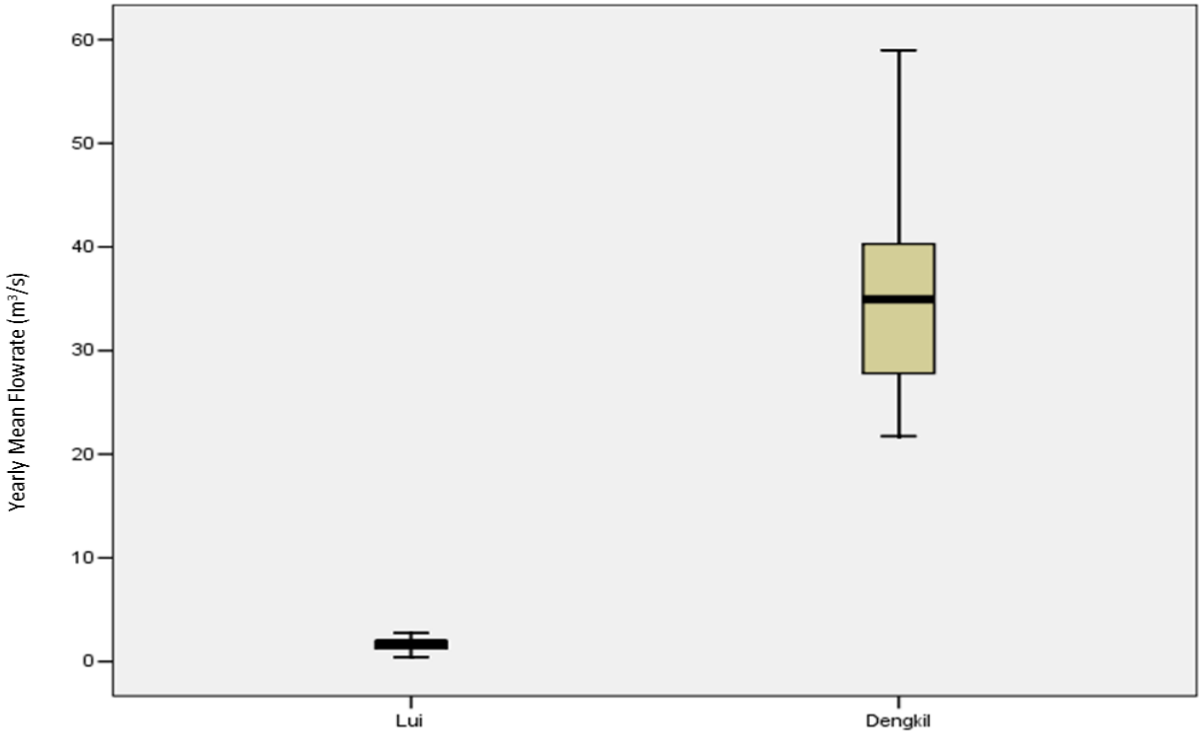


Figure 5. Box plot for the comparison of yearly mean flowrate for Lui and Dengkil sub-basin.

Table 6. Monsoon seasons experienced in Malaysia.

Monsoon	Month
South-West monsoon (SWM)	November, December, January, February and March
North-East monsoon (NEM)	May, June, July, August and September
Inter monsoon	April and October

Table 7. Comparison of Monsoons rainfall contributions in study area and Peninsular Malaysia.

Sub-basin	Annual rainfall (mm)	NEM rainfall		SWM rainfall		Total monsoons Rainfall	
		(mm)	(%)	(mm)	(%)	(mm)	(%)
Lui	2351.30	931.12	39.60	900.73	38.31	1831.85	77.91
Dengkil	2252.29	1033.56	45.89	884.98	39.29	1918.54	85.18
Peninsular Malaysia[a]	2334.00	1034.00	44.00	861.00	37.00	1894.00	81.00

Note: a-Wong et al., 2009; NEM: North-East Monsoon; SWM: South-West Monsoon.

are some inconsistencies of the period of different rain gauge stations. This is mainly due to the different start-up time for the station's operation and the requirement of the rainfall data for activities such as agricultures, flood controls and monitoring and water resources management. Some of the new start-up stations such as rainfall gauge station 2917001 and 3119002 were purposely set to measure the daily rainfall intensity in one.

Monthly rainfall analysis

Malaysia in general experiences wet and humid tropical climate throughout the year that is characterized by high annual rainfall, humidity and temperature. Malaysia has uniform temperatures over the year of 25.5 to 32°C and normally the annual rainfall amount is between 2000 to 4000 mm while annual number of wet days ranges from 150 to 200 days (Suhaila and Jemain, 2007). In facts, the rainfall distribution in Malaysia is severely affected by monsoon particularly SWM and NEM. Overall, the western part of the Peninsular Malaysia that is exposed to SWM tends to be drier while the east coast of Peninsular Malaysia that experienced NEM are generally wetter (encountered more rainfall events during the monsoon seasons). The summary of the monsoon seasons that is experienced by the Peninsular Malaysia is shown in Table 6.

The monsoonal effect on rainfall contributions in study area and Peninsular Malaysia was analyzed and compared (Table 7). Overall, the NEM has higher contribution compared to SWM in the study area of Lui and Dengkil sub-basin ranging from 39.60-45.89% of the mean annual rainfall according to the respective locations. The difference of contribution from NEM and SWM of Lui sub-basin is finite. On the other hand, the SWM has lower in rainfall contribution ranging from 36.01-39.96% of the mean annual rainfall. This might bedue to the lower wind speeds than the NEM. Most winds during SWM come to Peninsular Malaysia from Sumatra, where the high mountain ranges create rain sheltering effects for the west coast of Peninsular Malaysia. As the Strait of Malacca becomes wider towards the north, the land-sea breeze and convection become the more important and may cause regional and local differences in rainfall patterns (Wong et al., 2009). In the respect of total monsoon rainfall, the contribution is well above 77% of the study location. Wong et al. (2009) states that the mean annual rainfall in the entire Peninsular Malaysia was approximately 2300mm where 81% of the mean annual rainfall is originated from monsoon rainfall which is approximately the same as the study area of Langat River sub-basin. Hence, the large amount of NEM rainfall clearly stands out from the study area as well as Peninsular Malaysia as a whole.

To have better visualization on the intensity of rainfall events, the percentage rainfall received by each rainfall station under the study area was classified into different class of rainfall intensity as shown in Table 8. The 4 classes of rainfall intensity proposed by Juahir et al. (2010) was modified to become 5 classes consisting: 0 mm/day (no rainfall), 1 to 10 mm/day (light), 11 to 30 mm/day (moderate), 31 to 60 mm/day (heavy) and >60 mm/day (very heavy). It was observed that all the stations in the study area have more than 40% in the classification of no rainfall with seven stations above 50 and 60%, respectively. Only three stations has more than2% very heavy rainfall events that is., station DID: 3119002, during the 12 years record (1997-2009), received 2.53% very heavy rain followed by DID: 2917001 (2.28%) and Universiti Kebangsaan Malaysia or UKM (2.09%) thus making these stations receiving the

Table 8. Class of rainfall (%) for all rainfall stations within Langat River Basin.

Rainfall station	Duration	No. of observation	Classification of rainfall (%)				
			No rain	Light	Moderate	Heavy	Very heavy
DID: 3118102	1972-2009	10715	53.92	26.49	12.94	5.28	1.36
DID: 3119002	1997-2009	8846	67.60	15.58	9.69	4.60	2.53
DID: 3218101	1955-2009	17402	58.87	22.31	11.92	5.30	1.60
MMD: RG1	1989-2003	4875	51.20	27.90	13.87	5.52	1.52
DID 11	1970-2009	12838	61.26	17.06	13.73	6.07	1.88
DID: 3117070	1955-2009	18991	53.66	24.66	13.78	6.03	1.87
DID: 3118069	1955-2009	16334	57.81	19.60	13.78	6.98	1.83
DID: 2917001	1998-2009	3684	63.17	18.32	10.64	5.05	2.28
MMD RG2	1975-2003	9264	53.24	26.32	13.43	5.60	1.41
DID: 2818110	1965-2009	14239	60.66	22.60	10.60	4.86	1.28
DID: 2918109	1965-1996	11341	63.24	18.39	11.99	5.15	1.23
DID: 2819002	1960-2009	17572	64.88	19.15	10.69	4.32	0.96
DID: 2818003	1965-1996	7331	65.67	15.88	12.59	4.80	1.06
UKM	1980-2009	6754	45.54	29.12	15.99	7.25	2.09

Note: No rain-0 mm/day; Light-1 to 10 mm/day; Moderate-11 to 30 mm/day; Heavy-31 to 60mm/day and Very heavy >60 mm/day.

highest amount of rainfall for the period. On the other hand, station DID: 2819002 recorded the minimum events of very heavy daily rainfall (0.96%) during the 49 years measuring period.

Based on the collected daily data from DID, MMD and UKM rain gauge stations, monthly mean rainfall pattern was categorized into maximum, mean and minimum (Figure 6). The graph shows that the maximum rainfall mainly occurred in the month of March or May and October while the minimum rainfall was observed in the month of January and February or June and July. The monthly mean rainfall pattern was similar to those observed by Othman (2008) in the same study area but of different study period. Also, the dry season can be identified in January and February, and June and July. On the contrary, the wet season was always in the month of April and November based on the mean value.

Yearly rainfall trend

In order to indicate the yearly rainfall trend of the two sub-basins, the graphs of the annual mean rainfall against year was plotted (Figure 7). Also, statistical analysis summary in Table 9 gives the result of linear regression where the value of coefficient of determination (R^2) and the significance level were shown. Orange et al. (1997) states that rainfall is only the input for the larger watershed in the water balance equation, so the intensity as well as duration of rainfall has directly and indirectly effects BF of the study area in some extend. Based on the results, the annual trends of rainfall in the Lui sub-basin consisting of three rainfall (DID: 3118102, DID: 3119002 and DID: 3218101) shows the increasing trend of rainfall while the Dengkil sub-basin illustrated decreasing trends. The value of coefficient of correlation (R) in general is not strong for all stations.

The standard error of mean (SEM) is a measure of the extent to which the sample mean deviates from the true but unknown population mean. In other words, SEM viewed as the standard deviation of the error in the sample mean relative to the true mean. It is the standard deviation of the random sampling distribution of mean, that is, means of multiple samples from the same population. As such, it measures the precision of the statistic as an estimate of population (Kirch. 2008). The SEM of Lui is 72.2201 while Dengkil recorded the value of 44.1645. The small SEM means the sample means should be quite similar as in Dengkil Sub-basin, so a big difference between two sample means is unlikely. In contrast, a large SEM in Lui sub-basin implies us that big differences between the mean of two random samples are more likely (Field, 2009).

BF Index (BFI) for Lui and Dengkil sub-basin

According to UKIH smoothed minima BF separation method, the BF is separated from the daily flowrate data for year 2008 and 2009 in both Lui and Dengkil sub-basin (Figure 8). The selection of the year 2008 and 2009 in the BFI analysis is for the purpose to evaluate the BF pattern response to the recent LULC changes. As observe in figure below, BF separation cannot start on the first day

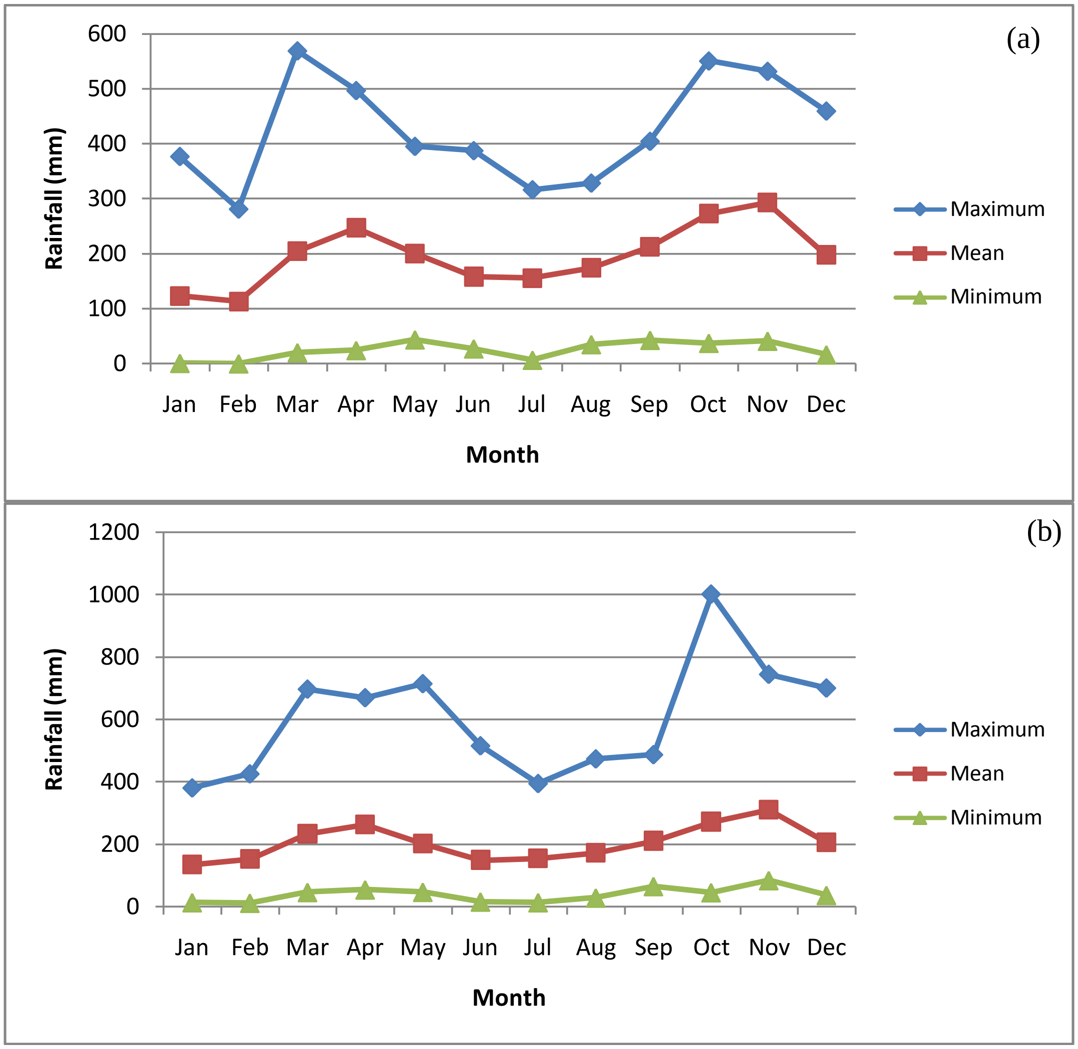


Figure 6. Mean monthly rainfalls in (a) Lui and (b) Dengkil sub-basins.

and finish on the last day of the year. Often the starting and end dates of the BF hydrograph coincided with the starting and end of the turning points based on which the volume of flow beneath the BF hydrograph was calculated. BFI is sensitive to missing data as only one day may result in several days of data omitted from the BF separation (Tallaksen and Van Lanen, 2004). Graph of BFI versus time is plotted for both Lui and Dengkil sub-basin (Figure 9) to visualize the long-term BF response of the catchment. The BFI trend of the Lui sub-basin almost no changes with time, with the line gradient of 0.0001 or almost negligible. On the other hand, BFI of the Dengkil sub-basin presented downward trend through time. In addition, the BFI line of the Dengkil sub-basin is very steep and the gradient is much larger (0.0051) if compared to the Lui sub-basin. For statistical analysis, Lui sub-basin has coefficient of determination (R^2) value of 0.0001 and coefficient of correlation (R) value of 0.01 (little if any correlation), and the analysis is not significant at 0.05 level. The insignificance result may be due to the numerous of missing and unusable data especially those of 1996 and 1997 which was identified as outlier. For Dengkil sub-basin, the coefficient of determination (R^2) is 0.2461, coefficient of correlation (R) is 0.50 (moderate correlation) and the analysis is significant (δ=0.0005) at 0.05 level. To determine stability of the BF regime standard deviation of annual BFI is analysed. The upstream and downstream area have values of 0.09 and 0.14 respectively, which are close to the stable value BFI of 0.04 recommended by UKIH (1980).

Average BFI for Lui and Dengkil sub-basin were recorded as 0.5616 and 0.5005, respectively. This implies that 56.16 and 50.05% of water in the river were contributed by groundwater storage and/or shallow

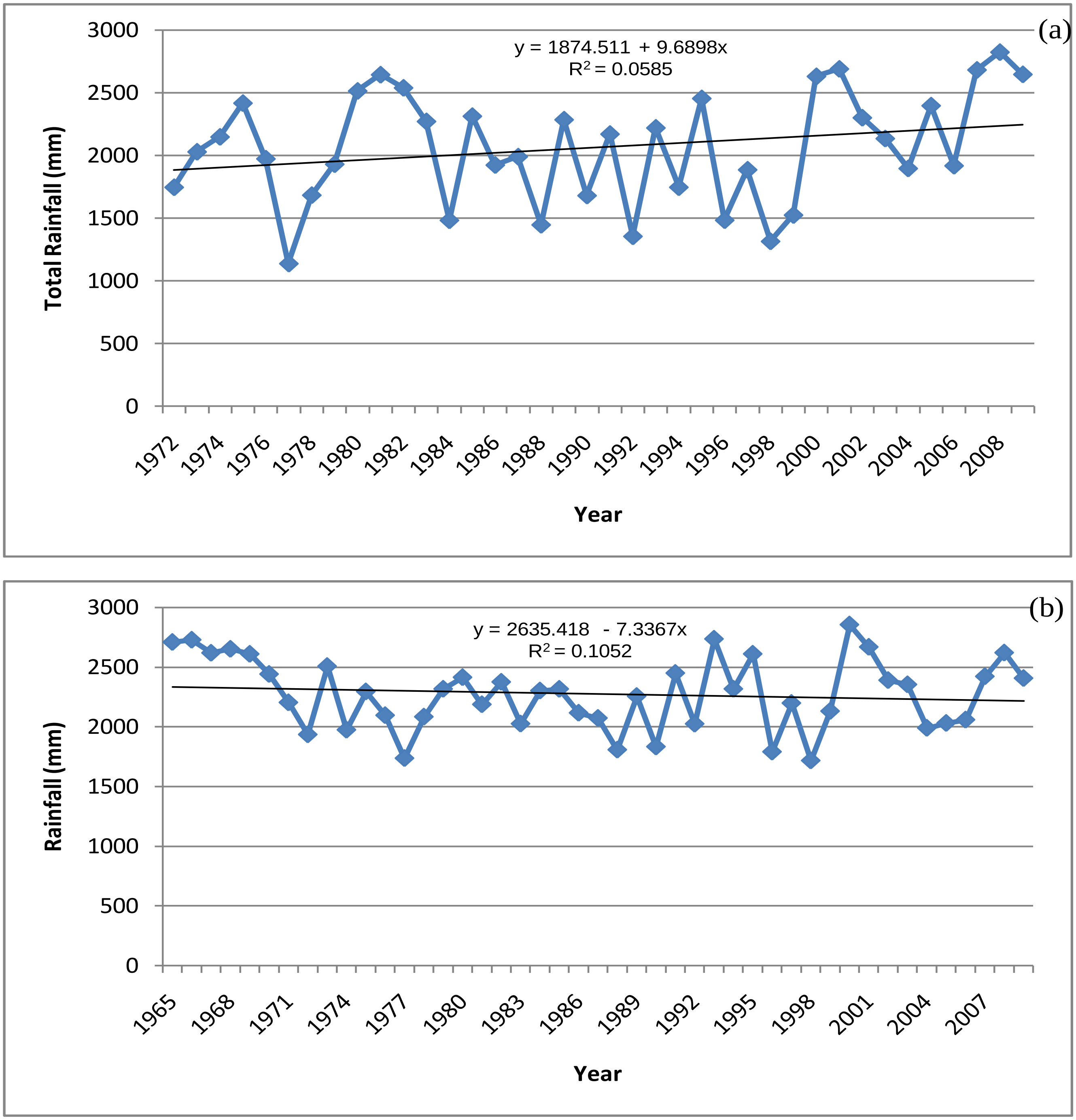


Figure 7. Mean yearly rainfalls in (a) Lui and (b) Dengkil sub-basins.

Table 9. Statistical analysis summary for yearly mean rainfall of the sub-basins.

Sub-basin	Data duration	Coefficient of determination (R^2)	Coefficient of correlation (R)	Standard error of the mean (SEM)	Trend and significance value
Lui	1972-2009	0.0585	0.2419	72.2201	↑, Not significance (δ=0.1435)
Dengkil	1965-2009	0.0142	0.1192	44.1645	↓, Not significance (δ=0.4358)

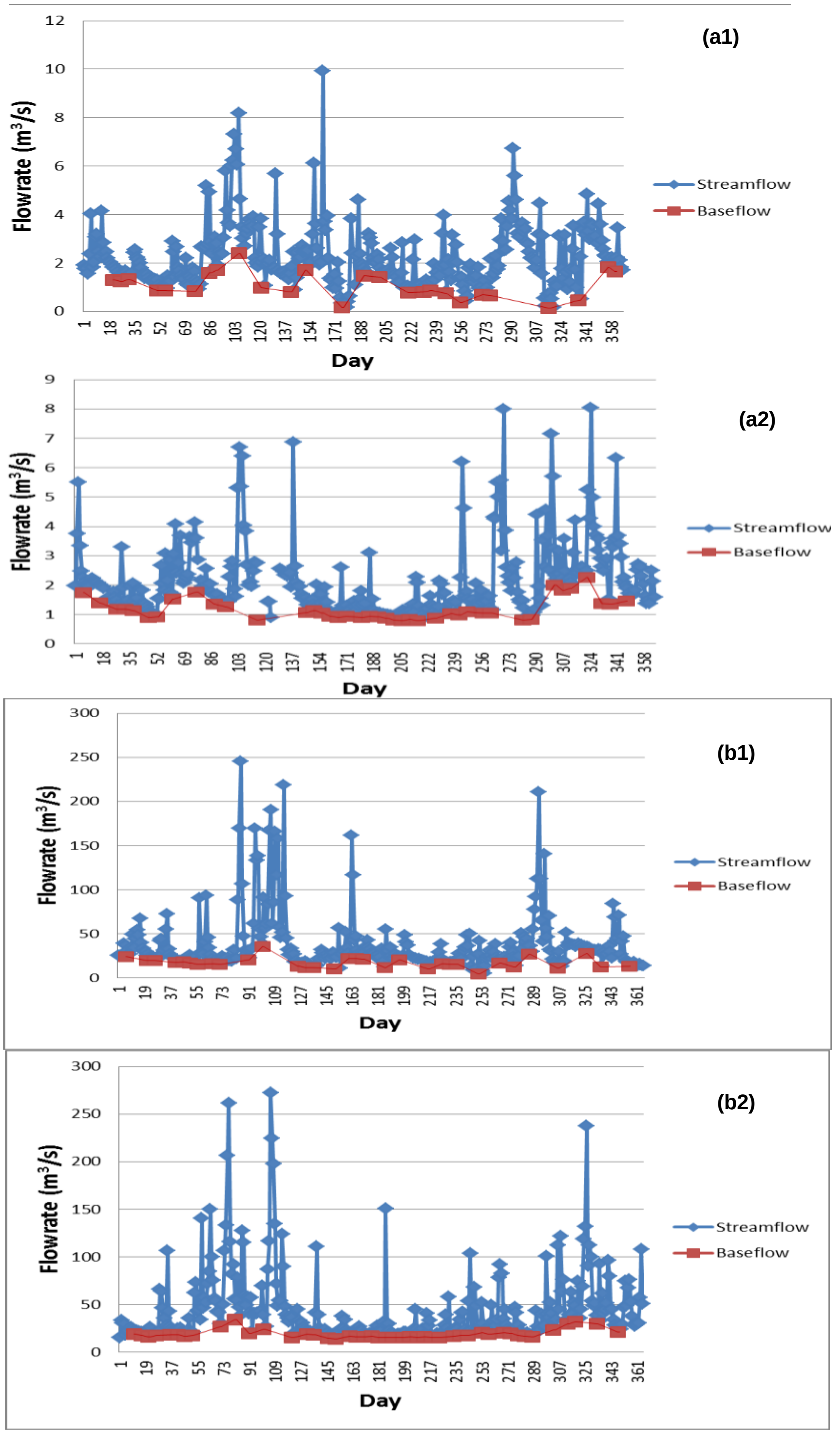


Figure 8. UKIH smoothed minima BF separation for Lui (a1) 2008 (a2) 2009 and Dengkil sub-basin (b1) 2008 and (b2) 2009.

subsurface storages while the other 43.84 and 49.95 of river flow were made of quickflow or SW from rainfall events that included surface flow (overland flow or runoff), rapid lateral movement in the soil profile (interflow) and direct precipitation onto the stream surface for both upstream and downstream area. This quantity of BF volume is important to maintain background level of a river by seepage from groundwater storage or known as

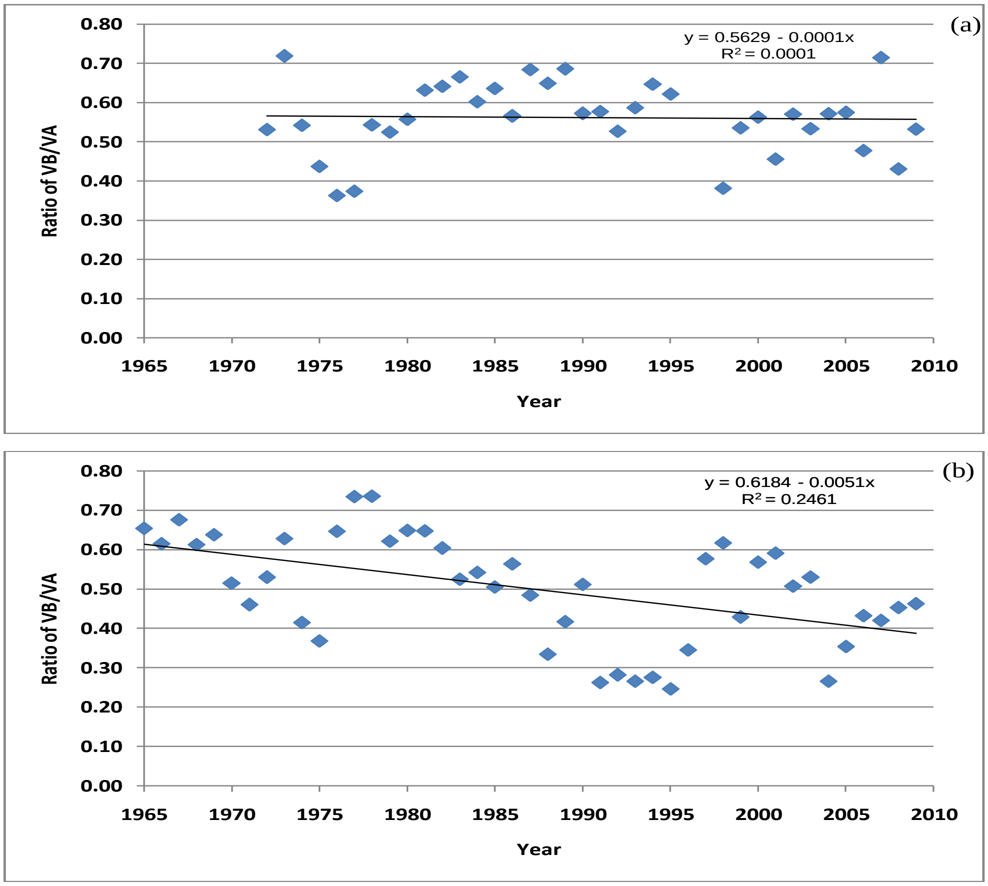


Figure 9. BFI for (a) Lui sub-basin for the year 1972 to 2009 and (b) Dengkil sub-basin for the year 1965 to 2009.

Table 10. Landuse status in Lui and Dengkil sub-basins from year 1990 to 2009.

	Land use	Lui River Sub-basin				Langat-Dengkil Sub-basin			
		1990		2009		1990		2009	
		Hectare	(%)	Hectare	(%)	Hectare	(%)	Hectare	(%)
1	Forest	4,671.90	67.90	4,208.42	61.12	45,389.16	36.27	39,866.48	32.16
2	Mangrove	-		0.16	0.00	15.84	0.01	64.94	0.05
3	Oil Palm	-		2.69	0.04	8,025.03	6.41	1,317.85	1.06
4	Agriculture	2,201.94	32.00	2,480.36	36.02	59,150.34	47.27	46,636.59	37.62
5	Grassland	1.17	0.02	3.35	0.05	2,620.08	2.09	1,456.72	1.18
6	Bareland	-		43.14	0.63	5,287.86	4.23	2,218.24	1.79
7	Urban	5.22	0.08	146.53	2.13	3,374.55	2.70	30,722.41	24.78
8	Water bodies	-		0.86	0.01	1,282.32	1.02	1,691.01	1.36

Source: Earth Observation Center (EOC), UKM, 2011.

groundwater recharge. Recharge sometimes referred to groundwater runoff in which water infiltrates the soils and that soaks into aquifer system by natural methods (Debarry, 2004).

Landuse and land cover (LULC) status

The BFI of Lui and Dengkil sub-basin have very close relationship with the LULC changes. The landuse status

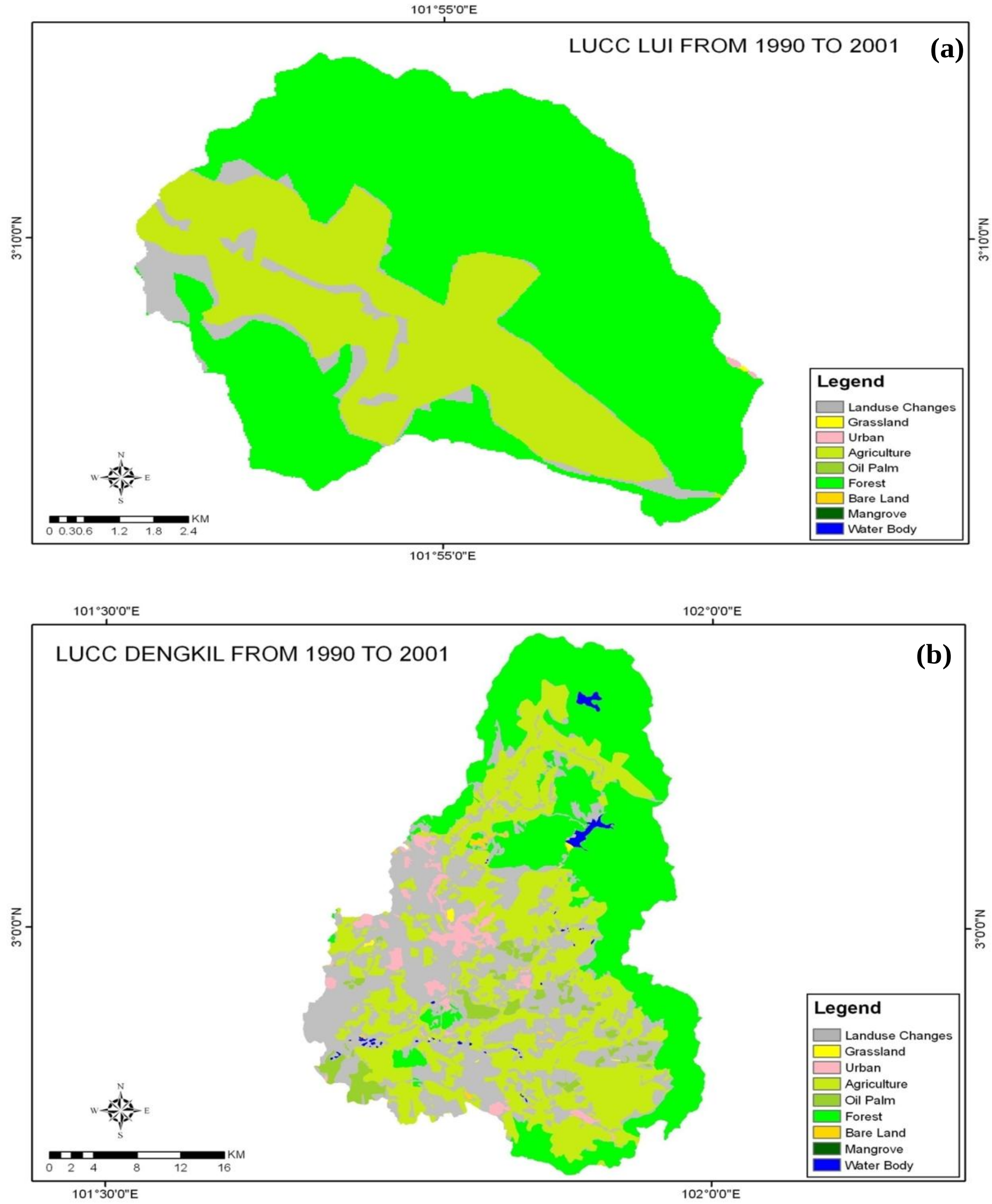


Figure 10. Landuse and Land cover changes in (a)Lui and (b)Dengkil sub-basin from 1990 to 2009. Source: Earth Observation Center (EOC), UKM 2011

in Lui and Dengkil sub-basin from year 1990 to 2009, as shown in Table 10, has been classified into eight categories consisting: forest, mangrove, oil palm, agriculture, grassland, bareland, urban and water bodies. Figure 10 shows the satellite image of LULC in Lui and Dengkil sub-basin from year 1990 to 2009. Total size of Lui sub-basin is approximately 6,880.23 ha while 125,145.18 ha for Dengkil sub-basin. Forest remain as the dominant land cover in the Lui sub-basin with the value of 4,671.90 ha in year 1990 and slightly decrease to 4,208.42 ha in year of 2009, but is always more than 60% of overall land cover. Hence, the originality of the land status remains as in the past which in turn leads to the constant BFI. Besides, agricultural constitute the second largest of the LULC in Lui sub-basin with the value of 2,201.94 ha in year 1990 and increase to 2,480.36 ha in the year of 2009. Other landuses such as mangrove, oil palm, bareland and water bodies only appeared in year 2009. These four landuses represent a very small area in Lui sub-basin which was approximately 46.85 ha or 0.68%.

Agricultural was the dominant landuse in the Dengkil sub-basin covering 59,150.34 ha (47.27%) in year 1990 but has decreased to 46,636.59 ha (37.62%) in year 2009. Forest which is the second most dominant land cover has also reduced in size from about 45,389.16 ha in 1990 to 39,866.48 ha in year 2009, a reduction of about 4.11% in terms of overall land area of the sub basin. The two lowest landuse of Dengkil sub-basin (<2% coverage) was mangrove and water bodies. Water bodies includes mining sites, quarries, pits, excavation sites, lake, dams and water recreation centre.

Both sub basins had experienced increase of urban landuse, with the downstream region (Dengkil sub-basin) undergoing much more rapid transformation. In the year 1990, there are only 5.22 ha of urbanize area in Lui sub-basin and it has increased to 146.53 ha in year 2009, but still covering less than 3% of overall land area. On the other hand Dengkil sub-basin urban area which covered 3,374.55 ha (2.70%) in year 1990 has increased immensely to 30,722.41 ha (24.78%) in year 2009. In the time period of 19 years, urbanized area of Dengkil sub basin has increased by more than 9 times. The rate of urbanization is expected to increase further due to the upsurge of the population in Dengkil sub-basin in which Putrajaya and Cyberjaya sit. The conversion of agricultural, forest, grass, and wetlands to urban areas converted the permeable ground into impermeable surfaces of rooftops, sidewalks, driveways and roads. The net effect of these changes is to reduce opportunity of water infiltrating into ground and lowering of water tables. This threatens BF contribution by reducing the groundwater contribution to total streamflow especially during dry period (Tang et al., 2005). BF is critical in ensuring sustainable water supply and maintaining ecological health of streams. It is anticipated that Dengkil sub-basin will experience further decrease in trend of BFI if the rate of landuse change, in particular urbanization continues.

Lowflow analysis

World Meteorological Organization, WMO (1974) defines lowflow as flow of water in a stream during prolonged dry weather while Smakhtin (2001) defines lowflows as actual flows in a river occurring during the dry season of the year and it is a seasonal phenomenon, and an integral component of a flow regime of any river. To analyze the lowflow regimes of the both Lui and Dengkil sub-basin, the technique of annual 7-day lowflow (7Q1) was used. The other hydrologically-based design lowflow methods are 7-day 10-year low flow (7Q10) and 7-day 2-year low flow (7Q2). The graph of annual 7 day lowflow against time (year) for both Lui and Dengkil sub-basin is plotted as shown in Figure 11.

The annual 7 day low-flow for Lui and Dengkil sub-basin has presented an upward trend through time (Figure 11). In Lui sub-basin, trend line is moderately steep at 0.0047. The result of simple regression analysis shows that the coefficient of determination (R^2) is 0.0267 and coefficient of correlation (R) is 0.1634 (little if any correlation). The 7 day lowflow for Dengkil Sub-basin shows steeper upward trend than the Lui sub-basin (0.0295 > 0.0047). The result of simple regression shows that the coefficient of determination (R^2) is 0.0133 and coefficient of correlation (R) is 0.1153 (little if any correlation). In facts, trend for both Lui and Dengkil sub-basin is not significant at 0.05 levels. The increasing trend of the 7Q1 for both sub basins indicated that annual 7-day average continuous low flows tend to increase over the study period and are apparently positively affected by the landuse changes.

Conclusion

Unquestionably, landuse change has affected the hydrological regimes of the sub basins as shown from the result of analysis on river flowrate, precipitation distribution, and the BF regime in term of BFI. According to the monthly mean analysis, the flowrate was higher in April and November compared to other months while it was lower in the month of February and August. These trends were the same for both Lui and Dengkil sub-basins. For minimum flowrate, the Lui sub basin has shown water flowrate of less than 1 m^3/s with the value ranging from 0.19-0.88 m^3/s while Dengkil sub-basin has higher minimum value for every month being of much larger basin. The maximum mean monthly values of 2.31-6.18 m^3/s for Lui is fluctuating in a smaller and stable range, while Dengkil has inconsistent flowrate with high flowrate fluctuation.

For yearly mean flowrate, both of the Lui and Dengkil sub-basin exhibit an upward trend. The increasing trend of flowrate of Lui sub-basin was consistent with the upward trend of the rainfall within the basin. The same however cannot be said for Dengkil sub-basin. It was observed that the annual rainfall for this basin for the same study period showed a decreasing trend. Again this phenomenon may be related to the landuse changes that had happen during this period, in particular within the lower sub- basin of Dengkil. The increasing size of impervious surfaces in this sub basin together with the reduction of trans-evaporation (due to reduce agriculture and forest cover) has caused more rain to flow directly into streams during each rainfall event, contributing toward

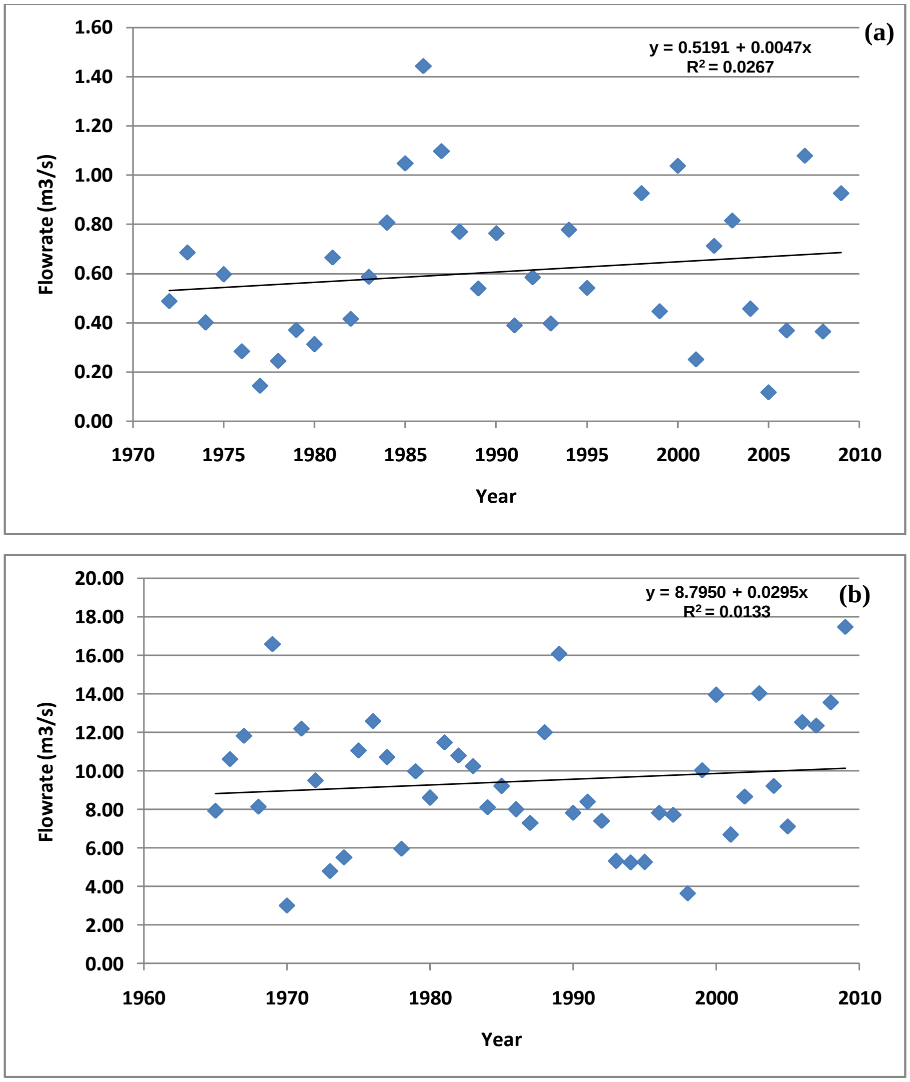


Figure 11. Annual 7 day (7Q1) low flow for (a) Lui and (b) Dengkil sub-basins.

higher total flow.

In the aspect of rainfall data analysis, the monthly rainfall analysis shows NEM has higher contribution in comparing to SWM in the study area of Lui and Dengkil sub-basin ranging from 39.60 to 45.89% of the mean annual rainfall according to the respective locations. In term of total rainfall, monsoonal rainfall contributed more than 77% of the study area.

The Lui sub-basin has showed almost constant annual BFI based on the trend analysis carried out within the stable range of 0.04 as recommended by UKIH (1980). On the other hand, Dengkil sub-basin exhibited downward BFI trend. This has indicated that the contribution of the BF on total flow of the sub basin has reduced over the years. The land disturbances and the increase size of imperviousness has certainly reduce the opportunity for infiltration of rainwater into the ground and has most probably reduce the quantum of ground water to recharge the river system during intervening periods between rainfall events. Analysis on trend of annual 7-day lowflow (7Q1) however, seems to show increasing trend for both sub basins. This seems to contradict with the decreasing trend of BF, in particular those of Dengkil sub-basin. Most probable reason for such phenomena is the type and sequent of landuse changes. The quantum increase of urbanised area within this sub basin which mainly consists of new townships has occurred at the expense of forest and agriculture land. These changes have inevitably affected the hydrologic profile of the area in terms of discharges of used water that continuously feeds the river system. This shall need further investigation.

ACKNOWLEDGEMENTS

This study is based on the M. Eng. Thesis of the first author. Author would like to express my deep and sincere gratitude to my Master project supervisor Ir. Dr. Othman Bin Jaafar, for his supervision and guidance from the very early stage of this research as well as giving me extraordinary experiences throughout the work. Next, Author would like to take this opportunity to thank Department of Irrigation and Drainage (DID), Malaysian Meteorological Department (MMD) and Faculty of Social Science and Humanities, UKM who have provided us secondary data and advices. In addition, Author would extend appreciation and gratefulness to the staff members from Earth Observation Centre (EOC), UKM for their participation in completion of the project.

Abbreviations: UHI, Urban heat island; **MR,** Mississippi River; **LULC,** land-use and land-cover; **MSC,** multimedia super corridor; **BFI,** baseflow index; **UKIH,** United Kingdom Institute of Hydrology; **DID,** Department of Irrigation and Drainage; **MMD,** Malaysian Meteorological Department; **SWM,** South-West monsoon; **NEM,** North-East monsoon; **7Q1,** annual 7-day lowflow; **UKM,** Universiti Kebangsaan Malaysia; **SEM,** standard error of the mean; **Q,** streamflow; **SW,** stormflow; **WMO,** World Meteorological Organization.

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