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Hydrological Trend Analysis Due to Land Use Changes at Langat River Basin

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Abstract

This present study was carried out to detect the spatial and temporal change (1974-2000) in hydrological trend and its relationship to land use changes in the Langat River Basin. To obtain a clear picture of the hydrological parameters during the study period, rainfall data were analyzed. With the help of GIS and non-parametric Mann-Kendall (MK) statistical test the significance of trend in hydrological and land use time series was measured. Trend analyses indicated that a relationship between hydrological parameters namely discharge and direct runoff and land use types namely agriculture, forest, urban, waterbody and others was evident. This analysis indicates that rainfall intensity does not play an important role as a pollutant contributor via the rainfall runoff process nor does it directly influence the peak discharges. Land use shows tremendous changes in trend surrounding Dengkil station compared a little changes surrounding Lui station. Mann-Kendall test of trend shows an increasing trend (*p-value*< *0.01*) of annual maximum-minimum ratio for Dengkil station, while no significant trend is observed for Lui station. There is evidence that regional variability in discharge behaviour is strongly related to land use or land cover changes along the river basin.

Keywords: trend analysis; temporal change; Mann-Kendall; land use; hydrological

1. Introduction

Urbanization is the most important land use type which is took place within the river basin. These changes of undeveloped to developed area may contribute the changes of discharge and direct runoff volume into Langat River. The urbanization will increase the pervious and impervious area, which is identified as main factor in increases of direct runoff volume as well as increases pollution loading into Langat River. The growing population pressure of the past decades, deforestation, lake reclamation, and embankment construction on riverbanks all exacerbated the flood situation (He and Jiao, 1998).

Langat River Basin is one of the most important basin which supply water to two third of the state of Selangor. However, rapid urbanization within Langat River Basin due to the changes in economy policies by Malaysian Government, involved the changes in land use activities. The Langat Basin is chosen as one of the major areas for economic growth especially in developing manufacturing zones in Selangor. Apart from the rise of export intensive industrial zones in the Basin, the Kuala Lumpur International Airport, West Port at Klang, the Multimedia Super Corridor (MSC) and Putrajaya, all of which are situated in the Basin also generate diversified development activities that in turn attract the widespread building of infrastructures and utilities. These infrastructure and facilities had been developed to attract foreign investors and thereby contributed to the building of capacities to compete at global level in terms of trade and technology development.

Detection of temporal trends is one of the most important objectives of environmental monitoring. Trend analysis has proven to be a useful tool for effective land use planning, design and management since trend detection provides useful information on the tendency change of land use in the future. In this study, the changes of land use, discharge and direct runoff were measured based on the changes in trend. Non-parametric trend analysis was carried to investigate there is any significant relations between the changes in land use trend and both hydrological parameter (discharge and direct runoff).

The present study on temporal trends of land use, discharge, direct runoff as well as precipitation is based on available land use, hydrological and meteorological secondary data. Correlations of long-term trends between land use, hydrological and meteorological variations at the Langat River Basin have been carried out. These help in further understanding is there any relationship the changes in trend of land use may gives the changes in hydrological parameters (discharge and direct runoff). Trend analysis has proved to be useful tool for effective water resources planning, design and management since trend detection of land use and hydrological variables such as discharge, direct runoff and precipitation provides a useful information on the possibility of change tendency of the variables in the future (Hamilton *et al*., 2001; Yue and Wang, 2004).

The purpose of this study was to apply non-parametric methods of trend analysis to the land use areas, discharge and direct runoff data for Langat River Basin to detect trend and the possible relationship between land use and discharge as well as direct runoff.

2. Methodology

2.1. GIS Data Preparation

The use of topographical maps and aerial photographs also provide a good database for land use change information within the Langat River Basin. One of the problems of these methods is the different scales that limit sequential analysis. To overcome this limitation, a GIS technique was employed to extrapolate land use changes from various sources (topographical map and aerial photograph) at a uniform scale. This section describes the methodology for quantitative analysis of land use changes using GIS-ArcInfo-based software.

Ten years land use data were evaluated from 1974, 1981, 1984, 1988, 1990, 1991, 1995, 1996, 1997 and 2000. All the data were provided by Consultancy Unit of University Malaya (UPUM) and Ecosystem Health of Langat Basin Study by LESTARI, Universiti Kebangsaan Malaysia (UKM).

This study used ArcView 3.2 and ArcGIS 8.3 in preparing and updating GIS spatial data. In addition to the core module, spatial analyst and Patch Analyst 2.2 extension were also used to perform part of the analysis. Additional ArcView extensions used include the editing tools for data editing. In addition to ArcView 3.2 and ArcGIS 8.3, a number of other softwares have also been used such as Arc/Info 7.0 for spatial data editing and map projection conversion and MapInfo Professional 8.0 for supplementary map editing and attribute data entry

All spatial data were prepared in ArcView shapefile format. A standard 5% margin of error was maintained for spatial accuracy, whenever possible. This study however, has little control over externally sourced data but they are properly documented.

40 map layers were prepared in the spatial database. For data management purpose, the spatial database is divided into 2 main categories:

a) Geographical Database: consists of administrative/political data, geological and hydrological data, land use data and transportation network data.

b) Environmental Database: consists of all monitoring stations and pollution sources data within the Langat River basin.

2.2. Discharge and Direct Runoff Analysis

Streamflow (cubic meter per second (cumecs)) data used for this study were extracted at two gauging station namely Dengkil (station no. 2816441) and Lui (station no. 2917401) selected in this study to investigate any significant impact of land use changes on discharge along the river basin. The Dengkil gauging station is downstream of Langat River (101° 30’ 35” N, 2° 48’ 69”E). This station provides daily discharge (m^3/s) and is maintained by DID since 1960. Discharge data observed from 1970 to 2000 were used in this analysis. On the other hand, the Lui gauging station is upstream of Langat River (03° 09’ 45”N, 101° 52’ 10”E) where daily discharge (m^3/s) is observed. The data used in this study are from 1978 to 2000.

The main purpose of this analysis is to examine the extent of influence that the land use land cover change along the river has on the discharge behaviour of the Langat River. Time series graphs for annual mean, maximum and minimum discharge and maximum-minimum ratio graphs were constructed to discern hydrological patterns and to evaluate the effect of land use land cover change on flow in the lower and upper reaches of the Langat River. Multivariate tests were also applied to measure any significant differences in the data for the different years.

Direct runoff analysis was also carried out using the Web based Hydrograph Analysis Tool (WHAT) system (Lim and Engel, 2004). Direct runoff was calculated via the process of separating the base flow component from the streamflow hydrograph and is called the “hydrograph analysis” (Lim *et al*., 2005). Discharge data from two stations namely Dengkil and Lui were used in this calculation. The direct runoff (cubic meter per second (cumecs)) was computed by uploading a file containing discharge data. Once the base flow is separated from the discharge, direct runoff and base flow output values result.

The direct runoffs were computed in order to investigate its relationship with effective rainfall (the rainfall intensity which influences the peak discharge) during storm events (very heavy rainfall). This analysis provides the evidence of the contribution of rainfall as a pollutant transport via the rainfall runoff process into the river system. The direct runoff data was screened by using rank and 90th percentile method to identify 90% of the data that fall below a certain value. The maximum value obtained from rank and 90th percentile analysis were then used for further analysis. Multi-variate test was applied to measure any significant differences in the data for the different years.

2.3. Precipitation analysis

To obtain a clear picture of the hydrological parameters during the study period, rainfall data were analyzed at eight rainfall station (Station no. 2815001, 2818110, 2916001, 2913001, 2917001, 3018101, 3118102 and 3119104) based on the availability of data. These stations are the nearest stations relative to the area under study. All stations are manned by the Department of Irrigation and Drainage (DID), Selangor. Mean monthly rainfall analyses were carried out for years 1981, 1984, 1988, 1990, 1995 and 1997.

2.4. Non-parametric test of trend

Detection of temporal trends of discharge and direct runoff within Langat River Basin of the most important objectives of this study and analyzed by using trend analysis. The Mann-Kendall trend test (Kendall, 1975; Mann, 1945) were applied to examine the performance of a class of non-parametric trend test, which were first proposed by El-Shaarawi (1993). According to Gilbert (1987), Mann-Kendall test is the available approach can be used because only the relative magnitudes of the data rather than their measured values. The basic principle of Mann-Kendall tests for trend is to examine the sign of all pairwise differences of observed values. The Mann-Kendall test is based on the statistic S. Each pair of observed values y_i, y_j (i>j) of the random variable is inspected to find out whether $y_i>y_j$ or $y_i<y_j$. The test statistic for the Mann-Kendall test is given as

$$S = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k) \qquad (1)$$

Where the x_j and x_k are the sequential data values and j>k, n is the length of the data set and

$$\text{sgn}(x_j - x_k) = \begin{cases} 1 & if \quad x_j - x_k > 0 \\ 0 & if \quad x_j - x_k = 0 \\ -1 & if \quad x_j - x_k < 0 \end{cases} \qquad (2)$$

which is the number of positive differences minus the number of negative differences. Variance of S, computed by

$$Var(S) = \lfloor n(n-1)(2n+5) - \sum_t (t-1)(2t+5) \rfloor / 18 \quad (3)$$

And is asymptotically normal (Hirsch and Slack, 1984), where *t* is the extent of any given tie and the summation over all ties. For the case that *n* is larger than 10, the standard normal variate *z* is computed by using the following equation (Douglas *et al.*, 2000).

$$z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \qquad (4)$$

Thus, in a two-sided test for trend, at a selected level of significance α, the null hypothesis of no trend is rejected if the absolute value of *Z* is greater than $z_{\alpha/2}$.

3. Results and discussion

3.1. Precipitation analysis

Fig. 1 shows the rainfall and discharge station taken into consideration in this study. The means of monthly rainfall are listed in Table 1. The standard deviation for each station shows the mean variation of the monthly rainfall from the average for each month. To allow comparison of the variations of rainfall among the different stations, the coefficient of variation was computed. It is observed that at station 2916001 the coefficients of variation are relatively high compared to that of the other stations for all the years from 1970-2000. These differences in the coefficient of variation are due to the location of each station. Station 2913001 is located nearer to the coastal zone, and receives high precipitation compared to stations located inland. Monthly rainfall pattern shows that the highest rainfall was registered in November 1980 (station 2913001: 5225 mm), April 1971 (station 2815001 and 2818110: 1807 and 2150 mm), August 1987 (station 2917001: 1709 mm), August 1995 (station 3018101: 1260 mm) and April 1981 (station 3118102: 2077 mm). The lowest rainfall during the period (955 and 951 mm) were recorded in November 1993 and January 1996 at the 3119104 and 2916001 rainfall stations. Table 2 shows the percentage rainfall received by each rainfall station under this study classified into different classes of

Table 1. Descriptive summary of each rainfall station for years 1974 to 2000.

	Rainfall station							
Statistic	2815001	2818110	2913001	2916001	2917001	3018101	3118102	3119104
No. of observations	9497	9497	10227	2192	9497	9497	11323	3288
Total rainday	3376	4458	3621	512	4250	1348	4466	1061
Minimum	0	0	0	0	0	0	0	0
Maximum	1807	2150	**5225**	951	1709	1260	2077	955
Mean	39.88	49.60	42.85	26.64	57.23	47.31	49.06	36.24
Standard deviation	102.61	117.83	121.55	85.78	125.94	112.73	122.39	96.74
Variation coefficient	2.57	2.38	2.84	**3.22**	2.20	2.38	2.49	2.67
Skewness	4.37	4.00	10.91	5.02	3.57	3.70	4.51	4.11
Kurtosis	28.70	25.14	340.83	31.56	17.58	17.66	31.65	20.72
Sum	378709	471075	438273	58398	543519	155539	555504	119144

rainfall intensity. The 4 classes of rainfall were identified based on precipitation of 1 to 10 mm (light), 11 to 30 mm (moderate), 31 to 60 (heavy) and >60 mm (very heavy). It is observed that station 2917001, during the 26 years record (1975-2000), received 22.6% very heavy rain and 6.2% heavy rain, thus making it the station receiving the highest amount of rainfall for the period. On the other hand, station 2916001 recorded the lowest amount of rain within the 26 years. In general, Mann-Kendall test of trend at two rainfall stations (station 3018101 and 3118102) located at the upstream showed increasing rainfall trends but no significant trends were obtained for the other stations (Table 3).

3.2. Trend analysis

A higher discharge value was observed at Dengkil station (2816441) at 27.62 m^3s^{-1} for year 2000 and a low 9.04 m^3s^{-1} for year 1995 (Table 4). Lui station (2917641) gave a lower discharge at 12.32 m^3s^{-1} in the year 1984 and 3.92 m^3s^{-1} for year 1996 (Table 4). To gain a clearer picture of the temporal changes in discharge due to land use changes, multivariate tests were employed to justify if there are any significant differences in discharge pattern. Only selected years of discharge data were tested according to the availability of water quality (1970-2002) data. Thus, in order to see the effect of land use change on discharge of Langat River, only discharge data from 1984 to 2000 is needed for analysis. Nevertheless, availability of data for gauging station Dengkil from 1974 to 2000 and Lui from 1978 to 2000 prompted the use of all discharge data for this analysis. These gauging stations were selected to represent two different sub-basins which manifest two different land use patterns.

Table 2. Class of rainfall (%) for all rainfall stations within Langat River Basin.

Rainfall station	**Record length**	**Classification of rainfall (%)**			
		Very heavy	**Heavy**	**Moderate**	**Light**
2815001	1970-2000	16.8	5.3	6.1	71.9
2818110	1970-2000	18.9	5.5	7.2	68.4
2913001	1973-2000	17.4	5.2	6.2	71.3
2916001	1995-2000	**11.2**	**3.4**	**4.1**	**81.3**
2917001	1975-2000	**22.6**	**6.2**	**7.2**	**63.9**
3018101	1992-2000	18.9	5.5	6.9	68.7
3118102	1970-2000	19.4	5.4	6.5	68.7
3119104	1992-2000	15.1	5.4	5.4	74.0

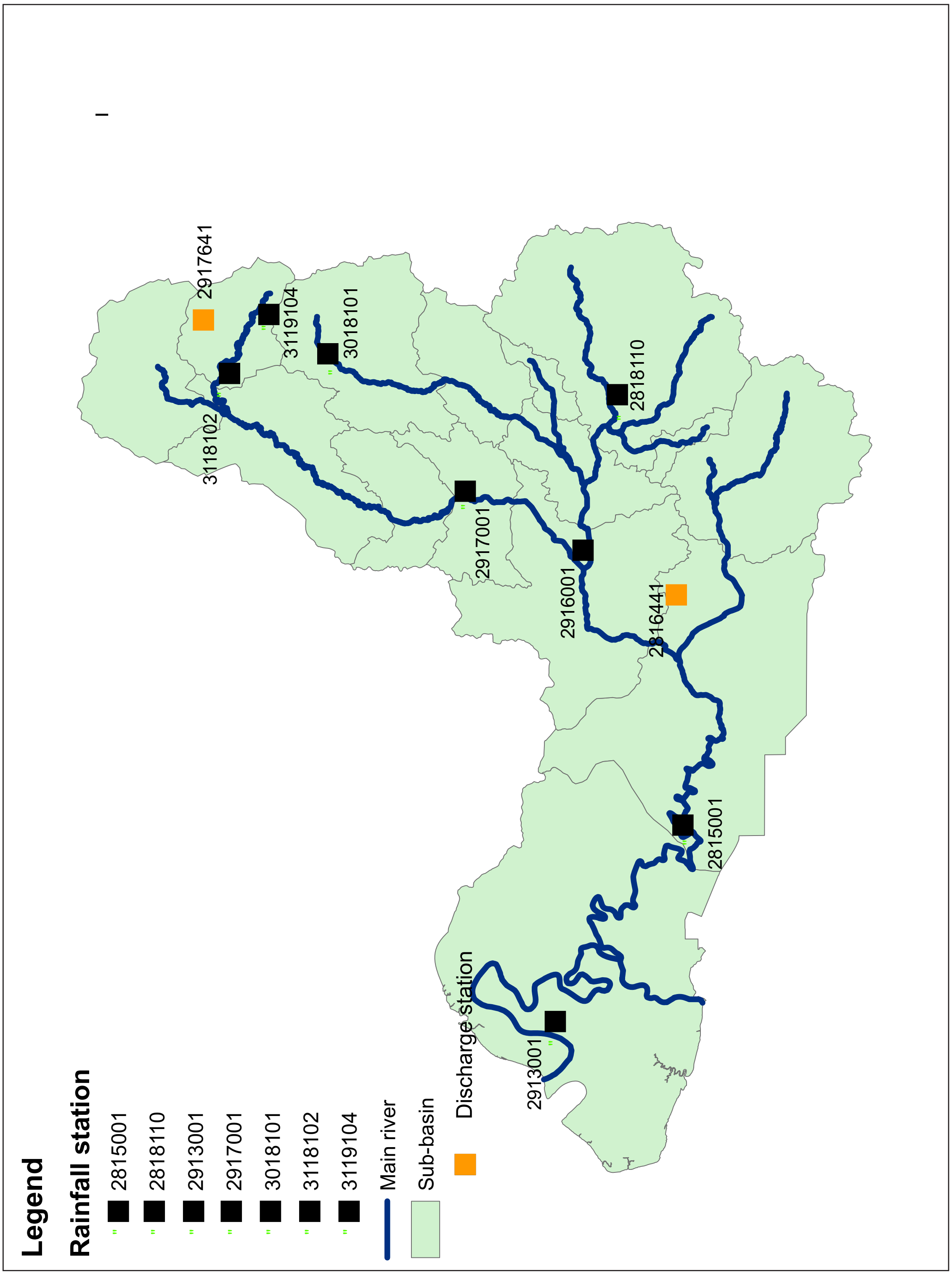

Figure 1. Rainfall and discharge stations within the study area.

Table 3. Mann-Kendall test of trend for rainfall during 1970-2000

Rainfall station	**Mann-Kendall test**		
	S	Z	Trend
2815001	-49	-0.816	NT
2818110	-7	-0.12	NT
2916001	-7	-1.127	NT
2913001	12	0.217	NT
2917001	69	1.499	NT
3018101	20	1.981	↑
3118102	115	1.938	↑
3119104	8	0.73	NT

Note: ↑ *-upward trend*; NT-*no trend*

Table 4. Descriptive statistics for discharge at Dengkil and Lui stations (1970-2000).

Statistic	**Station**	
	Lui	Dengkil
Minimum	3.921	9.039
Maximum	12.322	27.621
Range	8.401	18.582
Mean	7.522	17.336
Variance	3.673	22.210
Standard deviation	1.917	4.713
Skewness	0.809	0.315

Multivariate tests (Table 5) carried out for the Dengkil and Lui stations support the decision that the discharge for Dengkil (2816441) station is significantly different for years 1970-2000 (*p-value* < *0.05*). However, all season discharge at Lui station (2917401) exhibited non significant difference at 95% significance level. Multivariate tests also show non-significant differences in discharge (*p-value* > *0.05*) and thus, itcan be said that there is no significant difference between the discharge volumes for years 1978-2000 at Lui station (2917401).

Fig. 2 depict box and whisker plots for annual mean, minimum, maximum, and maximum-minimum ratio for both gauging stations between 1970-2000. The

Table 5. Multivariate tests for discharges at both sampling stations.

Station	**Test**	**Value**	**F**	**Hypothesis diff.**	**Sig.**
1) Dengkil (2816441)	Pillai's trace	0.636	5.282[a]	3.00	0.022
	Wilk's lambda	0.362	5.282[a]	3.00	0.022
	Hotelling's trace	1.761	5.282[a]	3.00	0.022
	Roy's largest root	1.761	5.282[a]	3.00	0.022
2) Lui (2917401)	Pillai's trace	0.339	1.538[a]	3.00	0.339
	Wilk's lambda	0.661	1.538[a]	3.00	0.339
	Hotelling's trace	0.513	1.538[a]	3.00	0.339
	Roy's largest root	0.513	1.538[a]	3.00	0.339

Note: Each F tests the multivariate effect of discharges. These test are based on the linearly independent pairwise comparisons among the estimated marginal means. a. Exact statistic

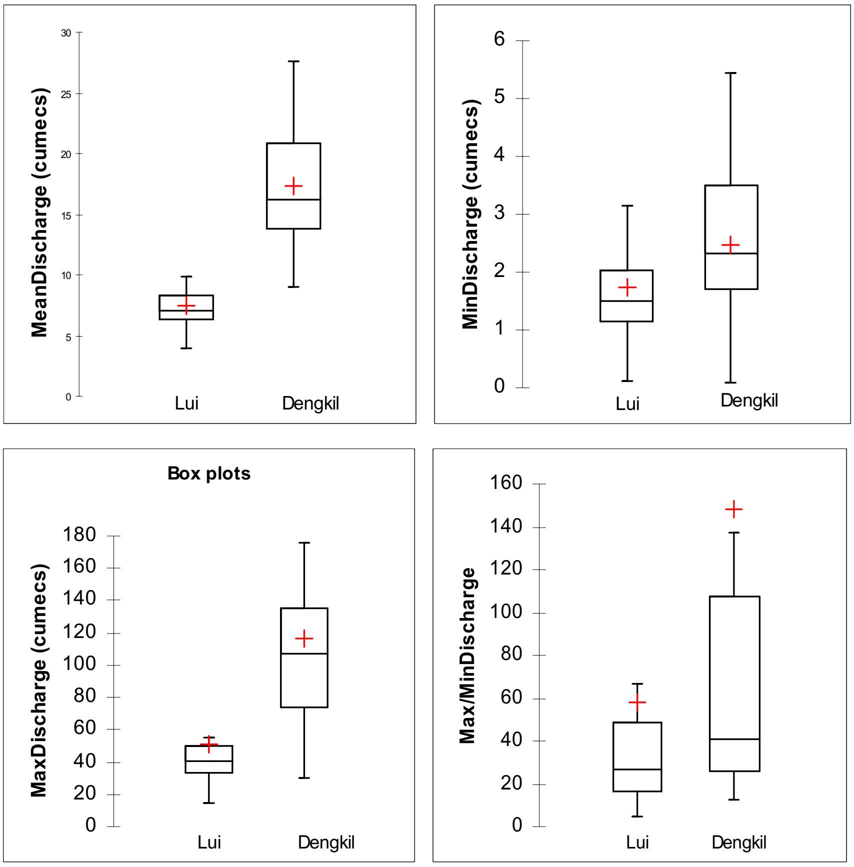

Figure 2. Box-and-whisker plots for mean, minimum, maximum and maximum-minimum ratio of discharge for Dengkil and Lui stations.

central box covers the middle 50% of the data; the lower and upper box, represent the lower and upper quartiles and the horizontal line drawn through the box is the median. The single point inside the box is the mean. The whiskers (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). Box and Whisker plots show that Lui station, which is located at the upper Langat River, had lower annual mean, minimum, maximum, maximum-minimum and annual fluctuations in its discharge compared to the Dengkil station. There is evidence that regional variability in discharge behaviour is strongly related to land use or land cover changes along the river basin. The Mann-Kendall test of trend shows significant increment in annual discharge for Dengkil station, while no significant trend is observed at Lui station (Table 6).

Mean annual flows of both (Dengkil and Lui) stations are shown in Fig. 3 and 4. Mean discharge for Dengkil station shows an increase in discharge, where

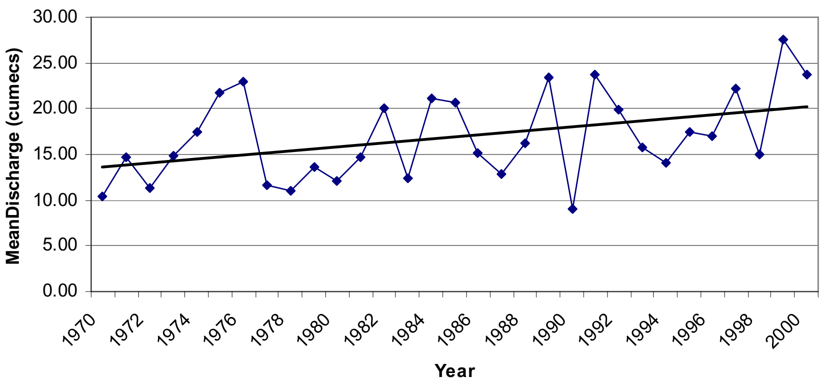

Figure 3. Mean discharge at Dengkil station (2816441).

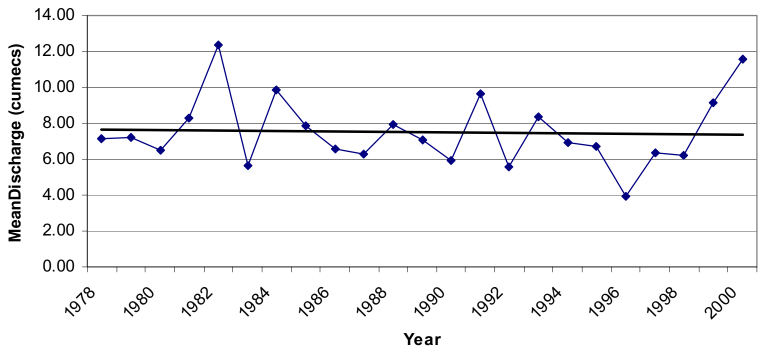

Figure 4. Mean discharge at Lui station (2917641).

there is a statistically significant increase (*p=0.033< 0.05*) before and after year 1990. On the other hand, mean discharge at Lui station fluctuated within the usual historical range before and after year 1990. Lui station has the lowest mean discharge, and annual fluctuation of its discharge is smaller compared to Dengkil station, which is located downstream. There is evidence of regional variability in discharge behaviour, related to land use or land cover change along the Langat River. Mann-Kendall test of trend (Table 6) clearly shows that there is a significant increasing trend (*p-value<0.01*) of mean annual discharge detected at Dengkil station, while there is no significant trend (*p-value<0.1*) at Lui station. The increment trend of discharge at Dengkil station is consistent with the increasing trend of urban development and the decrease of agriculture and forest areas within the region.

Annual maximum and minimum flows (Fig. 5 and Fig. 6), or the so called extreme daily flows, is a more suitable indicator for land surface disturbances such as land cover or land use changes and reservoir construction (Lu *et al*., 2003; Lu, 2004). Annual maximum discharge for Dengkil station shows significant increment trend (*p-value<0.01*) from year 1970 to 2000. The same is also observed for annual maximum discharge at Lui station (*p-value<0.05*). Annual maximum discharge at Lui station showed an overall fluctuation within the usual historical range both before and after 1990, from 1978 to 2000. The highest annual maximum discharge value for Dengkil station is observed in the year 1985 where the value is 320 m^3s^{-1}. On the other hand the highest annual maximum discharge at Lui station is observed in the year 1982 where the value is 206 m^3s^{-1}. Annual minimum discharge (Fig. 7) shows decreasing trend (*p-value<0.05*) at Dengkil station, while no significant trend was detected at Lui station (Fig. 8). A decrease in annual minimum discharge is observed at Dengkil station in 1994, and was probably due to dam in-filling (Semenyih Dam located at upstream), which took place

Table 6**.** Mann-Kendall test of trend for discharge due to five categories of land use.

	Variables	**Discharge station**	
		Lui	Dengkil
Land use	Agriculture	NT	NT
	Forest	↓**	↓**
	Urban	↑***	↑***
	Waterbody	↑***	↑***
	Others	NT	NT
Discharge	MeanDischarge	NT	↑***
	MaxDischarge	NT	↑***
	MinDischarge	NT	↓**
	Max-MinDischarge	NT	↑***

Note : ↑- upward trend; *↓- downward trend*; *NT- no trend*; **-p-value<0.1*; ***-p-value<0.05*; ****-p-value<0.01* in the dry season of the same year. The lowest annual minimum discharge is observed at Dengkil station in year 1994 (0.08 m^3s^{-1}) and for Lui station the lowest annual minimum discharge is observed in year 1996 (0.13 m^3s^{-1}). Mann-Kendall test of trend shows an increasing trend (*p-value*< *0.01*) of annual maximum-minimum ratio for Dengkil station, while no significant trend is observed for Lui station (Fig. 9 and Fig. 10).

In this study, direct runoff is also computed to investigate the effectiveness of rainfall in giving significant influence to the increase in discharge level. Effective rainfall refers to the volume of rainfall which gives significant increase to the discharge volume. In this work, the rainfall during storm event is considered as an effective rainfall. Only two rainfall stations (2818110 and 2917001) show significant Spearman correlations (*p-value*< *0.05*) (Table 7) with direct runoff (Dengkil station) during very heavy rainfall periods. However, other rainfall stations do not show any significant correlation (*p-value*> *0.05*) with direct runoff calculated for Dengkil. This analysis indicates that rainfall intensity does not play an important role as a pollutant contributor via the rainfall runoff process nor does it directly influence the peak discharges.

Table 8 shows the cumulative area for the five land use activities based on both gauging stations Lui and Dengkil, where the direct runoff value was generated. Cumulative land use area based on Lui reference station is given by three sub-basins namely Pangsoon, Ulu Lui and Hulu Langat. On the other hand, cumulative land use area based on Dengkil gauging station is given by 13 sub-basins namely Pangsoon, Ulu Lui, Hulu Langat, Cheras, Kajang, Hulu Semenyih, Semenyih, Branang, Rinching, Batang Benar, Bangi Lama, Batang Labu dan Putrajaya. For both reference stations, land use percentage change for agriculture shows increment from 1974-2001. The agriculture area for Lui gauging station increased by 20.13 km^2, while for Dengkil

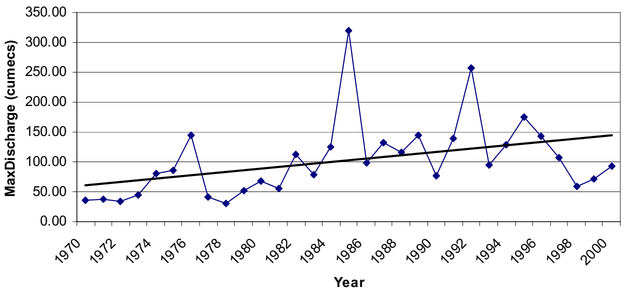

Figure 5. Maximum discharge at Dengkil station (2816441)

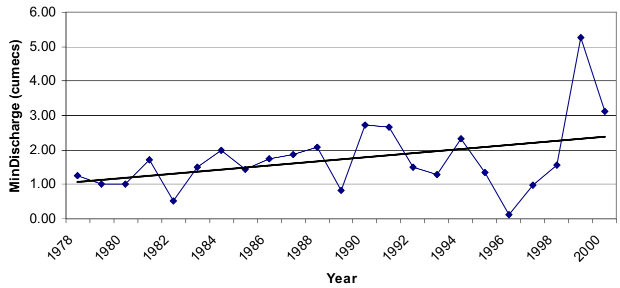

Figure 8. Minimum discharge at Lui station (2917401).

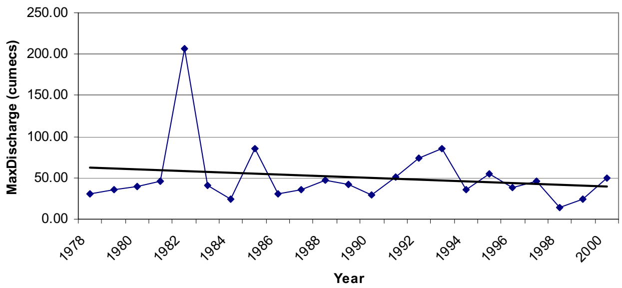

Figure 6. Maximum discharge at Lui station (2917401)

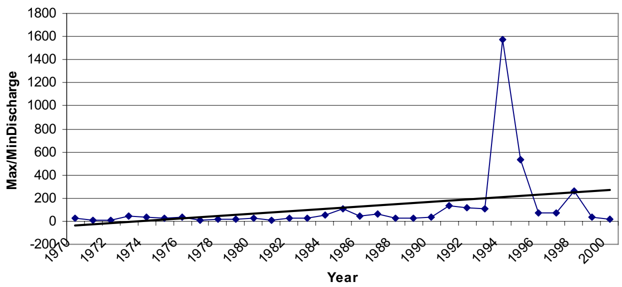

Figure 9. Max/Min Ratio discharge at Dengkil station (2816441).

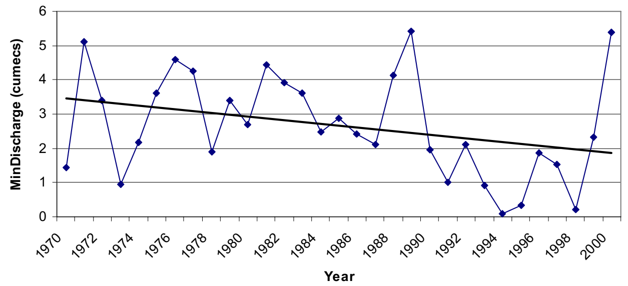

Figure 7. Min discharge at Dengkil station (2816441).

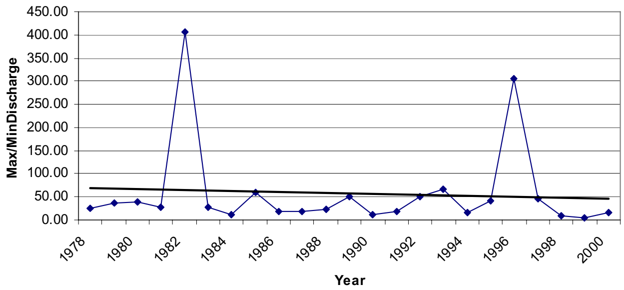

Figure 10. Max/Min Ratio discharge at Lui station (2917401).

Table 7. Correlation (Spearman) test of rainfall and hydrological parameters.

Variables	Rainfall station no.						
	2815001	2818110	2913001	2917001	3018101	3118102	3119104
Q2816441	-0.00331	**0.052814**	0.005065	**0.062493**	0.055272	0.025267	0.077453
Q2917401	0.029437	**0.110423**	0.032457	**0.108916**	**0.080829**	0.022871	0.026731
DR2816441	0.001846	**0.101749**	0.032064	**0.096408**	0.069223	0.019555	0.017798
DR2917401	0.043474	0.003381	-0.03895	-3.2E-05	0.065556	-0.00817	0.035072

Note: Bold number indicate the value significant at 0.05

station, the area increased by 310.19 km^2. Forest area, on the other hand, decreased for both stations (about 76.89 km^2 for Lui reference station and 1825.55 km^2 for Dengkil station). Urban area is one of the most important land use types which can increase direct runoff to river systems. Dengkil gauging station exhibited extreme increment of urban area (cumulative urban area from 13 sub-basins) from 1974-2001, where the increment value is about 1241.37 km^2 compared to Lui reference station (80.58 km^2). The increment of cumulative urban area is consistent with the increment in trend for both mean and maximum value of direct runoff from year 1971 to 2000 at Dengkil gauging station. Mann-Kendall test of trend for this station shows upward trend for mean (S=+135, *p-value*< *0.05*) and maximum (S=+177, *p-value*< *0.05*) value of direct runoff (Fig. 12 and Fig. 14). However, no significant trend is detected for mean (S=+3, *p-value*> *0.05*) and maximum (S=+3, *p-value*> *0.05*) direct runoff observed from Lui station (Fig. 11 and Fig. 13). This illustrates that the increment in urban area by 80.58 km^2, did not result in any significant changes in trend (upward or downward) at Lui station. Clearly, the cumulative increment of urban area from year 1974 to 2001 at Lui station is considered small compared to the increment of cumulative urban area at Dengkil station. As a result, cumulative urban area for Dengkil which is relatively bigger than Lui, also results in a relatively bigger cumulative impervious surface area which will significantly effect peak runoff. Land use modifications with urbanization such as removal of vegetation, replacement of previously pervious areas with impervious surfaces and drainage channel modifications invariably result in changes to the characteristics of the surface runoff hydrograph (Goonetilleke *et al*., 2005; USGS, 2007). Previous research conducted by ASCE (1975), Codner *et al.* (1988), and Mein and Goyen (1988), found that the hydrologic changes that urban catchments commonly exhibit are, increased runoff peak, runoff volume and reduced time to peak.

ANOVA was carried out for both gauging stations to identify the difference between direct runoff pattern from 1974-2001. For Lui station, the ANOVA results show that the F value ($F=11.42$) is greater than $F_{critical}=1.88$ with $p\text{-value}<0.05$. Therefore, we can

Table 8. Cumulative land use area (km^2) based on both reference stations Lui (upstream) and Dengkil (downstream).

Year	Cumulative land use area (km^2)									
	Agriculture		Forest		Urban		Waterbody		Others	
	Lui	Dengkil	Lui	Dengkil	Lui	Dengkil	Lui	Dengkil	Lui	Dengkil
1974	323.73	4987.98	266.53	4106.7	4.21	65.03	0	0	9.01	40.86
1981	335.18	5164.28	253.4	3904.22	7.63	117.61	0	0	8.11	36.8
1984	368.82	5682.73	224.95	3465.97	10.41	160.31	0	0	3.95	17.93
1988	354.64	5464.04	185.47	2857.81	44.92	691.87	0.26	0.6	13.68	62.75
1990	387.8	5974.9	185.86	2863.57	33.26	512.64	0.26	0.6	2.26	11.24
1991	356.08	5486.59	182.85	2817.26	38	585.42	0.45	1.04	17.71	79.41
1995	351.22	5411.29	193.98	2988.83	52.45	807.95	1.08	5.79	6.27	27.67
1996	368.38	5676.09	168.04	2589.26	58.44	900.3	4.39	24.15	3.38	14.77
1997	337.56	5201.11	198.21	3053.88	60.14	926.56	1.5	8.07	6.77	29.46
2001	343.86	5298.17	148.06	2281.15	84.79	1306.4	5.32	28.56	12.96	54.43

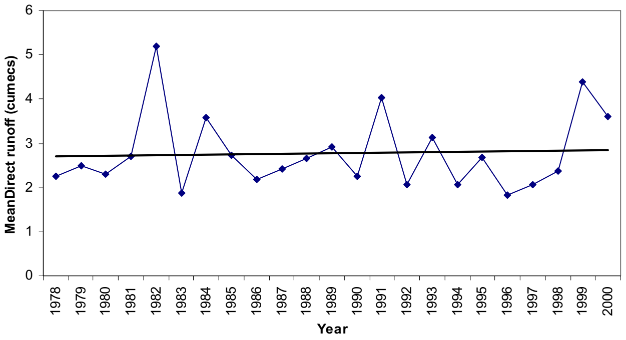

Figure 11. Mean direct runoff at Lui station (2917401)

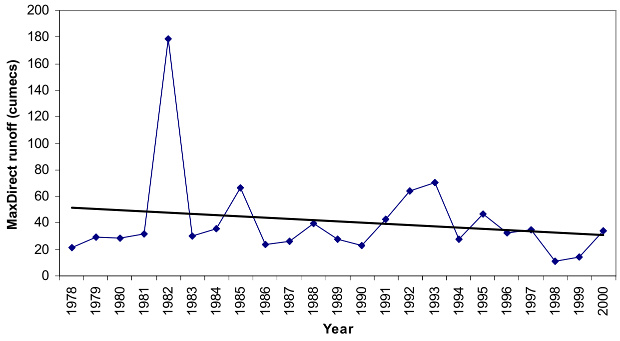

Figure 13. Maximum direct runoff at Lui station (2917401)

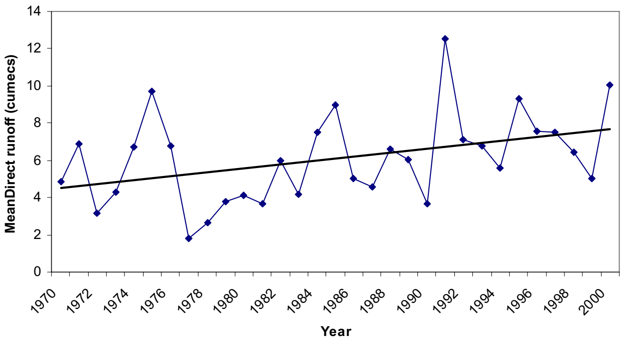

Figure 12. Mean direct runoff at Dengkil station (2816441)

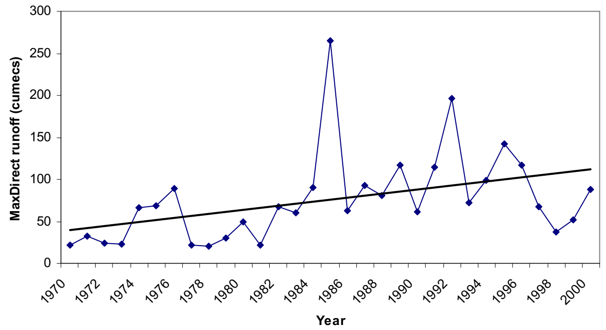

Figure 14. Maximum direct runoff at Dengkil station (2816441)

conclude that there was a significant difference in direct runoff pattern at Lui station. Similarly, the ANOVA results for Dengkil reference station show that the *F-value=4.96* is greater that the $F_{critical}=2.61$ with *p-value<0.05*. This result also shows that there was a significant difference in direct runoff pattern for Dengkil gauging station from 1974-2001. The difference in direct runoff pattern at Dengkil station is quite certainly due to changes in land use activities.

4. Conclusion

To study the relationship between land use and meteorological parameters, data from eight rain monitoring stations within the Langat River basin were analyzed. Upon comparison of the variation coefficient for each of the station, the density of rain water was divided into four main classifications; light, moderate, heavy and very heavy. It is observed that the station located near the coastal zone (2913001) received the highest rainfall compared to the station located inland. Station no. 2917001 has the highest percentage of heavy rainfall as compared to the other stations. Mann-Kendall analysis of trend indicated that two stations located at the upper reaches showed an increasing trend from years 1992 to 2000 for the station no. 3018101 and from year 1970 to 2000 for station no. 3118102. In this study rainfall analysis was carried out due to its influence upon the discharge volume into the river which in turn affects pollutant transport via the rainfall-runoff process.

Hydrological data analysis was also carried out in order to observe trends in discharge and direct runoff based on observation data from two DID hydrological stations, Lui station (2917641) at the upper reaches and Dengkil station (2816441) at the lower reaches. From the results it can be concluded that only discharge and direct runoff from Dengkil Station exhibit significant changes ($p<0.05$) from years 1970 to 2000. Mann-Kendall trend analysis shows that the trend for discharge and direct runoff from the Dengkil station had increased, meanwhile Lui station did not indicate any trend from year 1970 to 2000. This scenario indicates slowness in land use change within the upper reaches which results in very little change in trend of discharge and direct runoff from the Lui station. Drastic land use changes had, however, impacted the trend in discharge and direct runoff from years 1970 to 2000 at the Dengkil station.

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