Chapter 4

Hydrological Trend Analysis Integrated with Landscape Analysis at the Watershed Scale (Case Study: Langat Basin, Malaysia)

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Additional information is available at the end of the chapter

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Abstract

In this study, the trends of water and sediment data collected from three hydrometer stations over the past 25 years of development in the state of Selangor, Peninsular Malaysia, were analyzed using the Mann–Kendall and Pettitt's tests. Landscape metrics for establishing the relationship between land use changes and trends of hydrological time series were calculated. The hydrologic trends were also studied in terms of rainfall variations and man-made features. Results indicated upward trends in water discharge at the Hulu Langat sub-basin and sediment load at the Semenyih sub-basin. These increasing trends were mainly caused by rapid changes in land use. Upward trends of hydrological series at the Hulu Langat sub-basin matched its rainfall pattern. At the Lui sub-basin, however, trends of hydrological series and variations in rainfall and land use were not statistically significant.

Keywords: trend analysis, Mann–Kendall test, Pettitt's test, landscape metrics, water discharge, sediment load

1. Introduction

Globally, increased sediment load (SL) and intense flooding due to land use changes at river basins are very challenging problems [1–4]. The impacts of human activities and climate change on hydrological processes occurring at river systems are well documented [5–10]. Understanding time series trends of water discharge (WD) and SL can be a key solution in determining how hydrological systems are affected by climate change and anthropogenic disturbances [4].

Zhang et al. [4] determined time series changes in water and sediment discharge at the Zhujiang (Pearl River) Basin in China. They applied Mann–Kendall (MK) as a gradual trend test and Pettitt's as an abrupt change test on annual WD and SL from 1950 to 2004 at nine hydrometer stations. Their study showed that long-term changes in annual WD, which were originally controlled by variation in precipitation, were not significant. SL at all main hydrometer stations showed declining trends during the study period. Declining trends were principally influenced by the construction of reservoirs and dams. In a mountainous tributary of the lower Xinjiang in China, hydrological response to changes in precipitation and anthropogenic activities were tested using MK and Pettitt's tests [11]. The power of MK and Spearman's rho tests to assess the significance of hydrological trends has been studied by Yue et al. [12]. They demonstrated that the power of both tests is directly proportional to trend slope, sample size, and predetermined significance level and inversely proportional to time series variation.

Ouyang et al. [6] established a relationship between soil erosion and landscape metrics at the Logliu catchment in China. They showed that landscape pattern significantly impacted soil erosion and sediment transportation. In several other studies, landscape metrics were applied at the landscape and patch levels to determine how hydrological conditions of the basin are affected by human activities such as land use change [13–17].

In recent decades, the Langat Basin has experienced rapid development towards urbanisation, industrialisation, and intense agriculture [18]. The Langat Basin is also a main source of drinking water for surrounding areas and a source of hydropower and has an important role in flood mitigation. Over the past four decades, the Langat Basin has served approximately 50% of the Selangor State population. However, the Selangor State is currently facing water shortage problems, especially in urban areas [19, 20].

This study was conducted to assess the impact of land use change, rainfall variation, and other anthropogenic manipulations on hydrological trends in selected upper catchments within the Langat Basin over a period of 25 years.

2. Methodology

2.1. Study area

The Langat Basin is located at the southern part of Klang Valley, which is the most urbanised river basin in Malaysia. It is believed that the Langat Basin is currently experiencing "spillover" effects due to the excessive development in the Klang Valley. Hydrometeorologically, the Langat Basin is affected by two types of monsoons, i.e., the Northeast (November–March) and the Southwest (May–September) [21]. The average annual rainfall is approximately 2400 mm. The wettest months are April and November, with an average monthly rainfall exceeding 250 mm, whereas the driest month is June, with an average monthly rainfall not exceeding 100 mm. Topographically, the Langat Basin can be divided into three distinct areas in reference to the Langat River, i.e., mountainous area in the upstream, undulating land in the centre, and flat flood plain in the downstream (**Figure 1**). The Langat Basin consists of a rich diversity of landform, surface feature, and land cover [21, 22].

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Sub-basin	**Lui**	**Hulu Langat**	**Semenyih**
Main river	Lui	Langat	Semenyih
Geographic coordinate	3°07′–3°12′N and 101°52′–101°58′E	3°00′–3°17′N and 101°44′–101°58′E	2°55′–3°08′N and 101°49′–101°58′E
Drainage area (km^2)	68.25	390.26	235.62
Basin length (km)	11.5	34.5	26.5
Average slope (%)	35	29.4	27.4
Max. altitude (m)	1207	1479	1070
Min. altitude (m)	61	20	21
Ave. altitude (m)	354	277.4	243.9
Ref. hydrometer station	Sg. Lui	Sg. Langat	Sg. Semenyih
WD ($\times10^6$ m^3/y)	55.05	289.64	146.11
SL ($\times10^3$ ton/y)	5.88	146.6	36.81
Runoff (mm/km^2/y)	806.57	742.16	620.11
Sediment yield (ton/km^2/y)	86.22	375.65	156.22
Ref. rainfall station	Kg. Lui	UPM Serdang	Ldg. Dominion
Precipitation (mm)	2188.3	2453	2548.8
Land covers*	Forest 80.35%, cultivated rubber 9.85%, orchards 2.6%, mixed horticulture and crops, urbanised area, and mining land 7.2%	Forest 54.6%, cultivated rubber 15.6%, orchards 2%, urbanised area 15%, horticulture and crops, oil palm, lake, and mining land 12.8%	Forest 53.8%, cultivated rubber 17.4%, oil palm 6.3%, urban area 5.6%, secondary forest 3.6%, scrub land 2.4%, mining, other crops, mixed horticulture, orchard, bare land, marshland and aquaculture 10.9%

*Based on the land use map dated 2006.

Table 1. General information of the studied sub-basins.

Based on the availability of hydrometric stations in the Langat Basin, three sub-basin (upstream of the Langat River) were investigated. The descriptions about these sub-basin are given in **Table 1**.

2.2. Data set

WD, SL, and precipitation data between 1984 and 2008 recorded at all three hydrometer and rain gauge stations under study (**Table 1**) were obtained from the Department of Irrigation and Drainage (DID) of Malaysia. The geographic location and general information of the hydrometer stations are presented in **Figure 1** and **Table 2**. Land use maps dated 1984, 1988, 1990, 1995, 1997, 2001, 2002, 2005, and 2006 were obtained from the Soil Resource Management and Conservation Division, Department of Agriculture, Malaysia.

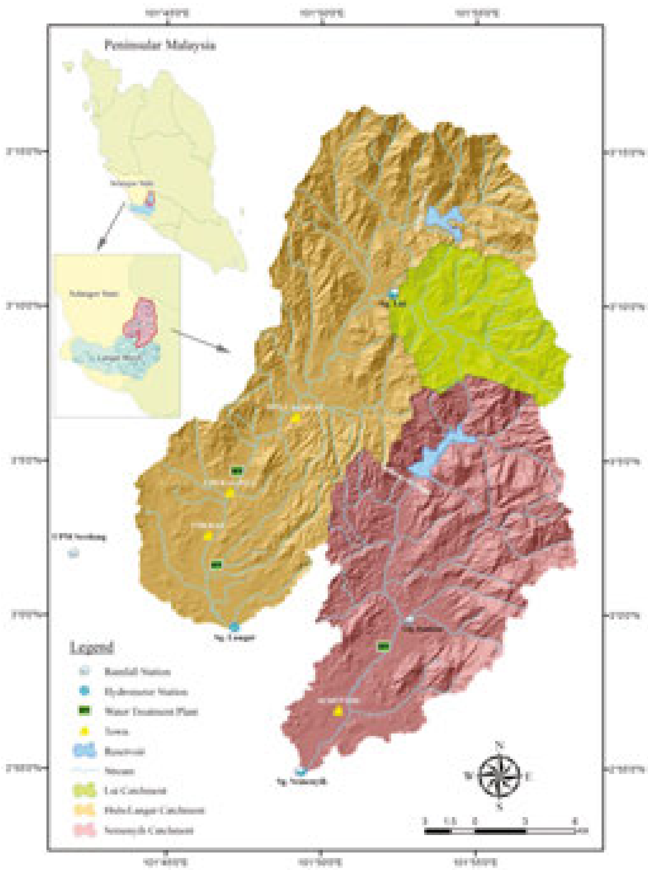

Figure 1. Geographic locations of the three study sub-basins.

2.3. Trend analysis

In this study, non-parametric tests, such as MK and Pettitt's, were used to detect gradual and abrupt changes in the hydrological data sets. According to Zhang et al. [4], non-parametric tests are preferred over parametric tests due to their strength in handling non-normally distributed data and missing data. The MK equation that is based on the *S* statistic is as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{1}$$

where *xi* and *xj* are sequential data values, *n* is the length of time series, and

$$\text{sgn}(\theta) = \begin{cases} 1 \ \ if\ \theta > 0 \\ 0 \ \ if\ \theta = 0 \\ -1 \ \ if\ \theta < 1 \end{cases} \tag{2}$$

Mann (1945) and Kendall (1975) (as cited by Yue et al. [12]) have posted that, when $n \geq 8$, S is almost normally distributed with the following mean and variance:

$$E(S) \ = \ 0 \tag{3}$$

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i i(i-1)(2i+5)}{18} \tag{4}$$

where t_i is number of ties of the extent i.

The standard Z statistic is calculated as follows:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \tag{5}$$

Z_{MK} pursues the standard normal distribution with μ=0 and δ=1.

The probability (P) of the S statistic is estimated by normal cumulative distribution function as follows:

$$P = 0.5 - \Phi(|Z|)$$

$$\Phi(|Z|) = \frac{1}{\sqrt{2\pi}} \int_{0}^{|Z|} e^{\frac{-t^2}{2}} dt \tag{6}$$

Statistical significance of the data trend was based on 95% confidence level [12].

The MK test is not robust against autocorrelation [4, 11, 23]. As such, an autocorrelation test was performed on the data set to determine the degree of autocorrelation. The autocorrelation coefficient is estimated as follows [24]:

$$r_k = \frac{\frac{1}{n-k}\sum_{t=1}^{n-k}(X_t - \bar{X})\left(X_{t+k} - \bar{X}\right)}{\frac{1}{n-1}\sum_{t-1}^{n}(X_t - \bar{X})} \tag{7}$$

where X=t=1$nXtn$, n is the sample size, and k is the lag.

For a completely random series, $r_k \approx 0$ for all $k \neq 0$. If a series of r_k (for $k \neq 0$) fall between the 95% confidence level estimated by $\frac{u}{l} = \left(-1 \pm Z_{1-\propto/2}\sqrt{n-2}\right) / (n-1)$ (where n is the length of tested time series, l and u are the lower and upper limits, α is the significance level, and Z is the critical value of standard normal distribution for a given α), then the tested series will be independent at the 95% confidence level [23]. The WD and SL data showed significant autocorrelation. Therefore, Zhang's method of data pre-whitening [25] was used to eliminate significant autocorrelation within the data.

Sen's non-parametric method was used to estimate the change magnitude (i.e., slope of the linear trend). Sen's method is robust against non-normally distributed data, missing values, and extreme outliers (Sen, 1968) (as cited by Zhang and Lu [11]).

Considering a sequence of random variables X_1, X_2, …, X_t, which have a change point at τ [X_t for t = 1, 2, …, τ have a common distribution function $F_1(x)$ and X_t for t=τ+1, …, T have a common distribution function $F_2(x)$ and $F_1(x) \neq F_2(x)$], Pettitt's test (1979) (as cited by Zhang et al. [4] and Wolfe and Schechtman [26]) was used to detect one unknown change point in the pre-whitened WD and SL time series. In the Pettitt's test, null hypothesis (H_0): no change (τ=T) is tested against alternative hypothesis (H_a): change ($1 \leq \tau < T$)) by the non-parametric K statistic, as follows:

$$K_t = max_{1\leq t\leq T}\left|U_{t,T}\right| = \max\left(K_T^+, K_T^-\right) \tag{8}$$

where $U_{t,T} = \sum_{i=1}^{t}\sum_{j=t+1}^{T} \mathrm{sgn}(X_t - X_j)$, $\mathrm{sgn}(\theta) = \begin{cases} 1\,(if\ \theta > 0) \\ 0\,(if\ \theta = 0) \\ -1\,(if\ \theta < 0) \end{cases}$. $K_T^+ = max_{1\leq t\leq T} U_{t,T}$ for downward shift and $K_T^- = -min_{1\leq t\leq T} U_{t,T}$ for upward shift. The significance level of K_T^+ or K_T^- is estimated by $P = \exp\left(\frac{-6K_T^2}{T^3 + T^2}\right)$. When K_T occurs, the time t will be the point of change. When P is smaller than the specific significance level, H_0 is rejected.

The above procedures were performed using XLSTAT and R statistical packages.

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2.4. Landscape analysis

To assess the changes in land use patterns over the period 1984–2006 (including nine records), Patch Analyst 3.0 (Grid) extension in ArcView 3.3 was applied to calculate landscape metrics [27], which are fundamental indices for the detection of trends in land use change [6]. A brief description of the six selected landscape metrics for this work is given below [28, 29]:

The number of patches (NUMP) is ≥1.

The patch size coefficient of variation (PSCOV) is the variability of the patch size relative to the mean patch size.

$$PSCOV = \frac{PSSD}{MPS}(100) \tag{9}$$

where PSCOV ≥ 0, PSSD is the standard deviation in patch size and MPS is mean patch size of the corresponding patch type.

Edge density (ED) equals the sum of lengths (m) of all edge segments involving the corresponding patch type divided by the total landscape area (m^2) in meters per hectare.

The Shannon's diversity index (SDI; at the landscape level) is a measure between 0 and 1. SDI equals 0 when the landscape comprises only one patch (i.e., no diversity) and increases with increasing number of patch types. SDI equals 1 when the different patch types are distributed proportionally.

$$SDI = -\sum_{i=1}^{m}(P_i.lnP_i) \tag{10}$$

where P_i is proportion of the landscape occupied by the patch type (class) i.

The Shannon's evenness index (SEI; at the landscape level) is a measure between 0 and 1. SEI equals 0 when the landscape comprises only one patch (i.e., no diversity) and approaches 0 as the areal distribution of patch types becomes uneven (i.e., dominated by one type). When the areal distribution of patch types is perfectly even, SEI equals 1.

$$SEI = \frac{-\sum_{i=1}^{m}(P_i.lnP_i)}{lnm} \tag{11}$$

where m defines the number of patch types (classes) present in the landscape including the landscape border.

The interspersion and juxtaposition index (IJI) is the observed interspersion over the maximum possible interspersion for a given number of patch types. IJI approaches 0 when the corresponding patch type is adjacent to only one other patch type and is 100 when the corresponding patch type is equally adjacent to all other patch types.

$$IJI = \frac{-\sum_{k=1}^{m'}\left[\left(\frac{e_{ik}}{\sum_{k=1}^{m'} e_{ik}}\right) ln\left(\frac{e_{ik}}{\sum_{k=1}^{m'} e_{ik}}\right)\right]}{\ln(m'-1)}(100) \tag{12}$$

where e_{ik} is the total length (m) of edge in landscape between the patch types (classes) i and k, and m' defines the number of patch types (classes) presented in the landscape.

3. Results

3.1. Hydrological trend analysis

The autocorrelation test reveals that the WD series (except that at Sg. Lui hydrometer station) and SL series have at least one autocorrelation coefficient that is significant at the 95% confidence level (**Figure 2**). The autocorrelation coefficients of the WD series at both Sg. Langat

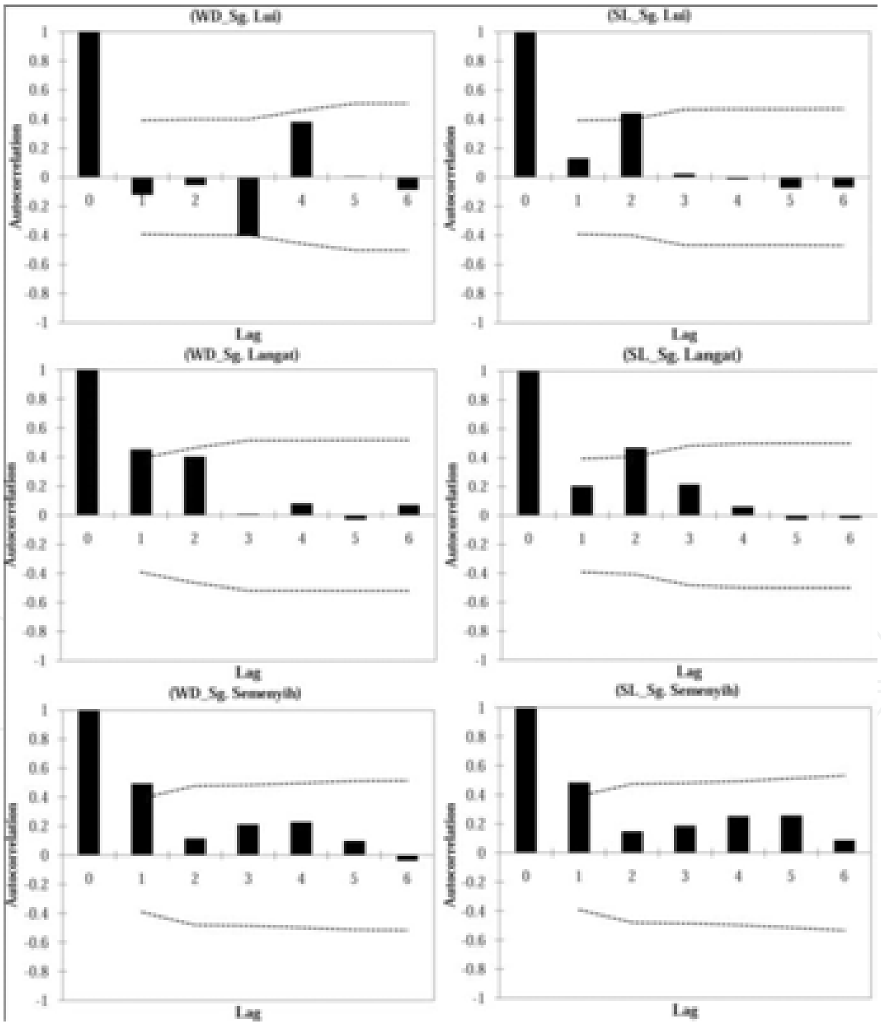

Figure 2. Autocorrelograms, resulted from autocorrelation test on WD and SL at the selected hydrometer stations.

and Sg. Semenyih hydrometer stations are significant at the first lag. The SL series at Sg. Langat and Sg. Semenyih hydrometer stations have one significant autocorrelation coefficient at the second and first lags, respectively. The SL series at Sg. Lui hydrometer station is autocorrelated significantly only at the second lag.

The results of gradual trend analysis based on MK and Pre-Whitening MK (PWMK) tests for WD and SL data are shown in **Table 2**. At Sg. Langat, WD shows an increasing trend that is significant at the 95% confidence level; however, the ascendant trend of SL is not statistically significant. There are no significant trends in the hydrological time series of Sg. Lui and Sg. Semenyih.

Gradual changes in the hydrological time series at all three hydrometer stations are given in **Table 2**. At Sg. Lui, WD and SL are decreasing at a rate of $0.524{\times}10^6$ m^3/y and $0.119{\times}10^3$ ton/y, respectively. At Sg. Langat, however, WD and SL are increasing at a rate of $9.899{\times}10^6$ m^3/y and $1.415{\times}10^3$ ton/y. At Sg. Semenyih, WD and SL show declining tendencies at $3.686{\times}10^6$ m^3/y and $0.316{\times}10^3$ ton/yr.

Station name	Parameter	MK and PWMK trend tests			Sen's slope estimator			
		τ	*P*	Trend	Trend	Trend_P	Linear	Intercept
Sg. Lui	WD	−0.153	0.297	Decreasing	−0.524	−13.105	−0.525	62.723
	SL	−0.072	0.637	Decreasing	−0.119	−2.986	−0.471	4.596
Sg. Langat	**WD**	**0.326**	**0.027**	**Increasing**	**9.899**	**247.485**	**11.531**	**156.869**
	SL	0.130	0.385	Increasing	1.415	35.380	13.142	46.278
Sg. Semenyih	WD	−0.196	0.189	Decreasing	−3.686	−92.145	−3.912	187.036
	SL	−0.058	0.710	Decreasing	−0.316	−7.909	−3.611	20.707

Trend: Sen's slope (trend) per unit time; Trend_P: Sen's slope (trend) over the time period; Linear: least-squares fit trend; Intercept: intercept of the Sen's slope (trend).

Table 2. Results of MK and PWMK tests with the Sen's slope estimator (at α=0.05) applied on WD and SL (data in bold are significant).

The results of abrupt changes based on the Pettitt's test for WD and SL are shown in **Figures 3** and **4** and **Table 3**. The results show significant drastic changes in the hydrological time series at Sg. Langat and Sg. Semenyih hydrometer stations. At Sg. Langat, the mean level of WD (after 1998) shifted upward to $392.09{\times}10^6$ m^3/y, which corresponds to a 77% increase, whereas the mean level of SL (after 1999) shifted upward to $297.27{\times}10^3$ ton/y, which corresponds to a 380% increase (**Figure 3**). At Sg. Semenyih, the mean level of WD (after 1993) shifted downward to $111.18{\times}10^6$ m^3/y (44% decrease) and the mean level of SL shifted downward to $14.89{\times}10^3$ ton/y (78% decrease; **Figure 4**). At Sg. Lui, however, downward shifts in hydrological time series are not significant.

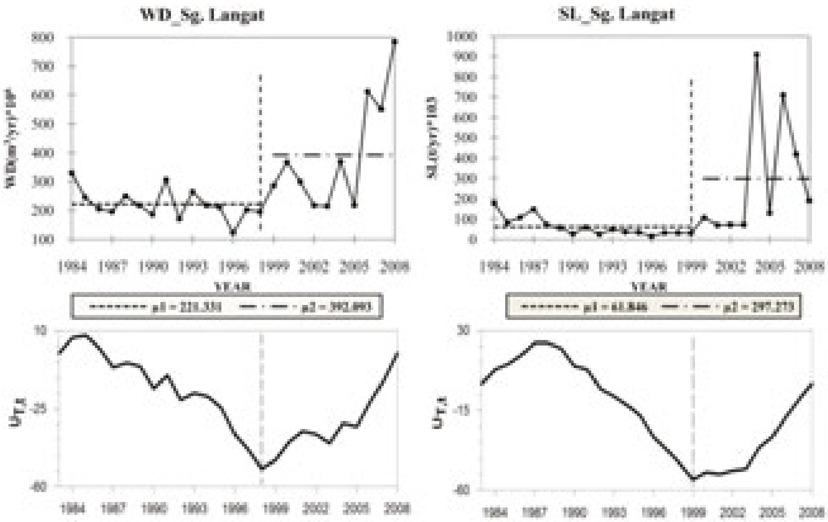

Figure 3. Abrupt changes in the mean level of WD and SL for Sg. Langat at the significance level of 0.05.

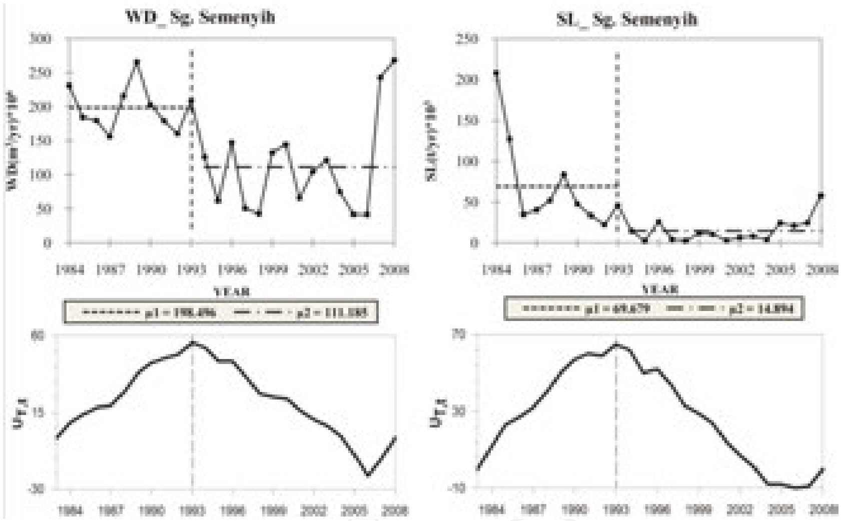

Figure 4. Abrupt changes in the mean level of WD and SL for Sg. Semenyih at the significance level of 0.05.

Station name	Parameter	K_T	*P*	Shift	*T*
Sg. Lui	Water	56.000	0.430	Downward	1987
	Sediment	82.000	0.084	Downward	1988
Sg. Langat	**Water**	**104.000**	**0.012**	**Upward**	**1998**
	Sediment	**108.000**	**0.009**	**Upward**	**1999**
Sg. Semenyih	**Water**	**112.000**	**0.010**	**Downward**	**1993**
	Sediment	**130.000**	**0.005**	**Downward**	**1993**

Table 3. Results of Pettitt's test applied on WD and SL (data in bold are significant at the level of 0.05).

Based on the PWMK test, the gradual change in the Lui and Semenyih sub-basin are showing declining tendencies. It is important to know whether these declining tendencies will prevail after the change point. **Table 4** shows that all hydrological series have increasing tendencies after the change point, which are statistically significant only for SL series at Sg. Semenyih. Meanwhile, decreasing tendencies before the change point are statistically significant only for SL series recorded at Sg. Langat.

Station	Parameter	*T*	Time series	MK trend test		
				τ	*P*	Trend
Sg. Lui	WD	1987	Pre-T*	—	—	—
			Post-T	0.057	0.739	Increasing
	SL	1988	Pre-T	−0.666	0.308	Decreasing
			Post-T	0.184	0.269	Increasing
Sg. Langat	WD	1998	Pre-T	−0.331	0.112	Decreasing
			Post-T	0.405	0.127	Increasing
	SL	1999	**Pre-T**	**−0.582**	**0.004**	**Decreasing**
			Post-T	0.388	0.175	Increasing
Sg. Semenyih	WD	1993	Pre-T	0.000	1.000	—
			Post-T	0.143	0.511	Increasing
	SL	1993	Pre-T	−0.357	0.265	Decreasing
			Post-T	**0.450**	**0.028**	**Increasing**

*Limitation in number of records.

Table 4. Results of the MK and PWMK tests on WD and SL before and after the change points (data in bold are significant at the level of 0.05).

3.2. Landscape analysis

The relationships between landscape metrics and hydrological variables are given in **Table 5**. At the Lui sub-basin, all metrics with the exception of IJI and SEI are negatively correlated with WD and SL. SL correlates significantly with PSCOV and SEI, whereas WD correlates significantly with ED and NUMP.

At the Semenyih sub-basin, all metrics are negatively correlated with WD and SL. Correlations between these metrics and WD are statistically significant. Correlations between these metrics with the exception of IJI and PSCOV and SL are statistically significant. At the Hulu Langat sub-basin, on the contrary, all metrics are positively correlated with WD and SL but are not statistically significant.

In comparison, correlations between hydrological series and landscape metrics are more pronounced after the change point (**Table 5**). For example, at the Semenyih sub-basin, correlations between hydrological series and all metrics change from negative to positive and are only significant for PSCOV. Also, at the Hulu Langat sub-basin, correlations between WD and the metrics ED, SDI, and NUMP are statistically significant.

Table 6 shows the trend analysis of landscape metrics during the period 1984 to 2006. At the Lui **sub**-basin, only NUMP shows a significant increasing trend. At the Hulu Langat **sub**-basin, all metrics show increasing tendencies but are statistically significant only for PSCOV, ED, SDI, and NUMP. At the Semenyih **sub**-basin, all metrics with the exception of IJI show significant increasing trends.

Landscape metric	All records						Records after the change points					
	Lui		Hulu Langat		Semenyih		Lui		Hulu Langat		Semenyih	
	WD	SL	WD	SL	WD	SL	WD	SL	WD	SL	WD	SL
PSCOV	−0.625	**−0.788***	0.358	0.243	**−0.921****	−0.584	−0.408	0.081	0.460	0.674	**0.887***	**0.932****
ED	**−0.680***	−0.471	0.289	0.244	**−0.957****	**−0.790***	−0.549	−0.026	**0.941***	0.784	0.552	0.548
IJI	0.091	0.238	0.206	0.191	**−0.973****	−0.660	0.048	0.137	0.674	0.659	0.380	0.575
SDI	−0.556	−0.099	0.257	0.228	**−0.885****	**−0.865****	−0.532	−0.026	**0.981***	0.846	0.789	0.670
SEI	0.474	**0.951****	0.340	0.379	**−0.940****	**−0.873****	−0.150	0.168	0.481	0.646	0.389	0.398
NUMP	**−0.703***	−0.481	0.362	0.523	**−0.954****	**−0.704***	−0.584	−0.025	**0.955***	0.870	0.762	0.759

*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

Table 5. Correlations between the different landscape metrics and hydrological series using the Pearson correlation method.

Landscape metric	Lui	Hulu Langat	Semenyih
PSCOV	NS ↑	* ↑	* ↑
ED	NS ↑	* ↑	* ↑
IJI	NS ↓	NS ↑	NS ↑
SDI	NS ↑	* ↑	* ↑
SEI	NS ↓	NS ↑	* ↑
NUMP	* ↑	* ↑	* ↑

*Trend is significant at the 0.05 level.
NS, not significant. ↑, increasing; ↓, decreasing.

Table 6. Trend analysis of the landscape metrics during 1984 to 2006 at the studied sub-basins.

The categorisation of the landscape metrics using the clustering technique for all three sub-basins is given in **Figures 5–7**.

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At the Lui **sub**-basin, PSCOV, ED, and NUMP corresponding to years 1984, 1988, and 1990 are categorised in the first cluster, whereas landscape metric values of the remaining years are classified in the second cluster. Meanwhile, SEI (1984 and 1988) and SDI (1988 and 1990) are categorised in the first cluster, whereas the values of the remaining years are classified in the second cluster (**Figure 5**).

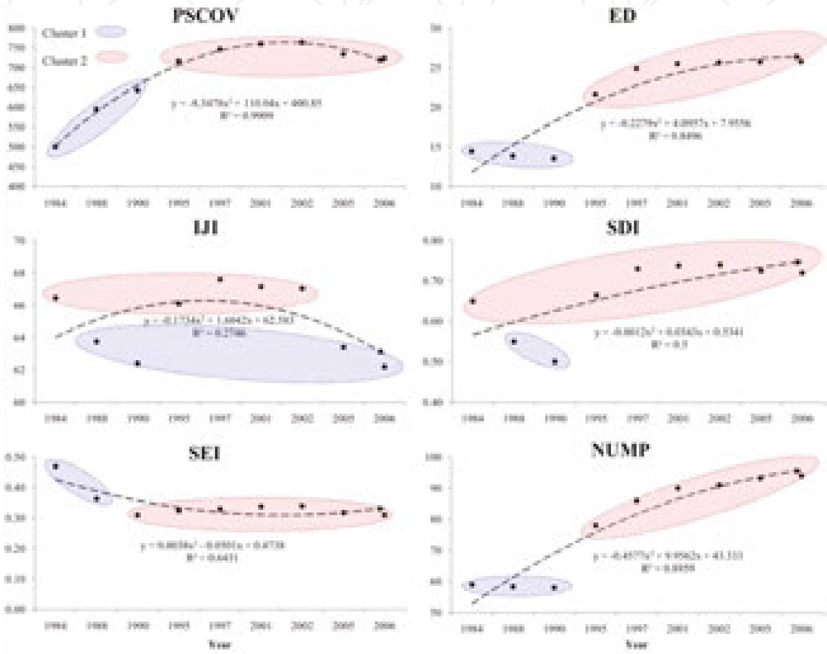

Figure 5. Change trends and classification of the landscape metrics at the Lui sub-basin during 1984 to 2006.

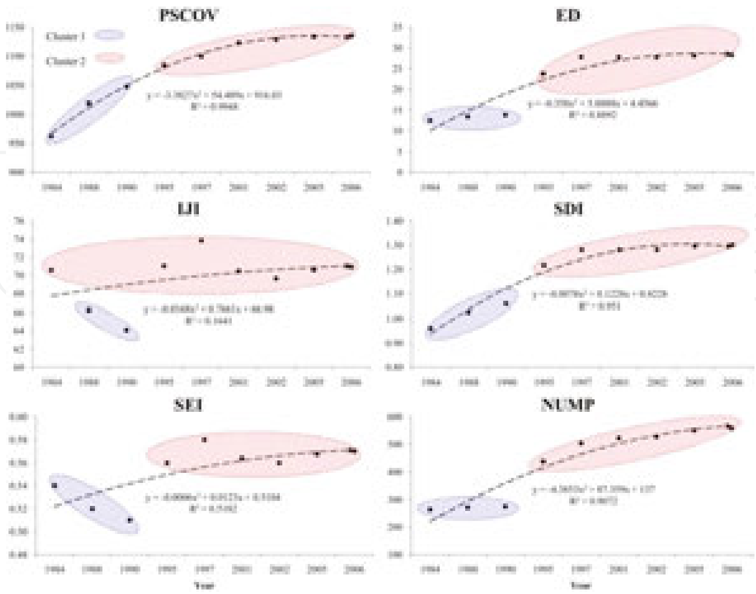

Figure 6. Change trends and classification of the landscape metrics at the Hulu Langat Sub Basin during 1984-2006.

All landscape metric values at the Hulu Langat (except for IJI) and Semenyih sub-basins corresponding to years 1984, 1988, and 1990 are grouped in the first cluster and the values of the remaining years are grouped in the second cluster (**Figure 6**).

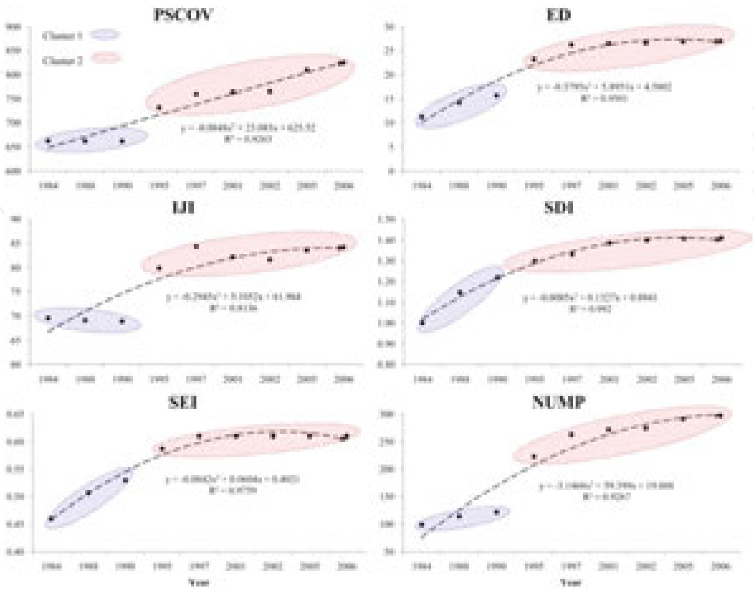

Figure 7. Change trends and classification of the landscape metrics at the Semenyih sub-basin during 1984 to 2006.

3.3. Land use change detection

Change detection was based on the land use maps dated 1984 and 2006. The results show noticeable gains in agriculture, bare land, mining, oil palm, and urban acreage and a remarkable loss in rubber acreage (**Table 7**).

Land use	Difference (2006–1984) in hectares		
	Lui	Hulu Langat	Semenyih
Agriculture	436.39	1545.32	451.57
Bare land	6.30	370.60	175.50
Forest	359.75	112.04	-237.72
Grassland	5.00	−471.70	382.30
Marshland/swamp	46.42	148.93	-39.73
Mining	16.67	395.27	147.57
Oil palm	3.44	21.81	1051.89
Rubber	−809.43	−7817.72	-3860.35
Urban/built-up area	111.09	5649.90	1501.61
Water body	0.00	45.55	427.36

Table 7. Land use change detection between 1984 and 2006 at the studied sub-basins.

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Increasing gradual trends (as determined by the MK test using the 1984–2006 time series) in agriculture and mining acreages are significant only at the Hulu Langat **sub**-basin, whereas increasing gradual trend in oil palm acreage is significant only at the Semenyih **sub**-basin. Decreasing gradual trend in rubber acreage is significant at both Hulu Langat and Semenyih sub-basins. At all three sub-basins, a change trend in forest area is not significant, whereas increasing trend in the urbanised area is significant (**Table 8**).

Land use	Lui	Hulu Langat	Semenyih
Agriculture	NS ↑	* ↑	NS ↑
Forest	NS ↓	NS ↓	NS ↓
Urban	* ↑	* ↑	* ↑
Rubber	NS ↓	* ↓	* ↓
Oil palm	NS ↑	NS ↑	* ↑
Mining	NS ↑	* ↑	NS ↑

*Trend is significant at the 0.05 level.
NS, not significant. ↑, increasing; ↓, decreasing.

Table 8. Trend analysis of land use change during 1984–2006 at the studied sub-basins.

4. Discussion

Based on the hydrological trend analysis, the Hulu Langat sub-basin showed a significant increasing trend of WD. However, the Semenyih and Lui sub-basins showed decreasing tendencies of WD and SL. Gradual increase in hydrological series after the change points is significant only in the case of SL at Sg. Semenyih. In the following sections, hydrological alterations are discussed in relation to land use change, rainfall fluctuations, and other anthropogenic manipulations.

4.1. Effect of land use/cover change (LUCC)

Based on the data from the Department of Statistics, Malaysia (2001) and the National Urbanisation Policy of Malaysia (1981), rapid development in the state of Selangor started in 1981. The rapid development was aimed at attracting approximately 18% of Malaysia's population to be settled in the state of Selangor by the year 2000 [30, 31]. The Langat Basin appears as a suitable barometer to measure urbanisation and agricultural/industrial development in the state of Selangor.

Based on **Tables 7** and **9**, rubber acreage at the Hulu Langat and Semenyih sub-basins decreased significantly between 1984 and 2006. During this period, at the Hulu Langat sub-basin, 34% of rubber acreage was transformed into urban areas, whereas another 11% was used for other agricultural production. Similarly, at the Semenyih sub-basin, 21% of rubber acreage was transformed into urban areas, whereas 15% and 6% were used for oil palm and other agricultural productions, respectively (**Table 7**). Based on these results and the work of Noorazuan et al. [22] and Juahir et al. [19], it is expected that these changes will affect the stream flow behaviour and characteristics.

1984	**2006**						
	Lui						
	Forest	**Rubber**	**Agriculture**	**Scrub/idle grassland**	**Oil palm**	**Urbanised/ industrial area**	**Water bodies**
Forest		1	1			1	
Rubber			21			5	
Scrub/idle grassland	47	11	33			4	
	Hulu Langat						
Forest		4				3.5	
Rubber			11			34	
Agriculture		17				26	
Scrub/idle grassland	38	17	10			31	
	Semenyih						
Forest		2.5				1.4	2.7
Rubber			6		15	21	
Agriculture		7		10	56	15	
Scrub/idle grassland	70	10				19	
Oil palm		8	8			34	
Swamp/ marshland		7	80		13		
Bare land		67					

Table 9. Land use change matrix for important transitions (frequencies in %) between the years 1984 and 2006 at the studied sub-basins.

Tables 6 shows the increasing trend in landscape change during 1984–2006, which is confirmed by correlation analysis (**Table 5**), especially after the change points [6, 32].

At the Hulu Langat sub-basin, cluster analysis shows that discriminant points between the clusters of landscape metrics (except for IJI) are within the period 1990–1997 (**Figure 6**). These points correspond to the points of change in WD and SL. At the Semenyih sub-basin, the change point in WD and SL (i.e., 1993) matches the discriminant point in all landscape metric clusters, with the exception of SDI (**Figure 7**). At the Lui sub-basin, points of change in WD and SL (1987 and 1988) match only the discriminant point in SEI. As indicated in **Table 6**, at the Lui sub-basin, change trends in landscape metrics are not statistically significant. This could have contributed to the insignificant impact of LUCC on the basin hydrological conditions.

4.2. Effect of rainfall variations

The rainfall stations (i.e., Kg. Lui, UPM Serdang, and Ldg. Dominion) were analysed for rainfall change trend. These three rainfall stations represent rainfall events at the Lui, Hulu Langat, and Semenyih sub-basins, respectively (**Table 10**). Increasing trend in the rainfall time series is only significant at UPM Serdang, which corresponds to increasing trends in WD and SL at Sg. Langat. Although the change point in rainfall series at UPM Serdang (i.e., 1998) is not statistically significant, it matches the change point in WD and SL at Sg. Langat. This point matches the critical water level at Langat Reservoir [33], which has been reported by Shaaban and Low [34]. At Kg. Lui, the change tendency of rainfall series after the hydrological change point matches the trend of WD and SL at Sg. Lui (**Table 11**). At Ldg. Dominion, the change tendency in rainfall does not match the available tendency in hydrological series at Sg. Semenyih, especially for SL after the change point.

Station name	MK trend test			Pettitt's test			
	τ	P	Trend	K_T	P	Shift	T
Kg. Lui	0.144	0.333	Increasing	70.000	0.188	Upward	2003
UPM Serdang	**0.341**	**0.020**	**Increasing**	78.000	0.079	Upward	1998
Ldg. Dominion	0.101	0.503	Increasing	68.000	0.231	Upward	1990

Table 10. Results of the PWMK and Pettitt's tests applied on the rainfall time series at the representative stations (data in bold are significant at α=0.05).

Rainfall station	T_Hydro series	Time series	PWMK trend test		
			τ	P	Trend
Kg. Lui	1988	Pre-T	−0.333	0.734	Decreasing
		Post-T	0.111	0.528	Increasing
UPM Serdang	1998	Pre-T	0.256	0.246	Increasing
		Post-T	0.066	0.858	Increasing
Ldg. Dominion	1993	Pre-T	0.444	0.117	Increasing
		Post-T	0.000	1.000	—

Table 11. Results of PWMK test applied on the rainfall time series before and after the hydrological change points.

Thus far, results reveal the significant impacts of land use and rainfall variations on WD at the Hulu Langat sub-basin. However, the impacts on the sub-basin SL are not statistically significant. At the Lui sub-basin, the change trends in rainfall and landscape variables are not statistically significant. Hence, the insignificance of hydrological series trend is expected. At the Semenyih sub-basin, the impact of land use change on hydrological series is driven by the significant increasing trend in SL after 1993. However, rainfall variations do not impact the trend of hydrological series.

From the preceding discussion, two questions are important. First, have the Semenyih Reservoir and its connected water treatment facilities at the Semenyih sub-basin impacted the basin WD significantly? Secondly, despite the significant impact of land use change on the change trend in WD at the Hulu Langat sub-basin, why is the change trend in SL not statistically significant? In the following discussion, these questions are addressed.

4.3. Effect of man-made structures

There are two strategic dams in the Langat Basin. The Langat Dam, constructed in 1979, has a drainage catchment area of 41.5 km^2 and a reservoir capacity of 37.5 Mm^3. The Semenyih Dam, built in 1985, has a drainage catchment area of 56.7 km^2 and a reservoir capacity of 62.6 Mm^3. Both these dams supply domestic and industrial water. The Langat Dam is also used to generate power supply at moderate capacity for consumption within the Langat Valley. Currently, there are three major water treatment plants (WTP; operating 24 hours a day) within the study area. The Sg. Langat and Cheras WTPs along the Langat River produce 386.4 and 27 million litres per day (MLD) of clean water, respectively. The Semenyih WTP along the Semenyih River produces 545 MLD of clean water [30, 33].

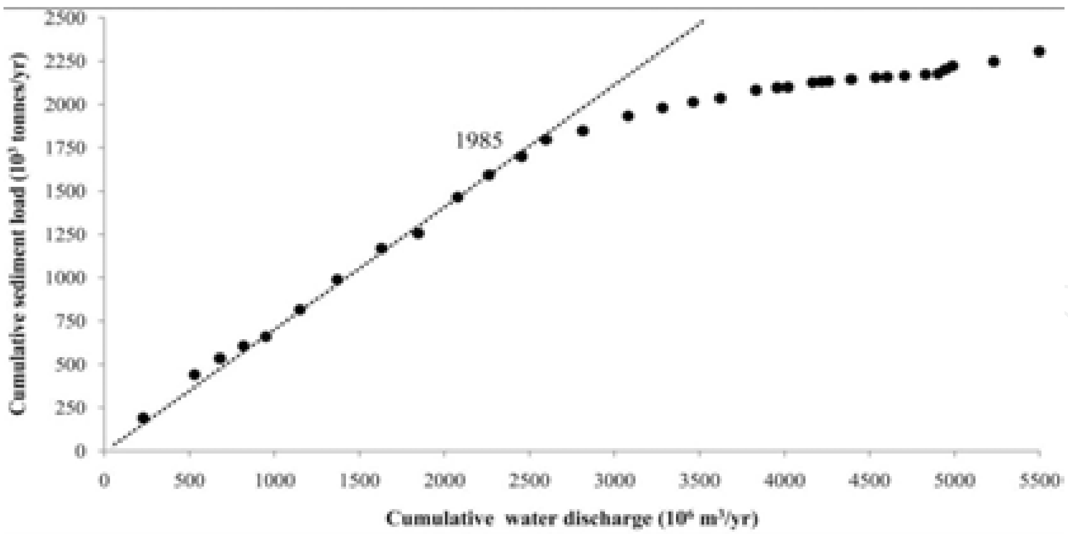

Figure 8. Cumulative double mass plot at Sg. Semenyih.

To evaluate the impact of Semenyih Dam construction on trends of hydrological time series, a double mass curve was plotted. As illustrated in **Figure 8**, at Sg. Semenyih, the hydrological time series trend after 1985 is seriously affected by the dam and WTP construction. The mean WD level changes from 231.8×10^6 m^3/y before 1985 to 141×10^6 m^3/y after 1985. The results of the Pettitt's test for WD and SL during the period 1975–1993 were statistically significant (P=0.018 and P<0.001, respectively). This confirms 1985 as the point of change during the period 1975 to 1993.

Shaaban and Low [34] showed that drought events reduced WD at the Semenyih sub-basin, particularly in the period 1993–1998. As such, WTP and dam together with the effect of drought have been able to reduce the increasing trend of WD, especially after 1993.

At the Hulu Langat sub-basin, due to the significant trend in urbanisation and agricultural activities (**Tables 7** and **9**), the number and size of natural or artificial ponds are expected to increase dramatically. Field observation from this study confirms that the quantity of natural and artificial ponds is higher at Hulu Langat compared to that at Semenyih. The ponds are believed to affect the sedimentation process by increasing the deposition rate, hence resulting in the reduction in SL of the basin (**Figure 9**). It is clear that the Langat Dam and other sediment trapping features (i.e., natural and artificial ponds) contributed to the insignificant trend of SL at the Hulu Langat sub-basin.

Figure 9. Ponds arisen from urban and agricultural development at the Hulu Langat sub-basin (extracted from SPOT 5 satellite images, dated 2006).

5. Conclusion

Increasing trend in WD at the Hulu Langat sub-basin was originally controlled by significant variations in land use and rainfall. However, increasing trend in SL was not significant due to dam construction and increase in the number and size of sediment trapping features, which is due to urbanisation and agricultural activities. At the Semenyih sub-basin, increasing trend in SL after 1993 was closely related to significant trends in landscape metrics and land use changes. However, WD did not increase significantly after 1993, primarily due to the impact of dam and water treatment facilities and continuous drought until 1998. At the Lui sub-basin, trends in land use and rainfall variations were mostly insignificant, thus causing an insignificant change in hydrological series.

This study demonstrates the power of the PWMK and Pettitt's tests for trend evaluation of hydrological time series. The results obtained in this work are consistent with studies done by other researchers [35–45]. Also, integrating landscape analysis with statistical analyses as emphasised in the work of several others [6, 13–17, 32, 46, 47] could increase the depth of interpretation with regard to the complex hydrological conditions of developed basins.

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