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Trend analysis of rainfall characteristics and its impact on stormwater runoff quality from urban and agricultural catchment

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Abstract. Climate change has significantly affected the rainfall characteristics which can influence the pollutant build-up and wash-off patterns from the catchment. Therefore, this study explored the influence of varying rainfall characteristics on urban and agricultural runoff pollutant export using statistical approaches. For this purpose, Mann-Kendall and Pettitt's test were applied to detect the trend and breakpoint in rainfall characteristics time series. In addition, double mass curve and correlation analysis were used to drive the relationship between rainfall-runoff and pollutant exports from both catchments. The results indicate a significant decreased in total rainfall and average rainfall intensity, while a significant increased trend for antecedents dry days and total storm duration over the study periods. The breakpoint was determined to be 2013 which shows remarkable trend shifts for total rainfall, average rainfall intensity and antecedents dry days except total duration. Double mass curve exhibited a straight line with significant rainfall-runoff relationship indicates a climate change effect on both sites. Overall, higher pollutant exports were observed at both sites during the baseline period as compared to change periods. In agricultural site, most of the pollutants exhibited significant ($p< 0.05$) association with total rainfall, average rainfall intensity and total storm duration. In contrast, pollutants from urban site significantly correlated with antecedent dry days and average rainfall intensity. Thus, total rainfall, average rainfall intensity and total duration were the significant factors for the agricultural catchment while, antecedents dry days and average rainfall intensity were key factors in build-up and wash-off from the urban catchment.

Keywords: change point; climate change; Mann-Kendall; rainfall-runoff; rainfall trend; stormwater runoff

1. Introduction

Stormwater runoff from the urban and agricultural land use have been considered as the two main sources of diffuse pollution. A number of factors, including catchment characteristics, land use pattern and hydro-climatic variability affects the quantity and quality of stormwater runoff. In recent years, the climatic variation has triggered increasing the occurrences of uneven weather events and rainfall patterns (Zhou *et al*. 2015). Recently in South Korea, the climatic variation and regional anthropogenic activities have increased significantly during the last three decades. Moreover, in the case of drought conditions, the Korean peninsula faced a severe dry period during 2012-2015. The total annual rainfall during this period was temporally less than 35-50% of the long term average from 1973 to 2015 (Lee *et al*. 2017). However, changes in rainfall trend and event characteristics can influence the storm water runoff pollutant build-up and wash-off from the catchment. In this perspective, the ability to quantify changes in runoff characteristics at local scales resulting from a variation of rainfall trends and land use changes is recognized as being vital for storm water management at the catchment level (Blair *et al*. 2014). Therefore, to detect trends, non-parametric tests, including Mann-Kendall trend test and Pettitt test are more widely used than the parametric ones due to their suitability for data with explicit distribution properties (Onyutha *et al*. 2015, Jaiswal *et al*. 2015).

Previous studies on Korean peninsula used non-parametric tests to detect the trends for spatial and temporal long term rainfall series and suggested an upward and downward trends in seasonal rainfall instead of annual variation for some stations (Jung *et al*. 2011, Park *et al*. 2011, Wi *et al*. 2016). However, the outcomes from prior studies were based on rainfall time series only and did not consider other rainfall characteristics (e.g. dry days, intensity and storm duration) which are also important factors in climate change and catchment hydrology. Moreover, previous studies did not consider the impacts of changing rainfall and rainfall variables on runoff quality

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and quantity. Therefore, it is important to determine the actual trends in rainfall and other rainfall variable time series to distinguish the impacts of climate change. In addition, the influence of changing rainfall variables on runoff quality and quantity is also crucial for devising stormwater management and treatment facilities at the catchment level.

Therefore, this study applied a non-parametric approach on hydro-meteorological time series data to investigate the actual annual trends for the rainfall variables during climate change period (2012-2014). Moreover, to assess the impacts of the varying rainfall conditions on different land use runoff, spatial and temporal pollutant loading exports were estimated from urban and agricultural catchment during monitoring periods. However, the specific aims of this study were: (a) to identify the significant trend and break point in rainfall variables; (b) to determine spatial-temporal pollutant load distributions during the climate change period and; (c) to identify the relationship between pollutant exports and rainfall variables to explore the key factors that influences the runoff pollutants at the catchment level.

2. Material and methods

2.1 Study area

The study area was the Geumhak watershed, located in Gyeonggi Province, Korea (Fig. 1). This watershed drains into Geumhak stream and eventually drains into the Paldang reservoir, the major source of drinking water for the Seoul metropolitan area and nearby provinces (Paule *et al*. 2014). It has an average annual precipitation approximately 1,312 mm and most rainfall events occur during the summer season (May to September). Two representative monitoring sites were selected on the basis of land use land cover (LULC) and hydrological characteristics to investigate the impacts of rainfall variability on stormwater runoff characteristics. Site 1 was considered as "agriculture" because more than 50-60% of the total area use for farming, and no livestock farms exist there. Site 2 was categorized as "urban" because 100% built-up land use, including residential and commercial area. This site has a separate sewer system which is adequate infiltration and exfiltration in the stormwater drainage pipes. These monitoring sites were considered based on the catchment characteristics (inclusive land use) on pollutant wash-off and rainfall-runoff process by climatic variability including rainfall characteristics.

2.2 Monitoring strategies and analysis

A total of 15 storm events between June 2012 and October 2014 were monitored at the outlets of selected catchments as shown in Table 1. For each site, grab samples (n=10-20 samples) were collected from the beginning of a storm in 10-15 min interval when the flow is rising and then at 20-30 min interval for receding flow. These sampling schemes were considered to: ensure that there is a sufficient runoff would discharge; allow some accumulated pollutants to wash-off; and ensures that the storm event would be a

Table 1 Characteristics of monitored runoff events

Event No	Event Date	TDUR (hrs)	ADD (day)	RD (mm)	RI (mm/hr)
1	29-Jun-12	16	31	88.3	5.5
2	18-Jul-12	8.6	3	33.5	3.9
3	12-Aug-12	9.2	23	28.5	3.1
4	4-Sep-12	12.9	3.8	65.7	5.1
5	22-Oct-12	8.3	11	30.5	3.7
6	18-Jun-13	12.7	3	45.6	3.6
7	2-Jul-13	6.5	4	17.2	2.6
8	22-Jul-13	9.4	3	89.4	9.5
9	29-Aug-13	8	5	30.6	3.8
10	28-Sep-13	12.4	3	17.2	1.4
11	24-Nov-13	9.8	6	17.4	1.8
12	18-Jul-14	7.8	7	14.8	1.9
13	22-Jul-14	14.1	3	23.5	1.7
14	20-Aug-14	14.5	1	39.5	2.7
15	20-Oct-14	12.8	20	18	1.4

*Note: TDUR: Total duration; ADD: Average dry days; RD: Rainfall depth; RI: Rainfall intensity

"representative" (e.g. typical for the area in terms of intensity, depth and duration). Prior to the start of rainfall or stormwater runoff, flow meters were fixed at monitoring sites. For Site 1, flow was monitored by the current velocity meter (AEM1-D, Japan). In Site 2, however, automatic flow meter (PCMF NIVUS, Germany) was used. Continuous flow was recorded using 1 min (automatic) and 10 min (manual) interval at the same location as stormwater samples were taken. All stormwater samples (2-L sterile polyethylene bottles; stored at < 4 °C) were collected at the outlet of both catchments and analyzed within 24 h in the laboratory. The collected runoff samples were examined for chemical oxygen demand (COD), total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN) in accordance with the standard methods for examination of water and wastewater (APHA 2005 and 2009). While the fecal indicator bacteria (FIB), including Escherichia coli (EC) (APHA 9221F) and Fecal streptococci (FS) (ES 05706.1a) were determined using the American (APHA 2005 and 2009) and Korean (Korea Ministry of Environment 2011) standards for the examination of water.

2.3 Hydrometric data collection and analysis

Rainfall data were obtained through an automated rainfall gauge (HB-3207-09, Casella, UK) installed about 100m from Site 2. The runoff volumes for each storm event were estimated by using Eq. (1). Moreover, long term daily meteorological time series of length not less than 15 years (2002-2016) including rainfall variables (e.g. dry days, rainfall duration, total rainfall and average rainfall intensity) were acquired from the Korean Meteorological Administration (http://web.kma.go.kr/eng/index.jsp) for the Suwon rain gauge station, which is located (approx.19km) near to the study area.

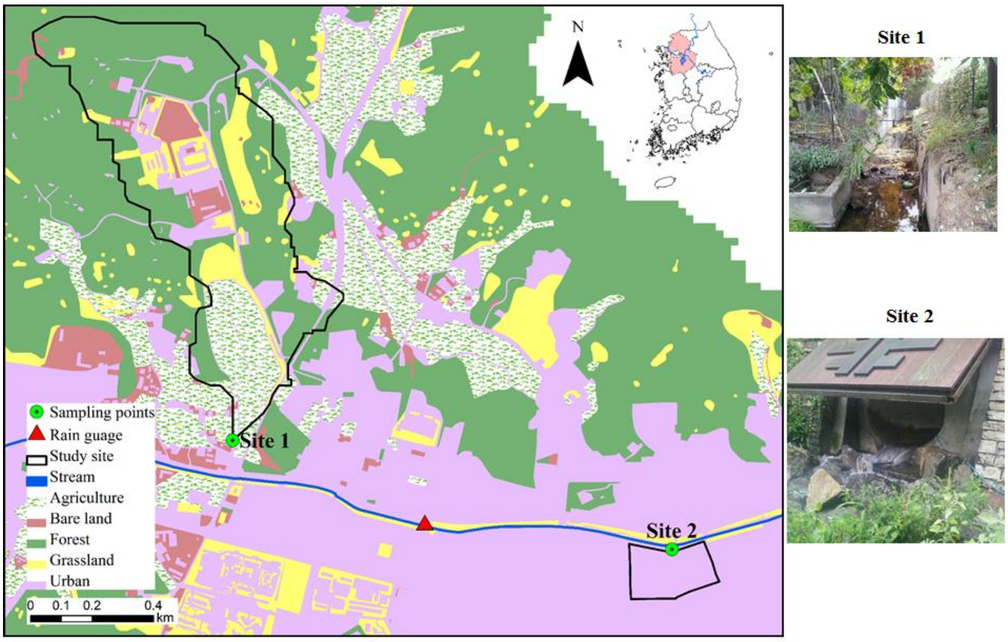


Fig. 1 Study area with land use distribution: Site (1) Agricultural; Site (2) Urban

$$RUNVOL = \frac{Ft \quad Dt}{60} \tag{1}$$

where *RUNVOL* is the runoff volume (m3); *Ft* is the flow of the sample during collection (m3/h), and *Dt* is the time interval during sample collection. The daily rainfall records were aggregated to monthly and yearly intervals and other required rainfall variables for the monitored years (2012-2014) were extracted.

2.4 Statistical analysis

2.4.1 Mann-Kendall trend test

The significance of the trends in annual rainfall time series was estimated by the non-parametric Mann-Kendall (M-K) test (Mann 1945 and Kendall 1975). The extracted daily rainfall time series and other variables (e.g. dry days, average rainfall intensity and total rainfall duration) over the study period (2012-2014) were subjected to trend analysis. This period was chosen since from 2012 to 2014 were characterized by significant changes in rainfall patterns in the Korean peninsula. The total annual rainfall during this period was significantly reduced to 50% of the long-term average from 1973 to 2015. The calculation for the Mann-Kendall statistical test is as follows;

$$S = \sum_{i=1}^{n=1} \sum_{j=i+1}^{n} \text{sgn}\,(xj - xi)$$

$$\text{sgn (t)} = \begin{cases} 1 & for\ \ t\ \ > 0 \\ 0 & for\ \ t\ \ = 0 \\ -1 & for\ \ t\ < 0 \end{cases} \tag{2}$$

where, x_j are the chronological data values, n is the length of the data set and, the value of S shows the direction of the trend. A negative and positive S value indicates a downward (upward) trend. Mann-Kendall has recognized that when, the test statistic S is approximately normally distributed with mean and variance as follows;

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2ti + 5)}{18} \tag{3}$$

where, m is the number of tied groups and t_i is the size of the tied group. The standardized test statistics Z is calculated as follows;

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{Var\ (S)}}\,, & for\ S > 0 \\ 0\,, & for\ S = 0 \\ \dfrac{S+1}{\sqrt{Var\ (S)}}\,, & for\ S < 0 \end{cases} \tag{4}$$

The standardized Mann-Kendall statistics Z_{MK} follows the standard normal distribution with zero mean and unit variance (Rai *et al*. 2010). If ≥ Z1 – (α/2), the null hypothesis about no trend is rejected at the significance level α (5, 10% in this study).

2.4.2 Breakpoint analysis

Identifying breakpoint is essential to meteorological time series, which aids in assessing homogeneity of data and the impacts of climate variability. For this purpose, a non-parametric Pettitt's test was applied to identify any significant abrupt changes within the annual aggregated rainfall variables series over the study periods. The Pettitt's test can be calculated from the following equation;

$$\text{Ut, n} = \sum_{j=1}^{t} \sum_{i=1}^{n} sgn\ (xj - xi), \quad (t = 1, \ldots n) \tag{5}$$

where the maximum Ut, corresponds to the breakpoint year in rainfall variable series. The significance level for the breakpoint exist was set to $p < 0.05$ in this analysis.

2.4.3 Double-mass curve method

The double-mass curve (DMC) method is quite simple, visual and widely used to examine the consistency and trends in climatic data (Wu *et al*. 2017). The DMC method can also be used to reflect the impacts of anthropogenic activities on the runoff (Gao *et al*. 2011). For this purpose, the relationship of cumulative runoff and cumulative rainfall was built using a DMC method to determine the baseline period and change period as follow;

$$\sum P = k \sum R + b \qquad (6)$$

where P denotes the precipitation, R is cumulative runoff, k denotes the rate of change in accumulated runoff with change in accumulated precipitation, and b represents the intercept. DMC was also used to determine the breakpoint in rainfall-runoff series as a reconfirmation of the Pettitt's test results. However, the baseline year would be considered as the reference year from which the modelled change in rainfall is calculated.

2.4.4 Characterization and correlation analysis

The stormwater runoff data sets were $\log_{10}$-transformed prior to analysis to achieve normal distribution. For each site, the pollutant unit loads were calculated using the method described by Jeon *et al*. (2013). The average total pollutant load (ATPL) was considered which is calculated as the mean of all computed unit loads for a single storm event over 3-year monitoring period. The FIB loads were computed using the simple method described by Thériault and Duchesne (2015). Pearson's correlation coefficient matrix with statistical significances ($p < 0.05$) level was used to identify the relationship between rainfall variables and runoff pollutants at both sites. All statistical analysis was performed using XLSTAT 2014 (Addinsoft SARL, New York, NY).

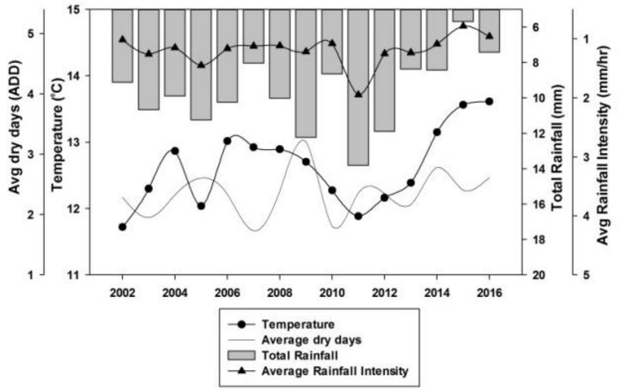
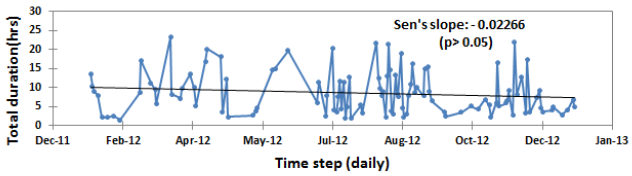
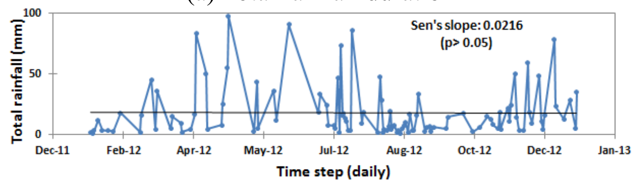


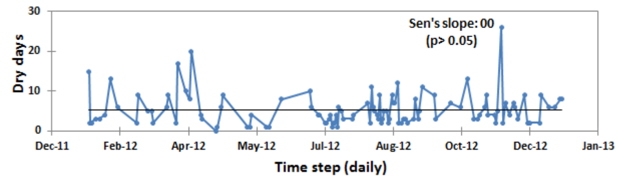
Fig. 2 Temporal variations of climatic variable over the study area



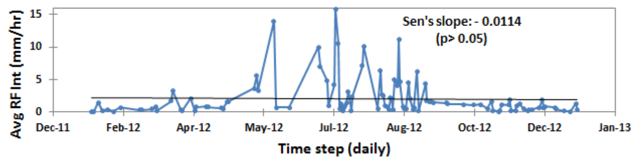
(a) Total rainfall duration



(b) Total rainfall



(c) Antecedent dry days



(d) Average rainfall intensity

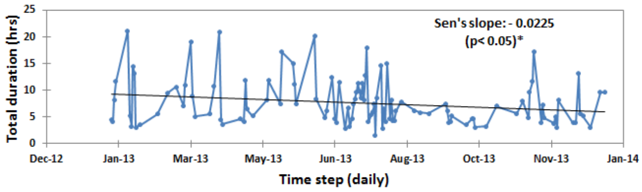
Fig. 3 Mann-Kendall test trend of rainfall variables in 2012

3. Results and discussion

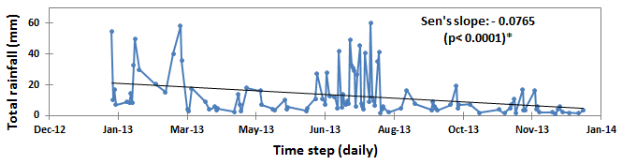
3.1 Trends in rainfall characteristics

Overall, the trend analysis of annual rainfall characteristics indicates that the total rainfall decreased about 25% over the study period, especially from 2012 to 2015 (Fig. 2). Therefore, the annual total rainfall in 2012 was 1674 mm which then later decreased to 1211 mm in 2013 and 1029mm in 2014. However, annual mean temperature and average dry days showed an upward trend with 2% increased over the monitoring period. While the average rainfall intensity showed a moderate to consistent trend as compared to other variables. In order to better understand the changes in climatic variables, Mann-Kendall trend test was used to explore the annual trend of rainfall characteristics, including antecedent dry days, total rainfall duration, total rainfall, and average rainfall intensity. Based on trend test, it can be seen from Fig. 3(a), (d), that there was a non-significant ($p > 0.05$) falling trend in total rainfall duration (Sen's slope: -0.022) and average rainfall intensity (Sen's slope: -0.011) in 2012 as compared to total rainfall which showed a non-significant higher trend, while no trend for antecedent dry days (Fig. 3 (b), (c)). Most of the storm events in 2012 occurred during early spring (March-May) and summer (June-August) with higher total rainfall and longer duration as compared to the average rainfall intensity which showed a higher trend only during peak summer (May-August).

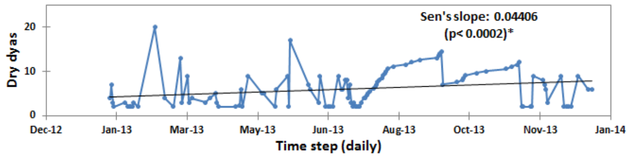
However, most of rainfall variables showed significant changes in 2013 (Fig. 4(a)-(c)). Total rainfall duration exhibited a significant decreasing trend (Sen's slope: -0.022, $p < 0.05$). A similar trend was observed for total



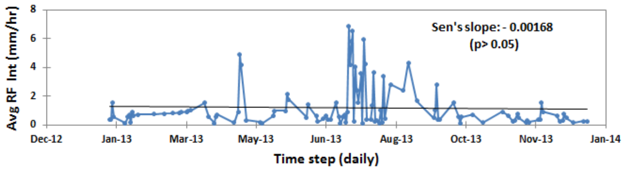
(a) Total rainfall duration



(b) Total rainfall

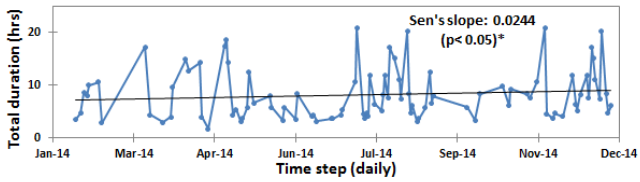


(c) Antecedent dry days

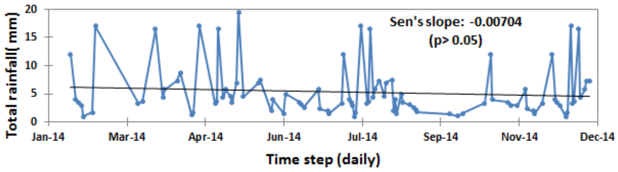


(d) Average rainfall intensity

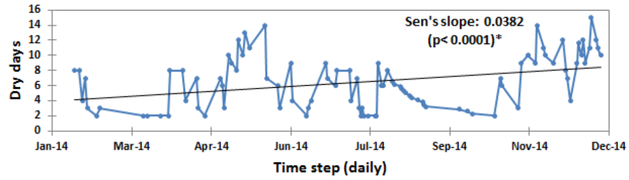
Fig.4 Mann-Kendall test trend of rainfall variables in 2013



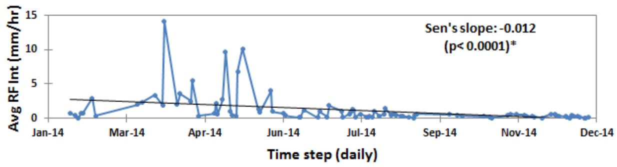
(a) Total rainfall duration



(b) Total rainfall



(c) Antecedent dry days



(d) Average rainfall intensity

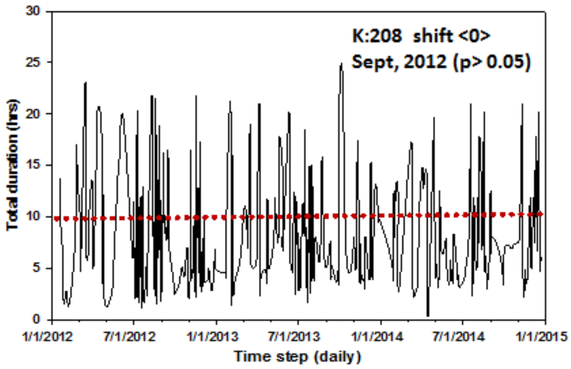
Fig.5 Mann-Kendall test trend of rainfall variables in 2014

rainfall (Sen's slope: -0.076, $p < 0.05$) with an annual mean decline of 463 mm (72%) total rainfall in 2013 as compared to 2012. Therefore, in 2013, most of the rainfall events occurred in the early spring (March-April) and during peak summer (June-July) which indicates the seasonal variation in the rainfall patterns. While in the late summer (August-October) and early winter the overall total rainfall was reduced with a decreasing trend due to infrequent storm events. In the case of antecedent dry days, which showed a significant increasing trend (Sen's slope: 0.04406) with an increment of mean 2 days in 2013 compared to 2012 (Fig. 4 (c)). On the other hand, average rainfall intensity showed a non-significant falling trend in 2013.

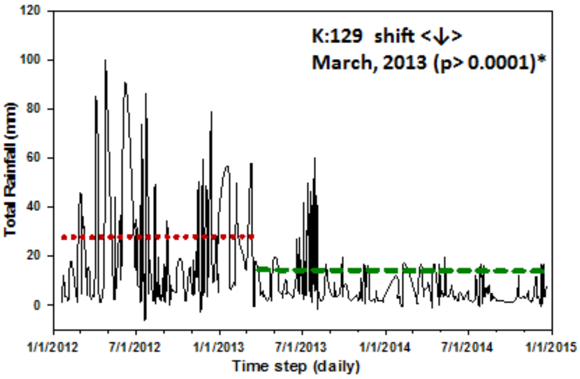
In 2014, total rainfall duration displayed a significant rising drift (Sen's slope: 0.024, $p < 0.05$) which indicates the occurrence of long duration storm events (Fig. 5(a)). While, total rainfall showed a non-significant lower trend with an annual mean decrease of 645mm (62%) as compared to the year 2012. A higher trend was observed for antecedent dry days with a slop of 0.0382 ($p < 0.05$) in 2014 which indicates the significant shift in rainfall patterns with sporadic rain events after prolonged dry conditions. Therefore, in 2014, the average rainfall intensity trend was significantly lower (Sen's slope: -0.012) as compared to preceding years. Most of the storm events with higher total rainfall and intensity occurred in the early spring (March-May) which then later showed a decreasing trend in the peak summer (June-August) indicating the prolong influence of winter rainfall patterns instead of monsoon effects.

3.2 Breakpoint in rainfall variables series

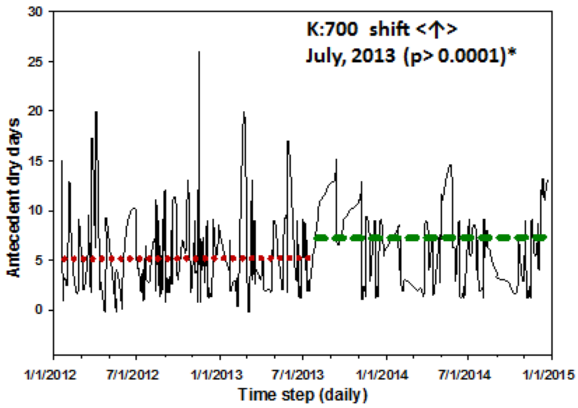
The recognition of breakpoint is a statistical technique that plays a vital role in spotting climate jumps in the whole meteorological data series (Palaniswami *et al.* 2018). The abrupt changes in aggregated rainfall variables series were examined using Pettitt's test. Fig. 6 shows the changes of K statistics of Pettitt's test for rainfall variables. Based on the results, no significant abrupt shift was detected in total rainfall duration series (Fig. 6 (a)). However, the M-K trend test found a significantly higher and lower trends in total storm duration series of 2013 and 2014, which could be due to the locality and seasonal variation in the respective years. The Pettitt's test failed to depict the breakpoint in aggregated rainfall duration series, which could be due to the inability of test to detect the minor changes in accumulated time series (Awotwi *et al.* 2017). The breakpoint analysis depicted a significant declining shift (K:129, $p < 0.05$) in total rainfall series with a break year of 2013 and further reconfirmed the results of M-K trend analysis. In the case of antecedent dry days, the breakpoint appeared in July 2013 with a significant positive shift (K:700, $p < 0.05$). For average rainfall intensity, there was a breakpoint detected in Feb 2013 (K:852, $p < 0.05$) with a significant falling shift (Fig. 6 (d)). This following pattern indicates the occurrence of high intensity rainfall events in 2012 as compared to change period (2013-2014). However, the average rainfall intensity was significantly reduced during the change period, except for the July 2014 which



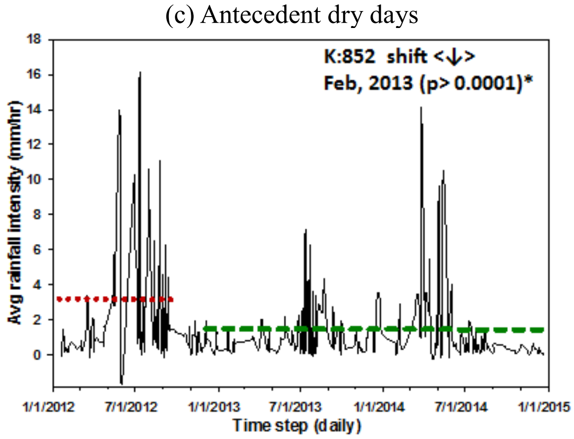
(a) Total rainfall duration



(b) Total rainfall



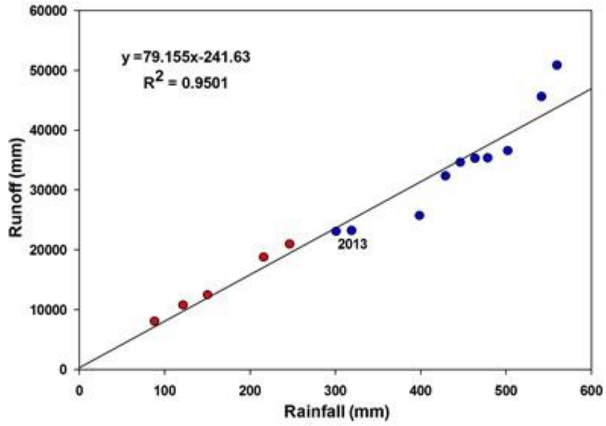
(c) Antecedent dry days



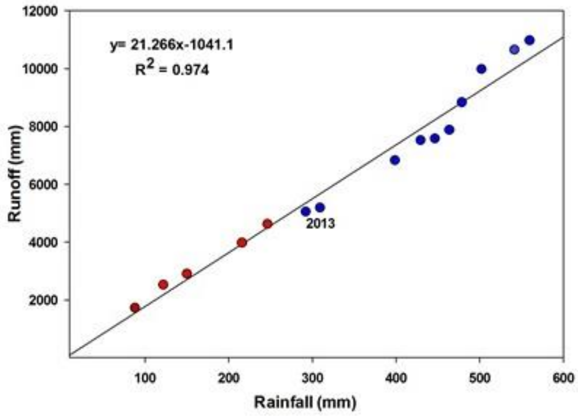
(d) Average rainfall intensity

Fig. 6 Results of breakpoint analysis of rainfall variable

indicates the infrequent high intensity rain events in the respective month.



(a) Agriculture site

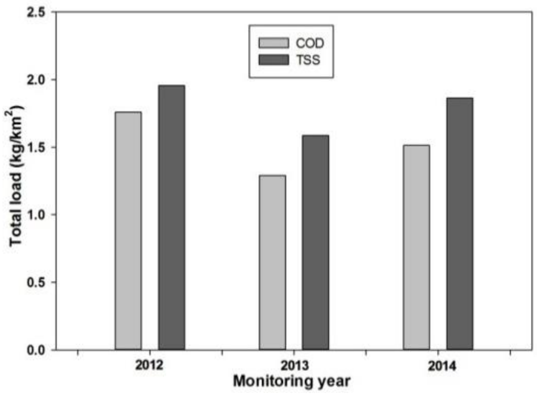


(b) Urban site

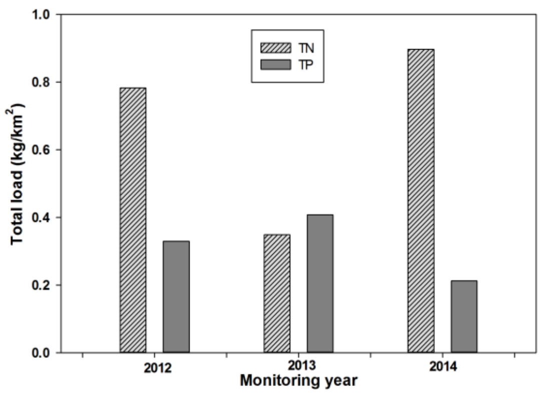
Fig.7 Rainfall-runoff relationship over study period (2012-2014)

3.3 Rainfall-runoff relationship

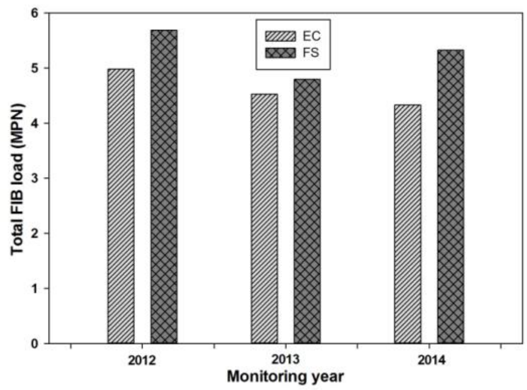
Rainfall-runoff curve was built using aggregated rainfall and runoff series to further analyze the consistency, breakpoint and to identify the baseline and change year by rainfall variation and anthropogenic activities in time series. Generally, rainfall-runoff curve without anthropogenic disturbance result in a straight line for DMC which indicate the impacts only triggered by climate change. However, when anthropogenic activities directly or indirectly impose effects on underlying series, the DMC will change and the location of offset points will also be the time when anthropogenic activities increased (Dong *et al.* 2017). Based on the rainfall-runoff relationship, double mass curve exhibited a straight line and strong correlation between rainfall and runoff in both sites (Fig. 7(a)-(b)). The correlation coefficient (R^2) between runoff and rainfall for the urban (0.974) and agriculture (0.950) site shows that the evolution of runoff in the both sites mainly affected by rainfall variation due to climate change. DMC further reconfirmed the results of Pettitt's test by detecting 2013 as a breakpoint in both sites rainfall-runoff series. In addition, the runoff trend in 2012 was higher as compared to 2013 and 2014 at both sites. Hence, combining the results of Pettitt's test and DMC method, year 2013 was the breakpoint which signifies the impacts of changing rainfall pattern on runoff.



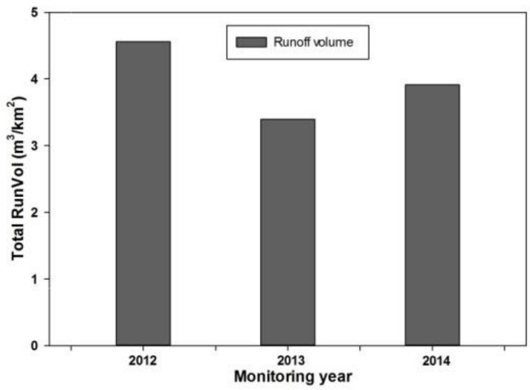
(a) COD-TSS



(b) TN-TP



(c) FIB (EC-FS)



(d) Runoff discharge

Fig. 8 Pollutant loading export from agriculture site during study periods

3.4 Spatial-temporal pollutant load distribution

The catchment characteristics and different rainfall conditions greatly influenced the variability of spatial and temporal runoff pollutant loads in both sites. In the case of Site 1, higher total runoff volume was observed in 2012 as compared to 2013 and 2014. Similarly, higher annual loads were observed for COD, TSS, TN and FIB except for the TP in 2012 (Fig. 8(a)-(d)). The possible reason for higher pollutant loads except TP attributed to the frequency of long duration events with heavy rainfall resulted in limited application of fertilizer in the catchment. However, annual TN export was observed higher in 2014, which indicates the extensive use of fertilizer due to sporadic storm events (Fig. 8(b)). In addition, Reza *et al*. (2016) also reported that rainfall characteristics such as rainfall depth and intensity largely influenced the TN export from the rural catchment.

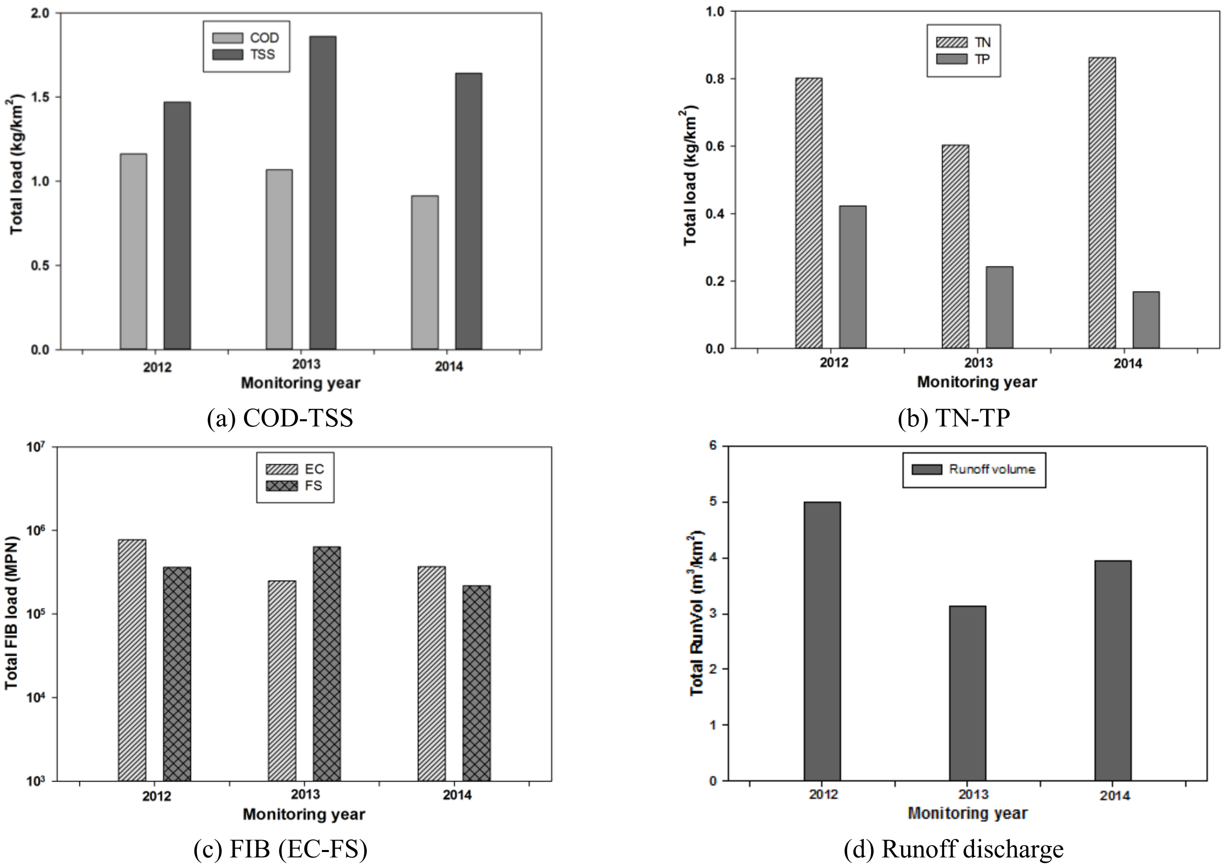
For Site 2, which has a smaller area and higher impervious cover, thus exhibited the first flush effect during the storm events (Fig. 9(a)-(c)). The total runoff volume was found to be higher in 2012 which then later showed a decreasing trend in 2013 and 2014. Therefore, higher annual exports of COD, TN, TP and EC were observed in 2012 except for TSS and FS compared to change period (2013-2014). However, higher TSS and FS export in 2013 and 2014 could be due to the variation of build-up and wash-off processes during rainfall events (Fig. 9(a), (c)). Similarly, the TN load was higher in 2014 than preceding years, which indicates the prolonged wash-off due to longer duration events with extended dry conditions.

3.5 Relationship between pollutants and hydro-meteorological variables

3.5.1 Agricultural catchment (Site1)

The relationship between runoff pollutant loads and hydro-meteorological variables were quite different in theagricultural site. In 2012, higher loads of TSS, EC and FS found to be significantly correlated with total rainfall, total duration and average rainfall intensity in the range of (r= 0.519-0.898, $p < 0.05$) as shown in Table 2. However, COD did not show any correlation with hydro-meteorological variables except with TSS and TP, Which means that higher TSS and TP runoff from agriculture activities during a storm event was responsible for higher COD load in 2012. Interestingly, TP showed a weak relationship with antecedent dry days (r= 0.559), but a strong correlation with COD and TSS (r= 0.867-0.864, $p < 0.05$).

For the change year (2013), lower observed loads of COD, TSS and TN were found to be significantly ($p < 0.05$) correlated with total rainfall (r= 0.912-0.95) and average rainfall intensity (r= 0.923-0896). EC showed a weak correlation with total rainfall compared to FS which showed a good correlation with total rainfall duration. Meanwhile, significant correlation was witnessed between higher TP load and antecedent dry days, whereas, a negative correlation was found with average rainfall intensity as shown in Table 2. Overall, less total rainfall and infrequent short duration events were responsible for the lower trends of pollutant loads in 2013. Higher TP load in 2013 indicates



(a) COD-TSS (b) TN-TP (c) FIB (EC-FS) (d) Runoff discharge

Fig. 9 Pollutant loading export from urban site during study periods

the extensive use of fertilizer because of insufficient rainfall and prolonged dry conditions. Therefore, the application of organic composts and chemical fertilizer in Korea has continued to increase due to variation of rainfall characteristics (Reza *et al*. 2016).

Higher annual loads of COD, TSS, TN and FS in 2014 significantly ($p < 0.05$) correlated with antecedent dry days, total rainfall and total rainfall duration in the range of (r= 0.878-0.983). This makes sense because of the long duration events and extended dry conditions in 2014 accounted for the prolong runoff of deposit pollutants from the catchment surfaces. In contrast, lower TP load showed a strong correlation with total rainfall and total duration, whereas, EC load significantly ($p < 0.05$) correlated with average rainfall intensity. However, lower TP and EC loads in 2014 were attributed to less total rainfall and lower average intensity which were not sufficient to generate enough runoff to wash-off the fertilizer from the catchment.

3.5.2 Urban catchment (Site2)

The correlation matrix of urban site suggested that the higher COD export in 2012 significantly ($p < 0.05$) correlated (r= 0.680-0.753) with total rainfall and runoff volume. However, the trend of total rainfall and runoff volume was observed higher during 2012, resulted in a discharge of higher COD load due to wash-off of accumulated organic matter from the catchment surface. On the other hand, TSS was highly correlated with total rainfall (r= 0.946), while FS showed a significant positive correlation with average rainfall intensity (r= 0.975). During 2012, higher TN, TP and EC load displayed a significant correlation with antecedent dry days (r= 0.640, 0.966, 0.856, $p < 0.05$). Additionally, TN and EC also showed a positive association with runoff volume as shown in Table 3. In 2013, which is considered as a change year, though a higher observed load of COD and TSS significantly linked with antecedent dry days (r= 0.634, 0.984, $p < 0.05$). TSS also showed a weak association with average rainfall intensity. However, lower export of TN, TP and EC during 2013 showed a significant ($p < 0.05$) connection with runoff volume (r= 0.970), total rainfall (r= 0.947), and average rainfall intensity (r= 0.897). The lower export of these pollutants were due to frequent storm events with minimum total rainfall and low intensity resulted in a lower runoff discharge in 2013.

In the case of 2014, COD only showed a significant association with runoff volume and weak correlation with TSS as shown in Table 3. While, lower TSS and TP load presented a good relationship with total rainfall (r=0.833-0.924) and average rainfall intensity (r=0.626-0.893). Higher TN and EC load significantly correlated with antecedent dry days (r=0.904 and 0.989). Meanwhile, FS witnessed a significant connection only with rainfall intensity which was significantly reduced in 2014 resulted in a lower FS export from the catchment. Overall, the urban catchment showed a varied loading trends of pollutants, especially in the case of COD, TSS and FIB which were influenced by prolonged build-up conditions due to an

Table 2 Correlation between pollutants and hydro-meteorological variables at Site 1

Year	Variables	COD ↑	TSS ↑	TN ↑	TP ↓	EC ↑	FS ↑	ADD	TRF	TDUR	ARFI	RunVol
	COD	1										
	TSS	**0.748**	1									
	TN	-0.159	-0.270	1								
	TP	**0.867**	**0.864**	-0.254	1							
2012	EC	-0.266	-0.375	-0.245	-0.276	1						
	FS	-0.417	-0.152	-0.065	-0.418	0.085	1					
	ADD	0.335	0.454	-0.455	**0.559**	0.014	-0.332	1				
	TRF	0.42	**0.519**	0.228	0.467	-0.395	0.037	0.412	1			
	TDUR	0.412	**0.516**	0.184	0.484	-0.325	**0.898**	0.509	**0.989**	1		
	ARFI	0.372	0.45	0.358	0.356	**0.899**	0.103	0.156	**0.960**	**0.911**	1	
	RunVol	-0.348	-0.281	-0.217	-0.225	-0.052	0.360	0.128	0.249	0.251	0.229	1
Year	**Variables**	**COD ↓**	**TSS ↓**	**TN ↓**	**TP ↑**	**EC ↓**	**FS ↓**	**ADD**	**TRF**	**TDUR**	**ARFI**	**RunVol**
	COD	1										
	TSS	**0.977**	1									
	TN	**0.890**	**0.933**	1								
	TP	0.776	0.669	0.433	1							
2013	EC	0.552	0.619	**0.965**	0.214	1						
	FS	-0.171	-0.226	0.031	-0.405	0.190	1					
	ADD	-0.53	-0.442	-0.364	**0.694**	0.048	-0.364	1				
	TRF	**0.912**	**0.938**	**0.951**	0.480	**0.529**	-0.080	-0.484	1			
	TDUR	-0.128	-0.076	0.141	-0.583	0.151	**0.896**	-0.449	0.085	1		
	ARFI	**0.923**	**0.947**	**0.896**	**-0.685**	0.455	-0.304	-0.380	**0.971**	-0.143	1	
	RunVol	-0.128	-0.107	-0.037	-0.306	-0.478	-0.16	0.074	0.182	-0.029	0.211	1
Year	**Variables**	**COD ↑**	**TSS ↑**	**TN ↑**	**TP ↓**	**EC ↓**	**FS ↑**	**ADD**	**TRF**	**TDUR**	**ARFI**	**RunVol**
	COD	1										
	TSS	0.437	1									
	TN	**0.986**	0.582	1								
	TP	-0.076	0.263	0.092	1							
2014	EC	0.288	0.294	0.548	-0.229	1						
	FS	-0.206	**0.970**	-0.367	-0.96	-0.053	1					
	ADD	**0.878**	-0.963	-0.340	-0.368	**-0.025**	**0.896**	1				
	TRF	0.513	**0.896**	0.649	**0.917**	0.374	-0.646	-0.936	1			
	TDUR	-0.101	**0.951**	**0.949**	**0.889**	**-0.253**	**0.983**	-0.961	0.802	1		
	ARFI	0.583	0.508	0.649	0.400	**0.801**	-0.641	-0.619	0.855	0.377	1	
	RunVol	0.696	0.950	**0.807**	0.663	0.577	-0.846	-0.83	0.673	**0.944**	**0.951**	1

*Note: ↑/↓: High/low load trend; ADD: Antecedent Dry Days; TRF: Total Rainfall; TDUR: Total Rainfall Duration; ARFI: Avgerage Rainfall Intensity; Values in bold are different from 0 with a significance level alpha<0.05

increasing trend of antecedent dry days. Higher pollutant loads may occur when a long dry period precedes the storm runoff. Moreover, the average rainfall intensity and runoff volume are also important factors to build-up and wash-off pollutants from the urban catchment.

4. Conclusion

This study explored the trends and impacts of hydro-meteorological changes on stormwater characteristics to determine the key driving factor affecting pollutant build-up and wash-off process from a rural and urban catchment.

- Based on Mann-Kendall test, total rainfall and average rainfall intensity significantly decreased, while a significant increasing trend was observed for antecedent dry days and total rainfall duration over the study periods (2012-2014). Moreover, Pettitt's test for homogeneity of the rainfall series data suggested a breakpoint in 2013 which indicates the significant shifts ($p < 0.05$) in total rainfall, antecedent dry days and average rainfall intensity except

Table 3 Correlation between pollutants and hydro-meteorological variables at Site 2

Year	Variables	COD ↑	TSS ↓	TN ↑	TP ↑	EC ↑	FS ↓	ADD	TRF	TDUR	ARFI	RunVol
	COD	1										
	TSS	0.668	1									
	TN	0.451	0.421	1								
	TP	**0.991**	0.992	0.435	1							
2012	EC	0.724	0.666	**0.936**	0.697	1						
	FS	-0.447	-0.458	0.595	-0.461	0.289	1					
	ADD	0.573	0.433	**0.640**	**0.966**	**0.856**	-0.235	1				
	TRF	**0.680**	**0.946**	-0.529	0.469	-0.197	0.627	0.281	1			
	TDUR	0.480	0.610	-0.308	0.653	0.044	-0.912	0.499	**0.970**	1		
	ARFI	0.338	0.306	-0.676	0.329	-0.375	**0.975**	0.115	**0.981**	0.908	1	
	RunVol	**0.753**	0.597	**0.725**	0.676	**0.886**	0.068	0.714	**0.881**	0.335	-0.071	1
Year	Variables	COD ↑	TSS ↑	TN ↓	TP ↓	EC ↓	FS ↑	ADD	TRF	TDUR	ARFI	RunVol
	COD	1										
	TSS	**0.869**	1									
	TN	0.328	0.241	1								
	TP	0.318	0.835	**0.829**	1							
2013	EC	0.881	0.585	0.736	0.728	1						
	FS	0.920	**0.979**	0.601	0.592	0.983	1					
	ADD	**0.634**	**0.984**	0.595	0.596	0.666	0.520	1				
	TRF	-0.772	0.519	-0.753	0.947	-0.809	-0.829	-0.798	1			
	TDUR	0.318	-0.333	-0.29	0.597	-0.167	0.013	-0.846	0.355	1		
	ARFI	0.512	**0.570**	-0.686	-0.678	**0.897**	**0.893**	-0.611	0.964	0.097	1	
	RunVol	-0.547	0.647	**0.970**	0.671	-0.878	-0.777	-0.941	**0.954**	0.618	0.841	1
Year	Variables	COD ↓	TSS ↓	TN ↑	TP ↓	EC ↑	FS ↓	ADD	TRF	TDUR	ARFI	RunVol
	COD	1										
	TSS	**0.650**	1									
	TN	-0.36	-0.977	1								
	TP	0.701	0.981	-0.917	1							
2014	EC	-0.120	-0.109	**0.936**	-0.1	1						
	FS	-0.141	-0.874	0.572	-0.774	0.253	1					
	ADD	0.523	0.574	**0.904**	0.699	**0.989**	-0.135	1				
	TRF	-0.620	**0.833**	0.697	**0.924**	0.690	0.429	-0.936	1			
	TDUR	-0.504	-0.498	**0.987**	-0.669	-0.312	0.391	-0.961	0.802	1		
	ARFI	-0.789	**0.626**	0.224	**0.893**	0.661	**0.895**	-0.618	0.855	0.855	1	
	RunVol	**0.933**	0.213	-0.210	0.398	0.667	0.057	0.426	-0.417	**0.717**	-0.674	1

*Note: ↑/↓: High/low load trend; ADD: Antecedent Dry Days; TRF: Total Rainfall; TDUR: Total Rainfall Duration; ARFI: Avgerage Rainfall Intensity; Values in bold are different from 0 with a significance level alpha<0.05

total rainfall duration.

• The double mass curve for both catchments exhibited a straight line with a significant rainfall-runoff relationship. In addition, DMC further reconfirmed thePettitt's test results by detecting a breakpoint in rainfall-runoff series.

• Overall, higher pollutant loads were observed for both catchments in the baseline year (2012) as compared to change period (2013-2014). However, most of the pollutants in agricultural site exhibited significant ($p < 0.05$) association with total rainfall, average rainfall intensity and total rainfall duration. In contrast, pollutants from urban site significantly correlated with antecedent dry days and average rainfall intensity.

In summary, total rainfall, average rainfall intensity and rainfall duration were the significant factors for the agricultural catchment while, antecedent dry days and average rainfall intensity were key for the urban catchment. However, further hydro-meteorological modeling studies are required by using long term meteorological and pollutant loading series data to identify more accurate build-up and wash-off variables for the different land use catchments.

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