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Determination of rainfall-runoff relationship using SCS- CN method in Batticaloa lagoon area, Sri Lanka

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ABSTRACT

The dynamic nature of the Batticaloa lagoon demands proper management to ensure sustainable use of the lagoon for the local communities' well-being and promote the district's long-term economic and social development. This lagoon receives runoff water from urban and rural areas, which might typically contain a broad range of pollutants that can affect lagoon water quality. In this context, studying the variation of rainfall and runoff which affect the lagoon is essential to ensure proper management of the lagoon. Therefore, the present study was conducted to estimate the runoff volume into the lagoon with the varying rainfall. Rainfall data and land-use patterns of the surroundings of the lagoon area were collected. Precipitation Concentration Index (PCI) was used to analyse the rainfall variability in the study area. The flow generated by rainfall and governed by catchment characteristics was calculated using the Soil Conservation Service (SCS) - Curve Number (CN) method. Regression and correlation analysis were performed using MS Excel and SPSS version 22 statistical software. The study found an increasing trend of rainfall (r=0.316, p=0.039) over the 43 years studied. According to the PCI values, nearly 39.5%, 46.5% and 14% of the years received very high concentration, high concentration and moderate concentration of rainfall, respectively. It was estimated that the maximum runoff into the lagoon was 1430.9 mm in 2011 and the minimum was 457.1 mm in 1981. Further, more than half of the rainwater received in the study area was lost as runoff (1107.1 mm), and the effective rainfall was 618.6 mm. It is also found that there are highly significant relationship between runoff and rainfall (r =0.988, p<0.01). These findings, especially the trend analysis of rainfall and runoff estimation, will be helpful in planning, designing, and managing water related projects in the Batticaloa district.

Keyword: *Precipitation Concentration Index, rainfall, runoff, SCS-CN method*

INTRODUCTION

Coastal lagoon ecosystems are vulnerable to natural and anthropogenic activities as they are at the receiving end of pollutants. The Sri Lankan coastal lagoons are diverse in size, shape and ecosystem values and services (Silva *et al*.,2013). Batticaloa lagoon is located in the Eastern part of the country and is the largest lagoon in the Batticaloa district. This lagoon has also suffered from many recent developments such as unplanned exploitation of resources, encroachment, water pollution and eutrophication, which has lead to environmental degradation, and substantial changes in its ecosystem. The impacts would be further aggravated by the climatic hazards such as extreme floods, droughts, seawater intrusion (Sugirtharan *et al*., 2014), and varied flow regimes due to

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varied rainfall patterns and temperature rise. The variation in the duration, frequency and amount of rainfall, and degree of temperature may alter the favourable condition for humans, aquatic species, agriculture and livestock production.

A densely populated region surrounds the Batticaloa lagoon, and runoff water from these residential areas, drainage water from adjacent rivers like Galoya and Mundani and drainage water from several local irrigation schemes flows into the lagoon. Batticaloa lagoon receives urban runoff, which typically contains a broad range of pollutants that can affect lagoon water quality (Sugirtharan *et al*., 2019). Nutrients from fertilizer and animal wastes reach the lagoon and promote excessive growth of rooted aquatic plants and algae (Ngatia *et al*., 2019). The seasonal spread of *Eichornia sp* in the lagoon during the flood interrupts the light penetration and changes the dissolved oxygen content of the lagoon water. Therefore, a detailed analysis of rainfall data and runoff estimation is crucial to take appropriate management decisions. In this view, this study was conducted with the aim of finding the rainfall pattern and runoff volume from the surroundings of the Batticaloa lagoon to take necessary remedial measures and adaptation techniques against floods and droughts in the study area. There are several methods available to find the rainfall- runoff relationship. Soil Conservation Services and Curve Number (SCS–CN) technique is one of the simplest method for rainfall runoff estimation (Asif *et al*., 2017). The Soil Conservation Service and Curve Number (SCS–CN) method is useful for calculating volume of runoff from the land surface to the river or streams (Satheeshkumar *et al*., 2017) and uses the important properties of the watershed such as soil permeability, land use and antecedent soil water (Bansode *et al*., 2014). The present study aimed to estimate the surface runoff from a catchment area of the Batticaloa lagoon using Curve Number method.

METHODOLOGY

Description of the study area

Land use

The present study identified that the primary land use around the lagoon is agriculture; paddy and coconut cultivation in particular (Figure 1 and Table 1). Other land uses include urban areas, road networks and freshwater bodies adjoining the lagoon and marshy lands were identified using ArcGIS version 10.5 software.

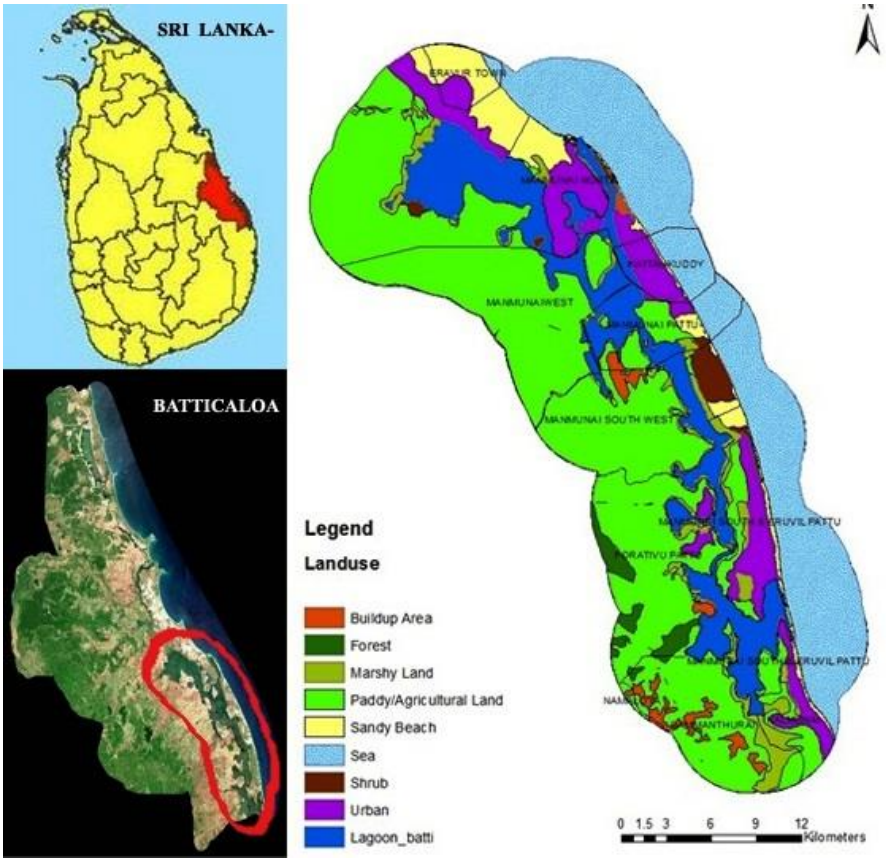

Figure1. Location of the study area

Table 1. Extent under different land use in the buffer zone.

Land use	**Area (km^2)**
Marshy land	40.90
Build u parea	13.64
Forest	11.23
Urban	75.01
Shrub	10.68
Sandy beach	41.78
Paddy/Agricultural land	358.88

Climate

Batticaloa district is located within the dry zone of Sri Lanka, which has a hot and humid tropical climate. The mean annual temperature is 27.4° C and ranges from 18ºC on nights during the rainy seasons to 38 ºC during the day in the dry seasons. The district receives about 1000-1700 mm of rainfall per annum, primarily from the Second Inter Monsoon (SIM) and Northeast Monsoons (NEM) from October to February. Batticaloa has a dry spell of five months from May to September (Fernando, 2014; Azaam and Sugirtharan, 2021).

Data collection and analysis

Rainfall

Mean monthly and daily rainfall data were collected from the meteorological department of the Batticaloa and Colombo district to find the rainfall trend and estimate the runoff from the surrounding areas of the lagoon. The minimum, maximum, mean, standard deviation (SD) and Coefficient of variation (CV) values of rainfall data were analysed using descriptive statistics. To find the variation of rainfall in different months, the CV value for each series were calculated as follows;

$$CV = \sigma / \mu \qquad \text{(Equation 1)}$$

where σ is the standard deviation and μ is the mean rainfall.

Analysis of rainfall

Rainfall distribution of the Batticaloa district was analysed based on Precipitation Concentration Index (PCI). Equation 2 was used to estimate the PCI (De-Lius *et al.*, 2011).

$$PCI_{Annual} = \frac{\sum_{i=1}^{12} p_i^2}{(\sum_{i=1}^{12} p_i)^2} \times 100 \qquad \text{(Equation 2)}$$

Where, p_i is the rainfall amount of the i^{th} month.

Estimation of runoff to Batticaloa Lagoon

Catchment characteristics govern the flow generated by a storm event, and this flow was calculated using the Curve Number (CN) method (Equation 3).

This method assumes that the ratio of direct runoff (surface runoff) (Q) to the rainfall depth minus the initial losses (P—Ia) is equal to the ratio of actual retention of rainfall to the retention capacity of the soil (S) (USDA, 1986).

$$\frac{Q}{P - Ia} = \frac{P - Q - Ia}{S}$$

Let Ia=0.2S, then

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \text{(Equation 3)}$$

Where;

Q = Direct runoff
P = Rainfall depth
S = Retention capacity of soil

Retention capacity S can be predicted by the Curve Number (Equation 4) as defined by the U.S Soil Conservation Service, USDA (1986),

For S in inch
$$S = \frac{1000}{CN} - 10 \qquad \text{(Equation 4)}$$

For S in mm
$$S = \frac{25400}{CN} - 254$$

Each land use was assigned to a different soil group (eg. A, B, C, D) based on the field condition. CN value was taken for each land use type assuming Antecedent Soil Moisture Condition II. Then the average CN value was estimated based on land use area and the corresponding CN number (Equation 5).

$$AverageCN = \frac{A1*CN1+A2*CN2\ldots\ldots+An*CNn}{A1+A2+\cdots.+An}$$

(Equation 5)

Descriptive statistics and correlation were used to analyse the rainfall data. Regression analysis was performed to find out the relationship between rainfall and runoff.

RESULTS AND DISCUSSION

Changing rainfall

The rainfall received in an area is important in determining the amount of water available to meet various demands, such as agricultural, industrial, domestic water supply, and hydroelectric power generation. Therefore, changing rainfall pattern was analysed using 43 years of (1975 to 2017) data. Based on the data, the average annual rainfall of Batticaloa is found as 1611 mm.

In the present study, total rainfall showed an increasing trend (r=0.316, p=0.039) over the 43 year studied (Figure 2). The maximum annual rainfall of 3,581 mm was recorded in 2011, and the minimum rainfall of 920 mm was recorded in 1983. The highest rainfall (1,347 mm) was received during January 2011 (Table 2). The district has experienced nearly half of its annual rainfall in just 12 days during January 2011. Because of this high rainfall, a vast flood occurred during January 2011.

October, November, December, January and February are the rainy months where the average monthly rainfall exceeds 130 mm. May, June, July and August are the dry months that record an average monthly rainfall of less than 76mm. Among these, month of May was identified as the driest month of the year. Standard deviation values are less than their corresponding mean values in the rainy months of September to February. Large variation in SD was observed during October to December. Whereas the SD values of the remaining months are higher than their corresponding mean values. According to Nyatuame *et al*. (2014), this relationship between SD and the average values revealed that the deviation from the normal distribution cannot be ignored because the coefficient of variation (CV) of these months are above one or close to one. CV is a statistical measure of the difference between the data points and the mean value of a series. CV values were greater than one in dry season months compared with rainy months. Greater values of CV indicate larger variability and vice versa.

The study also found that mean rainfall of 560.2 mm, 129.4 mm, 223.6 mm and 549 mm were received during Northeast monsoon, first inter-monsoon, Southwest monsoon and second inter-monsoon periods that indicates the rainfall is higher during SIM and NEM period.

The skewness and kurtosis were computed to test the distribution pattern of annual rainfall. From Table 3, it is clear that the rainfall data are positively skewed. Westfall (2014) explained that kurtosis measures data peakness or flatness relative to a normal distribution. The standard normal distribution has a kurtosis of zero. Positive kurtosis indicates a peaked distribution, and negative kurtosis indicates a flat distribution. According to that, the annual rainfall distribution of the present study results did not follow a normal distribution.

Table 2. Minimum, maximum and average rainfall of the 43years period. (1975-2017)

Month	Min (mm)	Max (mm)	Mean (mm)	SD (mm)	CV
January	1.8	1346.5	263.7	245.1	0.93
February	0.0	576.6	132.8	131.9	0.99
March	0.0	419.5	76.2	85.9	1.13
April	0.5	276.3	53.2	58.6	1.10
May	0.0	287.4	47.4	55.5	1.17
June	0.0	209.7	29.4	42.2	1.44
July	0.0	129.6	32.3	32.5	1.01
August	0.0	196.7	41.7	48.2	1.16
September	2.0	328.6	72.8	71.7	0.99
October	24.0	622.2	174.2	108.9	0.63
November	79.5	964.5	374.8	180.6	0.48
December	83.1	1164.2	427.4	249.5	0.58
Annual	**920.0**	**3581.3**	**1611.3**	**538.6**	**0.93**

Rainfall distribution based on Precipitation Concentration Index (PCI)

PCI of Oliver (1980), further developed by De-Lius et al. (2011), has equally been expressed as an indicator of annual rainfall concentration (Table 4). In the present study, PCI was calculated to analyse the rainfall distribution of the Batticaloa district.

PCI has been expressed as an indicator of rainfall concentration on annual scales (Table 3). The present study revealed that PCI values in all the years were higher than 10, indicating that none received normal rainfall distribution. Higher PCI values indicate that the rainfall is concentrated in a certain month/s in a year. Further, Table 3 shows that nearly 39.5%, 46.5%, and 14% of the years received very high, high and moderate rainfall concentration based on the PCI values.

A shortage of water due to prolonged dry weather is experienced in many places in the district, especially in the Western Part of Batticaloa, between June and September each year. Therefore, efficient water usage, water harvesting, and renovation of the damaged tanks to store excess rainwater are essential to reduce the flood impacts near lagoon areas during the rainy seasons and overcome the water scarcity in the district during dry seasons to a certain extent.

Table 3. Descriptive statistics of the annual rainfall data

Year	Min RF (mm)	Max RF (mm)	Annual RF (mm)	SD	Coefficient of Skewness	Kurtosis	PCI
1975	0.2	498	1470	139.5	1.99	4.63	18
1976	0.7	589.9	1585.3	199.5	1.62	1.55	26
1977	17.6	605.4	1615.7	168.7	2.31	5.74	20
1978	1.6	600.8	1816.2	179.3	1.88	3.13	19
1979	3.5	653.1	2429.1	233.6	1.12	0.13	19
1980	0.0	380.8	989.9	126.1	1.71	1.90	26
1981	1.7	292.9	1015.9	83.5	1.51	2.63	16
1982	0.0	509.6	1299.1	177.3	1.90	2.34	29
1983	0.0	373.2	920	116.1	1.86	3.15	26
1984	7.8	590.4	2313	218.1	1.24	-0.16	18
1985	0.4	491	1632.3	130.6	2.01	4.88	15
1986	1.7	428.5	1627.2	140.8	0.91	-0.24	17
1987	0.0	375.5	1358.9	111.5	1.19	1.45	16
1988	7.7	233.1	1250.8	80.3	0.39	-1.31	13
1989	0.2	311.1	1199.4	106.0	0.93	-0.43	17
1990	0.0	715.4	1722	203.4	2.29	6.02	24
1991	11.7	617.8	1599.1	172.8	2.29	5.93	21
1992	0.0	609.1	1270.3	182.5	2.39	5.52	31
1993	4.0	705.3	1625.7	243.4	2.06	2.84	33
1994	2.0	964.5	3080.7	304.8	1.34	1.23	19
1995	1.7	314.6	1403.7	104.5	0.84	-0.60	14
1996	1.5	302.2	1681.8	106.5	-0.07	-1.48	13
1997	1.8	438.6	1631.1	137.9	1.62	1.76	16
1998	5.0	255.5	1010.4	89.1	0.96	-0.41	17
1999	0.0	501.2	1990.3	185.3	0.97	-0.59	18
2000	0.0	544.6	2021.4	184.3	1.08	-0.08	17
2001	0.0	430.9	1636.3	140.9	1.10	0.31	16
2002	2.0	774.5	1872.8	224.9	2.22	5.28	24
2003	17.8	722.2	1858.5	204.4	2.37	5.67	22
2004	2.3	926.2	2594.7	271.1	1.85	3.70	20
2005	0.0	408.7	1223.2	116.3	1.86	3.95	18
2006	0.1	314.1	1306.3	123.9	0.70	-1.41	18
2007	11.4	487.2	1570.2	130.9	2.01	5.00	16
2008	2.1	419.5	1987.3	147.8	0.45	-1.44	14
2009	0.0	897.9	2056	269.5	2.10	4.61	27
2010	1.1	711.4	1760.3	209.7	2.20	4.78	24
2011	0.0	1346.5	3581.3	385.7	2.03	4.81	21
2012	0.0	661.4	1786.4	204.0	1.70	2.69	23
2013	3.2	786.8	1973.7	219.5	2.37	6.31	22
2014	0.0	1164.2	2518.3	337.2	2.43	6.30	28
2015	13.6	622.2	1982.2	214.2	1.40	0.64	21
2016	0.0	323.1	1263.8	127.9	1.08	-0.64	20
2017	4.9	417.1	1677.8	132.4	1.02	0.32	15

Table 4: Classification of rainfall distribution based on PCI (De-Lius *et al*. (2011)

PCI	Description
<10	Low concentration (almost uniform rainfall)
11-15	Moderate concentration
16-20	High concentration
$\geq$20	Very high concentration

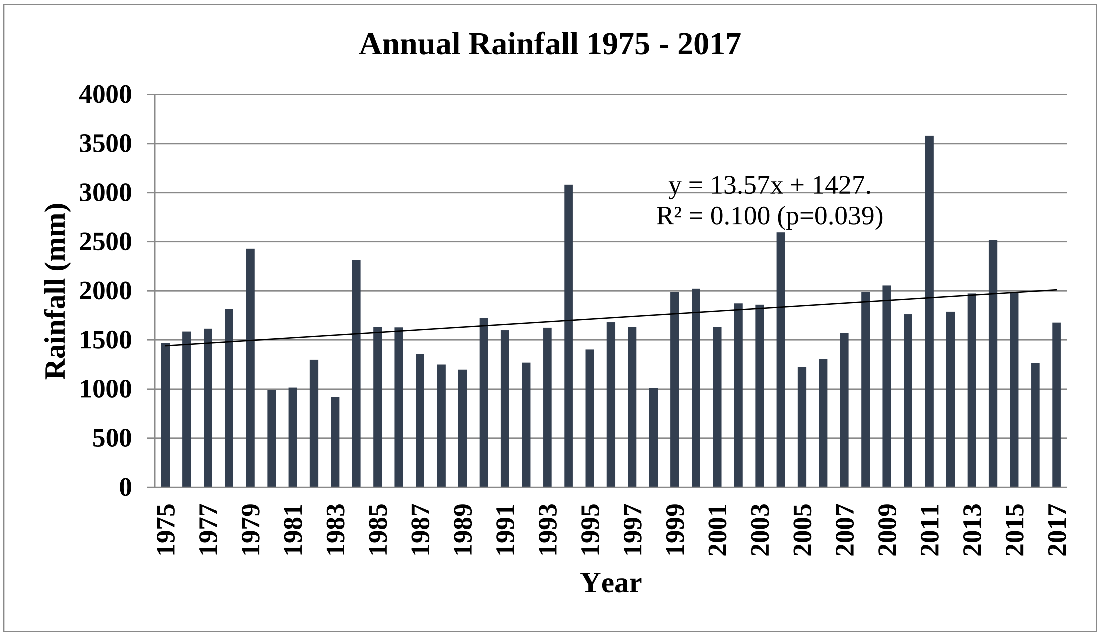

Figure 2: Annual rainfall during the period from 1975 to 2017

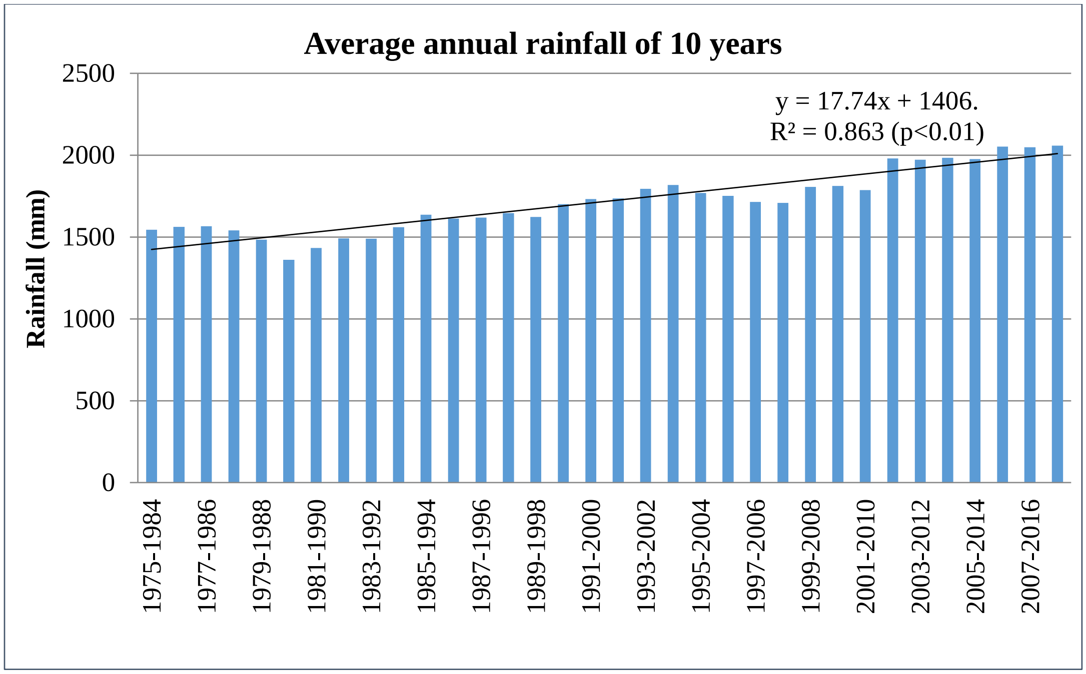

Figure 3: Average rainfall per decade

Jayawardena *et al*. (2005) studied rainfall between 1869 and 1993 for the Batticaloa region and reported a downward trend of rainfall (11.16mm/year). Malmgren *et al*. (2003) reported that the Batticaloa district received higher rainfall (14mm/month) by Southwest monsoon during 1869 and 2000. The present study also found that the annual rainfall (r=0.316, p=0.04) and the average rainfall per ten years (decade) (r= 0.929, p<0.01) has shown an increasing trend over 43 years from 1975 to 2017 (Figure 3). These variations could be an indication of a temporal change of rainfall.

Regional changes in precipitation patterns can significantly affect coastal lagoons' physical and ecological characteristics by altering freshwater inputs and associated changes in salinity and dissolved oxygen concentrations (Milly *et al*., 2005). Intense precipitation events would increase short-term freshwater inputs (Paerl *et al*., 2006) while locally decreasing salinity (Michener *et al*., 1997). Conversely, lower precipitation would reduce freshwater inputs and potentially result in higher salinity (Valiela, 1995). Sugirtharan *et al*. (2017) revealed that the variation of lagoon water salinity was mainly due to the rainfall pattern in the region and due to seasonal distribution of rainfall. IUCN (2012) also revealed that increasing or decreasing rainfall patterns across the Puttalam area will alter the salinity of the lagoon. According to these findings, the variation of rainfall and runoff characteristics in the lagoon surroundings will introduces a lot of suspended particles and changing the salinity level of the lagoon.

The flood is the major event that disturbed the day to day activities of the people, especially during the North-East monsoon period. During this time, pollutants are washed off from urban and agricultural lands and reached the Batticaloa lagoon. Flash floods and droughts may be unfavourable but, more rains with low intensity to the dry zone like the Batticaloa region may alter its environment to a more suitable landscape. At the same time, more intense rainfall and flooding could result in increased suspended solids, sediment yields and associated metal contaminants in the lagoon. Therefore, estimation of runoff is essential to take management decisions against floods and adapt to such conditions.

Estimation of runoff into Batticaloa lagoon using rainfall data

Batticaloa lagoon receives runoff water from its catchment. This catchment has various land uses (Figure 1 and Table 1). Changes in land use patterns can significantly impact catchment hydrology and thus runoff generation (Bronstert, 2002). It can alter turbidity, phosphorous and nitrogen concentration, and organic matter of lagoon water. Further, runoff water flowing across the lagoon surroundings transports various pollutants and contributes to non-point sources of pollution.

Catchment of Batticaloa lagoon is an ungauged catchment with no historical flow data for calibrating rainfall-runoff model parameters. Due to the unavailability of required flow data for the model calibration, this study attempted to estimate runoff depths using a simple runoff model, the SCS-CN method. Figures 4 to 6 show the runoff depths (mm) from 1975 to 2017 (43 years) based on the rainfall distribution.

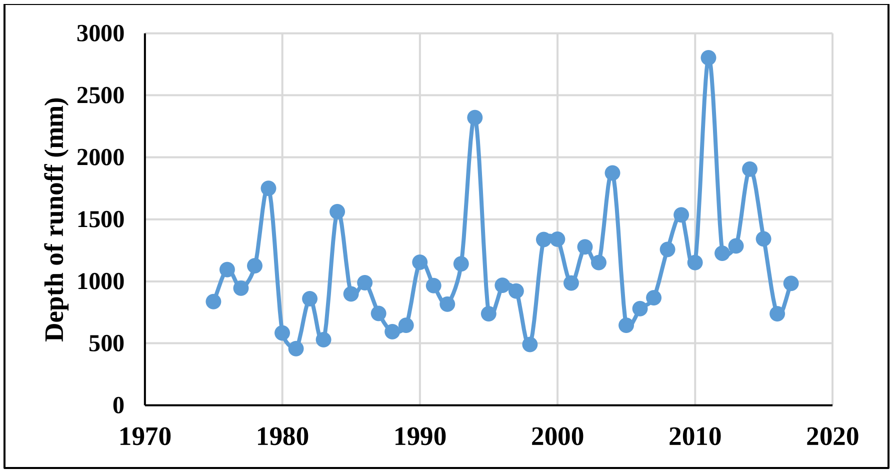

Figure 4: Annual runoff depths during 1975 to 2017

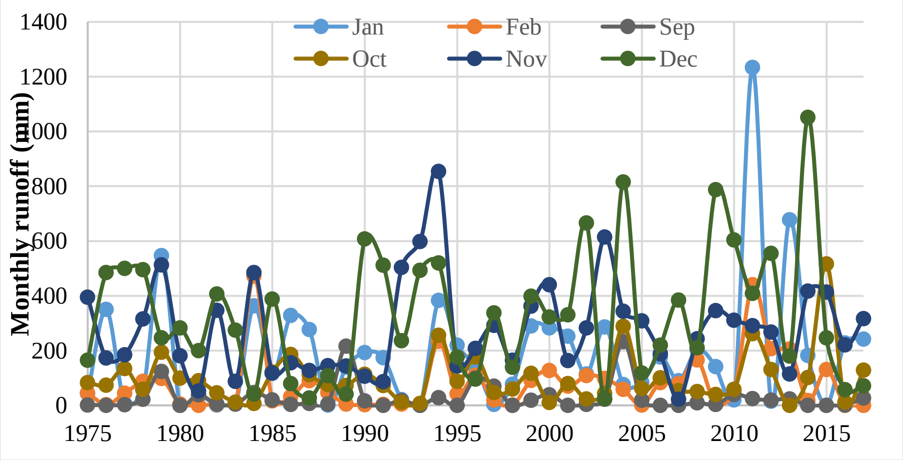

Figure 5. Variation of monthly runoff during 1975 to 2017 of rainy months

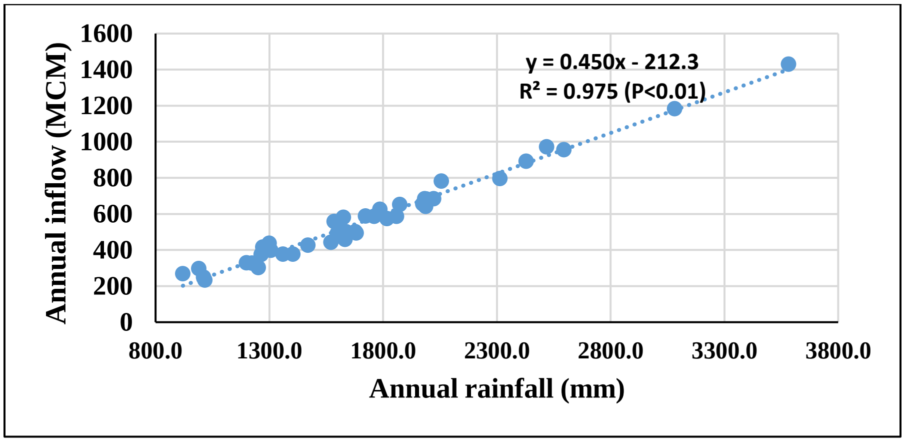

Figure 6. Annual inflow to the lagoon based on the rainfall

From SCS Curve Number, the maximum runoff into the lagoon was estimated to be 1430.9 mm in 2011 and a minimum runoff of 457.1 mm in 1981. Batticaloa district has experienced nearly half of its annual rainfall in just 12 days during January 2011. This high rainfall (1346.5 mm) lead to high runoff, resulting in huge flood during January 2011. Further, the present study found that more than half of the rainwater received in the study area was lost as runoff (1107.1 mm), and the effective rainfall is found as 618.6 mm. These runoff volumes generated in the study area is not used for agriculture. However, some portion of this volume is used to recharge groundwater of the surrounding areas of the lagoon. Rockstr and Falkenmark (2015) also reported that more than half of the rainwater is lost as runoff in sub-Saharan African. According to Carpenter *et al*. (1998) and Wayland *et al*. (2003), increased runoff carries nutrients from farm fields and contaminants from urban activities. Therefore, it is essential to manage rainwater by adopting rainwater harvesting to reduce the inflow to the lagoon, avoid flooding, and supply water to various needs in periods of the dry spell.

It is also found that a higher runoff was experienced during November, December and January periods due to the monsoonal rainfall received in the study area (Figure 5). Figure 6 shows that the occurrence and quantity of runoff are dependent ($r = 0.988$, $p < 0.01$) on the amount of rainfall. Satheeshkumar *et al*. (2017) also found that the rainfall and runoff are correlated with a correlation coefficient (r) value of 0.84 at the Pappiredipatti watershed in India. As rainfall intensity increases in Batticaloa, flash floods also increase; therefore, lagoons are inundated by runoff water that might cause changes in quality, especially water salinity, and possibly altering the species composition in the lagoon ecosystem.

CONCLUSION

Total rainfall of the study area has shown an increasing trend over the past 43 years (1975 to 2017) period. High rainfall is an important causal agent for the disturbance of the lagoon systems. The occurrence and quantity of runoff are dependent on the quantity of rainfall. Higher runoff leads to flash floods, and their impacts are severe during the rainy season. More than half of the rainwater received in the study area was lost as runoff. The results will serve as initial inputs for assessing water availability in the study sites. In addition, the finding of this study, especially the trend analysis of rainfall and runoff estimation, will be useful in planning, design and management of water related schemes such as clean water supply, reservoirs and drainage channels of the Batticaloa district.

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