Impacts of Changing Rainfall Patterns on Hydropower Generation: A Case Study of Kehelgamu Oya Sub-basin

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Abstract— Hydropower, the largest renewable energy source in Sri Lanka, generates approximately 50% of the total energy requirement. The annual electricity generation fluctuates greatly due to the variation of rainfall. Thus, the daily rainfall at Castlereagh and Norton stations of the Kelani River basin during the period 1960-2016 has been analysed on an annual, seasonal, and monthly basis. The aim of this research is to identify the impact of rainfall patterns on hydropower generation in Sri Lanka. Variability of the time series is assessed by detecting the trend using Spearmen's correlation coefficient test. Sen's slope estimator test was used to estimate the magnitude of the trend. Pearson correlation coefficient was used to find the relationship between rainfall and hydropower generation. A significant decrease in the annual rainfall and South-West monsoon rainfall observed at Norton and Castlereagh also shows a similar but not significant decreasing trend. A decreasing trend of monthly rainfall was also found at both stations. The results revealed that the future hydropower generation is in an alarming situation due to the decreasing trend of rainfall.

***Keywords*: climate variability, rainfall trends, Spearman's Rho trend test, Sen's slope, hydropower**

I.INTRODUCTION

Energy is one of the essential requirements in day-to-day life and hence surviving without energy would be a major challenge (Gray, 2017). On the way to sustainable development, Sri Lanka too considered energy as one of the focal points and thus took initiatives for ensuring access to affordable, reliable, sustainable and modern energy to all(GOSL, 2018). Nearly 50% of the national energy requirement of Sri Lanka is generated using renewable energy. According to Ceylon Electricity Board, main hydropower plants generated 34% and mini-hydropower plants generated 9% of the total capacity (CEB,2017). In general, there is a clear relationship between rainfall and hydropower generation; however, it was shown that hydropower generation would decrease due to climate change impacts especially in line with temperature and rainfall (Harrison & Wittington, 2002). Moreover, Beheshti *et al*., (2019) indicated that local studies are needed to study the climate change impacts on hydropower generation due to its regional behaviour.

Rainfall being one of the major factors on hydropower generation, Khaniya *et al.,*(2018) investigated the impact of rainfall on hydropower generation at Denawaka Ganga in Ratnapura district. Perera and Rathnayake (2019) also studied the climate variability and its effect on run-of-the-river hydropower plants in Ratnapura. These shows that local studies have been conducted in Sri Lanka at different locations.

The objective of this paper is to find the impacts of changing rainfall patterns on hydropower generation at plants located in Kehelgamu Oya, an upstream tributary of the Kelani river (Figure 1).

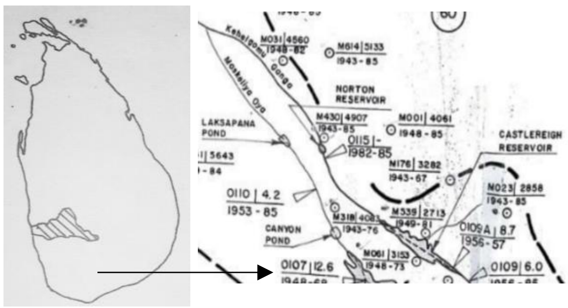

Figure 1. Study area in Kelani river basin
Source: CEB, 2014

This study covers two rainfall stations – Castlereigh and Norton - located in theKehelgamu Oya catchment. For both stations, daily rainfall data are available from 1960-2016 (57 years). The general characteristics of the two stations are given in Table 1.

Table 1 - General Characteristics of Selected Stations

Station	Latitude (N)	Longitude (E)	Elevation (m)	Catchment area (km^2)
Castlereigh	06 50 40	80 36 00	1027	114
Norton	06 54 56	80 31 06	893	131

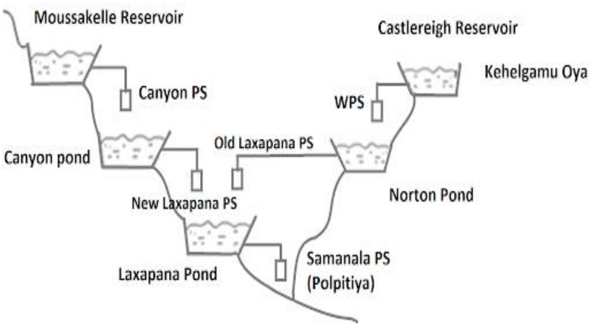

Figure 2. Reservoirs and hydropower plants at the study area
Source: http://www.laxapanacomplex.lk/oursys.html

Figure 2 shows that the Wimalasurendra power plant operates from rainwater collected at the Castlereigh reservoir and after the operation, water is collected at the Norton pond to generate power at the Old Laxapana power station (CEB,2017).

Rainfall variation is usually studied by detecting the trend pattern by using parametric or non-parametric tests. The parametric tests are not generally used for trend detection due to non-normality data series which is common in most hydro-meteorological data(Beheshti*et al.*, 2019). The use of non-parametric tests has been used in Sri Lanka at different locations for annual, seasonal and monthly time series(Alahacoon & Edirisinghe, 2021; Wickramaarachchi *et al.*, 2020).

A non-parametric test, Spearman's Rho (SR) or Spearman rank correlation method is widely used by many researchers to detect a trend in rainfall series(Ahmad *et al.*, 2015). More details on the SR test can be found in Dahmen & Hall (1990). Sen's slope method is generally used to estimate the magnitude of the slope of the data series (Khaniya *et al.*, 2018).

II. METHODOLOGY

Daily rainfall data at Castlereigh and Norton rainfall stations were collected for 57 years from 1960 – 2016 from the Department of Meteorology. After screening the rainfall data, annual, monthly and seasonal data series were prepared. The seasonal data series were prepared as North-East monsoon (NEM) from December to February, 1st Inter monsoon (1stIM) from March to April, South-West monsoon (SWM) from May to September and 2nd Inter monsoon (2ndIM) from October to November.

SR test was used to identify the trend pattern of the above data series. The rank correlation coefficient, R_{sp} is defined as follows:

$$R_{sp} = 1 - \frac{6\sum_{i=1}^{n} D^2}{n(n^2-1)} \quad (1)$$

where n is the total number of data, D is the difference between ranking, D = $K_{xi} - K_{yi}$, K_{xi} is the rank of the variable, in which x is the sequential order number of the observations and K_{yi} is the rank of the variable (y) in which y is the rank.

rainfall series in the ascending order of magnitude. The standardized test statistic is given in equation (2) (Dahmen and Hall, 1990),

$$t_t = R_{sp}\left(\frac{n-1}{1-R_{sp}^{2}}\right)^{0.5} \quad (2)$$

where t_t has student t-distribution with v= n-2 degree of freedom. A positive value of t_t shows an increasing trend while a negative t_t describes a decreasing trend. At a significance level of 5%, the two-sided critical region t_t is bounded by (Dahmen and Hall, 1990), $t\{v,2.5\%\} < t_t < t\{v,97.5\%\}$ and for a 57- year data series t_t should lie between -2.005 and 2.005.

To predict the magnitude of the slope of the rainfall time series,Sen's slope method was used(Perera and Rathnayake,2019).

$$d_k = \frac{(X_j - X_i)}{(j-i)} \quad (3)$$

For (1<i<j<n), where d_k is the slope, X_i and X_j are data values at time i and j, respectively, and n is the number of data. The median of n values of $d_k$is given as Sens slope estimator (Q_i) and given by,(Perera and Rathnayake,2019)

$$Q_i = \begin{cases} d\_((n+1)/2) \ (\text{n is odd}) & (4) \\ \frac{1}{2}\left(d_{\frac{n}{2}} + d_{\frac{n+1}{2}}\right) \ (\text{n is even}) \end{cases}$$

Due to the limitations of getting hydropower generation data, the rainfall-runoff graph method was used to estimate the generated hydropower during 2006- 2016 as explained by Harvey (1993). Finally, the Pearson correlation coefficient method is used to find the correlation between annual rainfall and hydropower generation data.

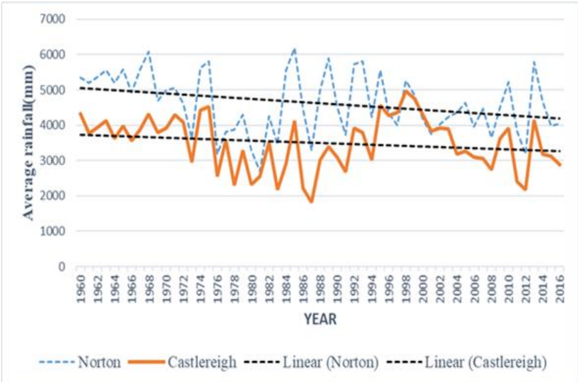

Figure 3. Annual rainfall trend analysis at Norton and Castlereigh

III. RESULTS AND DISCUSSION

The annual rainfall of 57 years at Norton and Castlereigh are shown in Figure 3 with the linear trend analysis. Figure 3. Annual rainfall trend analysis at Norton and Castlereigh

During the selected period, the maximum annual rainfall at Castleriegh and Norton is 4966 mm in 1998 and 6179 mm in 1985 respectively. The minimum annual rainfall observed at Castleriegh and Norton are 1812 mm in 1987 and 3291 mm in 1980 respectively. The annual average rainfall during the study period was 3499mm at Castlereigh and 4613mm at Norton.

Tables 2 and 3show the summary of trend analysis test results for the time series of selected rainfall stations for annual and seasonal rainfall respectively.

Table 2. Results of trend analysis for annual rainfall

Station	Test	Annual	Annual (1960-1987)	Annual (1988-2016)
Castlereigh	t_t	-1.51	**-3.77***	-1.77
	Q_i	-10.5	-14.6	-6.4
Norton	t_t	**-2.36***	**-2.47***	**-2.88***
	Q_i	-17.7	-10.5	-14.5

*Significant trends

Table 3. Results of trend analysis for seasonal rainfall

Station	Test	NEM	1^{st}IM	SWM	2^{nd}IM
Castlereigh	t_t	-0.37	0.23	-1.89	-1.24
	Q_i	-0.63	0.22	-9.19	-2.12
Norton	t_t	-1.31	-0.47	**-2.62***	-0.43
	Q_i	-1.74	-1.01	-14.67	-0.77

*Significant trends

At a significance level of five percent, the two sided critical region t_t is bounded by, t{v,2.5%} <t_t< t{v,97.5%} and for a 57 years of data, -2.005<t_t<2.005.

Significant decreasing trends on annual and SW monsoon rainfall were observed at Norton. Although Castlereigh shows a somewhat decreasing trend on annual and SW monsoon rainfall, it is not significant at the 95% confidence level.The highest slope of the trend of annual rainfall was found at Norton as -17.7 mm/year. The maximum slope for decreasing trend of seasonal rainfall was indicated as -14.67 mm/year at SW monsoon season of Norton.Having observed the significant decreasing trend in annual rainfall, the analysis was extended by splitting the time series into two series from 1960 – 1987 and 1988 - 2016. It was clearly seen that both subsamples at Norton demonstrated a significant decreasing trend. However, at Castlereigh, a significant trend was observed only in the first subsample.

In general, the SW monsoon provides the major portion of the annual rainfall in the wet zone of Sri Lanka and therefore, the decrease in SWM rainfall indicates a regional climate variation.

The trend analysis was further carried outconsidering monthly time series and the results are indicated in Table -4.

Table 4. Trend results for Monthly rainfall

Month	Castlereigh		Norton	
	t_t	Q_i (mm/month)	t_t	Q_i (mm/month)
January	-0.20	-1.06	-0.09	-0.60
February	-0.96	-0.59	-1.78	-1.19
March	0.92	0.45	-0.67	-0.37
April	0.04	-0.19	-0.81	-0.74
May	-0.38	-0.68	-0.74	-1.68
June	-0.25	-0.35	-1.14	-2.35
July	-1.68	-2.61	-1.62	-2.94
August	**-3.05** *	-3.19	**-2.14** *	-3.66
September	-1.17	-1.82	**-2.16** *	-4.18
October	-1.63	-2.05	-0.98	-1.02
November	-0.06	-0.105	0.49	0.71
December	0.03	-0.02	0.01	-0.04

*Significant trends

Table 4 clearly shows that a significant trend was detected at both stations in August. Further, Norton shows a significant trend during September too. Although the test statistic is not significant during July for both stations, it indicates more towards a significant negative trend. Monthly rainfall results clearly demonstrated the decreasing trend during SW monsoon rainfall. In contrast, a small-scale positive trend occurs during March to April (1^{st} IM) at Castlereigh and the same scale upward trend in November and December at Norton. The highest slope of decreasing trend, (-4.18 mm/month) was observed in September at Norton.

The correlation between annual rainfall and the generated hydropower is illustrated in Figure 4.
The results show that the correlation is 0.96 considering both stations.

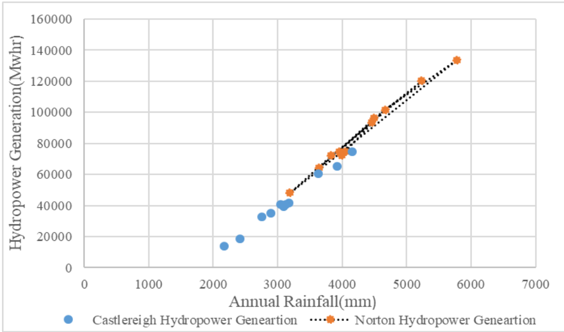

Figure 4. Hydropower generation over the annual rainfall

IV.CONCLUSION

This study investigated the trends in annual, seasonal and monthly rainfall using the Spearman's Rho test from 1960 to 2016 at Castlereigh and Norton rainfall stations in Kehelgamu Oya basin, which is a major tributary of the Kelani river. The magnitude of the trend was estimated using Sen's slope method. The trend results of the annual series showed a downward trend at both stations however at Norton, it was a significant trend. Although the South West monsoon greatly contributes to the annual rainfall, the findings emphasized that there is a significant reduction in the seasonal rainfall. The magnitude of the maximum decreasing seasonal trend was -14.67 mm/season at South-West monsoon while the maximum increasing trend was 0.22 mm/season at 1^{st} Inter Monsoon period.

According to the results, an alarming situation can be anticipated in future for hydropower generation due to significant decreasing trends on annual and south-west monsoon seasonal rainfall. The correlation between rainfall and hydropower generation may be changed with the availability of monthly generated hydropower data.

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