

Investigating the Teleconnection between Warm ENSO Phases and Seasonal Rainfall over Kotmale Catchment in Sri Lanka

S. S. K. Chandrasekara, S. K. Chandrasekara, V. Prasanna and H. H. Kwon

Abstract: Seasonal rainfall over Kotmale reservoir is changing at an alarming rate due to atmospheric oscillations taking place over Sri Lanka. Therefore, this study focused on the teleconnection between warm El-Nino Southern Oscillation (ENSO) phases and rainfall over the Kotmale catchment. Daily rainfall data obtained from 11 meteorological stations were used to identify the behaviour of the annual rainfall climatologies of the catchment. Inflow data of the Kotmale reservoir obtained for the period 1984 to 2012 were analysed to understand reservoir inflow trends. Sea surface temperatures were obtained from Japan Meteorological Agency to determine the warm El-Nino Southern Oscillation phase. The rainfall at the stations and the inflow to the reservoir have declined over the period selected. However, the rate of decrease has varied from station to station. Seasonal rainfall at all the stations considered between December and September showed a negative correlation with the mean sea surface temperature of the Nino 3 region. Warm El-Nino Southern Oscillation caused below average seasonal rainfall over the catchment between December and September. The northeast and southwest monsoon rainfall over the catchment has weakened because of warm El-Nino Southern Oscillation phase in the Nino 3 region. However, the effect has got reduced with the onset of monsoons.

Keywords: Warm ENSO phases, Seasonal rainfall, Kotmale

1. Introduction

In Sri Lanka, spatial and temporal availability of rainfall is an important hydrological parameter because of the effect it has on many sectors such as agriculture, fisheries, hydro-power generation, industries, drinking water supply, environment, tourism etc. It is therefore essential to get an understanding about the availability of rainfall and the management of the existing water resources in Sri Lanka. During recent decades, Sri Lanka has experienced frequent hydrological extremes in the rainfall (i.e. drought and floods) and scientists are in the process of identifying the possible reasons for these extremes.

El-Nino Southern Oscillation (ENSO) phenomenon is one of the primary modes of seasonal climatic variability, particularly in the tropics [1]. ENSO is a shift in the pattern of oceanic warming and atmospheric circulation centered around Pacific Ocean, typically recurring every 2-7 years across the tropics. The two phases of the ENSO phenomenon associated with warmer and colder than normal sea surfaces in the equatorial central and eastern Pacific oceans are referred to as El Nino and La Nina respectively. Many studies have shown ENSO as influencing the rainfall over Sri Lanka [1], [2], [3], [4], [5], [6], [7], [8], [9], [10],

[11]. There is also a strong link between seasonal rainfall anomalies in Sri Lanka and ENSO events [4].

During ENSO extremes also, the climate in Sri Lanka can change due to the alterations in the intensity and the location of the Walker cell [12]. Rainfall over Sri Lanka and India get

*Ms. S.S.K. Chandrasekara, M.Phil. Integrated Water Resources Management (University of Peradeniya), B.Sc. Agricultural Engineering (Hons) (University of Peradeniya). Reading Ph.D., Department of Civil Engineering, Chonbuk National University, Republic of Korea.
Email:sewwandhi@jbnu.ac.kr*

*Eng. S.K. Chandrasekara, C. Eng. (IESL-Sri Lanka), MIE(SL), B.Sc. Eng. (Hons) (Moratuwa), Civil Engineer, Mahaweli Authority of Sri Lanka.
Email:skchandrasekara@gmail.com*

*Dr. V. Prasanna, D.Sc. Environmental Science (Japan), M.Tech. Atmospheric Science (India), M.Sc. Space Physics (India), B.Sc. Physics (India), Researcher, National Institute of Meteorological Sciences (NIMS), Republic of Korea.
Email:prasa_arnala@yahoo.com*

*Eng. (Prof.) H. H. Kwon, Ph.D., Civil Engineering (Republic of Korea), M. Eng. Civil Engineering (Republic of Korea), B.Sc. Civil Engineering (Republic of Korea), Professor in Civil Engineering, Department of Civil Engineering, Chonbuk National University, Republic of Korea.
Email:hkwon@jbnu.ac.kr*



weakened during El Nino episodes that occur in the boreal summer i.e. between June and September, due to large-scale subsidence over the Central Indian Ocean region [13] and they get enhanced between October and December [1], [6], [10], [11]. During October - December season, the eastward displacement of the Walker cell in the Indian Ocean causes increased anomalies in the rainfall over Sri Lanka [14], [15]. Since Sri Lanka is a comparatively small island, ocean conditions around the country can modify the El-Nino effect [16].

2. Significance of the Study

This study consisted of a case study on the Kotmale reservoir in Sri Lanka through which the teleconnection between the warm ENSO phase and the rainfall over a reservoir catchment has been investigated to assist in the water management of the reservoir. Kotmale reservoir is one of the multipurpose reservoirs built in Sri Lanka in the 1980's. Storage volume of the Kotmale reservoir is very important due to many reasons. It is the upper most reservoir of the irrigation complex in Sri Lanka [17] and variations in its storage volume can affect the irrigation performance of downstream cascade reservoirs. The discharge from the Kotmale reservoir is regulated to increase the flow diverted at the Polgolla barrage into downstream cascade reservoirs for augmenting the quantity of water supplied by those reservoirs for irrigation purposes. Kotmale reservoir reduces flood peaks and their frequency, thus alleviating the floods in the Gampola area which is beneath it [18].

Furthermore, the quality of water stored in the Kotmale reservoir is degrading at an alarming rate due to sedimentation and eutrophication [19], [20], [21]. The reservoir storage goes down to dead storage level during the period August-September, even with an abundant inflow that come in between June and November [22], [23].

Thus, it is important to manage the water storage of the Kotmale reservoir efficiently and effectively if the water demands on it are to be met. An understanding of the teleconnection between the ENSO warm phase and the rainfall over the Kotmale reservoir will therefore be useful to develop an effective and efficient water management strategy for the Kotmale reservoir.

3. Data and Methodology

This study used daily rainfall data from 11 meteorological stations (Table 1). The Department of Meteorology, Sri Lanka manages the rain gauges at these stations, archives the data and, undertakes their quality controlling on a regular basis [24]. The identification of the outliers, cross checking for extreme values, checking for drifts in the data and cross correlation analysis were done to obtain robust quality data required for the study. The inflow data of the Kotmale reservoir for the period 1984 to 2012 were collected from the Mahaweli Authority of Sri Lanka (MASL). Sea surface temperatures (SSTs) were obtained from the Japan Meteorological Agency [25].

Table 1 - Descriptions of the 11 meteorological stations used in the study

No:	Station name	Extent (Ha)	Average annual rainfall (mm)
1	Ambewela	5423	2353
2	Annfield	4458	2771
3	Campion	989	2368
4	Helboda North	3729	3589
5	Holmwood Estate	6994	2196
6	Hope Estate	464	2748
7	Labukelle Estate	7531	3052
8	Nuwara Eliya	4273	1897
9	Oonagalla Estate	5821	3532
10	Sandringham	6797	2201
11	Watawala	166	4937

The daily rainfall climatologies of the stations were plotted to analyse the monthly rainfall variations at each station. Time series analysis of rainfall was carried for each station for 6 seasons {i.e. December-February (DJF), March-May (MAM), June-August (JJA), June-September (JJAS), September-November (SON) and October-December (OND)}. The mean SST values were correlated with the mean monthly rainfall values for each station and each season. Nuwara Eliya station was excluded from the SST analysis, because it did not have data for the period between 1960 and 2005. The analysis was done to ascertain whether there is a relationship between SST and the rainfall at the selected stations. Pentad daily rainfall data were also created for the warm ENSO phase. Finally, rainfall anomalies of each station during warm ENSO phases were examined to understand the variation of rainfall over the catchment area.

4. Results and Discussion

4.1 Quality Assessment of Station Data

The data obtained from all stations except Ambewela and Nuwara Eliya were in the range from -0.5 to 0.5 for the relationship with the anomaly and root mean square error (RMSE). Ambewela and Nuwara Eliya stations showed significant deviations during 1994 and between 1924 and 1927 as no data were available for several years. All stations had low frequency variations indicating the absence of extreme outliers. However, because of the low amount of data it had, Hope Estate station showed significantly lower values of correlations compared to the other 10 stations. Therefore, the quality of data of the Hope Estate station, according to the quality assessment procedure was not satisfactory and thus those data were not used in this study.

4.2 Observed Rainfall Trends

The annual rainfall at each station showed a decreasing trend over the selected time duration. However, the rate of decrease was different for each station. Three distinct rates for the decrease were identified (i.e. high rate of decrease, medium rate of decrease and low or insignificant rate of decrease). Holmwood Estate station showed a high rate of decrease in the rainfall during the period 1960-2000 (Figure 1). Since this station is located near the southern forests of Sri Lanka, the high deforestation of the southern forests may have caused this high rate of decrease in the annual rainfall [26], [27]. Nuwara Eliya, Campion, Helboda North and Watawala stations showed insignificant changes in the annual rainfall patterns. The data obtained from the Nuwara Eliya station were only for the period 1900 to 1961 and the recent rainfall trend could not be ascertained from those data. Literature shows that the annual rainfall at Nuwara Eliya had begun to decrease after the 19th century [28], [29]. The rest of the stations showed a medium rate of decrease in the rainfall.

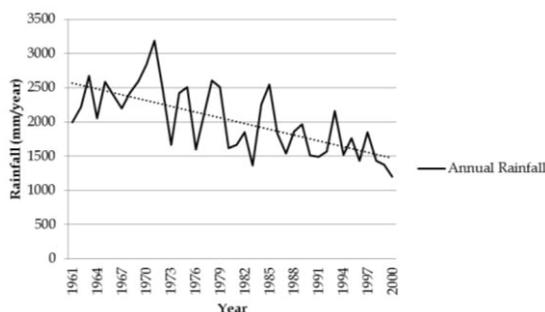


Figure 1 - Decreasing annual rainfall at the Holmwood Estate station

Previous studies have revealed that the rainfall at stations located at higher elevations had been decreasing during the last century [30], [28]. The stations used in this study are also located at higher elevations which could be the reason for the decreasing rainfall at these stations.

4.3 Identification of ENSO Impact on the Rainfall

At Oonagalla Estate and Watawala stations (Figure 2), seasonal rainfall during all the seasons (i.e. DJF, MAM, JJA, JJAS, SON and OND) showed a negative correlation with the mean SST of the Nino 3 region.

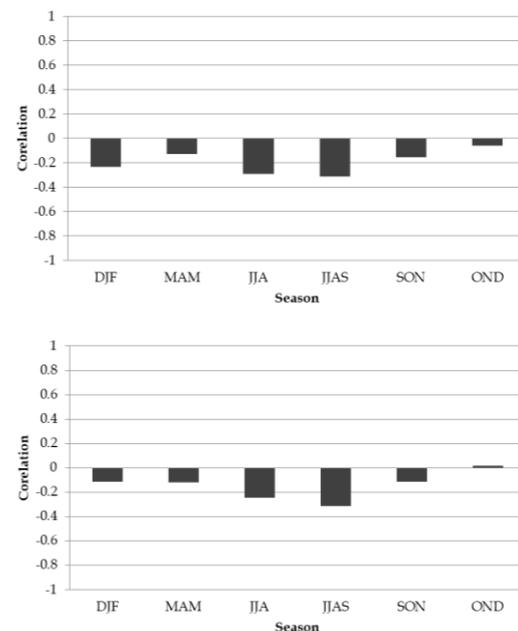


Figure 2 - Correlation of mean SST (Nino 3 region) with seasonal mean rainfall at stations at Oonagalla Estate (top) and Watawala (below)

For the remaining stations, the seasonal rainfall showed a negative correlation with the mean SST of the Nino 3 region for DJF, MAM, JJA and JJAS seasons and a positive correlation for SON and OND seasons (Figure 3)

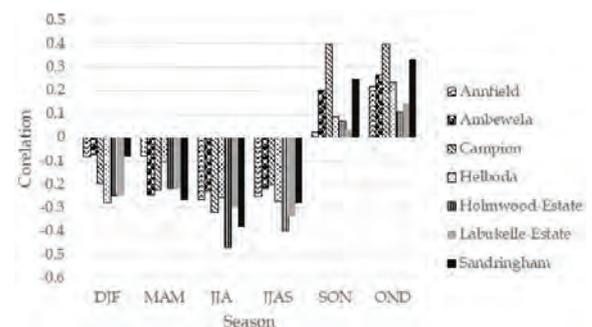


Figure 3 - Correlation of mean SST (Nino 3 region) with the seasonal mean rainfall at all stations except Oonagalla Estate and Watawala stations



4.4 Impact of ENSO on the Seasonal Rainfall

The warm ENSO phase is based on a SST anomaly threshold level of + 0.5°C. However during the period 1960 to 2011, there had been years that had ENSO phases of higher warming with the years 1982, 1983, 1987 and 1997 experiencing SST anomalies exceeding 1°C. Also, a majority of the warm SST phases fell in the DJF, JJA, JJAS, SON and OND seasons and the number of warm ENSO phases was lowest in the MAM season.

During warm ENSO years, below average seasonal rainfall was prominent for all the station in the catchment for DJF season. Campion, Helboda North and Labukelle Estate stations were more vulnerable to ENSO warm phases during DJF seasons. Although, a few stations (i.e. Sandringham, Helboda North and Ambewela stations) had experienced above average seasonal rainfall during the month of December, the amount of this rainfall was not significant to be considered. The seasonal rainfall at the Watawala station was less vulnerable to warm ENSO phases during the DJF season.

During warm ENSO phases, all the stations had experienced below average seasonal rainfalls during MAM, JJA and JJAS seasons. However, the seasonal rainfalls at the Ambewela, Campion and Holmwood Estate stations were highly vulnerable to warm ENSO phases during the MAM season and the number of El-Nino years during which the rainfalls at these stations were below average was higher compared to that of other stations. The seasonal rainfalls of the rest of the stations during the MAM season were moderately vulnerable to the warm ENSO phases. During the El-Nino in 1983, seasonal rainfalls received by all 9 stations during the MAM season were well below the average level. Moreover, the seasonal rainfalls of all the stations were highly vulnerable to the warm ENSO phases during JJA and JJAS seasons. In addition, all the stations except the Sandringham station received below average seasonal rainfall during the JJA seasons of more than 75% of the El-Nino years between 1960 and 2011. Ambewela, Helboda North and Oonagalla Estate stations showed below average rainfall during the JJAS seasons of all the El-Nino years in the period 1963 to 2005.

At most of the stations, above average seasonal rainfall was observed during the SON seasons of the warm ENSO phase. However, no specific

temporal pattern could be identified for the above average seasonal rainfall observed at these stations. Campion station had above average seasonal rainfall during most of the El-Nino years.

Above average seasonal rainfall was prominent at all the stations during the OND seasons of El-Nino years. The seasonal rainfall at the Labukelle Estate station was found to be more vulnerable to the ENSO warm phase during the OND season when compared with other stations and had below average rainfall during most of the El Nino years.

In addition to ENSO, there are several other phenomena which can influence seasonal rainfall over Sri Lanka. Indian Ocean Dipole (IOD) plays an important role as a modulator of precipitation in Sri Lanka [31]. Previous studies have shown that the seasonal rainfall between September and March has had a strong and robust association with the IOD during the period 1869 to 2000 [32]. It is found that in Sri Lanka, IOD has a high positive correlation with the seasonal rainfall during SON season [33]. Moreover, the influences of IOD and ENSO are statistically inter-linked and the IOD influence will be highly significant even when there is no ENSO influence and when the two are in competition, the IOD influence will prevail preponderantly over that of ENSO [34].

Because of the specific position of Sri Lanka within the Indian Ocean, the changes in the ocean characteristics could have an impact on the rainfall over Sri Lanka. The rainfall over tropical regions surrounding the Indian Ocean appears to vary highly due to IOD [33]. Previous studies have suggested that anomalously warm SSTs in the western Indian Ocean enhance the seasonal rainfall during the period between September and March, a period during which positive IOD events take place [34]. Also, during the positive IOD events, the rainfall over the eastern half of the Indian Ocean decreases whereas it increases in the western half [35 & 36]. During the OND season which coincides with the mature and decay stages of ENSO events, a strong positive correlation coefficient is observed between SST anomalies in the Indian Ocean and rainfall over Sri Lanka [8].

4.5 ENSO Impacts on the Inflow of Kotmale Reservoir

In the months between June and November, the inflow of Kotmale reservoir is higher than

during the remaining months of the year (Figure 4). As has already been mentioned, during the DJF season, the Kotmale catchment received below average seasonal rainfall during a considerable number of warm ENSO phases. This may have led to the reduction in the inflow to the reservoir during the DJF season. When there are prominent warm ENSO phases between October and November, Kotmale catchment receives above average rainfall and this can lead to an increased inflow to the reservoir.

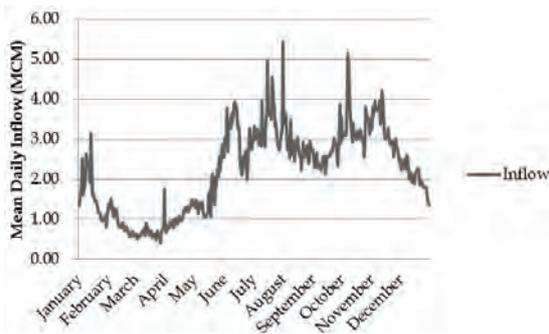


Figure 4 - Daily mean inflow (MCM) of the Kotmale reservoir

However, the inflow to the Kotmale reservoir has a decreasing trend (Figure 5). The amount of rainfall received at the stations has decreased with time and due to this reason the inflow to the reservoir has also decreased with time.

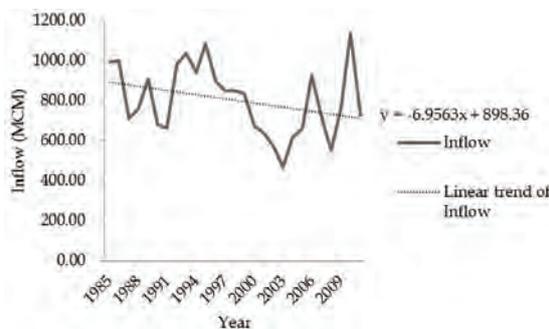


Figure 5 - inflow to the Kotmale reservoir between 1985 and 2009

5. Conclusions

5.1 Northeast Monsoon

Rainfall at each station and inflow to the Kotmale reservoir decreased during the selected time period. As already mentioned, northeast monsoon (NEM) season in Sri Lanka occurs during the period between December and January. During NEM, below normal rainfall over Kotmale catchment was evident during a considerable number of El Nino years, which implies that the warm ENSO phase has a high impact on the Kotmale catchment.

At the onset of NEM (i.e. between October and December), the Kotmale catchment has received above normal rainfall during warm ENSO years.

5.2 Southwest Monsoon

The onset of southwest monsoon (SWM) is the period between March and April and below normal rainfall was prominent in the Kotmale catchment during this period.

However, the seasonal rainfall at Labukelle Estate station which is highly vulnerable to the ENSO warm phase, caused below average seasonal rainfall. Since the catchment area and the average rainfall are higher at the Labukelle Estate station when compared to other stations in the catchment area, necessary precautions have to be taken to preserve the runoff area of the Labukelle Estate station.

As discussed, the behaviour of the Walker cell and SST gradients in the Indian Ocean, including IOD could make the teleconnection between the warm ENSO phase and the seasonal rainfall in Sri Lanka uncertain. Therefore, further studies on the teleconnection with other indices are recommended.

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