



## Effect of Indian Ocean Dipole (IOD) Events on the Second Inter-monsoonal Rainfall in the Wet Zone of Sri Lanka

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### ABSTRACT

The climatic variations in the Indian Ocean have a strong relationship with the rainfall anomaly of Sri Lanka. Indian Ocean Dipole (IOD) is an ocean-atmospheric coupled phenomenon associated with an east-west gradient in the tropical Indian Ocean Sea Surface Temperature (SST) anomalies. Identifying the impact of IOD phenomenon on the spatial and temporal variation of the rainfall pattern is a useful tool for seasonal climate forecasting. The present study examined the influence of IOD on the Second Inter-monsoon (SIM) rains of the Wet zone (WZ) of Sri Lanka. Considering 16 rain-gauge locations scattered in the WZ of Sri Lanka covering nine Agro-ecological Regions (AERs), daily rainfall time series for 44-years (1976-2019) were collected. The IOD-positive and IOD-negative years were extracted based on the Dipole Mode Index (DMI) over the neutral years. Five rainfall indices, namely, cumulative rainfall, the maximum rainfall received within a day, number of wet days, heavy rainfall events and the maximum consecutive dry days were statistically analysed. The results revealed a significant positive anomaly of mean cumulative rainfall in the SIM season during the IOD-positive years while in IOD-negative years this anomaly was negative ( $p < 0.05$ ). An apparent increase or decrease of number of wet days and heavy rainfall events was observed during IOD-positive or IOD-negative years, respectively. However, the mean maximum consecutive dry days showed a distinct negative anomaly with the positive IOD events and positive anomaly with the negative IOD events. Further investigations are suggested to elucidate the *El Niño* Southern Oscillation (ENSO)-induced anomalous variation over IOD impacts.

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## INTRODUCTION

Indian Ocean Dipole (IOD) is an Ocean-atmosphere interaction that may exemplify a characteristic internal mode of the Indian Ocean climate system (Saji *et al.*, 1999; Webster *et al.*, 1999). It is associated with the Sea Surface Temperature (SST) anomaly between two poles in the south-eastern and western equatorial Indian Ocean (Ashok *et al.*, 2001; Yamagata *et al.*, 2002). Similar to the dominant mode of ocean-atmosphere interaction in the tropical Pacific; *El Niño* Southern Oscillation (ENSO), IOD also has three phases, namely, neutral, positive (warm) and negative (cold) (Kousky and Higgins, 2007; McPhaden *et al.*, 2006; Philander, 1985). The positive phase of the IOD (associated with a warm SST) leads to enhanced rainfall in the western Indian Ocean and diminished rainfall in the south eastern Indian Ocean; while the opposite is true for the negative phase (Saji *et al.*, 1999).

In the neutral phase, warm water from the upper equatorial Pacific Ocean is transferred to the Indian Ocean, resulting in a warm SST in the islands of Indonesia. Air rises above this area and falls allowing westerly winds to blow along the equator (Rao *et al.*, 2002). During the positive IOD phase, westerly winds weaken along the equator allowing warm water to shift towards Africa. Changes in the winds also allow cool water to rise up from the deep ocean in the east. This sets up a temperature difference across the tropical Indian Ocean resulting in higher rainfall in the countries around the Arabian Sea. Westerly winds intensify along the equator during the negative phase, allowing warmer waters to concentrate near Australia. This sets up a temperature difference across the tropical Indian Ocean, with an above-average rainfall over parts of southern Australia and Sumatra (Yuan *et al.*, 2008; Aparna *et al.*, 2012; Pentakota *et al.*, 2012; BOM, Australia, 2020). An IOD situation is a complex phenomenon with multiple variants, *i.e.* whether they be called true dipoles, pseudo dipoles, IOD Modoki, etc. (Verdon-Kidd, 2018).

Several studies have been carried out in different countries, especially those closer to the Indian Ocean, to find out the impact of IOD on the rainfall pattern and thereby the weather changes such as floods and droughts. Clark *et al.* (2003) and Black *et al.* (2003) reported that the rainfall in October to December, along the coastal belt in Kenya and Tanzania, correlates strongly with SST in the Indian Ocean. Ashok *et al.* (2001) showed that a positive IOD plays an important role in increasing the Indian summer monsoon (ISM) rainfall. Furthermore, the IOD influences the inter-annual

rainfall variability over central Brazil and subtropical La Plata Basin during the austral spring (Chan *et al.*, 2008). Through limited studies, a considerable influence of IOD events has been observed in the rainfall climatology of Sri Lanka (Zubair *et al.*, 2003; Jayawardene *et al.*, 2015).

Sri Lanka has four distinct rainfall seasons, namely, the first inter-monsoon (FIM), southwest monsoon (SWM), second inter-monsoon (SIM) and northeast monsoon (NEM) (Punyawardena, 2020). Based on these four rainfall seasons, the country has two cultivation seasons, *i.e.* *Yala* season comprising both FIM and SWM seasons (minor cultivating season; March – September) and *Maha* season comprising both SIM and NEM seasons (major cultivating season; October to February) (Punyawardena, 2020). During two monsoon seasons, rainfall is mainly received by the southwest and northeast monsoonal winds while during inter-monsoon periods, Sri Lanka receives rains by the convective activity and its enhanced phase with the passage of the Inter Tropical Convergence Zone (ITCZ) on or near to Sri Lanka (Punyawardena, 2008). Land preparation and crop establishment activities are initiated with the onset of the inter-monsoon rains in each growing season. Therefore, the positive and negative anomalies of the rainfall pattern in the inter-monsoon seasons would directly affect the crop production during the *Yala* and *Maha* seasons. The SIM is the most important rainy season to the country where the island receives a well distributed rainfall within two months (October and November), which is about 30% of the total annual rainfall (Chandrapala, 2007).

Wet zone (WZ) covers the south-western part of the low lands and central highlands of Sri Lanka, which receives over 2,500 mm of average annual rainfall (Punyawardena *et al.*, 2013). Though the major irrigated paddy-growing areas are not located in the WZ, the rainfed paddy, three major plantation crops (tea, rubber and coconut), export agricultural crops, and vegetables are mainly established in the WZ depending on the rainfall pattern (Punyawardena *et al.*, 2003). Further, the WZ precipitation causes a considerable impact on the economic progress of Sri Lanka as the main source of energy is hydropower (Jayawardene *et al.*, 2015). Therefore, it is important to ascertain the rainfall variation in the WZ of Sri Lanka under the effect of IOD in order to enhance the skill of weather predictions enabling to make appropriate on-farm decisions well before the onset of the *Maha* season.

**METHODOLOGY**

Daily rainfall data were collected from 16 meteorological observation stations scattered throughout the WZ of Sri Lanka, representing nine different Agro-ecological Regions (AERs), for a period of 44 years from 1976 to 2019 (Figure 1). Data were sourced from the Natural Resources Management Centre of the Department of Agriculture, Department of Meteorology, and the Tea Research Institute of Sri Lanka.

Several Ocean-atmospheric indices have been used to investigate the IOD events such as SST, Sea

Sub-surface Temperature, Sea Surface Heights, surface zonal winds and velocity potential ( $\chi$ ) fields (Ashok et al., 2001; Zubair et al., 2003; Rao and Yamagata, 2004; Chan et al., 2008; Xin-Yu et al., 2015). For the present study, SST defined by the National Oceanic and Atmospheric Administration (NOAA) of the United States Climate Prediction Centre (CPC) was considered (Reynolds et al., 2007). Intensity of the IOD was represented by the anomalous SST gradient between the western equatorial Indian Ocean (50E-70E and 10S-10N) and the south eastern equatorial Indian Ocean (90E-110E and 10S-0N) (Figure 2).

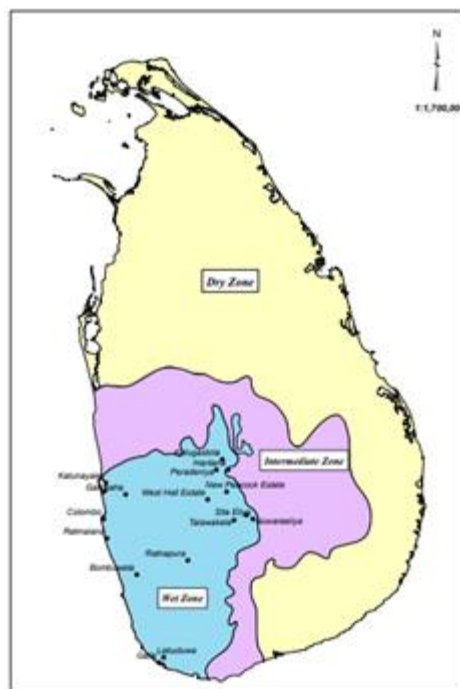


Figure 1: Rain gauge location map in the Wet zone considered for the study

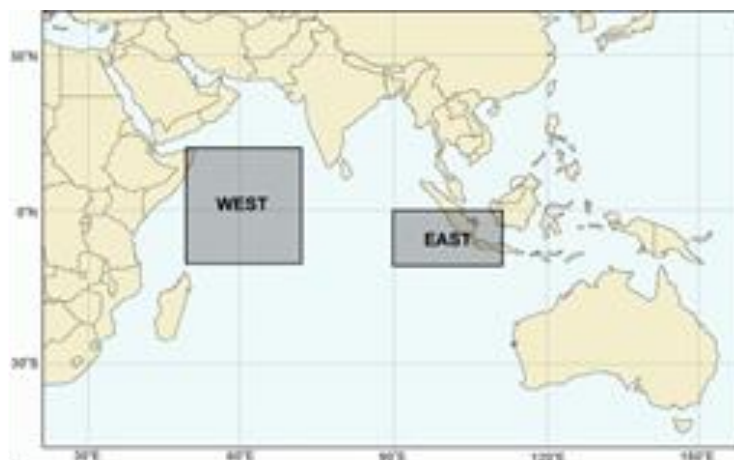


Figure 2: The two poles in the Indian Ocean (Image credit: BOM, Australia)

**Table 1: Rainfall indices used in the study**

Index	Definition
Cumulative rainfall (mm)	Total rainfall received during the season
Maximum rainfall per day (mm)	Maximum value of rainfall received within a day, during the season
Number of wet days	Total number of days that received rainfall >1mm during the season
Number of heavy rainfall events	Total number of days that received rainfall higher than the value of 90 <sup>th</sup> percentile of the standard average period of this study
Maximum consecutive dry days	The largest count of consecutive days that received rainfall <1mm during the season

This gradient is named as Dipole Mode Index (DMI). When the DMI is positive, the phenomenon is referred to as the IOD-positive and while a negative DMI is referred to as the IOD-negative (Saji *et al.*, 1999; Webster *et al.*, 1999). The periodically updated east and west SST anomalies, published by Physical Science Laboratory, NOAA (DMI: Standard PSL) was considered for the present study ([https://psl.noaa.gov/gcos\\_wgsp/Timeseries/DMI/](https://psl.noaa.gov/gcos_wgsp/Timeseries/DMI/)). Different IOD related studies shows a substantial variation in selecting the IOD events depending the spatial and temporal difference (Verdon-Kidd, 2018; Chan *et al.*, 2008; Hong, 2008). For the present study, the operationally used value of above +0.4 °C was considered as the positive IOD events and below -0.4 °C was considered as the negative IOD event (<http://www.bom.gov.au/climate/enso/#tabs=Indian-Ocean>). The DMI range of -0.4 °C to +0.4 °C is the IOD-neutral period. Based on this threshold values, IOD-positive, IOD-negative and neutral years were identified for the four rainfall seasons of Sri Lanka.

Five rainfall indices were considered to find the effect of IOD events on the rainfall variability of the country (Table 1). One-way ANOVA, Dunnett's test and Cross Tabulation-Chi-square test were used (p=0.05) to investigate the statistical significance, using Minitab statistical software.

## RESULTS AND DISCUSSION

The IOD-positive and IOD-negative years during the study period 1976-2019 within the four rainfall seasons are shown in Table 2. There were only 2 or 3 IOD events during NEM and FIM seasons in both positive and negative phases of the IOD. This clearly indicates that statistically

acceptable number of IOD events does not exist during the NEM and FIM seasons to proceed with further analysis. Within an IOD year, IOD events usually started around May or June, peaked in October and then decayed in December (Saji *et al.*, 1999).

Among the two rainfall seasons (SIM and SWM) where IOD was effective, only SIM season showed statistically significant observations, with a peak of IOD events within a year. The SWM season did not show any apparent increasing or decreasing trends of IOD events (data not shown). Therefore, the present study was mainly focused on the effect of IOD events on the SIM season. Previous studies have also revealed a positive anomaly of rainfall around the Arabian Sea during October-November period under the influence of a positive IOD (Black, 2005; Black *et al.*, 2003; Chan *et al.*, 2008). Zubair *et al.* (2003), using monthly datasets from 1869-2000, also reported an enhancement of *Maha* season rainfall during the positive IOD phase. Ashok *et al.* (2001) discovered that the ENSO-Indian Summer Monsoon rainfall (ISMR) correlation is low (high), when the IOD-ISMR correlation is high (low).

### Comparison of the Mean Cumulative Rainfall

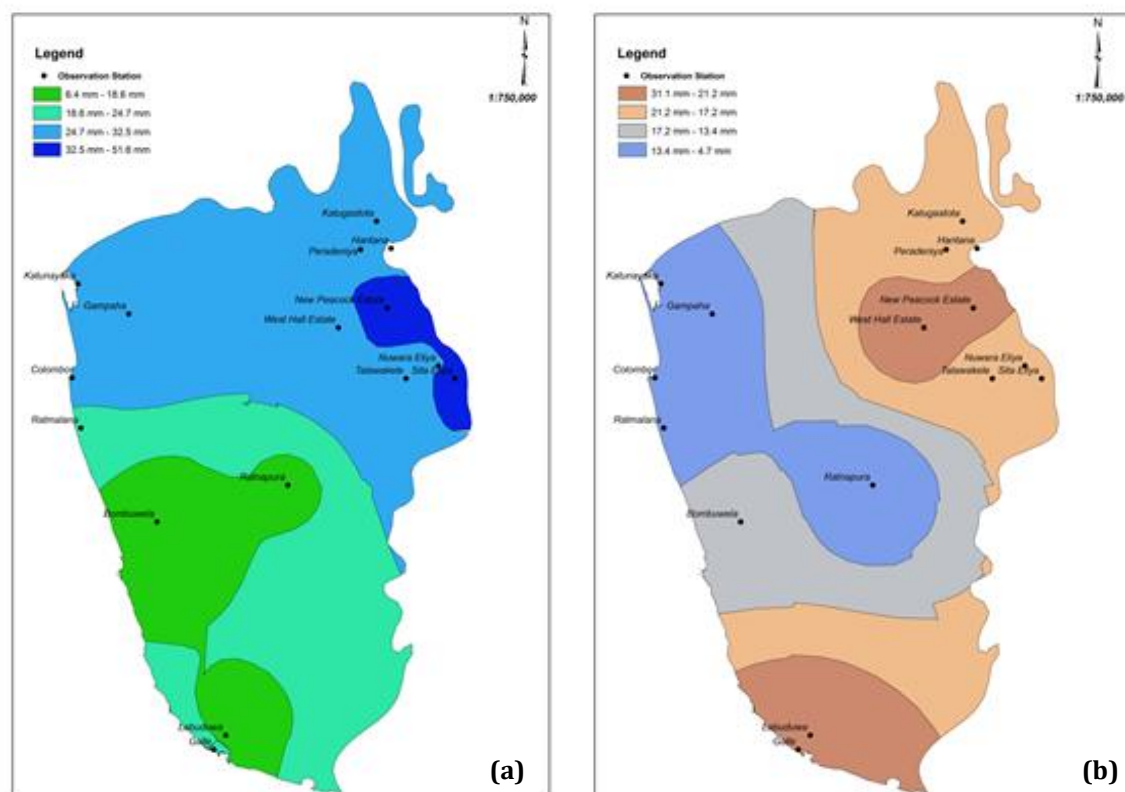
The spatial distribution of positive and negative mean cumulative rainfall anomalies over the neutral years are illustrated in Figure 3. An anomalous variation was prominent in Up-country WZ and Mid-country WZ mainly during the IOD-positive years.

The average of all 16 locations considered in the study showed a significant increase in mean cumulative rainfall during IOD-positive years while a significant decrease in IOD-negative years (p<0.05) (Table 3). Among all locations studied, the locations in the WU3 AER showed a significant positive anomaly.

**Table 2: IOD-positive and IOD-negative years within four rainfall seasons during the study period**

IOD-positive Years				IOD-negative Years			
FIM	SWM	SIM	NEM	FIM	SWM	SIM	NEM
2010	1983	1982	1998	1983	1980	1980	1978
2017	1994	1994	2019	1992	1981	1984	1983
	1997	1997			1989	1996	1985
	2012	2006			1992	1998	
	2015	2011			1996		
	2017	2015					
	2019	2018					
		2019					

Source: [https://psl.noaa.gov/gcos\\_wgsp/Timeseries/DMI/](https://psl.noaa.gov/gcos_wgsp/Timeseries/DMI/); IOD-positive years: anomalous east west SST gradient is > (+0.4 °C); IOD-negative years: anomalous east west SST gradient < (-0.4 °C); FIM: First Inter-monsoon; SWM: Southwest monsoon; SIM: Second Inter-monsoon and NEM: Northeast monsoon.



**Figure 3: Spatial distribution pattern of mean cumulative rainfall anomaly during (a) IOD-positive years and (b) IOD-negative years.**

The amount of water needed for crops can be supplied by rainfall, irrigation, or by a combination of both (Brouwer and Heibloem, 1986). Rainfed cultivation is prominent in the WZ as it receives a sufficient amount of rainwater during both cultivation seasons. The quantum of rainwater received is an important factor to be considered when planning a cropping season to select the crop variety and the extent of cultivation. The present study revealed that the

quantum of rainfall received within the SIM period in the WZ is in the range of 430 – 867 mm. During a positive IOD period, it has increased from 525 – 1,120 mm and decreased to a range of 370 – 825 mm during IOD-negative years (Table 3). Hence, if a positive IOD phase is predicted in a given year, excess soil moisture conditions in uplands and water-logging and/or flooding in low-lands can be expected during the SIM season.

**Table 3: Comparison of positive and negative IOD years with neutral years for mean cumulative rainfall (mm)**

Station	AER	Neutral	Positive	Negative
Thalawakele	WU2a	430.4	525.2 <sup>ns</sup>	372.9 <sup>ns</sup>
Pussallawa (West Hall)	WU2b	834.2	1030.0 <sup>ns</sup>	574.9 <sup>ns</sup>
Pussallawa (New Peacock )	WU2b	737.7	1119.0 <sup>ns</sup>	563.0 <sup>ns</sup>
Nuwara Eliya	WU3	455.8	601.4 <sup>s</sup>	371.1 <sup>ns</sup>
Sita Eliya	WU3	503.8	709.9 <sup>s</sup>	394.6 <sup>ns</sup>
Hantana	WM2b	535.3	665.5 <sup>ns</sup>	380.0 <sup>ns</sup>
Peradeniya	WM2b	566.6	719.9 <sup>ns</sup>	491.9 <sup>ns</sup>
Katugastota	WM3b	559.3	692.3 <sup>ns</sup>	459.1 <sup>ns</sup>
Ratnapura	WL1a	866.5	1005.7 <sup>ns</sup>	825.6 <sup>ns</sup>
Bombuwela	WL1b	800.8	859.8 <sup>ns</sup>	671.0 <sup>ns</sup>
Labuduwa	WL2a	716.5	762.3 <sup>ns</sup>	567.9 <sup>ns</sup>
Galle	WL2a	636.3	742.2 <sup>ns</sup>	437.8 <sup>ns</sup>
Colombo	WL3	634.0	833.7 <sup>ns</sup>	589.2 <sup>ns</sup>
Katunayake	WL3	650.5	853.9 <sup>ns</sup>	574.5 <sup>ns</sup>
Gampaha-Henarathgoda	WL3	615.3	806.5 <sup>ns</sup>	541.8 <sup>ns</sup>
Rathmalana	WL3	714.6	864.4 <sup>ns</sup>	627.2 <sup>ns</sup>
<b>Average</b>		641.1	799.5 <sup>s</sup>	527.7 <sup>s</sup>

AER: Agro-ecological Regions; within a row, compared with the neutral years (separately with positive and negative IOD years), means followed by 'ns' are not significantly different and those followed by 's' are significantly different at  $p=0.05$ .

Moreover, appropriate soil conservation measures should be adopted in sloping lands, especially in mid and up country regions of the WZ in such years. The IOD-negative years may not have a major impact on WZ crops, where even rice and tea being the crops that are highly influenced by variations of rainfall require a minimum of 200 mm of rainfall per month (De Costa, 2010).

### Comparison of the Mean Maximum Rainfall per day

The mean values of the maximum rainfall received per day did not show a significant positive or negative anomaly during the IOD-positive period (Table 4). However, the IOD-negative years showed below average values for every selected location except at Gampaha-Henarathgoda.

According to the study, the mean maximum rainfall received per day during a neutral year ranged from 60 to 130 mm. This range decreased to 51 - 124 mm during an IOD-negative phase (Table 4). Receipt of the maximum rainfall per day in a given location depends on several factors such as atmospheric pressure, wind speed and shear, convective activity, the position of the ITCZ, occurrence of low level atmospheric disturbances, and cyclonic storms resulting in high variability of daily rainfall during the SIM season

(Punyawardena, 2008). Therefore, the impact of IOD can be masked by these factors.

### Comparison of the Number of Wet Days

There was an association between IOD-phases and the number of wet days in all selected locations ( $p=0.05$ ) except in five locations, namely, Talawakele, Pussallawa-West Hall, Bombuwela, Labuduwa and Galle for IOD-positive years (Table 5). On average, 55.6% of the number of wet days were observed during the neutral years (range: 46.2% - 63.6%). This has increased to 62.9% with the positive impact of IOD phase (range: 56.4% - 72.5%) and decreased to 50.8% during an IOD-negative period (range: 37.7% - 67.6%).

Distribution of rainfall received during the season is also an important information to find out whether the crop water requirement is being met by rainfall alone. The reduction of rainfall during the IOD-negative phase may not affect the crop performance in the WZ because of the prevailing relatively low evapotranspiration regime of the region. Monthly evapotranspiration rate ranges from 45.6 mm to 67.0 mm during SIM in the WZ (DOA, 2018). The present study also revealed that more than 15 consecutive days of receiving rainfall of < 1 mm was hardly observed even during the IOD-negative phase in the SIM season (Data not shown).

**Table 4: Comparison of positive and negative IOD years with neutral years for mean maximum rainfall (mm per day)**

Station	AER	Neutral	Positive	Negative
Thalawakele	WU2a	60.9	61.7 <sup>ns</sup>	51.0 <sup>ns</sup>
Pussallawa (West Hall)	WU2b	90.1	89.3 <sup>ns</sup>	62.9 <sup>ns</sup>
Pussallawa (New Peacock )	WU2b	90.7	104.3 <sup>ns</sup>	73.7 <sup>ns</sup>
Nuwara Eliya	WU3	65.8	64.1 <sup>ns</sup>	62.2 <sup>ns</sup>
Sita Eliya	WU3	65.2	67.5 <sup>ns</sup>	58.5 <sup>ns</sup>
Hantana	WM2b	73.3	79.5 <sup>ns</sup>	69.9 <sup>ns</sup>
Peradeniya	WM2b	74.3	78.8 <sup>ns</sup>	66.9 <sup>ns</sup>
Katugastota	WM3b	79.8	76.3 <sup>ns</sup>	72.7 <sup>ns</sup>
Ratnapura	WL1a	95.9	108.8 <sup>ns</sup>	94.4 <sup>ns</sup>
Bombuwela	WL1b	128.5	114.2 <sup>ns</sup>	100.7 <sup>ns</sup>
Labuduwa	WL2a	113.2	120.0 <sup>ns</sup>	90.0 <sup>ns</sup>
Galle	WL2a	101.4	109.2 <sup>ns</sup>	85.9 <sup>ns</sup>
Colombo	WL3	125.4	96.1 <sup>ns</sup>	95.1 <sup>ns</sup>
Katunayake	WL3	109.1	104.7 <sup>ns</sup>	92.6 <sup>ns</sup>
Gampaha-Henarathgoda	WL3	95.1	88.3 <sup>ns</sup>	96.7 <sup>ns</sup>
Rathmalana	WL3	130.0	97.1 <sup>ns</sup>	123.8 <sup>ns</sup>
<b>Average</b>		93.7	145.9 <sup>ns</sup>	81.1 <sup>ns</sup>

AER: Agro-ecological Regions; within a row, compared with the neutral phase (separately with positive and negative IOD years), means followed by 'ns' are not significantly different at p=0.05.

**Table 5: Comparison of positive and negative IOD years with neutral years for number of wet days**

Station	AER	Neutral	Positive	Negative	p value for positive events	p value for negative events
		Total number of WD for the total of 1952 days	Total number of WD for the total of 488 days	Total number of WD for the total of 244 days		
Talawakele	WU2a	921	226	139	0.624	0.316
Pussallawa (West Hall)	WU2b	1241	295	165	0.201	0.214
Pussallawa (New Peacock)	WU2b	964	221	87	0.000*	0.072
Nuwara Eliya	WU3	1125	316	124	0.004*	0.043*
Sita Eliya	WU3	1135	336	133	0.000*	0.278
Hantana	WM2b	818	242	92	0.000*	0.012*
Peradeniya	WM2b	1005	282	120	0.013*	0.497
Katugastota	WM3b	1082	299	123	0.020*	0.137
Ratnapura	WL1a	1168	337	135	0.003*	0.052
Bombuwela	WL1b	1150	299	128	0.343	0.054
Labuduwa	WL2a	1039	284	130	0.197	0.623
Galle	WL2a	1046	275	124	0.273	0.414
Colombo	WL3	1055	320	109	0.000*	0.006*
Katunayake	WL3	1042	308	115	0.000*	0.065
Gampaha-Henarathgoda	WL3	918	313	108	0.000*	0.208
Ratmalana	WL3	1112	317	118	0.001*	0.011*

AER: Agro-ecological Region; WD: Wet days; '\*' Values are significant at p=0.05

### Comparison of heavy rainfall events

There was an association between IOD-phases and number of heavy rainfall events in all considered locations (p=0.05), except at Pussallawa-West Hall, Ratnapura, Bombuwela, Labuduwa and Galle for IOD-positive years (Table 6). On average,

10.7% of the heavy rainfall events were observed during the neutral years (range: 8.6% - 11.8%). This has increased to 15% with the positive impact of IOD phase (range: 11.9% - 19%) and decreased to 8.5% during an IOD-negative period (range: 5.7%-11.5%).

**Table 6: Comparison of positive and negative IOD years with neutral years for heavy rainfall events**

Station	AER	Neutral	Positive	Negative	p value for positive events	p value for negative events
		Total HRE for the total of 1952 events	Total HRE for the total of 488 events	Total HRE for the total of 244 events		
Talawakele	WU2a	182	56	19	0.015*	0.091
Pussallawa (West Hall)	WU2b	223	71	16	0.058	0.021*
Pussallawa(New Peacock)	WU2b	188	58	15	0.000*	0.305
Nuwara Eliya	WU3	221	82	23	0.001*	0.374
Sita Eliya	WU3	231	86	17	0.001*	0.024*
Hantana	WM2b	152	58	14	0.000*	0.129
Peradeniya	WM2b	182	68	18	0.003*	0.319
Katugastota	WM3b	214	72	18	0.020*	0.086
Ratnapura	WL1a	197	64	28	0.089	0.613
Bombuwela	WL1b	226	58	25	0.850	0.538
Labuduwa	WL2a	210	64	18	0.215	0.076
Galle	WL2a	207	67	16	0.051	0.048*
Colombo	WL3	220	76	27	0.009*	0.924
Katunayake	WL3	198	68	24	0.016*	0.881
Gampaha-Henarathgoda	WL3	203	75	26	0.004*	0.970
Ratmalana	WL3	217	74	26	0.014*	0.829

AER: Agro-ecological Region, HRE: Heavy Rainfall Events; \* Values are significant at p=0.05.

**Table 7: Comparison of positive and negative IOD years with neutral years for mean maximum consecutive dry days**

Station	AER	Neutral	Positive	Negative
Thalawakele	WU2a	7	5 <sup>ns</sup>	9 <sup>ns</sup>
Pussallawa (West Hall)	WU2b	7	6 <sup>ns</sup>	6 <sup>ns</sup>
Pussallawa (New Peacock)	WU2b	8	5 <sup>ns</sup>	10 <sup>ns</sup>
Nuwara Eliya	WU3	8	6 <sup>ns</sup>	10 <sup>ns</sup>
Sita Eliya	WU3	8	5 <sup>ns</sup>	9 <sup>ns</sup>
Hantana	WM2b	8	7 <sup>ns</sup>	9 <sup>ns</sup>
Peradeniya	WM2b	8	7 <sup>ns</sup>	9 <sup>s</sup>
Katugastota	WM3b	8	5 <sup>ns</sup>	10 <sup>ns</sup>
Ratnapura	WL1a	7	5 <sup>ns</sup>	10 <sup>s</sup>
Bombuwela	WL1b	7	5 <sup>ns</sup>	8 <sup>ns</sup>
Labuduwa	WL2a	8	7 <sup>ns</sup>	10 <sup>ns</sup>
Galle	WL2a	8	5 <sup>ns</sup>	12 <sup>ns</sup>
Colombo	WL3	8	4 <sup>s</sup>	12 <sup>ns</sup>
Katunayake	WL3	8	5 <sup>ns</sup>	10 <sup>ns</sup>
Gampaha-Henarathgoda	WL3	11	5 <sup>ns</sup>	10 <sup>ns</sup>
Rathmalana	WL3	7	4 <sup>s</sup>	9 <sup>ns</sup>
<b>Average</b>		8	5 <sup>s</sup>	10 <sup>s</sup>

AER: Agro-ecological Regions; within a row, compared with the neutral phase (separately with positive and negative IOD years), means followed by 'ns' are not significantly different and those followed by 's' are significantly different at p=0.05.

Black *et al.* (2003) has reported that extreme short rains are associated with increasing IOD events in East Africa. Heavy rainfall events can be considered as receiving intense rains within a short period of time. Receiving >25 mm of rainfall per hour is considered as an "erosive rain"

(Punyawardena, 2008). High intense rains result in soil erosion especially in the sloping terrain in the WZ (i.e., Mid and Up country WZ). Therefore, if an IOD event is predicted, agro-met advisories may emphasize on the importance of adopting soil



conservation measures in landscapes that are prone to soil erosion and land degradation.

### Comparison of the Mean Maximum Consecutive Dry Days

An apparent reduction of the mean value of the maximum consecutive dry days was observed with the positive IOD events in all selected locations. Colombo and Ratmalana in WL3 AER showed a significant decrease of the maximum consecutive dry days ( $p < 0.05$ ). During the IOD-negative period, 14 out of 16 locations showed an increasing trend in the maximum consecutive dry days, where a significant increase ( $p < 0.05$ ) was reported from Ratnapura (Table 7).

In the IOD-neutral phase, the maximum consecutive dry days ranged from 7 to 11, which decreased to 4-7 days during the IOD-positive phase, and increased to 6-12 days during the IOD negative phase (Table 7). In general, the maximum consecutive dry days is not a meaningful indicator for the WZ as rainfall has exceeded the evapotranspiration demand (DOA, 2018).

The IOD cannot be viewed in isolation from the ENSO. Instead, it is assumed that in some years, a strong ENSO forcing can create a bias in the Indian Ocean-coupled system (Ashok *et al.*, 2001; Black *et al.*, 2003; Zubair *et al.* in 2003; Chan *et al.*, 2008). As for the SIM season considered, five *El Nino* years and one *La Nina* year were observed during the IOD-positive period and one *La Nina* event was recorded during the IOD-negative period (Abeysekera *et al.*, 2017).

A positive anomaly of rainfall has been recorded during the *El Nino* years in the WZ of Sri Lanka for the SIM season while a below normal rainfall was recorded during the *La Nina* period (Hapuarachchi and Jayawardena, 2015; Abeysekera *et al.*, 2019). The locations and periods used in the previous studies (Abeysekera

*et al.*, 2017; 2019) were the same as in the present study. Therefore, further investigations are needed to understand the interaction effects of IOD and ENSO on the all four rainfall season of Sri Lanka.

### CONCLUSION

The present study identified the impact of the IOD events on the rainfall climatology of second inter-monsoon seasonal rainfall in the Wet zone of Sri Lanka. A robust statistical analysis revealed an apparent increase in cumulative seasonal rainfall, mean number of wet days and heavy rainfall events with the positive IOD events. The opposite of this was observed during IOD negative events. No discernible changes were observed for the mean maximum rainfall received per day within the season. The mean maximum consecutive dry days showed a distinct negative anomaly with the positive IOD events and positive anomaly with the negative IOD events. The influence of the IOD phenomenon on the Wet zone during the SIM season was evident in this study suggesting its usefulness as a tool for seasonal climate forecasting and agro-met advisories.

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