Research Paper

Relationship between the Indian Ocean Dipole (IOD) and Paddy Cultivation during *Maha* Seasons in Sri Lanka

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Abstract

Climate is one of the important factors that influence crop production. Paddy (*Oryza sativa* L.) is highly impacted by the variations in rainfall that occur within a growing season. This study was mainly focused on the major paddy-growing season in Sri Lanka, *Maha* season (October to February), under different phases of the Indian Ocean Dipole (IOD) phenomenon. Based on the IOD effective years, a comprehensive analysis was carried out using the paddy cultivation data recorded during the past 42 years (1979-2020). The observations were narrowed down to the major paddy-growing districts. A significant positive impact was found in all three paddy-growing ecosystems, namely, major irrigation and minor irrigation schemes and rainfed systems, during the IOD-positive years with an increasing rainfall. The rainfed cultivation showed the highest positive anomaly, followed by those under minor irrigation and major irrigation eco-systems during the IOD-positive period. The positive effect was more distinct in the gross harvested extent compared to the gross sown extent. The paddy production showed a statistically significant increase (P<0.05) and average yield also showed an apparent increase during IOD-positive years in almost all major paddy-growing districts. During IOD-negative years, negative anomalies of gross-sown and gross-harvested extents were observed in all three-paddy growing ecosystems. The paddy production and the average paddy yield also showed a reduction during IOD-negative years. The positive and negative impacts identified by this study during IOD-positive and negative years are useful for informed decision-making with a considerable lead-time during cultivation-planning for the *Maha* season.

Keywords: Indian Ocean Dipole, *Maha* season, Paddy cultivation, Second Inter-monsoon

Introduction

Adverse impacts of climate variability and climate change may influence crop yields, either synergistically or antagonistically with other factors (Waggoner, 1983). Climatic impacts mainly influence the crop production and productivity, resulting in food shortage and increase in the market prices with subsequent multi-faceted socio-economic problems.

Rice (de-husked paddy; *Oryza sativa* L.) is the staple food of Sri Lankan community. According to the Department of Agriculture (DoA), Sri Lanka, the annual per capita consumption of rice is about 112 kg (SEPC, 2023). About 34% of total cultivated area of the country is occupied by paddy (DoA, 2022). It plays a significant role in rural employment in Sri Lanka. Estimated paddy production for the year 2022 was 3.39 million Mt. However, it was a 34% reduction, compared to the year 2021 estimated paddy production of 5.15 million Mt (DCS, 2023).

The sown extent under paddy cultivation during 2021/22 *Maha* season was 775,846 hectares, of which 45.9% was reported under major irrigation schemes (with a command area of greater than 80 ha), and 26.2% under minor irrigation schemes (command area less than 80 ha) and 27.9% under rainfed. The largest extent of paddy cultivation was reported in Anuradhapura District (116,969 ha) in the north central province, which is 15.1% of the total extent of paddy cultivated in the country (DCS, 2023).

Paddy is a semi-aquatic plant and is cultivated in all 25 districts in Sri Lanka with spatial variations. Water availability is the major limiting factor of paddy cultivation in the country. 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, paddy cultivation is being done in two cultivation seasons, namely, *Yala* (FIM + SWM; minor cultivating season; March – September) and Maha season (SIM + NEM; major cultivating season; October to February) (Punyawardena, 2020). A particular season is defined considering the sown period or land preparation activities during inter-monsoon periods and harvesting activities at the tail end of the monsoonal seasons. The deviation in sown and harvested extent and the average yield of paddy in Sri Lanka are directly correlated with the deviations of the seasonal rainfall (Yoshino and Suppiah, 1983; Suppiah, 1985; Chithranayana and Punyawardena, 2014; Amarasingha *et al*., 2018).

Previous studies have revealed a significant relationship between the Indian Ocean Dipole (IOD) and seasonal rainfall in different countries including Sri Lanka (Saji *et al*., 1999; Webster *et al*., 1999; Clark *et al*., 2003; Zubair *et al*., 2003; Black, 2005; Chan *et al*., 2008). Within an IOD year, IOD events usually start around May or June, peak in October and then dissipate in December (Saji *et al*., 1999; Vinayachandran *et al*., 2009). Therefore, SIM and SWM seasons can be considered as IOD effective seasons in Sri Lanka (Abeysekera *et al*., 2020; Abeysekera *et al*., 2021).

Furthermore, IOD events were reported to exert a significant influence on the rainfall climatology of seasonal rains during the SIM season (Abeysekera *et al*., 2020; Abeysekera *et al*., 2021). The SIM is the most decisive rainy season of Sri Lanka, which nourishes the water availability during the major growing season (*Maha*) in Dry and Intermediate zones, where agriculture is the main livelihood of the communities. Paddy cultivation in these two major climatic zones accounts for about 90% of annual national paddy production. Hence, foreseeing the rainfall during SIM season is of paramount important for cultivation planning during the major paddy cultivation season.

Different climate forecasting agencies in the world such as Australian Bureau of Meteorology (BoM), European Centre for Medium-Range Weather Forecasts (ECMWF), United States Climate Prediction Centre (CPC), International Research Institute (IRI) for Climate and Society, India Meteorological Department (IMD) and Japan Meteorological Agency (JMA) are predicting the appearance of different climatic drivers that influence weather pattern in the world, with considerable lead time. The *El Nino* Southern Oscillation (ENSO) and IOD phenomena are some examples of such climatic drivers, resulting in due to variations in Sea Surface Temperature (SST), in the Pacific and Indian oceans, respectively.

This study was undertaken to ascertain the impacts of IOD events on the paddy cultivation during the *Maha* season in Sri Lanka. Considering the positive and negative impacts of the IOD, weather predictions can be made with a considerable lead time, allowing for effective planning of the cultivation season. Consequently, agro-met advisories can be issued, providing pertinent recommendations on agronomic decisions, such as strategic seasonal planning involving early or late planting, determining cultivation extent, selecting age-classes, implementing weed control methods, and scheduling irrigation. These advisories have been identified as invaluable decision-making tool during pre-season cultivation-planning meetings (*Kanna* meetings) and other field-level decision-making, where timely and relevant climatic information are of paramount importance.

Materials and Methods

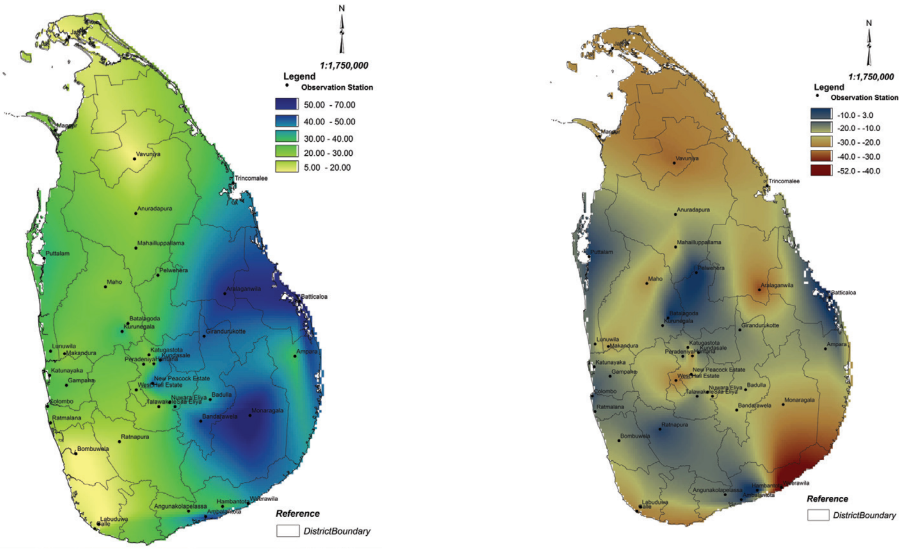
Paddy cultivation data were collected from the Department of Census and Statistics of Sri Lanka (DCS, various issues) for a 42-year period from 1979 to 2020 in 25 districts of Sri Lanka. The cultivation data included the gross sown extent (ha), gross harvested extent (ha), average yield (kg ha^{-1}) and total production (Mt) in each district under three different paddy-growing ecosystems, namely, major irrigation and minor irrigation schemes, and rainfed systems.

The IOD-positive, neutral and negative years were identified using the monthly SST values defined by the National Oceanic and Atmospheric Administration (NOAA) of the United States Climate Prediction Centre (CPC) (Reynolds *et al*., 2007). Dipole Mode Index (DMI) was used to find the intensity of the IOD events, which is represented by the anomalous SST gradient between the western equatorial Indian Ocean (50 °E – 70 °E and 10 °S – 10 °N) and the south eastern equatorial Indian Ocean (90 °E – 110 °E and 10 °S – 0 °N). The threshold values of DMI were selected as, above +0.4 °C typical of a positive IOD, and below −0.4 °C typical of a negative IOD events (https://psl.noaa.gov/gcos_wgsp/Timeseries/DMI/).

Previous studies (Abeysekera *et al.*, 2020; Abeysekera *et al.*, 2021) have clearly shown that, during IOD-positive years, significant increase of rainfall, while IOD-negative years, apparent reduction of rainfall, in SIM season, compared to the long-term average. The spatial distribution pattern of mean cumulative rainfall positive anomaly during (a) IOD-positive years and (b) negative anomaly during IOD-negative years, is shown in Figure 1 as a reference.

Paddy cultivation data related to the SIM season in a given year were extracted from the paddy statistics of the following year once the *Maha* cultivation is completed in late-February to mid-March. The Table 1 shows the positive and negative IOD years associated with the DMI, as well as the years in which, paddy cultivation was affected due to the influence of the IOD.

The paddy cultivation data were separately analyzed, based on the categorized years (Table 1, Column II and IV). A mean comparison was carried out by One-way ANOVA using the Minitab statistical software.



(a) (b)

Figure 1. Spatial distribution pattern of mean cumulative rainfall anomaly during (a) IOD-positive years and (b) IOD-negative years within SIM rainfall season (Abeysekera *et al.*, 2020; Abeysekera *et al.*, 2021)

Table 1. IOD-positive and IOD-negative years within the SIM season and the effective paddy growing years during the study period

IOD-Positive Years	Effective Paddy growing Year	IOD-Negative Years	Effective Paddy growing Year
I	II	III	IV
1982	1983	1980	1981
1994	1995	1984	1985
1997	1998	1996	1997
2006	2007	1998	1999
2011	2012		
2015	2016		
2018	2019		
2019	2020		

The statistical comparison of the impact of IOD on three different paddy ecosystems and the stage at which the impact is most pronounced, *i.e.*, during the sowing period or the harvesting period, and the percentage anomalous variation were calculated using equations 1-5 (Iizumi *et al*., 2014). The equations provided here serve as an illustrative example of the analytical procedure utilized to calculate the anomaly related to paddy production data.

For a given year (y), if the paddy production is expressed by 'Py', considering the above categorized years during the study period from 1979 to 2020, the mean paddy production during IOD-positive years $(P^M_{IOD-Positive})$ was calculated by using equation 1, where 'n' is the number of IOD-positive years and DMI is the Dipole Mode Index.

$$P^M_{IOD-Positive} = \frac{1}{n_{IOD-Positive}} \sum_{1979}^{2020} Py \qquad \text{Eq. (1)}$$
$$y = [If\ DMI > (+0.4)\ ℃] + 1$$

Similarly, the mean paddy production during IOD-negative years $(P^M_{IOD-Negative})$was calculated by using Equation 2

$$P^M_{IOD-Negative} = \frac{1}{n_{IOD-Negative}} \sum_{1979}^{2020} Py \qquad \text{Eq. (2)}$$
$$y = [If\ DMI < (-0.4)\ ℃] + 1$$

After removing the effect of IOD, the remaining years were classified as IOD-neutral years $(P^M_{IOD-Neutral})$ was calculated by Equation 3.

$$P^M_{IOD-Neutral} = \frac{1}{n_{IOD-Neutral}} \sum_{1979}^{2020} Py \qquad \text{Eq. (3)}$$
$$y = [If\ (-0.4)℃ < DMI < (+0.4)℃] = +1$$

Then the production anomaly $(P^A_{IOD-Positive})$ was calculated using the Equations 4 and 5.

$$\Delta P^M_{IOD-Positive} = P^M_{IOD-Positive} - P^M_{IOD-Neutral} \qquad \text{Eq. (4)}$$

$$P^A_{IOD-Positive} = \frac{\Delta P_{IOD-Positive}}{P_{IOD-Neutral}} \times 100 \qquad \text{(Eq. 5)}$$

Using the above shown method, anomalies of production, the average yield, gross sown and gross harvested extents were calculated for the 25 districts, seperately. Spatial relationships were investigated using interpolation method in Arc GIS software, using the Geographic Information System (GIS) technique.

Although the data analysis was conducted for all 25 districts in the country, the *Asweddumized* area of the paddy lands in certain districts did not cover a significant extent. For example, in the western province, it was only around 4% of the total paddy land areas of the country (Saddhananda, 2022). Considering the spatial variation of the crop (Figure 2), a decision was made with expert judgment to narrow the focus of observations to the major paddy-growing districts for the purpose of logical decision-making. To obtain a threshold value of identifying major paddy-growing areas, the districts were sorted using several parameters such as percentage of paddy lands out of the total arable lands (>30%), the average yield in each district (>4.3 t ha^{-1}), the districts located in the Dry and Intermediated zones (if it is spread in more than one zone, the zone with the higher extent was considered), and the contribution to the national paddy production (>2%) (DCS, 2023 and LUPPD, 2019).

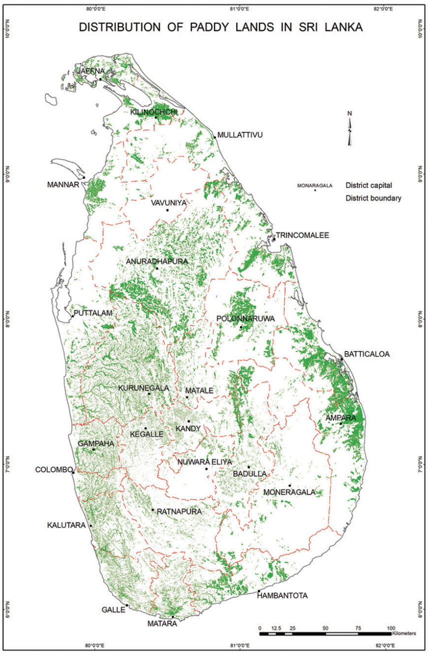


Figure 2. Spatial distribution of paddy lands in Sri Lanka (Data source: Survey Department)

Based on the aforesaid parameters, 15 districts were identified as the major paddy-growing districts of the country, eleven (11) from, Dry zone namely, Anuradhapura, Polonnaruwa, Ampara, Batticaloa, Trincomalee, Kilinochchi, Mullaitivu, Mannar, Vavuniya, Puttalam, Hambantota and four from the Intermediate zone, namely, Kurunegala, Badulla, Moneragala, and Matale.

Using the calculated cultivation anomalies related to the gross sown and harvested extents in three paddy growing eco-systems, as well as the paddy production and the average yield, the percentage of positive and negative impacts due to the influence of the IOD were detected. The level of influence was determined by calculating the confidence intervals using the Minitab statistical software.

Results & Discussion

During the positive IOD years, all three paddy eco-systems, under sown extent and harvested extent, showed a significant increase with increasing rainfall, compared to the neutral years. Results obtained for the all three pooled paddy eco-systems, in relation to the sown and harvested extents of selected 15 districts are shown in the Table 2.

During IOD-positive years, Anuradhapura and Hambantota districts showed a statistically significant increase (*P<0.05*) of seasonal total sown extent compared to the neutral years.

During IOD-negative years, there was a decreasing trend in sown extent and harvested extent in almost all major paddy-growing districts, however, this decrease was not prominent compared to that of IOD-positive years (Table 2). A study conducted to find the similar impact of SST gradient in the Pacific Ocean (ENSO), to wheat, maize and rice production in many parts of the world, particularly in Western Pacific countries and western coastal region of Central and South America has shown that there is a statistically significant relationship between ENSO events and global rice production compromising 26% response (Abdolrahimi, 2016).

The mean paddy production of the *Maha* season showed an apparent increase during IOD-positive years compared to the neutral years, in all major paddy-growing districts (Table 3). Anuradhapura, Trincomalee, Kurunegala, Puttalam, Vavuniya, Mullaitivu, Kilinochchi, Moneragala and Matale districts showed a statistically significant increase (*P<0.05*) in mean seasonal paddy production during IOD-positive years. All major paddy-growing districts, except Kurunegala, showed an apparent decrease in mean paddy production during IOD-negative years, over neutral years in *Maha* season. A previous study conducted has also revealed that *Maha* season paddy production generally increased during the positive SST (*El Nino*) phase and decreased during the negative SST (*La Nina*) phase (Zubair *et al*., 2003).

Table 2. The pooled mean gross sown extent and the pooled mean gross harvested extent in the *Maha* season, during IOD-positive, IOD-negative and neutral years

CZ	District	Total of sown and harvested extents - *Maha* season					
		Gross sown extent (ha)			Gross harvested extent (ha)		
		Neutral	Positive	Negative	Neutral	Positive	Negative
DZ	Kilinochchi	18,038	21,895	10,322	14,496	21,292*	10,146
	Mullaitivu	9,666	12,358	9,805	7,476	11,045*	7,900
	Mannar	10,151	13,110	10,496	8,760	12,697	9,252
	Vavuniya	9,029	12,830	9,064	7,742	12,321*	6,900
	Anuradhapura	56,158	79,627*	44,070	51,688	78,562*	42,799
	Polonnaruwa	48,379	55,019	39,040	47,449	54,788	38,828
	Trincomalee	23,675	29,216	25,004	21,369	28,625*	24,280
	Batticaloa	43,092	48,293	36,484	36,580	44,885	32,461
	Ampara	59,310	65,926	51,475	55,286	64,469	50,583
	Puttalam	12,551	15,580	11,643	11,400	14,843	10,843
	Hambantota	21,806	26,625*	19,471	21,472	26,368*	19,385
IZ	Kurunegala	66,397	72,851	67,801	59,921	70,657	66,225
	Badulla	21,616	23,614	18,998	20,881	23,368	18,775
	Monaragala	18,001	25,227	11,739	16,009	23,629	10,491
	Matale	15,617	17,215	14,428	15,047	16,959	13,673

CZ: Climatic Zone; DZ: Dry Zone; IZ: Intermediate Zone; Within a row, means followed by '' are significantly different compared with the neutral years, at P<0.05*

Table 3. Mean seasonal paddy production and the average yield during the *Maha* season in Sri Lanka during IOD-positive, IOD-negative and neutral years

CZ	District	Mean seasonal paddy production (Mt)			Average Yield (kg ha^{-1})		
		Neutral	Positive	Negative	Neutral	Positive	Negative
	Kilinochchi	41,368	69,357*	21,858	3,111	3,620	2,564
	Mullattivu	20,163	38,500*	18,196	2,819	3,581*	2,431
	Mannar	34,501	55,510	27,562	3,940	4,183	3,034
	Vavuniya	24,789	50,310*	17,326	3,256	4,059	2,967
	Anuradhapura	175,076	308,986*	123,764	4,118	4,715*	3,711
DZ	Polonnaruwa	196,099	243,127	153,132	4,607	4,999	4,440
	Trincomalee	69,437	101,787*	65,885	3,438	3,702	2,901
	Batticaloa	90,980	128,054	79,151	2,764	3,125	2,649
	Ampara	218,114	279,984	198,146	4,023	4,497	4,092
	Puttalam	31,862	49,531*	27,081	3,225	3,790	2,951
	Hambantota	90,790	121,075	69,308	4,713	5,094	4,094
IZ	Kurunegala	215,791	287,039*	224,119	3,618	4,021	3,388
	Badulla	72,112	82,013	57,194	4,012	4,077	3,563
	Moneragala	60,483	96,159*	33,237	3,722	3,973	3,210
	Matale	53,013	66,941*	44,346	3,896	4,329	3,608

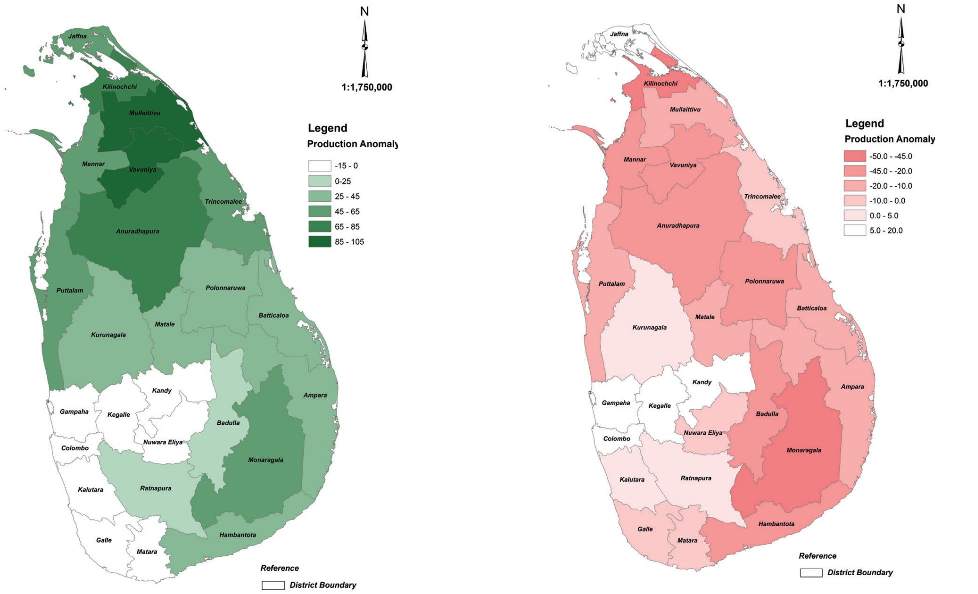
CZ: Climatic Zone; DZ: Dry Zone; IZ: Intermediate Zone; Within a row, means followed by '' are significantly different compared with the neutral years, at P<0.05*

The results of the present study further revealed positive yield anomalies in the average paddy yield during IOD-positive years in the *Maha* season in all 25 districts in Sri Lanka compared to that of neutral years (Table 3). During IOD-negative years, except in Ampara, the other 24 districts showed negative yield anomalies compared to the neutral years (Table 3). Anuradhapura, Mullattivu, and Jaffna showed a statistically significant increase ($P<0.05$) in average yield during IOD-positive years. No significant decreasing or increasing events could be observed for the average yield during IOD-negative years over neutral years.

A similar study conducted in the eastern China revealed that the Tropical Indian Ocean Dipole (TIOD)-like SST has a close correlation with the rice yield anomalies, with a temporal correlation coefficient of 0.43 for 53 years, passing the 99% significance level (Xu *et al*., 2021). Furthermore, the same study further highlighted that the climatic factors such as TIOD-like SST have far-reaching influence on the rice yield.

The spatial distribution patterns of mean total seasonal production anomalies during IOD-positive years and IOD-negative years over the neutral years are illustrated in Figure 3. Higher positive anomalies of production were observed in Vavuniya, Mullattivu, Anuradhapura and Kilinochchi districts (Figure 3a). Lower negative production anomalies were observed in Kilinochchi, Anuradhapura, Polonnaruwa, Vavuniya, Mannar and Moneragala districts during IOD-negative years (Figure 3b).

The analytical results of positive and negative percentage impacts of IOD indicated that there was an increase (*P<0.05*) in the gross sown extent of paddy under rainfed systems ranging from 15.3 to 40.6% during IOD-positive years (Table 4). A similar trend was observed in other two paddy-growing eco-systems (Table 4). The rainfed system showed the highest increase of gross sown extent during IOD-positive years while the major irrigation system showed the lowest. During IOD-negative years, a significant decrease (*P<0.05*) in the gross sown extent was observed in paddy under rainfed systems ranging from 8.8 to 39.0% (Table 4). The other two paddy-growing eco-systems also showed a similar negative impact while the rainfed, minor irrigation and major irrigation eco-systems showed the highest to the lowest reduction percentages of sown extents, respectively (Table 4).



(a) (b)

Figure 3. ***Maha*** **seasonal mean paddy production anomaly during (a) IOD-Positive years and (b) IOD-Negative years over neutral years.**

Table 4. Percentage impact of IOD on gross sown extent during the *Maha* season in three paddy eco-systems of major paddy-growing districts compared to the neutral years

	Percentage impact of IOD on gross sown extent (95% CI)	
Paddy eco-systems	**During IOD-Positive years**	**During IOD-Negative years**
Major Irrigation	13.4 to 25.0	-10.5 to -20.7
Minor Irrigation	20.5 to 37.5	-9.9 to -24.8
Rainfed	15.3 to 40.6	-8.8 to -39.0

CI: Confidence Interval

Results present in Table 5 revealed that there was a significant increase (*P<0.05*) in the gross harvested extent of paddy under rainfed systems ranging from 27.9 to 68.7%, during IOD-positive years compared to the neutral years, with a similar tendency in other two paddy-growing eco-systems. During IOD-positive years, the rainfed system showed the highest increase of gross harvested extent, while the major irrigation system showed the lowest. During IOD-negative years, the gross harvested extent of paddy under rainfed systems showed a 9.0 - 38.8% decrease (*P<0.05*), with a similar negative impact observed in the other two paddy-growing eco-systems (Table 5). The percentage reduction in the harvested extent was the highest in rainfed system and the lowest in major irrigation systems in IOD-negative years, compared to those of neutral years (*P<0.05*; Table 5).

Table 5. Percentage impact of IOD on gross harvested extent in the *Maha* season, in three paddy eco-systems of major paddy growing districts, compared to neutral years

	Percentage impact of IOD on gross harvested extent (95% CI)	
Paddy eco-systems	**During IOD-Positive years**	**During IOD-Negative years**
Major Irrigation	17.3 to 31.4	-11.2 to -19.2
Minor Irrigation	29.0 to 51.5	-8.9 to -22.6
Rainfed	27.9 to 68.7	-9.0 to -38.8

CI: Confidence Interval

The paddy production during the *Maha* season in the selected districts showed a 36.3-65.0% increase (*P<0.05*) during IOD-positive years, and a 14.6 - 29.1% reduction IOD-negative years, compared to the neutral years (Table 6), with a similar trend observed in average paddy yields. A study conducted to find the similar impact of SST changes in the Pacific Ocean (ENSO) has shown that under positive SST (*El Nino*) phase, the global-mean yields of maize, rice and wheat likely to change by (- 4.3) to 0.8%. The global-mean yields of all four crops during the negative SST (*La Nina*) phase tend to be below normal (- 4.5 to 0.0%) (Iizumi *et al*., 2014)

Findings of this study clearly showed that temporal variation of rainfall related to the IOD phenomenon during the SIM season directly influences the national paddy production and productivity during the *Maha* season.

Table 6. Percentage impact of IOD on seasonal total production and average yield in the *Maha* season, compared to neutral years

Percentage impact of IOD on seasonal total production and average yield (95% CI)		
***Maha* season**	**During IOD-positive years**	**During IOD-negative years**
Total production	36.3 to 65.0	-14.6 to -29.1
Average yield	8.6 to 16.2	-8.1 to -14.3

CI: Confidence Interval

When farmers experience higher rainfall at the onset of the *Maha* season, they tempt to cultivate more extents out of the *Asweddumized* extent resulting in an increased sown extent. Hence, in IOD-positive situation during the first two months of the *Maha* season have always led to an increase in sown extent of paddy in major paddy-growing districts of Sri Lanka. Meanwhile, increased rainfall of SIM due to the IOD-period have resulted in an increase in the harvested extent of paddy fields through assured irrigation water availability in reservoirs in both major and minor irrigation systems and also phreatic water availability in rainfed eco-systems. These favorable water availability conditions during IOD-positive years have in turn increased the total paddy production and the average paddy yield per hectare in the major paddy-growing districts of the country, mainly due to the absence of drought injuries and pest damages under improved water regime of the respective paddy tracts. Moreover, improved water availability also allows the correct land preparation practices with required intervals in between primary, secondary and tertiary land preparation stages and proper weed control. The IOD-positive years have favored better water management practices leading to an increase in the production and productivity of paddy cultivation in the major paddy-growing districts of Sri Lanka.

The available effective storage in reservoirs is the key factor for planning the cultivation season related to the irrigated paddy systems. Irrigation water issuing schedules highly rely on the availability of water in reservoirs and the amount of rainfall received during the season. Therefore, the major irrigation schemes are the least dependent of the increased rainfall due to IOD-positive impact, compared to the other two paddy eco-systems. The minor irrigation schemes are dependable on rainwater compared to the major irrigation schemes due to the lower capacity of the former thereby limiting the carryover storage. Rainfed systems are totally dependent on rain water; thus, increased rainfall during IOD-positive years will benefit the rainfed systems.

However, in addition to rainfall, several other factors influence paddy cultivation, namely, policies, extension programs of respective agencies such as Department of agriculture and Mahaweli Authority of Sri Lanka, provision of concessionary credits, availability of seed paddy of appropriate varieties at concessionary rates, and guaranteed output and input prices (Weerahewa *et al*., 2010). The significance of results of the study, hence, sometimes can be masked by these factors.

Hence, in an IOD-forecasted year, under the prediction of increased (positive IOD years) or decreased rainfall (negative IOD years), agro-meteorological advisories can be formulated with a reasonable lead-time focussing on suitable agronomic practices on harnessing the potential of positive impacts of enhanced SIM rainfall and minimizing the negative impacts of weak SIM rains, respectively.

Conclusion

This study has mainly focused on the production and productivity of paddy cultivation of major paddy-growing districts of Sri Lanka in response to variations of SIM rains influenced by the IOD phenomenon. The results of the study have revealed that during IOD-positive years, there was an apparent increase in gross sown extent, gross harvested extent, paddy production and average yield during the *Maha* season in all major paddy-growing districts of the country. Conversely, during IOD-negative years, a decrease in extent, production, and productivity impact was observed over neutral years. However, impact of IOD-negative years during SIM season was comparatively weaker than that of the IOD-positive years. Gross harvested extent showed a higher percentage of positive impact during IOD-positive years and higher percentage negative impact during IOD-negative years compared to neutral years. Among the three-paddy growing eco-systems, the rainfed system exhibited the highest impacts in response to IOD effect, followed by the minor and major irrigation eco-systems. Comparatively the least degree of influence from the IOD on the paddy grown under major irrigation schemes could be mainly attributed to be due to supplemental provisions through trans-basin diversion of water and hence, are less responsive to *in-situ* rainfall catch during the season, compared to minor irrigation and rainfed systems. Thus, the outcome of this study can be effectively utilized for weather-related informed strategic decision making, especially during pre-season cultivation-planning meetings (*Kanna meetings*).

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References

Abdolrahimi, M. (2016). *The Effect of El Niño Southern Oscillation (ENSO) on World Cereal Production.* (Master of Philosophy Thesis, Faculty of Agriculture and Environment, The University of Sydney.) Sydney Digital Theses. http://hdl.handle.net/2123/15498

Abeysekera, A. B., Punyawardena, B. V. R., Marambe, B., Jayawardena, I. M. S. P., Sivananthawerl, T. & Wickramasinghe, V. N. M. (2020). The effect of Indian Ocean Dipole (IOD) events on the Second Inter-monsoonal rainfall in the Dry Zone of Sri Lanka. *Proceedings of 6th International Conference on Dry Zone Agriculture*, Faculty of Agriculture, University of Jaffna. 6:32.

Abeysekera, A. B., Punyawardena, B. V. R., Marambe, B., Jayawardena, I. M. S. P., Sivananthawerl, T. & Wickramasinghe, V. N. M., (2021). Effect of Indian Ocean Dipole (IOD) Events on the Second Inter-monsoonal Rainfall in the Wet Zone of Sri Lanka. *Tropical Agricultural Research*, 32(3), 287-297. http://doi.org/10.4038/tar.v32i3.8492

Amarasingha, R. K., Suriyagoda, L. D. B., Marambe, B., Galagedara, L. W., & Punyawardena, R. (2018). Impact of climate change on rice yield in Sri Lanka: a crop modelling approach using Agriculture Production System Simulator (APSIM). *Sri Lanka Journal of Food and Agriculture*, 4(1), 21-26. https://doi.org/10.4038/sljfa.v4i1.54

SEPC. (2023). *Crop forecast: Maha 2022/23 final*, Socio Economics and Planning Centre, Department of Agriculture, Volume 6.

Black, E. (2005). The relationship between Indian Ocean sea–surface temperature and East African rainfall. P*hilosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 363*(1826), 43-47. https://doi.org/10.1098/rsta.2004.1474

Chan, S.C., Behera, S.K. & Yamagata, Y. (2008). Indian Ocean Dipole influence on South American rainfall. *Geophysical Research Letters*, 35, L14S12. https://doi/10.1029/2008GL034204

Chithranayana, R., & Punyawardena, B. (2014). Adaptation to the vulnerability of paddy cultivation to climate change based on seasonal rainfall characteristics. *Journal of the National Science Foundation of Sri Lanka, 42*(2), 119-127. https://doi.org/10.4038/jnsfsr.v42i2.6992

Clark, C. O., Webster, P. J., & Cole, J. E. (2003). Interdecadal Variability of the Relationship between the Indian Ocean Zonal Mode and East African Coastal Rainfall Anomalies. *Journal of Climate, 16*(3), 548-554. https://doi.org/10.1175/1520-0442(2003)016<0548:IVOTRB>2.0.CO;2

DoA. (2022). Rice: General information. Department of Agriculture. https://doa.gov.lk/rrdi_rice_introduction-2/

DCS. (2023). Paddy statistics. The Agriculture and Economics Statistics Division, Department of Census and Statistics, Sri Lanka. http://www.statistics.gov.lk/Agriculture/StaticalInformation/PaddyStatistics/PaddyStatistics

LUPPD. (2019). *Land use & Land Cover of Sri Lanka*, Land Use Policy Planning Department, Narahenpita, Colombo 05.

Iizumi, T., Luo, J. J., Challinor, A. J., Sakurai, G., Yokozawa, M., Sakuma, H., Brown, M. E. & Yamagata, T. (2014). Impacts of El Niño Southern Oscillation on the global yields of major crops. *Nature communications, 5*(1), 3712. https://doi.10.1038/ncomms4712

Punyawardena, B.V.R. (2020). Climate. In R.B. Mapa, (Ed.), *The Soils of Sri Lanka*. (pp. 13-22). *Springer, Switzerland.*

Reynolds, R. W., Smith, T. M., Liu, C., Chelton, D. B., Casey, K. S., & Schlax, M. G. (2007). Daily High-Resolution-Blended Analyses for Sea Surface Temperature. *Journal of Climate, 20*(22), 5473-5496. https://doi.org/10.1175/2007JCLI1824.1

Saddhananda, K. W. S. (2022). T*echnical Background of the Paddy Crop Cutting Survey in Sri Lanka.* Agriculture and Environment Statistics Division, Department of Census and Statistics.

Saji, N. H., Goswami, B. N., Vinayachandran, P. N., & Yamagata, T. (1999). A dipole mode in the tropical Indian Ocean. *Nature, 401*(6751), 360-363.

Suppiah, R. (1985). Four types of relationships between rainfall and paddy production in Sri Lanka. *GeoJournal, 10*, 109-118.

Vinayachandran, P. N., Francis, P. A., & Rao, S. A. (2009). Indian Ocean dipole: processes and impacts. *Current trends in science, 46*(10), 569-589.

Waggoner, P.E. (1983). Agriculture and a climate changed by more carbon dioxide. *Changing climate*. National Academy Press, Washington, DC. (pp 383–418).

Webster, P. J., Moore, A. M., Loschnigg, J. P., & Leben, R. R. (1999). Coupled ocean–atmosphere dynamics in the Indian Ocean during 1997–98. *Nature, 401*(6751), 356-360.

Weerahewa, J. Kodithuwakku, S. S. and Ariyawardana, A. (2010). The Fertilizer Subsidy Program in Sri Lanka. In Per Pinstrup-Andersen, S. E. Frandsen, A. Kuyvenhoven and J. von Braun (Eds.), C*ase study #7-11 of the program: "Food policy for developing countries: the role of government in the global food system" 2010*. Cornell University, Ithaca, New York.

Xu, J., Koldunov, N. V., Xu, M., Zhu, X., Fraedrich. K., Jiang, X., Zhu, S., and Zhi, X. (2021). Impacts of Indian Ocean Dipole–Like SST on Rice Yield Anomalies in Jiangsu Province. *Frontiers in Earth Science, 8*,568365.

Yoshino, M.M. & Suppiah, R. (1983). Climate and paddy production: a study on selective districts in Sri Lanka. In M.M. Yoshino, I. Kayane & C.M. Madduma Bandara (Eds.), *Climate, Water and Agriculture in Sri Lanka* (pp. 191-206). Institute of Geoscience, University of Tsukuba: Tsukuba, Japan.

Zubair, L., Rao, S.A. & Yamagata, T. (2003). Modulation of Sri Lankan *Maha* rainfall by the Indian Ocean Dipole. *Geophysical Research letters*, 30 (2). https://doi.10.1029/2002GL015639.