DEVELOPMENT OF EFFECTIVE WATER USAGE PLAN FOR DRY ZONE OF SRI LANKA: CASE STUDY IN MALWATHU OYA BASIN

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ABSTRACT

Cultivation in the dry zone of Sri Lanka is extremely vulnerable due to the increased water usage associated with the rapid population increase and climate change. The efficiency of dry-zone water usage can be improved by integrating water allocation, hydrological modeling and rainfall predictability. This study focuses on these three components and formulates a framework to propose an effective water usage plan for the dry zone. Drafted framework was tested to the Malwathu Oya basin, located in one of the typical dry zones, where Giant's tank plays an important role in water allocation. The hydrological modeling component consisted of Rainfall-Runoff-Inundation (RRI) and Tank Operation Models (TOM) as the initial stage. Then this study analyzed the temporal variability of local rainfall by using wavelet transform and coherence analyses and clarified relationships between the results and several global climate indices such as Indian Ocean Dipole (IOD) and Madden-Julian Oscillation (MJO). These indices were used for the short-term seasonal prediction of rainfall. The study also estimated income increase if the four typical climatological patterns including flood, normal, drought and hypothesis event scenarios are predicted well and the TOM optimized the Giant's tank operation plan. Green gram cultivation with paddy and inland fishers was also considered to optimize the tank operation. In addition, this study clarified one of the triggers of the flood in Anuradhapura city in 2011.

Keywords: hydrology, seasonal prediction, wavelet, coherence analysis, TOM

INTRODUCTION

Dry-zone water usage in Sri Lanka has been changing rapidly due to post-war peaceful conditions, rapid population growth with agricultural activities, and climate change. The dry zone shown in Figure 1, receives less than 1200 mm of rainfall per year. The rainwater is utilized mainly through three components. The most important component is water allocation for multiple usage, and the other two components are hydrological behaviors of the basin and seasonal conditions over the basin. Hydrological behaviors refer to rainfall-runoff relationship and the tank operations within the basin, and seasonal conditions are mostly related to rainfall over the basin. Therefore, this study examines these three components to formulate a framework for the development of an effective water usage plan for the dry zone. Drafted framework was tested in the Malwathu Oya basin, one of the typical dry zones in Sri Lanka, where Giant's tank played an important role in water allocation. The cultivation area under the Giant's tank scheme has rapidly increased since the termination of the inland war in 2009, which was proven through MODIS enhanced vegetation index images shown in Figure 2. The main source of water for this tank is the diverted water from the Malwathu Oya basin at the Thekkam weir. This basin is the second largest basin in Sri Lanka with five

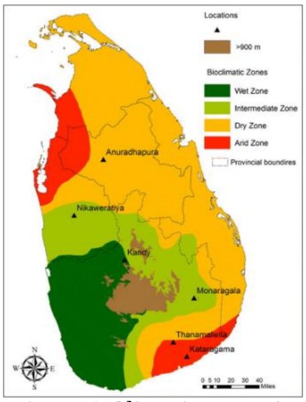

Figure 1 Climatic zones in Sri Lanka

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major cascade tanks to control water usage. Hence, it is an excellent opportunity to check the proposed framework in this basin.

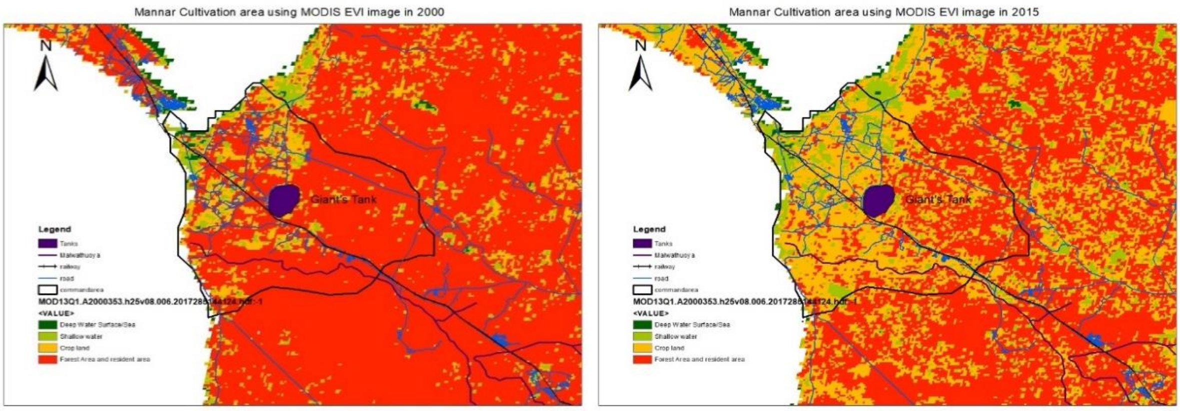

Figure 2 Reclassified MODIS Enhanced Vegetation Index for Giant's tank from 2000 to 2015

FRAMEWORK AND METHODOLOGY

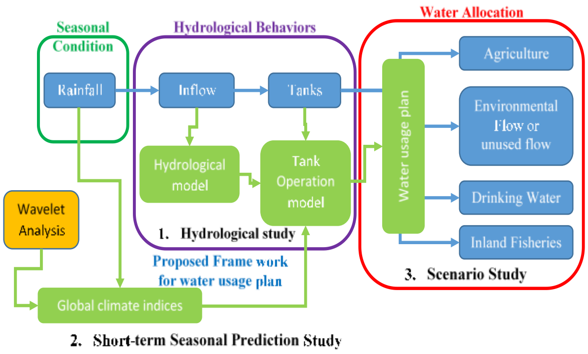

Figure 3 Framework for this study

The main objective of this study was to develop an effective water usage plan for the dry zone, considering three main areas of study, which were hydrological study, short-term seasonal prediction study, and scenario study, as shown in the proposed framework in Figure 3. In the hydrological study, the first step was the development of models such as a hydrological model with the capability of simulating rainfall to runoff and a tank operation model, which concentrates on storing and releasing water to multiple usage. Next, wavelet transform analysis was conducted using global climate indices to understand temporal changes in local rainfall and to formulate a platform for effective short-term seasonal prediction. Finally, both abovementioned tools were combined to come up with an effective plan for water usage on the basis of the scenario study for different predicted events.

The framework employed in this case study is detailed in the methodology flowchart in Figure 4. For the hydrological modeling, the Rainfall-Runoff-Inundation model (RRI model) was selected because the Malwathu Oya basin flows over a flat terrain which needs two-dimensional analysis. Then a separate Tank Operation Model (TOM) was developed with the knowledge gained in the field and the conditions given in the Irrigation Department design manual (Eng. A. J. P. Ponrajah, 1984). Next, wavelet transform analysis was used to identify signals in local rainfall. Global climate indices and wavelet coherence analysis were used to compare signals from rainfall. Global climate indices of Indian Ocean Dipole (IOD), El-Nino Southern Oscillation (ENSO), and Madden-Julian Oscillation (MJO), which influence rainfall over the South Asian region, were also compared in order to identify the best indices for prediction. The forecasted values of these indices were taken from the Japan Meteorological Agency

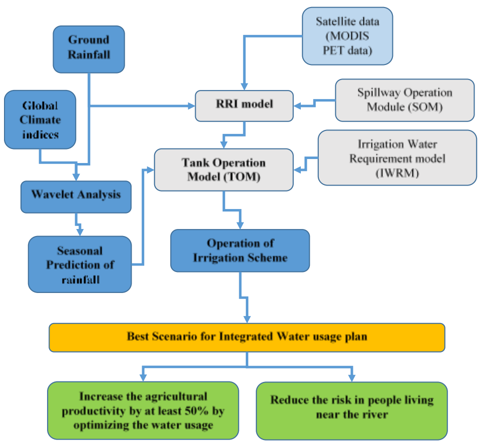

Figure 4 The methodology derived from the framework

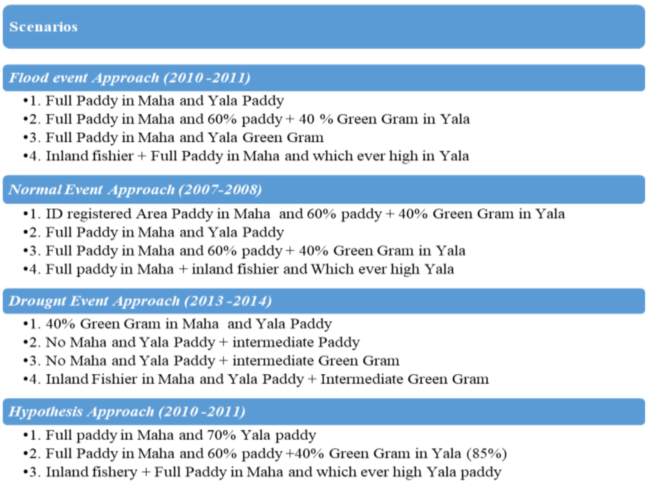

Figure 5 Scenario study approaches to find effective water usage plan

(JMA) and the National Ocean Atmospheric Administration (NOAA) for short-term seasonal prediction.

The third step was to use the prediction and hydrological tools for formulating event-based scenarios to find the best effective and optimized usage of water in this basin. These event-based scenarios were divided in four approaches shown in Figure 5, such as the flood event approach using a 2010-2011 dataset, the normal event approach using a 2007-2008 dataset, the drought event approach using a 2013-2014 dataset, and the hypothesis approach using a 2010-2011 dataset and considering the same level of inflow to the tank in both cultivation seasons. Here, the increased cultivation area in the wet season (Maha) taken from Figure 2 was 14164 ha while the actual cultivation area registered was 9889 ha, which is mostly dominated by paddy fields. But the cultivation area during the dry season (Yala) varies, depending on water availability and crop usage (e.g., in these simulations, paddy and green gram were considered as crops). Inland fishers were included as an additional income source.

Finally, this completed set of tools were used for practical usage of Giant's tank in the cultivation seasons such as the dry seasons in 2014 and 2015 and the wet seasons in 2014-2015 and 2015-2016. As the initial step, the coming season was predicted with forecasted IOD and MJO indices, and then a scenario was selected for the predicted season. Simulations were conducted using the RRI and TOM models to find the storage change in Giant's tank to check whether this procedure can show actual conditions and recognize improved water usage.

DATA

Data of ground rainfall, tank operation and river discharge were collected from the Irrigation Department of Sri Lanka and the Metrological Department of Sri Lanka. The yield of paddy and green gram, the price of rice in market, and the export amount of inland fishers were taken from the Department of Censers and Statistic of Sri Lanka and the National Aquaculture Development Authority of Sri Lanka. Especially 30 years of data were taken from the gauges in Figure 6 for the seasonal prediction study, and IOD index was taken from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). ENSO and MJO indices were taken from NOAA.

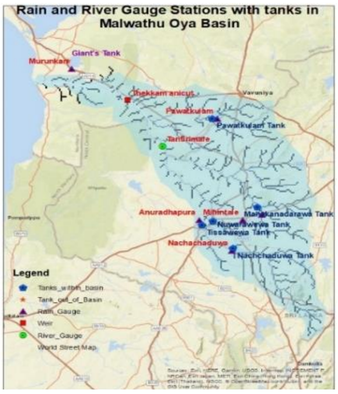

Figure 6 Rain and River Gauge station with tanks in Malwathu Oya Basin

RESULT AND DISCUSSION

The RRI model was simulated to collect discharge data for 2007-2008 at the Kappachi station by introducing boundary conditions at Nachchaduwa, Nuwarawewa, Tissawewa, and Mahakandarawa tanks shown in Figure 6. These normal years were selected to calibrate and validate data that were not collected during the high flood. After the initial calibration, the peak appears two days earlier than the observation. To resolve this problem, blocking structures like weirs, bridges, and small tanks inside the river were incorporated in the simulation with data recorded one day late in order to achieve a Nash Sutcliffe Efficiency (NSE) value of 0.6534 for the period from December 2007 to February 2008. Next, the calibrated model was validated for the March 2008 to May 2008 period and got a NSE value of 0.6136 with some errors noted among the observation and recorded data. Then the validated model was used to simulate for the period from October 2007 to September 2008 to specify the inflow to Giant's tank from the river diversion point at the Thekkam weir. The results revealed a high amount of water flow over the weir that cannot be diverted because of the tank capacity and the canal carrying

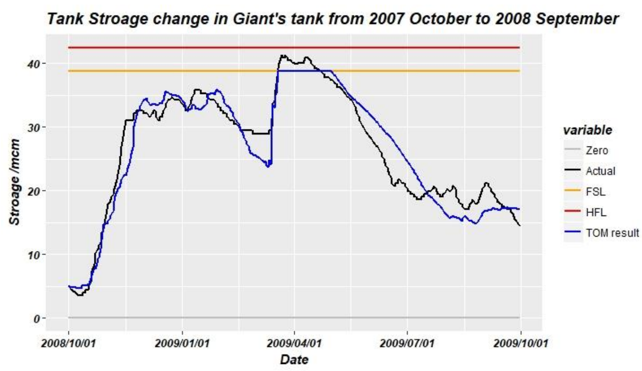

Figure 7 Results of TOM and Actual Storage of Giant's Tank in October 2007 to September 2008 year

capacity. Hence, the inflow was recalculated and used in TOM to visualize the storage change in Giant's tank, which shown in Figure 7. Both actual and simulated storage changes exhibited a similar pattern. Therefore, the hydrological tool was assumed to be working well in this basin.

Then the 30 years of rainfall data were checked for interdependence through an auto-correlation test and monotonic trend through the modified Mann-Kendall test. The results showed an auto-correlation but not a monotonic trend in the data from the Murunkan station, the nearest station to Giant's tank, with daily and monthly resolutions. Then these data were used in wavelet transform analysis through R language with WaveletComp 1.1 package with autocorrelation factors. The monthly data showed clearer signals than the daily data. The Murunkan station output image of monthly data, shown in Figure 8, was selected for further study. In Figure 8, the significance of the signals was shown as the peaks in the small graph and its observation in years express three main signals. The first signal shows in 2 to 4 months, the second one, called as inter-monsoonal signal, in 4 to 8 months, and the last one, called the interannual signal, in 8 to 16 months.

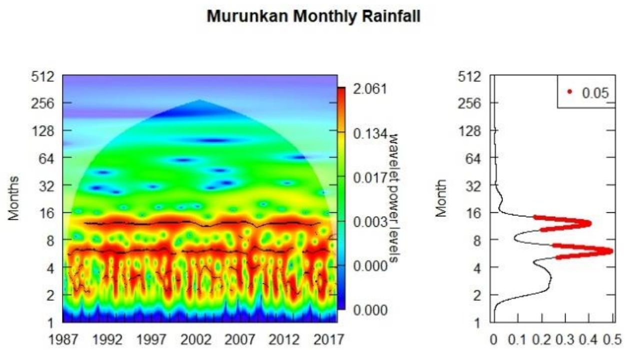

Figure 8 Wavelet Analysis result of Murunkan station in monthly resolution

The above mentioned three global climate indices were compared with the rainfall signals of the Murunkan station through wavelet coherence analysis with the same R package, and the results were shown in Figure 9. Then some R cording was used to identify the percentage of the correlation in Figure 9 and drafted Table 1. The results show that five signals were correlated but only the first three signals were prominent in the rainfall analysis. Thus, by considering those signals, IOD shows a higher correlation for the signals in 2 to 4 months and 8 to 16-months. MJO shows a higher correlation for the 4 to 8-month signal. Therefore, IOD and MJO were considered for the prediction process.

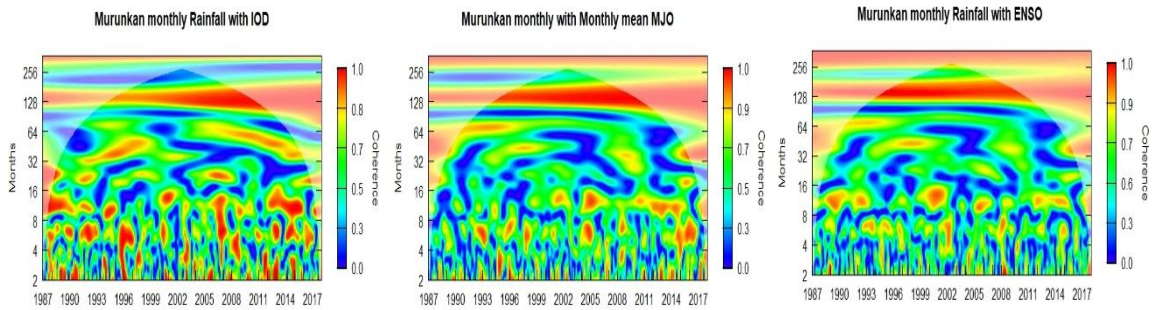

Figure 9 Wavelet Coherence analysis Results of Murunkan Station rainfall with IOD, ENSO and MJO

Table 1 The results of correlation percentage of wavelet coherence in Figure 9

Stations	Global Indices	Average percentage of coherence coefficient in different Signal Frequency in months signals				
		2 to 4	**4 to 8**	**8 to 16**	**16 to 32**	**32 to 64**
Murunkan	IOD	**54.95**	56.50	**56.17**	46.63	51.39
	MJO	52.23	**58.19**	54.89	44.32	54.82
	ENSO	50.11	52.49	55.95	46.56	56.50

First, the standardized anomaly index method was used to draw rainfall with the IOD and MJO indices in the same scale and observed patterns to draft conditions that would satisfy the real events. The drafted conditions were checked for the last seven years starting from 2010, and 65 % of the months satisfied these conditions. Hence, those conditions were taken for the prediction tool. Then the forecasted values of IOD and MJO indices were taken from JMA and NOAA and compared with the actual indices. These indices also exhibited a similar pattern. From that, the next month forecast shows that the IOD index value was positive and greater than 0.5 while the MJO index value was also positive and greater than 0.5. These results mean that in September 2018 standardized anomaly rainfall index may be negative. Therefore, the rainfall was predicted to be less, but the dry season cultivation already started, and thus well-controlled water management was needed These indices are an efficient tool to obtain a one-month seasonal prediction, but for decision making during the cultivation, at least three months of prediction is needed. Since the MJO index is forecasted for 15 days, the IOD index is considered as a primary indicator for seasonal prediction for decision making, and after 15 days, the prediction can be validated with the forecasted MJO index for changing the tank operation during the cultivation.

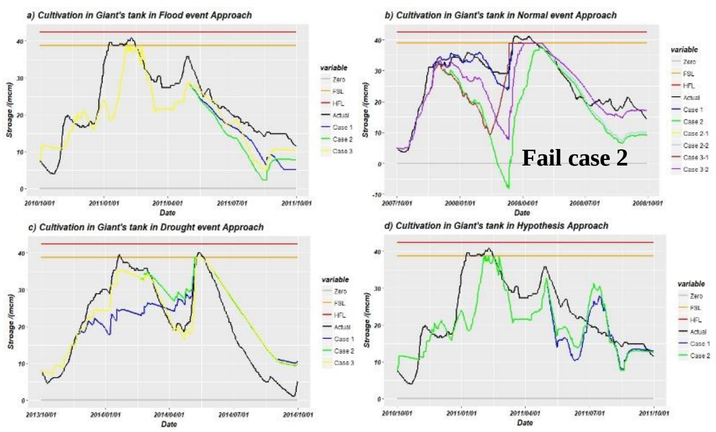

Figure 10 Scenarios results for every approach to find the effective usage of the water in Giant's tank a) flood, b) normal, c) drought and d) hypothesis

The results of the approaches listed in Figure 5 were shown in Figure 10. Almost all of the cases show successful application of each approach, except one case using the normal event approach, where the increased paddy area of 14164 ha was used for the wet cultivation. To achieve a success, two options were considered: one was to reduce the area by 15 % and the other was to introduce a paddy with 2.5 to 3.0 months old. The possible income generated through each approach was also studied with available data. The results were shown in Figure 11. By employing Case 4, the income can be increased by 51% in the normal event and by 90% in the flood event. In the drought event, the income can be as high as the income generated in the normal event. In the hypothesis approach, the income can be increased by 136% through Case 3. The outputs showed that the best option for water use to achieve a high income is the cultivation of paddy and green gram within the area in combination with inland fishers and coordinated tank operation with upper tanks.

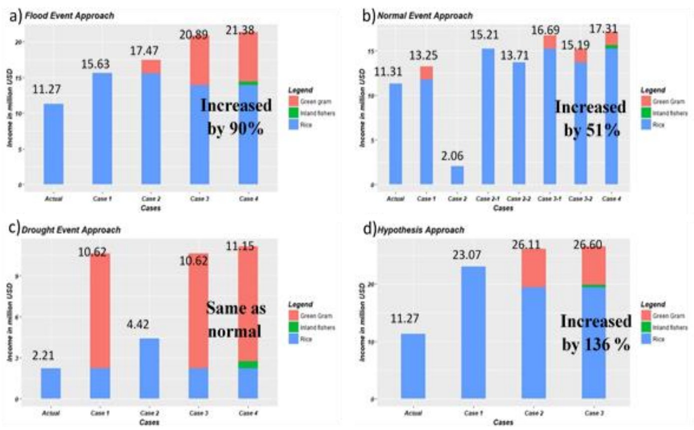

Figure 11 Calculated possible income generated for approached in a) flood, b) normal, c) drought and d) hypothesis

In accordence with the developed prediction tools, Table 2 was prepared to show predictions for the 2015 dry season and the 2015-2016 wet season with selected scenarios. Figure 12 presents the results of the RRI model and TOM in the same period. The actual condition and the selected scenarios exhibit a same pattern for the well-utilized water usage. The simulation found that the seasonal cultivation is interdependent. For example, the cultivation area was kept as 4500 ha during the dry season; if the area increases, then the next wet cultivation will result in failure. And the

Table 2 Predicted Seasonal cultivation condition used for 2015 -2016 year

	Cultivation Season					
	2015 dry			**2015 -2016 wet**		
Months	**May**	**June**	**July**	**November**	**December**	**January**
Forecasted IOD	P &>0.25	P &>0.25	P &>0.25	P &>0.5	P &>0.50	P &<0.25
Forecasted MJO	P &>0.5	P &>0.5		N &<-0.5	N &>1.0	
Predicted Std. A. Rainfall index	Negative value	Negative Value		Positive Value	Negative Value	
Selected Scenario	***Drought*** event approach is more suited			***Normal*** event approach is more suited		
Selected Cases	As present the farmers are not familiar with Green gram, so Case 1 is the best option			As present the farmers are not familiar with Green gram, so Case 2 is the best option		
Note: -P - Positive value, N- Negative value and Std. A. – Standardized Anomaly						

initial assumption of the second month is verified with the forecasted MJO. The practical usage of this completed tool depends on the 75% probability rainfall in the simulation.

Additional outcomes were revealed from the study. The maximum peak flood flow during the 2011 February flood was found as above 1000 m^3/s, and at the same time the flooding in Anuradhapura was proven to be due to blocking structures in the river. These pieces of information also helps in making decisions to modify or remove the structures for flood control and establish the path for the Disaster Management Center of Sri Lanka to develop soft measures for flash flooding.

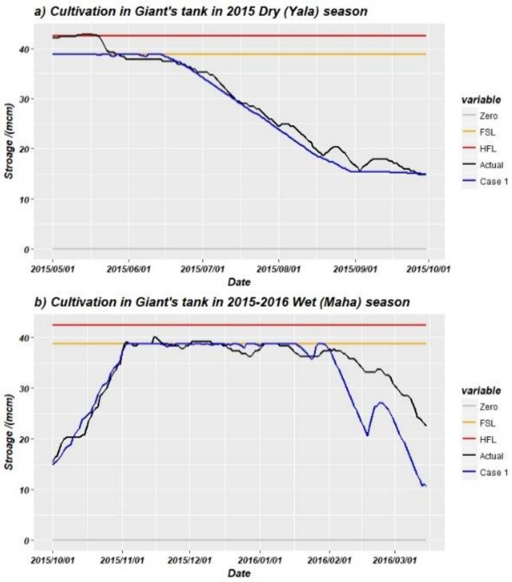

Figure 12 Comparison of predicted and actual cultivation in 2015 Dry and 2015-2016 Wet

CONCLUSION AND RECOMMENDATION

The results of this case study indicate that the prediction of seasonal conditions can change the tank operation in a positive way and improve the optimum water usage in Giant's tank, which can lead to the enhancement of income generation due to a stable inflow from the Malwathu Oya basin. The study also suggests that an effective water usage plan for Giant's tank can be developed with the proper use of the diverted water from Malwathu Oya basin. Based on the findings of this study, flood mitigation works in Anuradhapura city can be initiated. Finally, all these results confirm the proposed framework for the development of an effective water usage plan can be adopted for the Northern part of the dry zone in Sri Lanka, and it can be recommended for other parts of the dry zone.

In this study, green gram was used as the alternative plant for paddy in dry cultivation, but further study should be carried out for other dry season crops. Wavelet transform analysis and wavelet coherence analysis are the easiest-to-handle tools to understand rainfall and its connection to global climate indices useful for prediction. In this study, since they are applied to only one basin, further investigation should be done to implement them over Sri Lanka to produce effective short-term seasonal predictions.

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