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

Maheswaran Myuran*
MEE17731

Supervisor: Prof. Toshio Koike**
Asso. Prof. Mohamad Rasmy***
Dr. Mamoru Miyamoto****

ABSTRACT

Cultivation in dry zone is extremely vulnerable due to the increased water usage associated with the rapid population increase and the climate change. The dry zone water usage efficiency could be improved by integrating the way for water allocation, hydrological modeling and rainfall predictability. This study focuses on the above three components and formulates a framework to propose an effective water usage plan in a dry zone. This framework was applied to Malwathu Oya basin, one of the typical dry zones in Sri Lanka, where Giant's tank plays an important role in water allocation. The hydrological modeling component consists of Rainfall-Runoff-Inundation (RRI) and Tank Operation Models (TOM) as an initial stage. Then this study analyzed the temporal variability of local rainfall by using the 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). Then these indices were used for the short-term seasonal prediction rainfall. This study estimated the 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 the paddy and inland fishers were also considered in the tank operation optimization. In addition, this study identified the importance of construction of a tank above the Thekkam weir and 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 was changing rapidly due to the peaceful condition after the war, rapid growth of population with agricultural activities and climate change. This zone in Figure 1 receives less than 1200 mm of rainfall per year. The water received from the rain was utilized through main three components. Most important component was the water allocation for the usage, and the others are hydrological behaviors of the basin and seasonal condition over the basin. Hydrological behaviors were rainfall-runoff relationship and the tank operations within the basin and seasonal condition mostly related to rainfall over the basin. Therefore, this study is proposed to formulate a framework by studying about these three components for the development of effective water usage plan to the dry zone. This framework was implemented in the Malwathu Oya basin, one of the typical dry zone in Sri Lanka, where Giant's tank played an important role. Cultivation area under the Giant's tank scheme is rapidly increased after the termination of the inland war in 2009 and it was proven through MODIS enhanced vegetation index images shown in Figure 2. Main source of

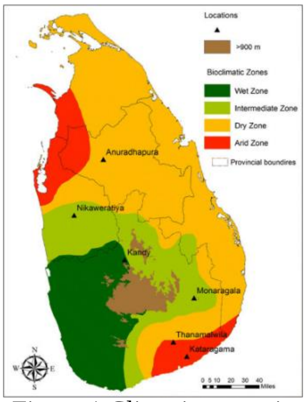

Figure 1 Climatic zones in Sri Lanka

---

* Irrigation Engineer, Department of Irrigation, Sri Lanka
** Director of ICHARM/Professor Emeritus of the University of Tokyo
*** Associate Professor GRIPS/Senior Researcher, ICHARM
**** Researcher, ICHARM

water for this tank is the diverted water from Malwathu Oya basin at Thekkam weir. This basin is the second largest basin in Sri Lanka with five major cascade tanks to control water usage. Hence, it is an excellent opportunity to check the proposed framework in this basin.

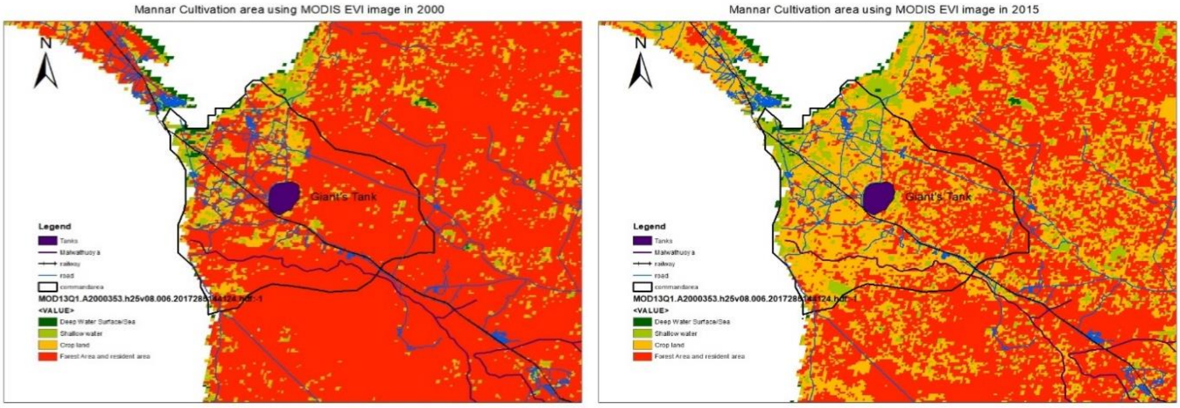

Figure 3 Reclassified MODIS Enhanced Vegetation Index for Giant's tank from 2000 to 2015

FRAMEWORK AND METHODOLOGY

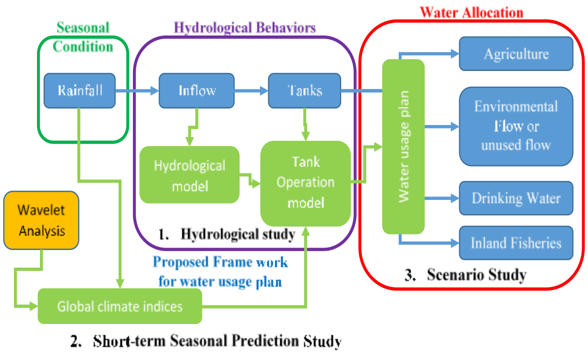

Figure 2 Framework for this study

The main objective of this study is to develop an effective water usage plan for the dry zone considering three main study areas. Such as the hydrological study, short-term seasonal prediction study and scenario study as shown in the proposed framework in Figure 3. In hydrology study the development of models such as a hydrological model with the capability of simulating rainfall to runoff and the tank operation model which concentrates on storing the water and releasing the water to the usage were involved. Next understanding of temporal changes in local rainfall with the global climate indices were analyzed through wavelet transform analysis and to formulate a platform for effective short-term seasonal prediction. And finally combine both above tool to come up with an effective plan for water usage through scenario study for different predicated events.

This framework was detailed as shown methodology flowchart in Figure 4 to employ in this case study. For the hydrological modelling the Rainfall-Runoff-Inundation model (RRI model) was selected because Malwathu Oya basin is flows over the 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 the wavelet transform analysis was used to identify the signals in the local rainfall and the global climate indices and wavelet coherence analysis was used to compare the signals from rainfall and the global climate indices such as Indian Ocean Dipole (IOD), El-Nino Southern Oscillation (ENSO) and Madden-Julian Oscillation (MJO) which influence the rainfall over South Asia region to identify the best indices for the prediction. Next forecasted values of these indices were taken from the Japan Meteorological Agency (JMA) and National Ocean Atmospheric Administration (NOAA) for the short-term seasonal prediction.

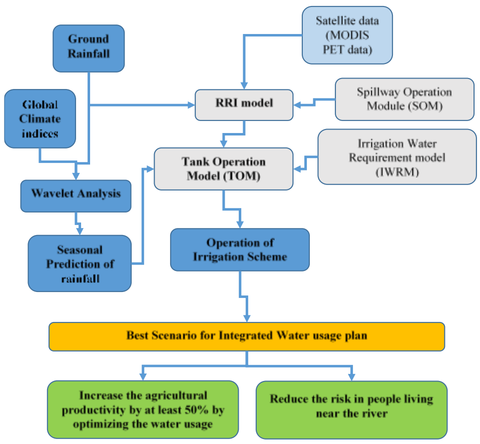

Figure 4 The methodology derived from the framework

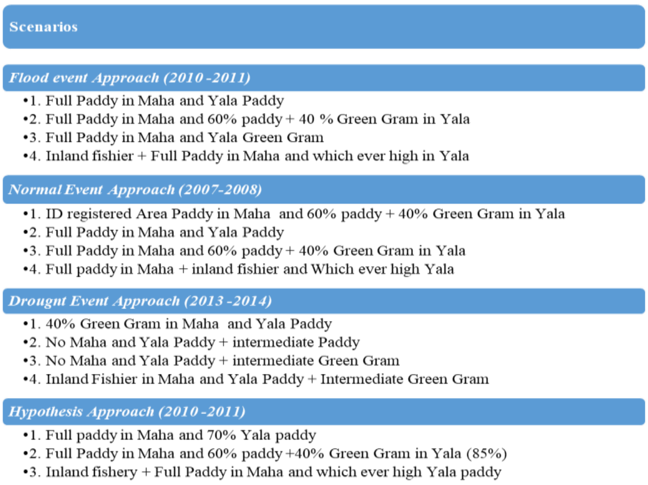

Figure 5 Scenario study approaches to find effective water usage plan

Third step is to use the prediction tool and hydrological tool for formulate 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 2010-2011 year data set, the normal event approach using 2007-2008 year data set, the drought event approach using 2013-2014 year data set and the hypothesis approach by considering the inflow to the tank as same in both cultivation season in 2010-2011 year data set. Here the increased cultivation area in wet season (Maha) was taken from Figure 2 as 14164 ha and actual cultivation area was registered as 9889 ha with paddy. But the cultivation area during the dry season (Yala) varies depending on the water availability and the crop usage (for example these simulations paddy and green gram were considered as the crops). The Inland fishers have been introduced as the additional income source.

Finally, this completed set of tools were used for practical usage in Giant's tank for the cultivation seasons such as 2014 and 2015 dry season and 2014-2015 and 2015-2016 wet season. As Initial step, the coming season was predicted with forecasted IOD and MJO indices, then the scenario was selected for the predicted season and simulated the RRI and TOM models to find the storage change in Giant's tank to check whether this procedure is showing the actual condition and to recognize improved class.

DATA

Ground rainfalls, tank operations and river discharges data were collected from the Irrigation Department of Sri Lanka, Metrological Department of Sri Lanka, and the yield of paddy and green gram, price of rice in market and the export amount of inland fishers were taken from Department of Censers and Statistic of Sri Lanka and 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 Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and ENSO and MJO indices were taken from NOAA.

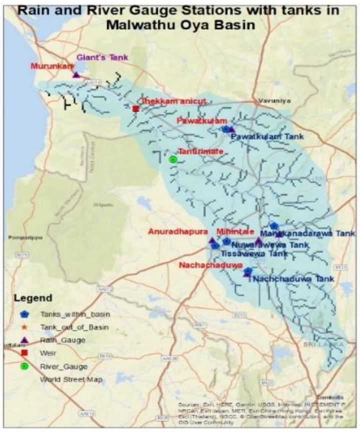

Figure 6 Rain and River Gauge station with tanks in Malwathu Oya Basin

RESULT AND DISCUSSION

The RRI model was simulated to take the discharge at Kappachi station by introducing boundary conditions at Nachchaduwa, Nuwarawewa, Tissawewa, and Mahakandarawa tanks in the locations shown in Figure 6 for the year 2007 -2008. This year was selected because during the high flood, data were not collected, hence normal year event was selected for calibration and validation. The initial calibration was shown two days earlier peak than the observation. To resolve this problem, the blocking structures like weirs, bridges, and small tanks inside the river were introduced with data recording one day delay, to achieve the Nash Sutcliffe Efficiency (NSE) value as 0.6534 for the period December 2007 to February 2008. Next, calibrated model was validated for March 2008 to May 2008 period and got the NSE value as 0.6136 with some errors noted among observation and recording data. Then the validated model was used to simulate for the period of October 2007 to September 2008, to get the inflow for the Giant's tank from the river diversion point at Thekkam weir. The result revealed a high amount of water

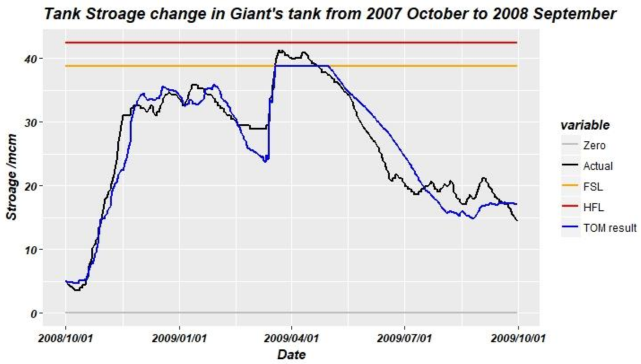

Figure 7 Results of TOM and Actual Storage of Giant's Tank in October 2007 to September 2008 year

flows over the weir that cannot be diverted because of the tank capacity and canal carrying capacity. Hence, the inflow was recalculated and used in TOM to visualize the storage change in Giant's tank which shown in Figure 7. In Figure 7 the both actual and simulated storage change was exhibited the similar pattern. Therefore, the hydrological tool was working well in this basin.

Then the 30 years of rainfall data were checked for the inter-dependence through the Auto-correlation test and monotonic trend through the modified Mann-Kendall test. The results showed the auto-correlation but not showed the monotonic trend in Murunkan station data which is 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 output of Monthly data was shown clear signals rather than the daily data. The Murunkan station output image of monthly data is shown in Figure 8 was selected for further study. In Figure 8 the significance of the signals were shown as the peaks in the small graph and its observation in years expresses three main signals such as 2 to 4 months signal, 4 to 8 months signal can be called as inter-monsoonal signal and the last one was 8 to 16 months signal can be called the interannual signal.

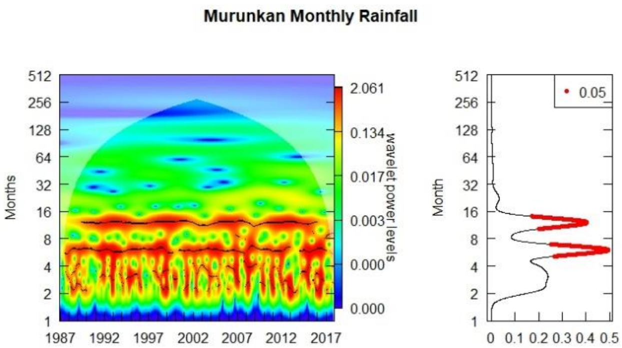

Figure 8 Wavelet Analysis result of Murunkan station in monthly resolution

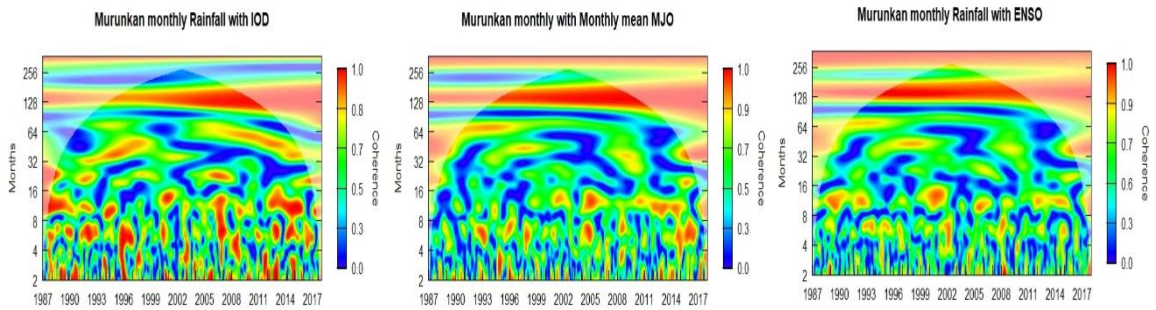

Figure 9 Wavelet Coherence analysis Results of Murunkan Station rainfall with IOD, ENSO and MJO

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

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 standardized anomaly index method was used for the rainfall to draw them with the IOD and MJO index in the same scale and observed the pattern to draft the conditions that satisfy the real events. The drafted conditions were checked for 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 took from JMA and NOAA and compared with the actual indices, these also exhipits the similar pattern. From that, the next month forecast shows that IOD index value was positive and it was greater than 0.5 and MJO index value was also positive and greater than 0.5, which means that next month may have a negative standardized anomaly rainfall index. Therefore rainfall may be less, but the dry season cultivation is already started, hence, well-controlled water management is needed. This is an efficient tool to obtain a one-month seasonal prediction but for the decision making during cultivation, at least three months of prediction is needed. Whereas the MJO index is forecasted for 15 days, so IOD index has been considered as a preliminary indicator for assuming the season for decision making and after 15 days it can be validated with the forecasted MJO index for changing the tank operation during the cultivation.

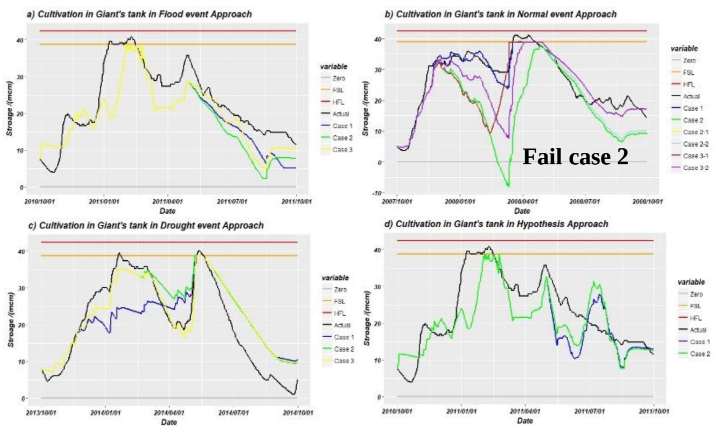

Figure 10 Scenarios results for every approach to find the effective usage of the water in Giant's tank a) flood, b) normal, c) drought and d) hypothesis

The results of the approaches in Figure 5 were shown in Figure 10, almost all of the cases in every approach were success, except one case in normal event approach, where the increased paddy area of 14164 ha was used for the wet cultivation. So to achieve the success two options were considered, one was to reduce the area by 15 % and another one was to introduce low age paddy as 2.5 to 3.0 month. Then the possible income generated through every approach was studied with the available data. The results were shown in Figure 11, by employing the case 4 the income can be increased in the normal event by 51%, in the flood event by 90% and in the drought event, it can achieve as the actual income generated in the normal event. In hypothesis approach income can be increased by 136% through the case 3. The outputs showed that best option for utilizing the water to achieve high income is to cultivation paddy and green gram within the area by including the inland fishers and cooperated tank operation with upper tanks.

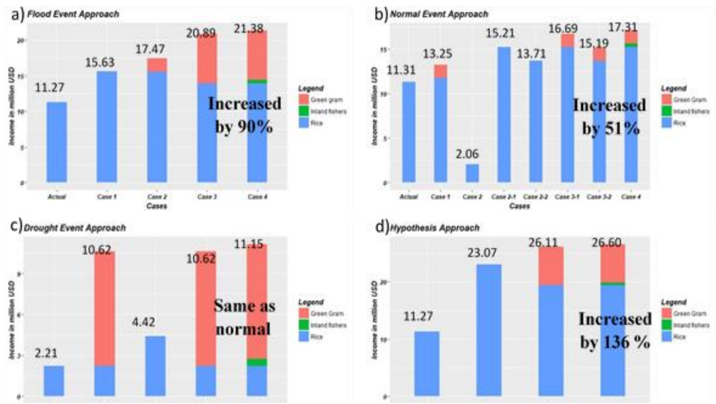

Figure 11 Calculated possible income generated for approached in a) flood, b) normal, c) drought and d) hypothesis

Accordence with the prediction tool, Table 2 was prepared with the predicted seasons for 2015 dry season and 2015 - 2016 wet season with the selected scenario and Figure 12 presents the results of the RRI model and TOM in the same period. The actual condition and the selected scenarios are exhibiting the 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 increased then the next wet cultivation will result in failure. And the initial assumption of the second month is verified with the forecasted MJO. The practical usage of this completed tool is depends on the 75% probability rainfall in the simulation.

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						

The additional outcomes from the study were that 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 is created by the blocking structures in the river was proven. This helps in making decisions to modify or remove the structures for the flood control and establish the path to develop the soft measures for the flash flooding through the Disaster Management Center of Sri Lanka.

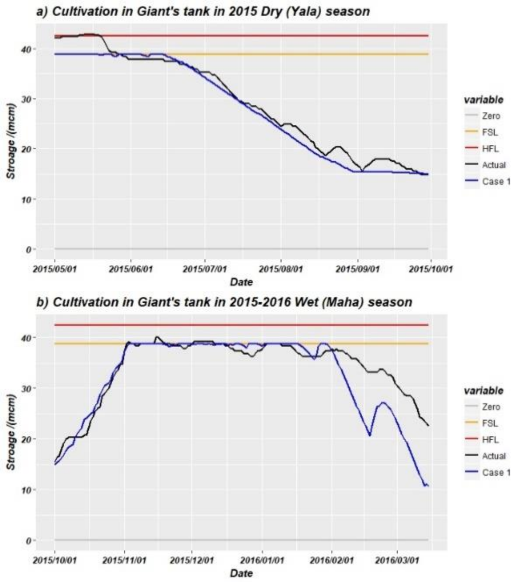

Figure 12 Comparison of predicted and actual cultivation in 2015 Dry and 2015-2016 Wet

CONCLUSION AND RECOMMENDATION

Accordance with the results achieved in this case study proven that the prediction of seasonal condition can change the tank operation in a positive way and it can improve the optimum water usage in the Giant's tank which can leads to the increment in income generation with the inflow from the Malwathu Oya basin. It was established that the effective water usage plan for Giant's tank is developed with the diverted water from Malwathu Oya basin. And through this study flood mitigation works in Anuradhapura city can be initiated. Finally, all these results confirm the proposed framework for the development of the effective water usage plan can be adapted for the Northern part of the dry zone in Sri Lanka and it can be recommended for the other parts of the dry zone.

In this study, Green gram was used as the alternative plant for the paddy in dry cultivation, but further studies can be carried out to another dry season crop also. The wavelet transformation analysis and wavelet coherence analysis are the easiest and best tools to understand the rainfall and its connection to the global climate index which helps for prediction. In this study it is used for only one basin, further investigation has to be done to implement in whole over Sri Lanka to produce an effective short-term seasonal prediction.

ACKNOWLEDGMENT

I'll embrace this opportunity to convey my greatest apperception to my supervisors and Director of ICHARM Professor. Toshio Koike and Associate Professor. Abdul Wahid Mohamad Rasmy and Dr. Mamoru Miyamoto for their valuable advice and unconditional guidance in my research. My special gratitude to JICA, GRIPS, ICHARM, and Department of Irrigation of Sri Lanka staffs who provided every knowledge and infrastructure support for this research. Finally my deepest thanks to the new friends in my course and my family for the fullest support.

REFERENCE

Sabrine Jemai, Manel Ellouze & Habib abida, 2017, "Variability of precipitation in Arid climate using the wavelet approach: case study of watershed of Gabes in Southeast Tunisia", *Atmosphere*, atmosphere 2017, 8, 178: doi:10.3390 /atmos8090178.

Eng. A.J.P. Ponrajah, *1984,* "Design of Irrigation Headworks for small catchment*", Irrigation Department of Sri Lanka*