

**CLIMATE CHANGE IMPACT ON THE SPATIAL
DISTRIBUTION OF DROUGHTS IN KIRINDI OYA
AND MADURU OYA DRY ZONE RIVER BASINS IN
SRI LANKA**

W.M.R.T.Y. Wijekoon

(228077B)

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

January 2024

**CLIMATE CHANGE IMPACT ON THE SPATIAL
DISTRIBUTION OF DROUGHTS IN KIRINDI OYA
AND MADURU OYA DRY ZONE RIVER BASINS IN
SRI LANKA**

W.M.R.T.Y. Wijekoon

228077B

Thesis submitted in partial fulfillment of the requirements for the degree
Master of Science in Civil Engineering

Department of Civil Engineering
Faculty of Engineering

University of Moratuwa
Sri Lanka

January 2024

DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date: 18/12/2023

The above candidate has carried out research for the PhD/MPhil/Masters thesis/dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Prof. R. L. H. L. Rajapakse

Signature of the Supervisor:

Date: 18/12/2023

Abstract

Climate Change Impact on the Spatial Distribution of Droughts in Kirindi Oya and Maduru Oya Dry Zone River Basins in Sri Lanka

Drought, a consequence of prolonged precipitation deficiencies, is a significant hazard exacerbated by climate change. Sri Lanka, highly susceptible to extreme climatic events, faces drought as its most prominent hazard, necessitating a comprehensive assessment of its impact. This study focuses on the escalating impact of drought intensified by climate change on the Maduru Oya and Kirindi Oya dry zone basins, crucial due to their vulnerability to altered hydroclimatic dynamics. With the substantial contribution of the dry zone to the paddy cultivation of the country, early detection of agricultural droughts is crucial for effective water allocation planning. Recognizing the importance of meteorological droughts as precursors to physical droughts, proactive monitoring and forecasting are essential for planning against subsequent agricultural droughts, while monitoring hydrological droughts is imperative for ensuring a reliable water supply for irrigation and other purposes. Thus, this research primarily focuses on evaluating meteorological and hydrological droughts.

The research employs the Standardized Precipitation Index (SPI) and the Streamflow Drought Index (SDI) for the monitoring of meteorological and hydrological droughts, respectively. It considers six CMIP6 (sixth Phase of the Coupled Model Inter Comparison Project) Global Climate Models (GCMs), and the CNRM-HR-1 model was selected as the preferred model. The two future projection scenarios, SSP1-2.6 and SSP5-8.5, were selected for the analysis. In the meteorological drought assessment, maps illustrating the spatial distribution of meteorological droughts were generated for both current and future climate scenarios. In order to generate maps, a future gridded rainfall dataset was developed by developing statistical relationships with the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) set and observed precipitation data. For the hydrological drought assessment, machine learning methods, including Recurrent Neural Network and Random Forest Algorithm, were used to predict future streamflow at specific gauging stations, with the Random Forest model selected for its superior performance. Additionally, the climatic indices formulated by the Expert Team on Climate Change Detection and Indices (ETCCDI) were used in this study to monitor the occurrence of climate extremes of precipitation in the past.

The meteorological and hydrological drought assessments reveal significant insights into the anticipated impacts of climate change. In the Maduru Oya basin, meteorological droughts exhibit varying percentage increases under SSP1-2.6 and SSP5-8.5 scenarios. Extreme and severe droughts experience increases of 18%, and 16%, respectively, under SSP1-2.6, and 31%, and 2%, under SSP5-8.5. Conversely, the Kirindi Oya basin displays significant susceptibility to extreme meteorological droughts, with increases of 49% under SSP1-2.6 and 37% under SSP5-8.5, particularly with extreme droughts surging by over 35% under both scenarios. Furthermore, the hydrological drought assessment highlights the heightened vulnerability of the Padiyathalawa sub-basin in the Maduru Oya basin, indicating a significant increase in the occurrence of moderate hydrological droughts at the 12-month timescale under both future scenarios. Conversely, the Wellawaya sub-basin in the Kirindi Oya basin also shows susceptibility to frequent moderate hydrological droughts along with an 80% increase in the occurrence of severe hydrological droughts under the SSP5-8.5 scenario at the 12-month scale. Therefore, both basins are expected to face water scarcity in the future, emphasizing the importance of implementing measures to ensure a reliable water supply for irrigation and domestic purposes, given the substantial impact of climate change on watershed hydrology.

Keywords: Climate-driven water stress, CMIP6 GCM projections, Drought resilience in water resources, Drought vulnerability

ACKNOWLEDGEMENT

Foremost, I would like to express my deepest gratitude to my research supervisor, Prof. R.L.H.L. Rajapakse, professor at the Department of Civil Engineering, University of Moratuwa, for his tremendous support, motivation, and enthusiasm. His guidance and extensive knowledge were instrumental throughout the research and writing of this thesis.

I also extend my sincere thanks to my co-supervisor, Dr. Karthikeyan Matheswaran, a Regional Researcher focusing on Water Productivity at the International Water Management Institute (IWMI-CGIAR), for the substantial support that contributed to the successful completion of my research. I appreciate the opportunity to collaborate with IWMI and express my sincere gratitude to all the experts and researchers at IWMI who supported me in conducting this research.

I express my sincere gratitude to the SAF-Madanjeet Singh Research Scholar scheme and the Department of Civil Engineering, University of Moratuwa for the financial assistance provided for me to complete this research successfully.

My gratitude extends to the Department of Civil Engineering for the guidance, and I sincerely thank the UNESCO Madanjeet Singh Centre for South Asia Water Management (UMCSAWM) staff for their assistance throughout the study. Simultaneously, I would like to thank my colleagues at the Department of Civil Engineering, University of Moratuwa, and the International Water Management Institute (IWMI), Colombo Headquarters, for their support and stimulating discussions throughout this research.

In addition, I express my gratitude to the Department of Irrigation and the Department of Meteorology for providing the data necessary to carry out this research.

W. M. R. T. Y. Wijekoon,
Graduate Research Assistant,
UNESCO Madanjeet Singh Center for South Aisa Water Management (UMCSAWM),
Department of Civil Engineering,
University of Moratuwa.

TABLE OF CONTENTS

1.	INTRODUCTION	1
1.1	General	1
1.2	Background.....	2
1.3	Problem Statement.....	3
1.4	Significance of the Research	4
1.5	Main and Specific Objectives.....	5
1.5.1	Main objective.....	5
1.5.2	Specific objectives	5
2.	LITERATURE REVIEW	6
2.1	Climate Change and Hydroclimatic Variability in Sri Lanka.....	6
2.1.1	El Niño-Southern Oscillation (ENSO).....	6
2.1.2	South Asian monsoon.....	7
2.1.3	ETCCDI climate change indices	7
2.2	Concepts of Drought Characterization	8
2.2.1	Drought types	9
2.2.2	Drought indicators.....	9
2.2.3	Characterization of droughts using drought indices.....	10
2.3	Drought Monitoring Indices	10
2.4	Future Climate Data.....	11
2.4.1	Downscaling of climate projections from GCMs	13
2.5	Machine Learning Methods for Streamflow Simulations	14
2.5.1	Prediction of streamflow using a neural network employing deep learning techniques.....	15
2.5.2	Prediction of streamflow using the ensemble machine learning approach of random forest algorithm.....	16
3.	METHODOLOGY	17
3.1	General	17
3.2	Methodology Flowchart	18
3.3	Study Area	18

3.3.1	Maduru Oya basin	19
3.3.2	Kirindi Oya basin	21
3.4	Data Collection and Data Checking	23
3.4.1	Single mass curve.....	25
3.4.2	Double mass curve	26
3.5	Calculation of ETCCDI Climate Change Indices.....	28
3.6	Bias Correction of GCM Output	28
3.7	Generation of Maps showing the Probability of Occurrence of Different Drought Categories.....	29
3.7.1	Development of a future gridded rainfall data set.....	29
3.7.2	Bias correction of CHIRPS satellite data	31
3.7.3	Generation of maps based on estimated SPI values.....	31
3.8	Streamflow Prediction	32
3.9	Estimation of the Streamflow Drought Index (SDI)	34
4.	RESULTS AND ANALYSIS.....	36
4.1	General	36
4.2	Bias Correction of GCM Output	36
4.3	ETCCDI Climate Change Indices	39
4.4	Statistical Relationship Between CHIRP Satellite Data and Observed Data	43
4.5	Bias Correction of CHIRPS Satellite Data	43
4.6	Generation of Maps	44
4.7	Streamflow Prediction based on Selected Machine Learning Approaches	47
4.7.1	Streamflow prediction using the random forest algorithm	49
4.8	Hydrological Drought Assessment Based on SDI.....	55
5.	DISCUSSION.....	63
5.1	Bias Correction of GCM Outputs.....	63
5.2	Streamflow Prediction by Machine Learning Methods.....	64
5.3	Vulnerability of the Maduru Oya and Kirindi Oya Basins to Droughts in the Future.....	65
6.	CONCLUSIONS	67
7.	RECOMMENDATIONS	69

BIBLIOGRAPHY	70
APPENDIX A: DOUBLE MASS CURVES.....	77
APPENDIX B: ETCCDI INDICES	81

LIST OF FIGURES

Figure 2.1: Origin and flow of physical droughts	9
Figure 3.1: Methodology flowchart	18
Figure 3.2: Maduru Oya basin and selected gauging stations.....	20
Figure 3.3: Kirindi Oya basin and selected gauging stations.....	22
Figure 3.4: Padiyathalawa streamflow response with rainfall from 2010/2011 to 2011/2012	24
Figure 3.5: Wellaway streamflow response with rainfall from 2004/2005 to 2005/2006.....	24
Figure 3.6: Single mass curves for the Maduru Oya basin	25
Figure 3.7: Single mass curves for the Kirindi Oya basin	26
Figure 3.8: Double mass curve for Polonnaruwa rainfall station (Maduru Oya river basin).....	27
Figure 3.9: Double mass curve for Bandaraeliya rainfall station (Kirindi Oya river basin)	27
Figure 3.10: Variation of the annual rainfall of selected GCM models	29
Figure 3.11: Thiessen polygon map (Maduru Oya basin).....	30
Figure 3.12: Thiessen polygon map (Kirindi Oya basin).....	30
Figure 3.13: Padiyathalawa subbasin of the Maduru Oya basin	33
Figure 3.14: Wellaway subbasin of the Kirindi Oya basin.....	34
Figure 4.1: Objective function values (Maduru Oya basin).....	36
Figure 4.2: Objective function values (Kirindi Oya basin).....	37
Figure 4.3: Variation of bias-corrected data with observed data at the Kandaketiya station	37
Figure 4.4: Variation of bias-corrected data with observed data at the Wellaway station	38
Figure 4.5: Thissamaharama Irrigation gauging station (Kirindi Oya basin) rainfall time series.....	38
Figure 4.6: Polonnaruwa gauging station (Maduru Oya basin) rainfall time series ..	39
Figure 4.7: Variation of CWD and CDD from 1985 to 2015 in the Kirindi Oya basin	39

Figure 4.8: Annual total rainfall on wet days recorded in the Maduru Oya basin	41
Figure 4.9: Annual total rainfall on wet days recorded in the Kirindi Oya basin	42
Figure 4.10: Variation of rainfall at Grid No. 39 of Kirindi Oya basin with observed rainfall at Bandaraeliya station	43
Figure 4.11: Hydrographs of the observed data at Wellawaya station and bias corrected data at Grid No. 32.....	44
Figure 4.12: Occurrence of extreme, severe, and moderate droughts in the Maduru Oya basin	45
Figure 4.13: Occurrence of extreme, severe, and moderate droughts in Kirindi Oya basin.....	46
Figure 4.14: Hydrographs obtained from the RNN model developed for the Padiyathalawa subbasin	48
Figure 4.15: Hydrographs obtained from the RNN model developed for the Wellawaya subbasin	48
Figure 4.16: Scatter plots obtained from the RF model developed for the Padiyathalawa sub-basin (Training period).....	49
Figure 4.17: Hydrographs obtained from the RF model developed for the Padiyathalawa sub-basin (training period)	50
Figure 4.18: Flow Duration Curves obtained for the training period for the Padiyathalawa sub-basin	50
Figure 4.19: Scatter plots obtained from the RF model developed for the Padiyathalawa sub-basin (Testing period)	51
Figure 4.20: Hydrographs obtained from the RF model developed for the Padiyathalawa sub-basin (Testing period)	51
Figure 4.21: Flow Duration Curves obtained for the testing period for the Padiyathalawa sub-basin	52
Figure 4.22: Scatter plots obtained from the RF model developed for the Wellawaya sub-basin (Training period)	52
Figure 4.23: Hydrographs obtained from the RF model developed for the Wellawaya sub-basin (training period)	53
Figure 4.24: Flow Duration Curves obtained for the training period for the Wellawaya sub-basin	53
Figure 4.25: Scatter plots obtained from the RF model developed for the Wellawaya sub-basin (Testing period).....	54

Figure 4.26: Hydrographs obtained from the RF model developed for the Wellawaya sub-basin (testing period)	54
Figure 4.27: Flow Duration Curves obtained for the testing period for the Wellawaya sub-basin.....	55
Figure 4.28: Variation of Streamflow Drought Index (SDI) during the historical period at different time scales at the Padiyathalawa gauging station....	56
Figure 4.29: Variation of Streamflow Drought Index (SDI) during the historical period at different time scales at the Wellawaya gauging station	56
Figure 4.30: Variation of SDI at the Padiyathalawa gauging station in the Maduru Oya basin for the future under SSP1-2.6	58
Figure 4.31: Variation of SDI at the Padiyathalawa gauging station in the Maduru Oya basin for the future under SSP5-8.5	58
Figure 4.32: Variation of SDI at the Wellawaya gauging station in the Kirindi Oya basin for the future under SSP1-2.6	59
Figure 4.33: Variation of SDI at the Wellawaya gauging station in the Kirindi Oya basin for the future under SSP5-8.5	60

LIST OF TABLES

Table 2.1: List of selected rainfall indices	8
Table 2.2: Drought type classification	11
Table 2.3: List of CMIP6 models selected for the study.....	13
Table 2.4: Bias correction methods.....	14
Table 3.1: Coordinates of the selected rainfall gauging stations for the Maduru Oya basin.....	20
Table 3.2: Coordinates of river gauging station of Maduru Oya basin.....	21
Table 3.3: Coordinates of the selected rainfall gauging stations for the Kirindi Oya basin	22
Table 3.4: Coordinates of river gauging stations of Kirindi Oya basin	22
Table 3.5: Data sources and resolution	23
Table 3.6: Recommended ranges for R^2	28
Table 3.7: Drought categorization based on SDI values	35
Table 4.1: Drought categorization based on SPI values.....	44
Table 4.2: Objective function values obtained for the developed RNN model	47
Table 4.3: Objective function values obtained for the developed RF model.....	47
Table 4.4: Occurrence percentages of different drought categories based on SDI in the historical period	60
Table 4.5: Occurrence percentages of different drought categories based on SDI under the SSP1-2.6 scenario.....	61
Table 4.6: Occurrence percentages of different drought categories based on SDI under the SSP5-8.5 scenario.....	61