

**ASSESSMENT OF DEFORESTATION AND LAND  
COVER CHANGE IMPACTS ON FLOOD PEAK  
DISCHARGE IN MADURU OYA BASIN, SRI LANKA**

Abdul Wahed Nab

(208358U)

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

February 2022

**ASSESSMENT OF DEFORESTATION AND LAND COVER  
CHANGE IMPACTS ON FLOOD PEAK DISCHARGE IN  
MADURU OYA BASIN, SRI LANKA**

Abdul Wahed Nab

(208358U)

Supervised by

Mr A. H. R. Ratnasooriya

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

UNESCO Madanjeet Singh Centre for  
South Asia Water Management (UMCSAWM)  
Department of Civil Engineering

University of Moratuwa  
Sri Lanka

February 2022

## DECLARATION OF THE CANDIDATE AND SUPERVISOR

“I declare that this is my own work and this thesis 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”.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

*UOM Verified Signature*

-----  
Abdul Wahed Nab

03-Feb-2022  
-----

Date

The above candidate has carried out research for the Master’s thesis under my supervision

*UOM Verified Signature*

-----  
Mr A. H. R. Ratnasooriya

03-Feb-2022  
-----

Date

---

## ABSTRACT

### Assessment of Deforestation and Land Cover Change Impacts on Flood Peak Discharge in Maduru Oya Basin, Sri Lanka

Population growth raises demand and competition for water resources and food stocks while it changes the landuse types by anthropogenic activities to adopt applicable measures for supplying water for domestic, agricultural, and industrial purposes. These changes alter the hydrological response of the river basins and can impose the communities to severe environmental risks like floods and landslides. Therefore, understanding of landuse change is crucial to study river basins' behavior and take mitigatory measures. The study presented here quantifies and analyzes the historical deforestation and landuse/landcover (LULC) change impacts on flood peak discharge of the Maduru Oya river basin, Sri Lanka using Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS) and remote sensing techniques. The Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Operational Land Imager-thermal Infrared Sensor (OLI-TIRS) images are acquired in 1976, 1994, 2009, 2021 and classified using maximum likelihood algorithm of supervised classification.

The analysis of LULC change revealed that LU change was faster and in high magnitude from 1976 to 1994 compared to the remaining period to 2021. The LULC change quantification by analyzing each scenario revealed a 24.9% deforestation while a 2.2%, 9.8%, 8.4%, and 4.5% increase in homestead/garden, paddy, scrubland, and water body between 1976 to 1994, respectively. The deforestation further continued to a rate of 4.1% and a 2.0% decrease in water bodies was also found in 2009 while homestead/garden, paddy, and scrubland continued to increase by 3.5%, 1.4%, and 1.5% compared to 1994 landuse scenario, respectively. In contrast, the 2021 landuse scenario indicated a 7.6% decrease in scrubland while 3.6%, 0.5%, 1.5%, and 1.8% increase in forests, homestead/garden, paddy, and water bodies. The classified images were subjected to accuracy assessment. The overall accuracy of 82%, 84%, 88%, and 91% are found for 1976, 1994, 2009, and 2021 LU scenarios while having kappa coefficients of 0.78, 0.80, 0.85, and 0.89 for respective years. The Normalized Difference Vegetation Index (NDVI) assessment of scenarios corresponds to the landuse classified images.

An event-based HEC-HMS model is used to simulate the flood events in the Welikanda catchment of the Maduru Oya river basin. The model is calibrated and validated using the 1976 landuse and then the subsequent landuses are applied to study LU change impact on flood peak discharge. For model performance evaluation, the Nash-Sutcliffe, RMSE Observations Standard Deviation Ratio (RSR) Percent Bias (PBIAS), and the Coefficient of determination ( $R^2$ ) were exploited. The average NSE, RSR, PBIAS, and  $R^2$  values of 0.92, 0.25, 17.60, and 0.94 achieved in calibration and 0.73, 0.50, -3.03, and 0.78 are found in the validation which all can be rated very good performance except for PBIAS as satisfactory in calibration and NSE as good in the validation. The land cover change resulted in an increase (22.3%) in flood peak from 842 m<sup>3</sup>/s in 1976 to 1,030 m<sup>3</sup>/s in 2021. As a result of the landcover changes, the volume is also increased (42.3%) from 178.16 MCM in 1976 to 253.52 MCM in 2021. This study provides useful information for land and water managers, forests conservation units, and hydrologist to understand the LULC change impacts on floods and paves the way for broad LU and hydrological studies in Sri Lanka which are rarely conducted. The same approach can be applied in different parts of Sri Lanka which are exposed to severe LU changes.

**Keywords:** Data Scarcity, Forests, HEC-HMS, Hydrological Modeling, Satellite Observations, Water Cycle

## **DEDICATION**

I would like to dedicate this study to my first teachers - my father and mother, in whom the existence gets a meaning, who have always stood up like the mountains against the challenges of life and have supported their children. When they were hardly surviving, they bought books and pens for their children to read, write and learn. It is with them that I feel big like the sky to spread the shade of kindness, smile, and supporting others. I owe them whatever I have in my life.

I also would like to dedicate this study to my family members, my brothers, and sisters who never spared to give me a hand when I was facing difficult times in my life.

I would like to honor the memory of my beloved late professor Ibrahim Najaf and my bachelor's degree supervisor Dr. Mohammad Hadi Asadi who have shaped my engineering life and dedicate this work to them.

Lastly, I would like to dedicate this work to my sweet homeland - Afghanistan in which I have grown up and do not know when to see it again, and Sri Lanka - my second homeland, the country that I have lived a life in so far.

## ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor Mr. Harsha Ratnasooriya for his persistent guidance, support, and continuous encouragement which enabled me to accomplish this study. My deep gratitude is extended to Dr. Janaka Bamunawala who instructed, guided, and provided me with his unsparing comments and assistance to shape this study.

I would like to honor and thank Prof. Lalith Rajapakse for his fruitful instructions, selfless cooperation, and invaluable guidance throughout this MSc. program. His unassuming approach to research and science is a source of inspiration. My deepest thanks go to Prof. Sohan Wijesekera for his lessons and unending inspirations. His vision, sincerity, and motivation have deeply inspired me throughout his lectures.

I wish to acknowledge the help provided by the panel members to accomplish this project, especially I would like to show my deep appreciation to Dr. Nimal Wijayarathna which helped me to figure out my research issues and obtain the required datasets. Taking the opportunity, I appreciate the Irrigation and Meteorological departments of Sri Lanka for providing the required datasets.

I would like to offer my sincere gratitude to the late Sri Madanjeet Singh for founding South Asia Foundation (SAF) and offering scholarships through UNESCO Madanjeet Singh Center for South Asia Water Management (UMCSAWM). The efforts by the SAF chapter of Afghanistan are highly appreciated which paved the way for obtaining the scholarship and processing of the documents.

I wish to acknowledge and thank the help provided by the technical and support staff in the UMCSAWM center especially Mr. Wajira Kumarasingh, Ms. Vinu Kalanika, and Ms. Janani Nisansala who patiently coordinated and cooperated throughout the course. I am fortunate to have been a student of the 6<sup>th</sup> intake and met my wonderful batchmates. I am indebted to all their cooperation during this MSc. course and project.

Nobody has been more important in persuading me to carry out my research successfully rather than my family and my beloved one that have always filled up my heart with their love, motivation, and inspiration.

---

**TABLE OF CONTENTS**

<b>Declaration of the candidate and supervisor .....</b>	<b>V</b>
<b>Abstract.....</b>	<b>VII</b>
<b>Dedication .....</b>	<b>IX</b>
<b>Acknowledgement .....</b>	<b>XI</b>
<b>Table of contents .....</b>	<b>XIII</b>
<b>List of figures.....</b>	<b>XVII</b>
<b>List of tables.....</b>	<b>XIX</b>
<b>List of abbreviations .....</b>	<b>XXI</b>
<b>Chapter 1 .....</b>	<b>1</b>
<b>1 Introduction.....</b>	<b>1</b>
1.1 Problem Identification .....	3
1.2 Problem Statement.....	4
1.3 Objectives.....	5
1.3.1 Main objective.....	5
1.3.2 Specific objectives.....	5
1.4 Project Area.....	5
1.5 Significance of the Study.....	8
<b>Chapter 2 .....</b>	<b>9</b>
<b>2 Literature review.....</b>	<b>9</b>
2.1 Landuse and Landcover Change Impacts on Flood Characteristics with a Focus on Deforestation .....	9
2.2 Runoff Variations due to Climate Change.....	10
2.3 Usage of HEC-HMS in LULC Studies.....	11
2.4 Literature on Hydrological Data Checking.....	12

## Table of contents

---

2.4.1	Rainfall data checking and gap filling .....	13
2.4.2	Streamflow Data Checking and Gap Filling.....	14
2.5	Secondary Datasets for Hydrological Modeling.....	15
2.5.1	ERA-40 Reanalysis Data .....	15
2.5.2	ERA5 Reanalysis Data .....	16
<b>Chapter 3</b>	.....	<b>19</b>
<b>3</b>	<b>Materials and methods .....</b>	<b>19</b>
3.1	Data Collection and Data Checking .....	21
3.1.1	Satellite Data Checking .....	22
3.1.2	Rainfall Data.....	22
3.1.3	Maduru Oya rainfall data checking .....	24
3.1.4	Visual data inspection.....	27
3.1.5	Streamflow Data.....	30
3.1.6	Maduru Oya streamflow data checking.....	32
3.2	Single Mass Curve.....	35
3.3	Correlation Between Rainfall and Streamflow.....	36
3.4	Deforestation and Landuse/Landcover Change Assessment.....	37
3.4.1	Landuse/landcover Change Induced by AMP (1976-1994) .....	39
3.4.2	Landuse/landcover Change Post-AMP (1994-2021).....	41
3.4.3	Accuracy Assessment.....	41
3.5	Normalized Difference Vegetation Index (NDVI).....	44
3.6	HEC-HMS Model Development .....	45
3.6.1	Model Setup .....	46
3.6.2	Assumptions .....	46
3.6.3	Basin Model .....	47
3.6.4	Event Selection.....	57
3.6.5	Model Calibration and Validation .....	63
3.6.6	Model Sensitivity Analysis.....	63
3.6.7	Model Performance Evaluation.....	64
<b>Chapter 4</b>	.....	<b>67</b>
<b>4</b>	<b>Results and analysis .....</b>	<b>67</b>



---

4.1	Deforestation and Landuse Change.....	67
4.1.1	Landuse Change Between 1976 – 1994 .....	67
4.1.2	Landuse Change Between 1994 – 2009 .....	68
4.1.3	Landuse Change Between 2009 – 2021 .....	69
4.1.4	Landuse Change Between 1976 – 2021 .....	70
4.1.5	Accuracy Assessment Results .....	76
4.2	Normalized Difference Vegetation Index (NDVI).....	78
4.3	Hydrological Modeling Results.....	83
4.3.1	HEC-HMS Model Calibration.....	83
4.3.2	HEC-HMS Model Validation.....	86
4.4	Sensitivity Analysis.....	90
4.5	NDVI and Peak Discharge Relationship .....	93
4.6	Assessment of Landuse Change Impacts on Flood Peak Discharge.....	94
<b>Chapter 5</b>	.....	<b>97</b>
<b>5</b>	<b>Discussion.....</b>	<b>97</b>
5.1	Satellite Data and Observations.....	97
5.2	Landuse Change Assessment.....	99
5.3	Hydrological and Meteorological Data .....	100
5.4	Hydrological Modeling .....	102
<b>Chapter 6</b>	.....	<b>105</b>
<b>6</b>	<b>Conclusions and recommendations .....</b>	<b>105</b>
6.1	Conclusions .....	105
6.2	Recommendations .....	106
<b>Bibliography</b>	.....	<b>109</b>
<b>Annexure 1</b>	.....	<b>119</b>
<b>7</b>	<b>Curve number for different landuse scenarios.....</b>	<b>119</b>

---

**LIST OF FIGURES**

Figure 1-1: Schematic of process interactions in landuse change effects on floods (Rogger et al., 2017)-----	2
Figure 1-2: Study area (Maduru Oya basin)-----	7
Figure 2-1: ERA5 family timeline (ECMWF, 2021)-----	17
Figure 3-1: Methodology flowchart -----	20
Figure 3-2: Gauging stations -----	26
Figure 3-3: Collected rainfall data chart -----	27
Figure 3-4: Batticaloa station annual rainfall -----	28
Figure 3-5: Batticaloa station monthly average rainfall -----	28
Figure 3-6: Seasonal variation of rainfall at Batticaloa station -----	29
Figure 3-7: Rainfall variation at Batticaloa station-----	29
Figure 3-8: Min, max, and average rainfall at Batticaloa station-----	30
Figure 3-9: Rainfall and Streamflow Data in Maduru Oya -----	31
Figure 3-10: Annual streamflow at Welikanda station -----	32
Figure 3-11: Monthly average observed streamflow at Welikanda-----	33
Figure 3-12: Seasonal variation of streamflow at Welikanda station-----	33
Figure 3-13: Streamflow variation in Welikanda station – box plot-----	34
Figure 3-14: Max, min, and average streamflow at Welikanda station-----	34
Figure 3-15: Single mass curve of Batticaloa rainfall station-----	35
Figure 3-16: Single mass curve of Welikanda streamflow gauging station-----	35
Figure 3-17: Correlation between Batticaloa rainfall and Welikanda streamflow station -----	36
Figure 3-18: LULC classification methodology flowchart-----	38
Figure 3-19: HEC-HMS model setup (subcatchments, reaches, junction, and streams)-----	48
Figure 3-20: Maduru Oya soil map (Source: Survey Department)-----	51
Figure 3-21: Gumbel’s probability distribution-----	61
Figure 3-22: Schematic of calibration procedure (USACE, 2000)-----	63
Figure 4-1: LULC Change from 1976 – 1994 -----	68
Figure 4-2: LULC Change from 1994 – 2009 -----	69
Figure 4-3: LULC Change from 2009 – 2021 -----	70
Figure 4-4: LULC Change from 1976 – 2021 -----	71
Figure 4-5: LULC Change from 1976 – 2021 -----	71

## List of figures

---

Figure 4-6: Landuse map of Maduru Oya basin (1976 scenario)-----	72
Figure 4-7: Landuse map of Maduru Oya basin (1994 scenario)-----	73
Figure 4-8: Landuse map of Maduru Oya basin (2009 scenario)-----	74
Figure 4-9: Landuse map of Maduru Oya basin (2021 scenario)-----	75
Figure 4-10: NDVI map of Maduru Oya basin (1976 scenario)-----	79
Figure 4-11: NDVI map of Maduru Oya basin (1994 scenario)-----	80
Figure 4-12: NDVI map of Maduru Oya basin (2009 scenario)-----	81
Figure 4-13: NDVI map of Maduru Oya basin (2021 scenario)-----	82
Figure 4-14: Calibration output (1961 Event)-----	84
Figure 4-15: Scatter plot for calibration (Event 1961)-----	84
Figure 4-16: Calibration output (1967 Event)-----	85
Figure 4-17: Scatter plot for calibration (Event 1967)-----	85
Figure 4-18: Validation output (1957 Event)-----	86
Figure 4-19: Scatter plot for validation (1957 Event)-----	87
Figure 4-20: Validation output (1960 Event)-----	87
Figure 4-21: Scatter plot for validation (1960 Event)-----	88
Figure 4-22: Validation output (1966 Event)-----	88
Figure 4-23: Scatter plot for validation (1966 Event)-----	89
Figure 4-24: Percentage change in simulated peak discharge plotted against the percentage variation in each parameter -----	90
Figure 4-25: Percentage change in simulated discharge volume plotted against the percentage variation in each parameter -----	91
Figure 4-26: Percentage change in simulated NSE plotted against the percentage variation in each parameter -----	91
Figure 4-27: Percentage change in simulated RSR plotted against the percentage variation in each parameter -----	92
Figure 4-28: Percentage change in simulated PBIAS plotted against the percentage variation in each parameter -----	92
Figure 4-29: Hydrograph variations due to different landuse scenarios simulation -----	94
Figure 4-30: Water volume increase due to landuse change -----	95
Figure 4-31: Water volume increase from 1976 – 2021 -----	96

---

**LIST OF TABLES**

Table 3-1: Data collection .....	21
Table 3-2: Data availability of rainfall gauging stations located within the catchment .....	22
Table 3-3: Collected rainfall data .....	25
Table 3-4: Collected streamflow data .....	31
Table 3-5: Landsat image acquired for LULC study.....	37
Table 3-6: Confusion matrix (error matrix) for accuracy assessment of 1976 image .....	42
Table 3-7: Confusion matrix (error matrix) for accuracy assessment of 1994 image .....	42
Table 3-8: Confusion matrix (error matrix) for accuracy assessment of 2009 image .....	43
Table 3-9: Confusion matrix (error matrix) for accuracy assessment of 2021 image .....	43
Table 3-10: Selected HEC-HMS methods .....	46
Table 3-11: Selected meteorologic models' methods .....	46
Table 3-12: Sub-catchments characteristics .....	47
Table 3-13: Curve number calculations for 1976 LU scenario .....	52
Table 3-14: Curve number calculations for 1994 LU scenario .....	52
Table 3-15: Curve number calculations for 2009 LU scenario .....	53
Table 3-16: Curve number calculations for 2021 LU scenario .....	53
Table 3-17: Time of concentration and lag time calculations .....	55
Table 3-18: Parameters calculations for flood return period estimation .....	59
Table 3-19: Flood return period estimation.....	60
Table 3-20: Estimation of confidence probability limits.....	62
Table 3-21: Selected events for model calibration and validation .....	62
Table 4-1: Modelling comparison of 1976 and 1994 landuse change scenarios in Maduru Oya basin .....	67
Table 4-2: Modelling comparison of 1994 and 2009 landuse change scenarios in Maduru Oya basin .....	68
Table 4-3: Modelling comparison of 2009 and 2021 landuse change scenarios in Maduru Oya basin .....	69
Table 4-4: Modelling comparison of 1976 and 2021 landuse change scenarios in Maduru Oya basin .....	70
Table 4-5: Accuracy assessment results for 1976 scenario .....	76
Table 4-6: Accuracy assessment results for 1994 scenario .....	76
Table 4-7: Accuracy assessment results for 2009 scenario .....	77

List of tables

---

Table 4-8: Accuracy assessment results for 2021 scenario .....	77
Table 4-9: Performance rating for evaluation metrics.....	83
Table 4-10: Performance rating of objective functions for calibration events .....	86
Table 4-11: Performance rating of objective functions for validation events .....	89
Table 4-12: HEC-HMS parameters ranking in respective to peak discharge and volume .....	93
Table 4-13: Water volume increment due to deforestation and landuse change .....	95
Table 7-1: Curve number calculations for 1976 landuse scenario .....	119
Table 7-2: Curve number calculations for 1994 landuse scenario .....	122
Table 7-3: Curve number calculations for 2009 landuse scenario .....	124
Table 7-4: Curve number calculations for 2021 landuse scenario .....	127

---

**LIST OF ABBREVIATIONS**

AMP	Accelerated Mahaweli Program
ANN	Artificial Neural Networks
C3S	Copernicus Climate Change Service
CN	Curve Number
DEM	Digital Elevation Model
DS	Direct Sampling
ECMWF	European Centre for Medium-Range Weather Forecasts
EDA	Exploratory Data Analysis
EDASM	European Digital Archive of Soil Maps
ERA 40	40-yr European Centre for Medium-Range Weather Forecasts Re-analysis
ERA5	Fifth Generation of Atmospheric Reanalysis of the Global Climate
ERA-Interim	ERA-Interim Represents a Third Generation Reanalysis
ET	Evapotranspiration
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization
FFPO	Fauna and Flora Protection Ordinance
GFDS	Global Flood Detection System
GIS	Geographical Information System
GSFC	Goddard Space Flight Center
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HRES	High-Resolution Forecast
LULC	Landuse/Landcover

MDP	Mahaweli Development Program
MERRA	Modern Era Retrospective-Analysis for Research and Applications
MI	Multiple Imputation
MLC	Maximum Likelihood Classifier
MLP	Multilayer Perceptron
MNN	Multivariate Nearest-Neighbor
MNP	Maduru Oya National Park
MSL	Mean Sea Level
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration.
NCEP	National Centers for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NIR	Near-Infrared Reflectance
NSE	Nash-Sutcliffe Simulation Efficiency
OLI	Operational Land Imager
PBIAS	Percentage Bias
PRF	Peak Rate Factor
R <sup>2</sup>	Coefficient of Determination
RED	Red Reflectance
REGEM	Regularized Expectation–Maximization Algorithm
RSR	Root Mean Square Error Observations Standard Deviation Ratio
SCS	Soil Conservation Service
SOM	Self-organizing Map
SRTM	Shuttle Radar Topography Mission

Tc	Time of Concentration
TM	Thematic Mapper
UH	Unit Hydrograph
UN-REDD	United Nations-Reducing Emissions from Deforestation and Degradation
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey