Modelling Optimum Water Release for Agricultural Lands Using Goal Programming Approach

A Thesis Submitted in Partial Fulfillment of the Requirements for the

Master of Science in Operational Research

By

S.A.S Rasangika

199524N

2022

Modelling Optimum Water Release for Agricultural Lands Using Goal Programming Approach

Master of Science in Operational Research

By
S.A.S Rasangika
199524N

External Supervisor:
Dr. D.M Samarathunga

Internal Supervisor:
Dr. P.M. Edirisinghe

Department of Mathematics
University of Moratuwa
Moratuwa.

Declaration

I declare that this dissertation has not been previously accepted in substance for any degree in the University or any other Institution. I state that this dissertation is the result of my own independent work, except where otherwise indicated or acknowledged under the supervision of Dr. D.M. Samarathunga, (Senior Lecturer, Faculty of Science, University of Ruhuna) and Dr. Pasan Edirisinghe, (Senior Lecturer, Faculty of Engineering, University of Moratuwa).

.....
S.A.S.Rasangika
199524N
Department of Mathematics
University of Moratuwa
Moratuwa
22 / 03/ 2023

External Supervisor :

.....
Dr. D.M Samarathunga
Senior Lecturer
Department of Mathematics
University of Ruhuna
Matara
22 / 03 / 2023

Internal Supervisor :

.....
Dr. P.M. Edirisinghe
Senior Lecturer
Department of Mathematics
University of Moratuwa
Moratuwa
22 / 03 / 2023

Acknowledgment

First of all I would like to express deep gratitude to my guide Dr. D.M. Samarathunga, Senior lecturer in department of Mathematics for his guidance, encouragement, and gracious support throughout the course of my work, for his expertise in the field that motivated me to work in this area and for his faith in me at every stage of this research.

I would like to thank Dr. Pasan Edirisinghe, Senior Lecture and the coordinator of the Master degree programmer for his timely guidance and coordination in the event of being success of my project

Also, I am grateful to the staff members of Technical services division at water management unit in Walawa who help me to supply the data for the research.

Finally I would like to thank for my parents and friends who help me to success this research and I wish to grant my heartful gratitude for anyone whom I could not mention in particular.

Abstract

The agricultural sector is one of the main sectors which benefits from several sources of water supply. This sector faces several challenges in securing water supply for its respective crops. Since the demand for water is increasing due to several factors, including population growth and an increased level of water dependent activities, and changes to crop selection influenced by various factors, including ever changing demand, the need for optimal use of water is identified as a priority for the rural agriculture sector in Sri Lanka. Past inflow data was used to obtain inflow values from the Udawalawa reservoir by using a forecasting model and the seasonal ARIMA model which was a statistical forecasting model used to forecast the inflow using RStudio software. In this respect water reservoir management is a crucial factor for allocating water for agricultural crops for study, a Goal programming model was formulated to determine the optimum water release for agricultural lands in Udawalawa region. Six main agricultural land divisions of the Udawalawa irrigation scheme were selected, and two of them received water from the right bank canal while the other four received water from the left bank canal of the Udawalawa reservoir. A Goal programming model with a 246 number of variables, 72 equality constraints, and 138 inequality constraints is solved using the MATLAB programming language and results show that water allocation from each reservoir can be used to fulfill the water demand throughout the year by using the water flow and allocation for each crop according to the priorities. In this case, it was assumed that 60% of the farming land used to cultivate paddy while the remaining 40% of the farming land used to cultivate other crops. These findings can be used by the stakeholders when making decisions on water allocation, not just based on the demand but also meeting a balance of crop selection.

Key words: Water Release Optimization, Goal Programming, Forecasting

Contents

1 Introduction **1**

1.1 Background of the study 3

1.2 Problem Statement 3

1.3 Research Question 3

1.4 Research Objectives 4

1.5 Significance of the Research 4

1.6 Limitations and Assumptions 5

1.7 Outline of the thesis 5

2 Literature Review **6**

3 Methodology **11**

3.1 Linear Programming (LP) 11

3.2 Goal Programming (GP) 13

3.3 Study Area 15

3.4 Data Collection 17

3.4.1 Inflow 17

3.4.2 Storage of the reservoirs 17

3.4.3 Demand 17

3.5 Problem formulation 18

3.5.1 Model 1 : Linear programming model 18
3.5.2 Model 2 : Goal programming model 22
3.6 Forecasting the inflow to the Udawalawa reservoir 27
3.6.1 Time series 27
3.6.2 Forecasting Methods 33
3.6.3 Fitted values and Residuals 36
3.6.4 Statistical Test 38

4 Analysis, Results and Findings **40**
4.1 Forecasting the inflow to the Udawalawa reservoir 41
4.1.1 Time series analysis for inflow data to Udawalawa reservoir 41
4.1.2 Forecasting Methods 45
4.2 Results for Optimization methods 62
4.2.1 Results for model I 62
4.2.2 Results for Model II 70
4.2.3 Deviation Values for Goals 85

5 Conclusion, Discussion and Future Directions **86**
5.1 Conclusion 86
5.2 Discussion 87
5.3 Future Direction 88

References **92**

List of Tables

4.1 The results of the portmanteau test for simple forecasting methods 52
4.2 Summary of the basic forecasting methods 53
4.3 Mann-Kendall trend test and unit root test for observed mean monthly Inflows 54
4.4 Performance values of the three best models 57
4.5 Parameter estimates for SARIMA (0, 0, 3) (0, 0, 2) model 57
4.6 Autocorrelation and Heteroscedasticity tests 59
4.7 Forecasting values for 2021 In SARIMA 61
4.8 Release from Udawalawa reservoir measured by hectare meter 62
4.9 Release water from other reservoirs 64
4.10 Release water for the paddy cultivated land 66
4.11 Ratio for paddy and other crops 67
4.12 Release from Udawalawa reservoir 70
4.13 Release water from one reservoir to other 72
4.14 Release for the Cultivated area 74
4.15 Release for the Chandrikawewa region 76
4.16 Release for the Angunukolapelessa region 77
4.17 Release for the Sevanagala region 78
4.18 Release for the Habaraluwewa region 79
4.19 Release for the Kiriibanwewa region 80
4.20 Release for the Andarawewa region 81

4.21 Proportion of land allocation for paddy and other crops 82
4.22 Areas of land allocation for paddy and other crops 83
4.23 Deviation Values for First Goal 85
4.24 Deviation Values for Second Goal 85

List of Figures

3.1 Overview of the study area 15
3.2 Land allocation of the study area 16
3.3 Plan for Water releasing 20
3.4 Plan for Water releasing 24
3.5 Four examples of time series showing different patterns. 28
3.6 Example for time series plot 29
3.7 Example for seasonal plot of monthly 30
3.8 Example for STL plot 32
3.9 A tidy forecasting workflow 33

4.1 Inflow to the Udawalawa from 1996 to 2020 41
4.2 Seasonal plot for inflow to Udawalawa 42
4.3 The seasonal sub series plot 43
4.4 STL- Decomposition 44
4.5 Mean method forecast appiled to Inflow in Udawalawa 45
4.6 Naive method forecast appiled to Inflow in Udawalawa 46
4.7 Seasonal naive method forecast appiled to Inflow in Udawalawa 47
4.8 Drift method forecast appiled to Inflow in Udawalawa 48
4.9 Visualized representation 49
4.10 Residual diagnostic graphs for simple forecasting methods 50

4.11 Autocorrelation function (ACF) and partial autocorrelation functions (PACF) for Udawalawa Reservoir inflows 55

4.12 Seasonally differenced autocorrelation function (ACF) and partial autocorrelation functions (PACF) inflows water of Udawalawa Reservoir 56

4.13 The residuals for the best model 58

4.14 Forecasts of monthly Inflow data in Udawalawa using the SARIMA $(0,0,3)(0,0,2)_{[12]}$ model 60

4.15 Release water from Udawalawa reservoir 63

4.16 Release water from Other reservoirs 65

4.17 Release water to the cultivated areas 67

4.18 Release water to the cultivated areas 68

4.19 Land allocation optain by Linear programming technique 69

4.20 Release from Udawalawa reservoir 71

4.21 Release water from other reservoirs 73

4.22 Release water to the cultivated areas 75

4.23 Release water to the Chandrikawewa area 76

4.24 Release water to the Angunukolapelessa area 77

4.25 Release water to the Sevanagala area 78

4.26 Release water to the Habaraluwewa area 79

4.27 Release water to the Kiriibbanwewa area 80

4.28 Release water to the Andarawewa area 81

4.29 Release water to the cultivated areas 83

4.30 Land allocation optain by Linear programming technique 84