

**RAINWATER HARVESTING PRACTICES IN SRI
LANKA AND AN INVESTIGATION ON COST
EFFECTIVE DESIGN CONSIDERATIONS FOR WET
AND DRY ZONES**

Munaver Jaman

(138662 V)



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Degree of Master of Engineering in Water Resources

Engineering and Management

Department of Civil Engineering

University of Moratuwa

Sri Lanka

August 2014

**RAINWATER HARVESTING PRACTICES IN SRI
LANKA AND AN INVESTIGATION ON COST
EFFECTIVE DESIGN CONSIDERATIONS FOR WET
AND DRY ZONES**

Munaver Jaman

(138662 V)



Supervised by
University of Moratuwa, Sri Lanka.
Dr. R. L. H. & Rajapakse
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Engineering in Water Resources Engineering and Management

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

University of Moratuwa
Sri Lanka

August 2014

DECLARATION

I declare that this is my own work. This thesis does not incorporate without acknowledgement of any material previously submitted for a Degree or Diploma in any other university or institute of higher learning to the best of my knowledge and belief and it does not contain any material previously published or written by another person expect where the acknowledgment is made in text.

In addition, 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).

.....

Munaver Jaman University of Moratuwa Sri Lanka.
Date
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

The above candidate has carried out this research for the Master's thesis under my supervision.

.....

Dr. R. L. H. L. Rajapakse


.....

Date

TABLE OF CONTENTS

DECLARATION.....	i
TABLE OF CONTENTS	ii
LIST OF TABLES	v
LIST OF FIGURES	vii
LIST OF ABBREVIATIONS	ix
ACKNOWLEDGEMENT.....	x
ABSTRACT	xi
1. INTRODUCTION	1
1.1 General	1
1.2 Overall Objectives	3
1.3 Specific Objectives	4
1.4 Research Approach and Thesis Outline	4
2. LITERATURE REVIEW	6
2.1 General	6
2.2 Rainwater Harvesting in General	6
2.3 Roof Rainwater Harvesting and Associated Components.....	8
2.3.1 Catchment system.....	8
2.3.2 Conveyance system	10
2.3.3 Water Quality System.....	11
2.3.4 Storage Tank.....	14
2.4 History of Rainwater Harvesting in Sri Lanka	16
2.5 Policy Planning and Legislative Support for Rainwater Harvesting.....	16

3.	METHODOLOGY	20
3.1	Methodology Flowchart	20
3.2	Study Area	21
3.2.1	Climate	21
3.2.2	Topography.....	21
3.2.3	Temperature.....	22
3.2.4	Rainfall	22
3.2.5	Population.....	23
3.2.6	Dry zone	24
3.2.7	Wet zone.....	26
3.3	Field Study.....	26
3.4	Data Collection.....	27
3.5	Data Checking.....	28
4.	ANALYSIS	30
4.1	Storage Tank Size.....	30
4.1.1	Mass balance method	31
4.1.2	Analytical method	32
4.1.3	Sequent peak algorithm method	32
4.1.4	Daily water balance equation method	32
4.2	Intensity Duration Frequency (IDF) Curve	33
4.3	First Flush Diverter.....	33
4.3.1	Manual system.....	34
4.3.2	Fixed volume system.....	34
4.3.3	Flow rate system.....	35
5.	RESULTS AND DISCUSSION.....	36


 University of Moratuwa, Sri Lanka
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

5.1	Storage Tank Size.....	36
5.2	Updating of IDF Curves	43
5.3	First Flush Diverter.....	45
5.4	Proposed System	46
6.	CONCLUSION	48
7.	BIBLIOGRAPHY	51
	APPENDICES.....	58
	Appendix A: Mass Balance Method.....	59
	Appendix B: Analytical Method.....	65
	Appendix C: Sequent Peak Algorithm Method.....	73
	Appendix D: Daily Water Balance Method.....	84
	Appendix E: Intensity Duration Frequency (IDF) Curve.....	87



University of Moratuwa, Sri Lanka.
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF TABLES

Table 2-2 Building categories as per UDA Guideline.....	19
Table 3-1: Co-efficient of determination (R^2) values for Puttalam data	28
Table 3-2: Co-efficient of determination (R^2) values for Trincomalee data	29
Table 3-3: Co-efficient of determination (R^2) values for Colombo data.....	29
Table 5-1: Calculated tank sizes for all regions	36
Table 5-5: Benefits of roof rainwater harvesting – A house with Type 1 Roof in Trincomalee	41
Table 5-6: Benefits of roof rainwater harvesting – A house with Type 1 Roof in Colombo	42
Table 5-9: Comparison of IDF curves - Colombo.....	44
Table A1: Mass balance method: Puttalam – Roof 1	58
Table A2: Mass balance method: Puttalam – Roof 2	59
Table A3: Mass balance method: Puttalam – Roof 3	59
Table A4: Mass balance method: Trincomalee – Roof 1	60
Table A5: Mass balance method: Trincomalee – Roof 2	60
Table A6: Mass balance method: Trincomalee – Roof 3	61
Table A7: Mass balance method: Colombo – Roof 1	62
Table A8: Mass balance method: Colombo – Roof 2	62
Table A9: Mass balance method: Colombo – Roof 3	63
Table A10: Results of Mass balance method	63
Table B1: Analytical method for Puttalam Roof 1	65
Table B2: Analytical method for Puttalam Roof 2.....	66
Table B3: Analytical method for Puttalam Roof 3.....	66
Table B4: Analytical method for Trincomalee Roof 1	67
Table B5: Analytical method for Trincomalee Roof 2.....	67
Table B6: Analytical method for Trincomalee Roof 3.....	68
Table B7: Analytical method for Colombo Roof 1	69

Table B8: Analytical method for Colombo Roof 2	69
Table B9: Analytical method for Colombo Roof 3	70
Table B10: Maximum deficient of three regions of 29 years analysis	71
Table B11: Results of Analytical method	72
Table C1: Sequent peak algorithm table – Puttalam Roof 1	74
Table C2: Sequent peak algorithm table – Puttalam Roof 2	75
Table C3: Sequent peak algorithm table – Puttalam Roof 3	76
Table C4: Sequent peak algorithm table – Trincomalee Roof 1	77
Table C5: Sequent peak algorithm table – Trincomalee Roof 2	78
Table C6: Sequent peak algorithm table – Trincomalee Roof 3	79
Table C7: Sequent peak algorithm analysis table - Colombo Roof 1	80
Table C8: Sequent peak algorithm analysis table - Colombo Roof 2	81
Table C9: Sequent peak algorithm analysis table - Colombo Roof 3	82
Table C10: Results of Sequent peak algorithm method	83
Table D1: Excel worksheet format for daily water analysis method	85
Table D2: Reliability percentage for Puttalam, Trincomalee and Colombo of Roof 1, Roof 2 and Roof 3	86
Table E1: 24, 48 and 72 hour maximum rainfall for Puttalam	88
Table E2: 24, 48 and 72 hour maximum rainfall for Trincomalee	89
Table E3: 24, 48 and 72 hour maximum rainfall for Colombo	90
Table E4: Statistical analysis using Gumbel (EV1) distribution for Puttalam	91
Table E5: Statistical analysis using Gumbel (EV1) distribution for Trincomalee	93
Table E6: Statistical analysis using Gumbel (EV1) distribution for Colombo	95
Table E7: Rainfall Depth - Puttalam	102
Table E8: Rainfall Depth - Trincomalee	103
Table E9: Rainfall Depth - Colombo	103
Table E10: Rainfall intensity for Puttalam	104
Table E11: Rainfall intensity for Trincomalee	105
Table E12: Rainfall intensity for Colombo	106
Table E13: Rainfall depth of Puttalam	109
Table E14: Rainfall depth of Trincomalee	109
Table E15: Rainfall depth of Colombo	110

LIST OF FIGURES

Figure 2-1: Schematic diagram of Roof Rainwater Harvesting components.....	9
Figure 3-1: Methodology Flowchart	20
Figure 3-2: Annual Average Rainfall (mm) of Sri Lanka	23
Figure 3-3: Map of Sri Lanka with the locations of Puttalam, Trincomalee and Colombo	24
Figure 3-4: Puttalam rainfall data (1982-2010).....	25
Figure 3-5: Trincomalee rainfall data (1982-2010).....	25
Figure 3-6: Colombo rainfall data (1972-2000)	26
Figure 5-1: Cost of Storage Tank	37
Figure 5-2: Reliability percentage cross checking of Puttalam result.....	38
Figure 5-3: Reliability percentage cross checking of Trincomalee result.....	39
Figure 5-4: Reliability percentage cross checking of Colombo result	40
Figure C1: Sequent peak algorithm graph for Puttalam Roof 1	74
Figure C2: Sequent peak algorithm graph for Puttalam Roof 2.....	75
Figure C3: Sequent peak algorithm method for Puttalam Roof 3	76
Figure C4: Sequent peak algorithm method for Trincomalee Roof 1	77
Figure C5: Sequent peak algorithm method for Trincomalee Roof 2.....	78
Figure C6: Sequent peak algorithm method for Trincomalee Roof 3	79
Figure C7: Sequent peak algorithm method for Colombo Roof 1	80
Figure C8: Sequent peak algorithm method for Colombo Roof 2	81
Figure C9: Sequent peak algorithm method for Colombo Roof 3	82
Figure E1: 24 hour data Gumbel Distribution for Puttalam	97
Figure E2: 24 hour data Gumbel Distribution for Trincomalee	97

Figure E3: 24 hour data Gumbel Distribution for Colombo	98
Figure E4: 48 hour data Gumbel Distribution for Puttalam	98
Figure E5: 48 hour data Gumbel Distribution for Trincomalee	99
Figure E6: 48 hour data Gumbel Distribution for Colombo	99
Figure E7: 72 hour data Gumbel Distribution for Puttalam	100
Figure E8: 72 hour data Gumbel Distribution for Trincomalee	100
Figure E9: 72 hour data Gumbel Distribution for Colombo	101
Figure E10: Rainfall Intensity Frequency curve - Puttalam	104
Figure E11: Rainfall Intensity Frequency curve – Trincomalee	105
Figure E12: Rainfall Intensity Frequency curve – Colombo.....	106
Figure E13: Logarithmic graph of Rainfall Intensity Frequency Curves - Puttalam	107
Figure E14: Logarithmic graph of Rainfall Intensity Frequency Curves – Trincomalee.....	107
Figure E15: Logarithmic graph of Rainfall Intensity Frequency Curve – Colombo	108



University of Moratuwa, Sri Lanka.
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF ABBREVIATIONS

AHP	-	Analytical Hierarchy Process
CWSSP	-	Community Water Supply and Sanitation Project
GBCSL	-	Green Building Council of Sri Lanka
GO	-	Government Organisation
IDF	-	Intensity Duration Frequency
LRWHF	-	Lanka Rainwater Harvesting Forum
NGO's	-	Non-Governmental Organisations
NWSDB	-	National Water Supply and Drainage Board
RDA	-	Road Development Authority
RRWH	-	Roof-top Rainwater Harvesting
RRWHS	-	Roof-top Rainwater Harvesting System
RWH	-	Rainwater Harvesting
WSSCC	-	Water Supply & Sanitation Collaboration Council
UDA	-	Urban Development Authority
VAO	-	Village Administrative Officer



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
Rainwater Harvesting
www.lib.mrt.ac.lk

ACKNOWLEDGEMENT

My sincere thanks are extended to Late Shri Madanjeet Singh for his visionary and noble idea that paved the platform for providing me with a scholarship to pursue this course, and South Asia Foundation (SAF), UNESCO Madanjeet Singh Centre for South Asia Water Management (UMCSAWM), Department of Civil Engineering, University of Moratuwa, for all the support given to complete this study successfully and make my stay in Sri Lanka an enjoyable one.

I take this opportunity to extend my sincere and heartfelt gratitude to Dr. R. L. H. Lalith Rajapakse, my research supervisor, for his continuous guidance, support, encouragement and valuable advice throughout the study. The outcome of this report and development of my research calibre was due to his strong commitment and conviction. He has been a true guardian.

Further, I wish to express my deep appreciation to Dr. R.L.H Lalith Rajapakse for rendering his unending support and guidance provided both in terms of academic and logistic welfare during my stay. He has always been a source of inspiration.

I also wish to express my gratitude to Professor N.T.S. Wijesekera, Centre Chairman and Overall Program Director-UMCSAWM, for his support since the inception of the research project work. I would also like to extend my gratitude to all the Governmental and Non-government Organisations, and their staffs for sharing their experiences and findings.

My sincere thanks are extended to Ms. Gayani Edirisinghe, Mr. Wajira Kumarasinghe and all other support staff at UMCSAWM for the continuous support in GIS related applications and for all their assistance to make my stay comfortable.

I am grateful to my brother and my wife for all their wisdom and guidance. I am thankful to all my Masters degree classmates for their support and motivations rendered to successfully complete the course.

ABSTRACT

All over the world, masses of human beings consume water for both potable and non-potable uses. While access to safe drinking water is explicitly acknowledged as a basic human need, water has an economical value in today's world market. The water crisis and impending climate change impacts highlight the immediate need for adopting alternative solutions to relieve the pressure on conventional water sources and Rain Water Harvesting (RWH) is ascribed as one of the most sustainable, low cost solutions equally applicable to both the urban and rural water management systems. In consideration of ever growing need for water conservation and as a measure in addressing the future issues of sustainable water management, the Government of Sri Lanka (GOSL) has recently implemented policies, rules and regulations to promote rainwater harvesting and one of the technologies recommended by the government is the Roof-top Rainwater Harvesting Systems (RRWHS). However, the initial investment cost for the storage tank is relatively high for rural communities in need and lack of information on tank size selection, cost recovery time, etc., hinder the popularizing and adopting of RRWHS among both rural and urban communities. In this study, an evaluation and assessment of presently existing RRWH practices in Sri Lanka have been undertaken in an attempt to identify the probable reasons that hinder popularising of RRWH among both communities, while a special consideration is given to the design aspects lacking concerns of cost, making RRWHS unaffordable especially to rural communities in need. To investigate the design considerations under the constraints of economical and reliability aspects, the design of storage tank, conveyance system and quality system of RRWHS are considered. Based on the findings of the present study, the estimation of the storage tank size is recommended to be achieved by daily water balance equation method and the excel worksheet model developed in this study was found to be more effective than the mass balance, analytical, and sequent peak algorithm methods presently in practice. The conveyance system is recommended to be designed based on updated rainfall intensity values (from updated IDF curves) and the quality of water harvested can be improved by incorporating a fixed volume first flush diverter. The time for cost recovery estimated based on present tariff for pipe-borne water and average household water use has been recognized as a fact to justify use of RRWH in urban setups, further to other indirect benefits. The recommendations for the best methodologies and possible further improvements are proposed based on the benefits of cost reduction estimated according to the present water consumption rate using present water tariff and calculating the cost recovery period for the RRWH systems.