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

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Department of Civil Engineering

University of Moratuwa
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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.

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

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Dr. R. L. H. L. Rajapakse Date

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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

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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.

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1. INTRODUCTION

1.1 General

All over the world, masses of human beings consume water for potable and non-potable uses including cultivation, gardening, industries, food processing, feeding animals and birds, etc. Drinking water or potable water should be clean and safe enough to be consumed by humans according to the present drinking water standards, and should not pose risk of immediate or long term harm or health hazard (Abdulla & Al-Shareef, 2008). When good quality water is naturally not available or when water sources are polluted as a result of adverse human interventions (i.e. contaminated with disease vectors, pathogens or unacceptable levels of toxins or suspended solids), it is required to restore the quality of potable water by effective treatment methods. The cost of water treatment is constantly on the rise as a result of the advanced technology, high standard chemicals and expertise needed, hence, water has an economic value in the today's world market (Cain, 2010). Groundwater is considered as an alternative resource but over extraction of groundwater can lead to various adverse effects ranging from short and long term decline of water tables to sea water intrusion, land subsidence and water quality contamination (Ani, Shaari, Sairi, Zain, & Tahir, 2009)

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The global water crisis is predicted to kill 39 – 76 millions of people by 2020 and the impending loss of life from the water crisis and water related diseases is higher than that caused by AIDS crisis (Cain, 2010). Global demand for water has doubled roughly every 21 years in the recent past (Li, Boyle, & Reynolds, 2010). According to the present circumstances, about half of the people who live in the developing countries do not have access to safe drinking water and 73% of the people do not have proper sanitation which causes subsequent contamination of water bodies (Lekwot, Samuel, Ifeanyi, & Olisaemeka, 2012). Water security is defined as "Easy accessibility, reliability and timely availability of adequate safe water to satisfy basic human need" (Ariyabandu, 1999). Lately, global climate change and its impact on rainfall availability and variability in time and space is becoming a concern. These developments point to a potentially threatening future for global water availability and the United Nation (UN) comprehensive assessment of the world freshwater resources estimates that about a third of the world's population live in countries suffering from water stress where there is shortage of surface water (Kjellen & Mcgranahan, 1997).

The above facts highlight the immediate need for adopting alternative solutions to relieve the pressure on conventional water sources and Rain Water Harvesting (RWH) could be the most sustainable, low cost solution equally applicable to both the urban and rural water management systems. Further to the direct benefits in mitigating the water crisis problem, the secondary benefits of implementing RWH may help to reduce the burden on traditional water sources, alleviate non-point source pollutant loads, control water logging problems, prevent flooding, control climate change impacts, contribute to the storm water management, and so forth.

Rainwater harvesting is a technology that has long been used even by the ancient civilizations in the water scarce regions in Asia and Africa for collecting and storing rainwater from rooftops, the land surface or rock catchments using simple techniques such as jars and pots as well as more complex techniques such as underground dam 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 Rainwater Harvesting Systems (RRWHS). Roof Rainwater Harvesting (RRWH) is the general term that refers to the action of collection and storage of rainwater intercepted by roof surface areas during wet period and use over the course of the subsequently followed dry period upon domestic water requirements.

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Populations in the urban areas of Sri Lanka are mainly dependent on the pipe water supply system for potable water (pipe borne water) from the sole service provider - National Water Supply & Drainage Board (NWSDB). A major drawback of this water supply system is that the people have to use the same water for non-potable purposes as well. Therefore, the users have to pay an equal cost for both potable and non-potable usage of water. Similarly, some of the rural areas of Sri Lanka are also dependent upon the pipe water supply system, mainly for potable water, from the NWSDB. The users in such areas are also facing the same problem of paying high cost water bills as a result of present tariff system that levies both potable and non-potable uses at the same rate. Most other rural areas depend on the spring water, tube-well water, water from dug wells and boreholes, etc., but in some of these regions, the groundwater is either saline, acidic or, contains other contaminants, therefore, in future the populations in these regions may also expect NWSDB connections and will have to face similar excessively high water cost problems.

In order to overcome the problems aforementioned leading to indiscriminately high water bills for both urban non-potable water uses and potable use in rural areas, and also as a premeditated measure against increasing costs of water purification, RRWH can be promoted amongst urban populations specifically to fulfil their non-potable water needs by using their house roof as a catchment surface to collect rainwater. The RRWH is recommended also for the rural communities in the dry and intermediate zones of the country, where the water in abundance during the relatively short wet season can be stored and used over the dry period for non-potable uses, saving cleaner water sources for drinking, food processing and other hygienic purposes alone.

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However, it has been noted that despite the regulations and numerous promotional schemes carried out by governmental as well as non-governmental organizations over the past decades, the RRWH is still lacking in adoption among both rural and urban communities. Recent survey results from other similar regions have revealed that the factors affecting the adoption of rainwater harvesting in the target communities range from those affecting the motivation of residents to collect rainwater to those affecting their ability or affordability to do so.

1.2 Overall Objectives

The overall objective of the present study is focused on evaluating the currently existing practices of roof rainwater harvesting systems to investigate cost effective design approaches in optimizing storage tank size, conveyance system, and first flush diverter for the applications in wet and dry zones of Sri Lanka, which would help to promote adopting the systems and popularising amongst needy communities.

1.3 Specific Objectives

The overall objective aforesaid is attained by following the specific objectives as listed below.

- Evaluate the present roof rainwater harvesting practices in Sri Lanka.
- Collecting data on recent rainfall patterns, water demand quantity for dry - wet zones, and cost of tank and average household per house.
- Investigating the need for updating Intensity-Frequency-Duration (IDF) curves with recent rainfall data.
- Comparison of design rainfall intensity values with previous study values.
- The tank size analysis based on mass balance, analytical, sequent peak algorithm and daily water balance equation methods, and necessary improvements for higher reliability and cost effectiveness..
- Water quality system prioritisation based on the need/absence of a person field during operation.
- Assess the benefits of cost reduction based on present water consumption rate and the cost recovery period for the RRWHS and recommendations for cost efficient/high reliable systems.

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1.4 Research Approach and Thesis Outline

In this study, an evaluation and assessment of presently existing RRWH practices in Sri Lanka have been undertaken in an attempt to identify the potential reasons that hinder popularising of RRWH among both rural and urban communities, while a special consideration is given to the design aspects lacking concerns of cost, making RRWHS unaffordable especially to rural communities in need.

At present, a considerable investment, i.e. approximately 75% of total investment (Ariyananda & Wickramasuriya, 2009) is required for the construction of a rainwater storage facility which is an essential component of any RRWHS. Currently, the

Municipality Council guidelines speculate the calculation of the storage tank size requirement based on average rainfall and roof area (Lanka Rain Water Harvesting Forum, 2009) while the NGO's promoting RRWHS recommend methods based on the highest demand as identified from mass curve analysis method (Lanka Rain Water Harvesting Forum, 2009).

Firstly, the design of storage tank by mass balance, analytical, sequent peak algorithm and daily water balance equation methods were investigated under the conditions of cost effectiveness (economical) and reliability. Reliability is defined as the ratio of the number of days over which the harvested rainwater can be used for their non-potable uses to the total number of days used for the analysis. Daily rainfall data of 29 years was used from both wet and dry zone study areas for the study.

Secondly, the NGO's following a thumb rule of 1 cm^2 gutter cross-section area per 1 m^2 of roof surface catchment area (having 0.9 runoff co-efficient) to design the conveyance system was scrutinized (Lanka Rain Water Harvesting Forum, 2009). The present implications on climate change and subsequent changes rainfall patterns with increased peaks and the possible occurrence of more frequent extreme events (Simonovic & Peck, 2009) exceeding the parameter values determined based on existing design criteria may lead to cause damage to the RRWHS infrastructure and other associated facilities. Further, the possible cost reduction achievable in optimizing channel sizes of the conveyance system with present rainfall data and updated IDF curves is also investigated.

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Furthermore, the commonly used RRWHS at present designed with manual first flush diverters requires a person in the field to operate the device during the period of a storm event. Therefore, the use of an alternative device with automatic diversion system as the first flush diverter is also investigated.

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 and calculating the cost recovery period for the RRWHS.

2. LITERATURE REVIEW

2.1 General

During the initial phase of this study, a detailed and systematic literature review was conducted focusing on present practices of roof rainwater harvesting in Sri Lanka, methods adopted to determine storage tank size, conveyance system and further, covering the particulars of widely practiced water quality improvement systems. This review presents a brief, yet comprehensive summary of the Rain Water Harvesting (RWH) and Roof Rain Water Harvesting (RRWH) related literature reviewed and appraised during the course of the present study.

2.2 Rainwater Harvesting in General

Rain Water Harvesting (RWH) is the general term that refers to the action of collection, storage and use of rainwater for common water needs like domestic use, agriculture, etc. Rainwater harvesting can be categorized broadly into two types based on the method of collection. The first is by means of using land surface as the catchment and the second is by means of roof surface as the catchment. The first method is used to store water in large scale and huge quantities like reservoirs, dams, ponds, which can be used for agriculture, fisheries and numerous other water based domestic, industrial and recreational functions. If the collected water is used for drinking, it requires proper treatment prior to distribution and consumption.

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The latter is adopted by building owners to store the roof water in large tanks or containers for future use depending on their water requirements. If the collected water is used for non-potable purposes, the system needs good maintenance and if it is used for drinking purposes, the collected water is required to be treated properly.

It is argued that large projects like dams and reservoirs result in significant social and environmental impacts during both construction and operational phases for water storage, supply and distribution despite the fact that it has not been proven that such large scale projects can meet the need of ever growing population (Cain, 2010). On the contrary, RRWH systems are said to have either minimal or no adverse environmental effects and even claimed to be having positive environmental impacts (Cain, 2010). Further, the RRWH is the simplest technology readily available onsite, whereas the thumb rule implying that one millimetre of rainfall is equal to one litre of rainwater per square meter (Helmreich & Horn, 2009) can effectively be used in deriving initial estimates.

In domestic RRWH, the conserved water is used not only for the household water supplies, but it also saves the environment from flooding by curtailing the magnitude of peak runoff and improves the groundwater availability by recharging aquifer systems though retarded discharge or soakage over time. In industrial applications, the RRWH not only supplies the part of the water demand, but also saves the energy by means of ensuring water availability on-site instead of dependability on off-site reservoirs which leads to extra conveyance and pumping costs. Besides these direct benefits, the RRWH creates a micro environment inside the industry zone which causes cooling effect as a result of masses of stored water (Jothiprakash & Sathe, 2009). Therefore, the RRWH is considered as one of the simplest green technology systems which incurs low cost in exchange for a high return (Lim & Jiang, 2013)

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In the context of Sri Lanka as a lower-middle income country with a significantly large rural community group, the initial investment cost of RRWH systems is still relatively high for the poor people. However, these costs are well justifiable especially in rural settings when compared with the opportunity cost of time required to carry water from longer distances. By considering these benefits and drawbacks, it is obvious that the rich easily implement the system but poor people are expecting financial assistance from the Government, NGO's, welfare organisations (Cain, 2010) to meet those initial expenses. The rain water harvesting system helps to reduce the unduly high water demand of urban communities by using harvested rainwater for non-potable purposes (Basinger, Montalto, & Lall, 2010). The cost incurred in the use of rainwater by means of a rainwater harvesting system is relatively higher than the cost required in using readily available water, but the significantly high direct and indirect environmental benefits can compensate for those additional costs through the use of harvested rainwater for groundwater recharging and flood retardation (Dwivedi, Patil, & Karankal, 2013).

In the process of RRWH, if the catchment area is unpolluted, reasonably good quality water can be harvested and if the downpipe is designed properly, the overflowing water issues will be minimized. In addition, if the storage tank size is optimally and effectively designed based on rainfall, total demand and dry period water demand, the cost of tank can be minimized. Therefore, further study and discussion about these main four components of RRWHS is required for this study.

2.3 Roof Rainwater Harvesting and Associated Components

There are mainly four important components that should be considered in designing of the system. The diagrammatic representation of RRWHS is shown in Figure 2.1.

Catchment system

- The building roof is the collection system which collects rainwater.

Conveyance system

- The conveyance system transfers collected water from the roof to the storage tank. Gutter and downpipe are the parts of the conveyance system.

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Water Quality system

- The devices used to filter the waste component like leaf, other suspended particles to avoid contamination of stored water in the storage tank.

Storage tank

- This is the main component in the rainwater harvesting system which is used to store water and supply on the demand time.

The system flow of RRWH is to capture the rainwater by catchment area, convey through the device (gutters and downpipe), filter and store the rainwater in storage tank. The collected water can be used for gardening, domestic use, flushing toilet, car washing, and groundwater recharge.

2.3.1 Catchment system

Catchment systems are classified into two types

- Roof of the building
- Open area surrounding the building

Rainwater can be harvested by the roof as well as by the surrounding area. This study is based on the RRWHS, where the rainwater harvesting practise by means of roof of the building as the catchment is considered.

The diagrammatic representation of the RRWHS is presented in Fig. 2-1.

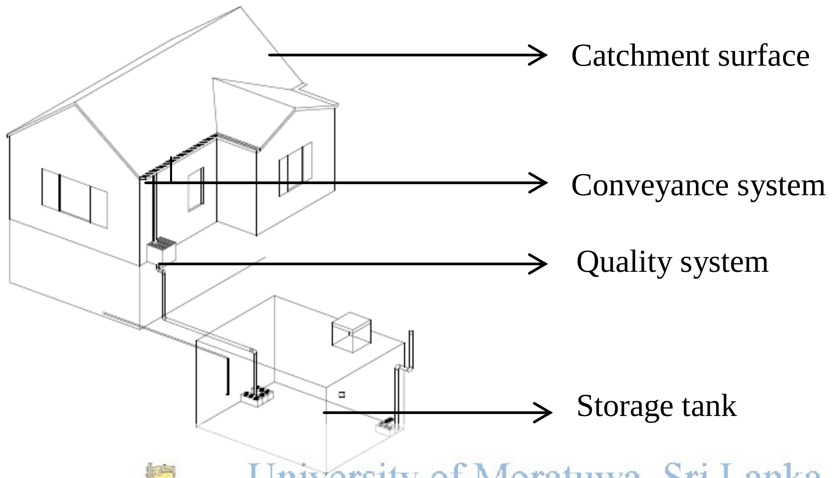

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Figure 2-1: Schematic diagram of Roof Rainwater Harvesting components

There are large number of materials used to construct the roof and structuring the roof as sloping and flat type. Roof materials and roof types vary thus affecting the value of runoff co-efficient. Farreny et al. (2011) conducted a survey and classified the value of runoff co-efficient based on the roofing and roof material types. In water quality concern of the RRWHS, catchment surface is playing a vital role therefore roofs require cleaning and re-coating for every two to four years (Rowe, 2011). Types and constituent material of the roof result in variation in the run-off co-efficient (Farreny, et al., 2011), therefore the average value of runoff coefficient of 0.9 is considered for this study. Runoff volume is calculated by using the general formula;

$$V_R = A * C * R$$

Where

V_R - Rainwater volume, m^3

A	-	Area of catchment surface, m^2
C	-	Run off co-efficient
R	-	Rainfall, m

2.3.2 Conveyance system

Conveyance system is the component used to direct the flow of rainwater from roof to the storage tank. The conveyance system is made of gutter, downpipe and mechanical filter. Gutter is fixed at the lower edges of roof to collect the rainwater falling on the roof, downpipe is to carry the rainwater from the gutter to the storage tank and mechanical filter is placed in the inlet of downpipe to remove larger particles. Downpipe is joined with the gutter at one end and the other end is connected to the storage tank. Therefore, the downpipe is the middle component between the gutter and the storage tank. It is clear that the gutter and downpipe of RRWH system are playing an important role in the water conveyance without losses and damages to the building.

British Standard Institution (BSI, 2010) guidelines states that the sizes of the gutter and downpipe for flat and sloped roofs are designed based on the rainfall intensity value (mm/hr). Sizes of the gutter and downpipe are estimated by the use of intensity duration frequency (IDF) curves prepared by relevant authorities, while in most cases it is the Meteorology Department (Handia, Tembo, & Mwiindwa, 2003).

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Calculating rainfall intensity from the historical rainfall data is required to subsequently estimate the size of pipe which collects the rainwater from the roof and sends to the storage tank without overflowing and to prevent flood around the house area (Abdulla, 2012).

Sri Lanka is presently following the IDF curves intended for irrigation headwork designs which is prepared by Irrigation Department in 1984. Therefore, for the present study, it is deemed required to update and redraw IDF curves incorporating more recent rainfall data. Abdulla (2012) recommended the calculation of rainfall intensity from the historical rainfall data to construct rainwater harvesting set up to estimate the downpipe size in which rainwater flows from the roof to the storage tank without overflowing while preventing risk of flooding around the house area.

The rainfall intensity in this method is calculated through Intensity-Duration-Frequency (IDF) curve method analysis.

AlHassoun (2011) recommended that regular updating of the rainfall frequency is required for maximum reliability of the system in Riyadh. Bureau of Meteorology (2012) recently revised Intensity – Frequency - Duration (IDF) design rainfall intensities based on more recent rainfall data and it is presumed that th updated values are better suited to the current needs of practitioners undertaking design flood studies.

Liew et al. (2012) added that the updated IDF curves are more applicable to the areas of heavy and long duration rainfall.

Slobodan, Simonovic, and Peck (2009) found that updated IDF curves for City of London was associated with an upward change in average rainfall intensities in the range of 20%.

Michigan Department of Transportation (2000) recommended that rainfall frequency studies be updated on a regular basis for maximum reliability.

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2.3.3 Water Quality System

The safe use of collected rainwater for domestic use requires additional consideration to maintain the quality of the water conforming to the standards and guidelines through a properly designed water quality system.

Debris, dirt and dust spread on the roof during non-rainy (dry) periods due to pollution, bird and animal dumping, long dry periods, etc., makes initial rainwater falls and subsequent runoff on the roof highly contaminated. If this contaminated water flows into the storage tank, it makes the stored water of the tank unfit to use. Once the roof is washed out with initial water and flushed for a certain short period due to oncoming rain drops and flowing runoff, the water collected in the aftermath becomes considerably safer.

A significant improvement of rainwater quality can be achieved through cutting off the initial amount of rainfall volume by using a first flush water diverter (Helmreich & Horn, 2009). Microbial content presents in the roof area is washed out through rainwater falls on the roof, and if not removed prior to entering the conveyance system, again deposits at the bottom of tank which causes quality difference at bottom and top levels of water in the storage tank due to mixing. The mere use of a filter screen placed before the RWH storage tank is not adequate to remove the microbial and other solute contaminants, thus it is required to incorporate a first flush diverting system which help maintaining the quality of water in RRWHS (Amin & Han, 2011).

If the rainwater is collected for drinking purposes, it needs to be filtered by a simple method like sponge based filter to prevent incoming waste to the storage tank or chlorine addition, bio sands, ceramic vessels or the combination of the above two approaches could give more effective results (Cain, 2010).

Rainwater harvesting through land and road surfaces can only be used for irrigation or gardening/washing purposes but for domestic and drinking uses, the best practise is to harvest by roof surfaces. This also results in organic compounds and other pollutants to accumulate in the storage tank but it can be diverted through cutting off a small amount of first flush runoff volume (Zhu, Zhang, Hart, Liu, & Chen, 2004).

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In the present evaluation and study on water quality of roof rainwater harvesting systems, the important components missing in the design were the first flush diverter, filter screen and chlorination for disinfection. These components were very crucial to this system so the water quality is directly affected due to the absence and added that quality of rainwater can be increasing by the use of screen filter, first flush diverter, chlorination, a slow sand filter, regular cleaning and proper maintenance of catchment roof area & storage tank between intervals of rainfall (Aftab, Hasnain, & Iqbal, 2012). To minimize the turbidity level and high organic pollutant rate from the collected rainwater undergoes the water treatment method of combination technology of hydro cyclone desande and rough and low filter (Guozhen, Yuanchao, Xiaodong, & Weina, 2011).

A proper water quality system like the first flush diverter, filtration unit and other treatment method is chosen depending upon the user requirements. In most cases, the harvested water is used to fulfil non-potable water usage. Therefore, the use of a first flush diverter is adequate for most of the time to fulfil the requirement.

Rainwater collection systems should meet the water quality standards as stipulated by relevant authorities and expected by the people. If the users require the harvested rainwater for drinking purposes, the system should include necessary water treatment equipments and for non-potable purposes, the collected water should be clear, free from odour, leaves, etc. For identifying specific issues associated with this case, review on the world practise is needed.

Abdulla and Al-Shareef (2009) recommended a simple method of first flush where the system consists of a standpipe and a gutter down-spout located ahead (upstream) of the down-spout from gutter to the tanks or cisterns.

Amin and Han (2011) recommend the filter medium of type: VF6, WFF 100, AFS 200 to get better quality of water once it passes the medium.

Basinger, Montalto, and Lall (2010) recommended to follow the standards stipulated by the Texas Water Development Board (2005).which states that after consecutive 3 dry days "between 1 and 2 gallons/100 ft^2 of roofing" is collected as first flush diverting volume.

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Gikas and Tsihrintzis (2012) extended the down drain of the RWHS which trapped a certain volume of water (0.11-0.13 mm) before filling to the storage tank.

Guozhen et al. (2011) used hydrocyclones desande and organic filter to remove suspended solids and treat bacteria to achieve the national drinking water standards.

Helmreich and Horn (2009) stated membrane technology is the most potential disinfection technique for a safe drinking water supply.

Oni et al. (2008) proposed an accessory which replaced the downspout system of container with a filter to remove all trash before entering into the tank.

Vieira, Weeber, and Ghisi (2013) proposed a filtration concept in which water from the catchment is passed through a filter medium, and once the maximum storage level is reached in the storage tank, the float value in the system gets closed and the diverted water will backwash the filter.

2.3.4 Storage Tank

Storage tank is used to store the water which collected from rooftops. The appropriate method to store rainwater without seepage, less evaporation losses and least interference with atmosphere is analysed by Analytical Hierarchy Process (AHP) and the results have indicated that reinforced concrete (RC) water tanks are more effective than surface storage and groundwater recharging (Jothiprakash & Sathe, 2009). The evaporation rate of storage tank is not considered in the event of the top opening is closed (Khastagir & Jayasuriya, 2010).

Campisano and Modica (2012) has introduced a simulation model based on regression analysis method to estimate the water savings and tank overflow, and the results of the approach pointed out that the economical advantage of large tank diminishes as the rainwater availability decreases.

Gamage (2006) used daily water balance equation by using daily runoff and daily demand data. Gathenya, Kinyari, and Home (2010) created a model based on 67% reliability to establish the tank size required to supply the demand using monthly rainfall data. The curve shows required tank size, demand volume and roof size to meet 67% of reliability.

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Ghisi, Bressan, and Martini (2007) sized the storage tank based on demand volume requirement using Neptune computer programme.

Handia, Tembo, and Mwiindwa (2003) chose the tank size by mass curve analysis from maximum capacity requirement. For a pilot project, he used 10 m^3 of storage tank for 120 m^2 roof area.

Health Facilities Scotland (2013) reported an estimation method of the size of the storage tank based on rainfall volume and intensity, size and type of roof, intended application and conveyance losses. Further investigation is required in the area of size of resources, suitability of use and cost of installation.

Hunt et al. (2012) designed rainwater harvesting systems based on BS 8515 sizing method and for economic criteria, stating that installation of this system result long payback period in which non–potable demands are low and payback period will be shortest in which non-potable water demands are high.

Jothiprakash and Sathe (2009) considered the months having a rain volume higher than the demand volume as wet months and those with lesser than the demand volume as dry months. The required volume of storage tank can be established by subtracting the sum of all demands of the dry months from the total runoff volume. Mean annual rainfall data is used in the analysis where the surplus and deficit from the monthly rainfall and cumulative deficit are analysed for all years and tabulated, finally choosing the maximum cumulative deficit value as required storage tank size.

Following the procedure aforementioned, Jothiprakash and Sathe (2009) presented a graph of cumulative net flow versus time period. For any peak P_1, the next following peak P_2 should be higher than the P_1 and is named as sequent peak P_i. The lowest point between these two peaks is termed as trough T_i. The required tank size is calculated from the maximum value of (P_i-T_i).

Khastagir and Jayasuriya (2010) plotted a unique curve of different tank sizes versus reliability. The required inputs are the demand volume, annual mean rainfall and roof area. The user can select the tank size based on reliability and demand volume.

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Mohammad and AlHassoun (2012) presented a methodology based on mass curve analysis through water balance equation and estimated the probability of failure. Effective tank size is chosen from this curve based on the lowest probability of failure.

Mun and Han (2012) analysed the tank volume requirement by mass balance method using water balance equation. Analysis of operational parameters like rainwater use efficiency, water saving efficiency and cycle number enables the volume of harvestable water to be increased based on the water balance equation.

Rahman, Keanea, and Imteaz (2012) developed a similar approach based on water balance simulation method through daily operations and developed estimates of water savings, reliability and financial viability for three different tank sizes. It is noted that higher tank size is preferable due to increased benefit and cost ratio.

Rowe (2011) used the water balance equation in a spreadsheet model and find out the maximum optimum capacity and concluded that increasing the tank size exceeding this range will not lead to any higher benefits.

2.4 History of Rainwater Harvesting in Sri Lanka

As a country with an agriculture based economy, the value of water has been well recognized in Sri Lanka, as discerned by the notable quotation of the ancient king, the great Parakramabahu (1153-1186 A.D.); i.e. "Not a single drop of water received from rain should be allowed to escape into the sea without being utilized for the benefit of human kind" (Ariyananda & Wickramasuriya, 2009; Ranaweera, 2010). The ancient tanks in the dry zone, the complex water collection and distribution system of the Sigiriya rock fortress, and cascade tank (reservoir) systems serving irrigational needs in dry and intermediate zones show the above fact (Ariyananda & Wickramasuriya, 2009).

The traditional manner of rainwater harvesting in medieval Sri Lanka is reported to be based on collecting of water from trees by using banana leaves or stems which are working like gutters. By using this traditional system up to 200 litres may be collected from a large tree in a single storm (Ranaweera, 2010).

From the historical development of RWH in Sri Lanka, it is clear that the practicing of this approach was targeted at the provision of low cost alternative source of water for domestic and agriculture purposes.

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A very old system of rainwater harvesting is seen in Kayts Hospital-Jaffna, and the system consists of four numbers of underground tanks each having a capacity of 60 m^3, an arrangement that is used to flush out initial rainwater and filter system to prevent debris entering the storage tanks (Gamage, 2006).

2.5 Policy Planning and Legislative Support for Rainwater Harvesting

The water scarcity issues in the dry and intermediate zones of the country during extended drought periods and flash flood occurrence in urban neighbourhoods and suburbs during monsoonal periods mainly due to increased impervious areas have motivated the Government of Sri Lanka to develop and implement legislatives and policies and continually invest in water conservation and management, and use the conserved water for agriculture, water supply, recharge groundwater aquifer systems and other activities.

The Government of Sri Lanka accepted a "National Policy on Rain Water Harvesting & Strategies" in June, 2005. The policy objective is aimed at encouraging communities to control water near its source by harvesting rainwater, thus minimising the use of treated water from NWSDB for the secondary purposes which help minimize the water cost (Ariyananda & Wickramasuriya, 2009).

In line with the aforementioned Government policies, the Ministry of Urban Development and Water Supply (2005) published a list of authorities working on rainwater harvesting as follows.

1. Amendments to Municipal Council / Urban Development Authority (UDA) by-laws on drainage, in order to accommodate Rainwater Harvesting as a strategy for localized flood control, groundwater infiltration facility development, and improved sanitation activities in both existing and future constructed buildings. Amendments include the provision of RRWH as a requirement in the Building application and it is also linked with the 'Certificate of Conformity' of new buildings to incorporate rainwater harvesting facilities.
2. Amendments to Road Development Authority (RDA) by-laws on drainage in the construction of roads; roadside drainage facilities should be allocated with porous drains to increase ground infiltration.
3. Amendments to NWSDB by-laws to incorporate rainwater harvesting as a source of domestic water with equal status to that of other traditional sources.
4. Amendments to Apartment Ownership Act for provisions on rainwater, over and above that would be required by amended Municipal Council / UDA by-laws.

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The report submitted to Water Supply & Sanitation Collaboration Council (WSSCC), National Water Supply & Drainage Board stated "Effectiveness of rainwater harvesting system as a Domestic water supply option". It clearly identifies that for domestic water supply needs, the household people can use the harvested rainwater (National Water Supply & Drainage Board, 2012).

The certification issued by the Green Building Council of Sri Lanka (GBCSL) is a significant achievement for the industries and that entails the recipients with a high level ranking among other counterpart organizations. In evaluation of the above ranking, the rainwater harvesting systems are categorized under water efficiency of innovative technology and that covers 2 marks out of 100 marks (Green Building Council of Sri Lanka [GBCSL], 2014).

Following above initiatives, the Urban Development Authority (UDA) has developed a guideline to determine the storage tank size requirement based on the depth of rainfall, building category and roof area (Ministry of Urban Development and Water Supply, 2005) as presented in Table 2.1.

Lanka Rain Water Harvesting Forum (LRWHF) is one of the NGOs persistently working for the development and promotion of RRWH practices in Sri Lanka. LRWHF recommends the selection of tank size based on the maximum demand worked out using mass curve analysis method and designing conveyance system using the thumb rule of 1 cm^2 gutter cross-section area per 1 m^2 of roof catchment area having 0.9 runoff co-efficient (Lanka Rain Water Harvesting Forum, 2009).

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Table 2-1: Tank size requirement upon rainfall event

Minimum equivalent rainwater holding provision requirement						
Annual rain band (mm)		Minimum volume (m^3) required per 100 (m^2) of roof land area and hard paved area				
		Residential		Commercial	Industrial	Institutional
		Domestic	Apartments / Condominium			
1	750-1000	1.5	2.5	5	8	10
2	1000-1500	1.5	2.5	3	8	10
3	1500-2000	1.5	2.5	3	5	10
4	2000-2500	1.5	2.5	3	3	5
5	2500-3000	1.5	2.5	2	2	3
6	3000-4000	1.5	2.5	1	1	2
7	4000-5000	1.5	2.5	0.5	1	1
8	5000-6000	1.5	2.5	0.5	0.5	0.5

Source: (Ministry of Urban Development and Water Supply, 2005)

The categories of buildings as defined in the guideline based on the functional use and type are given in Table 2.2.

Table 2-2 Building categories as per UDA Guideline

Use and Type of Buildings		
No.	Uses	Type of Building
1	Residential	Including Houses, Multiple Dwellings, Apartments, Home for elders
2	Commercial	Including office buildings, hotels, motels, guest house, public lodging, shopping centres, super markets, restaurants, car parks.
3	Industrial	Including factories, workshops, ears house, industrial establishments, infra-structure services centre.
4	Institutional	Government buildings, semi-government buildings and other public buildings.

Source: (Ministry of Urban Development and Water Supply, 2005)

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The Government of Sri Lanka recommends the estimation of storage tank size for RRWHS based on the thumb rule of roof area and average annual rainfall, as per the guideline provided by the Urban Development Authority. The non-governmental organisations, including the LRWHF, are estimating the rainwater storage tank size by following a design approach using mass curve analysis. Nevertheless, neither the cost considerations nor reliability aspects are incorporated in the above two methods, and thus, it is required to analyse storage tank systems also considering the economical and reliability perspectives in order to optimize design procedures.

3. METHODOLOGY

3.1 Methodology Flowchart

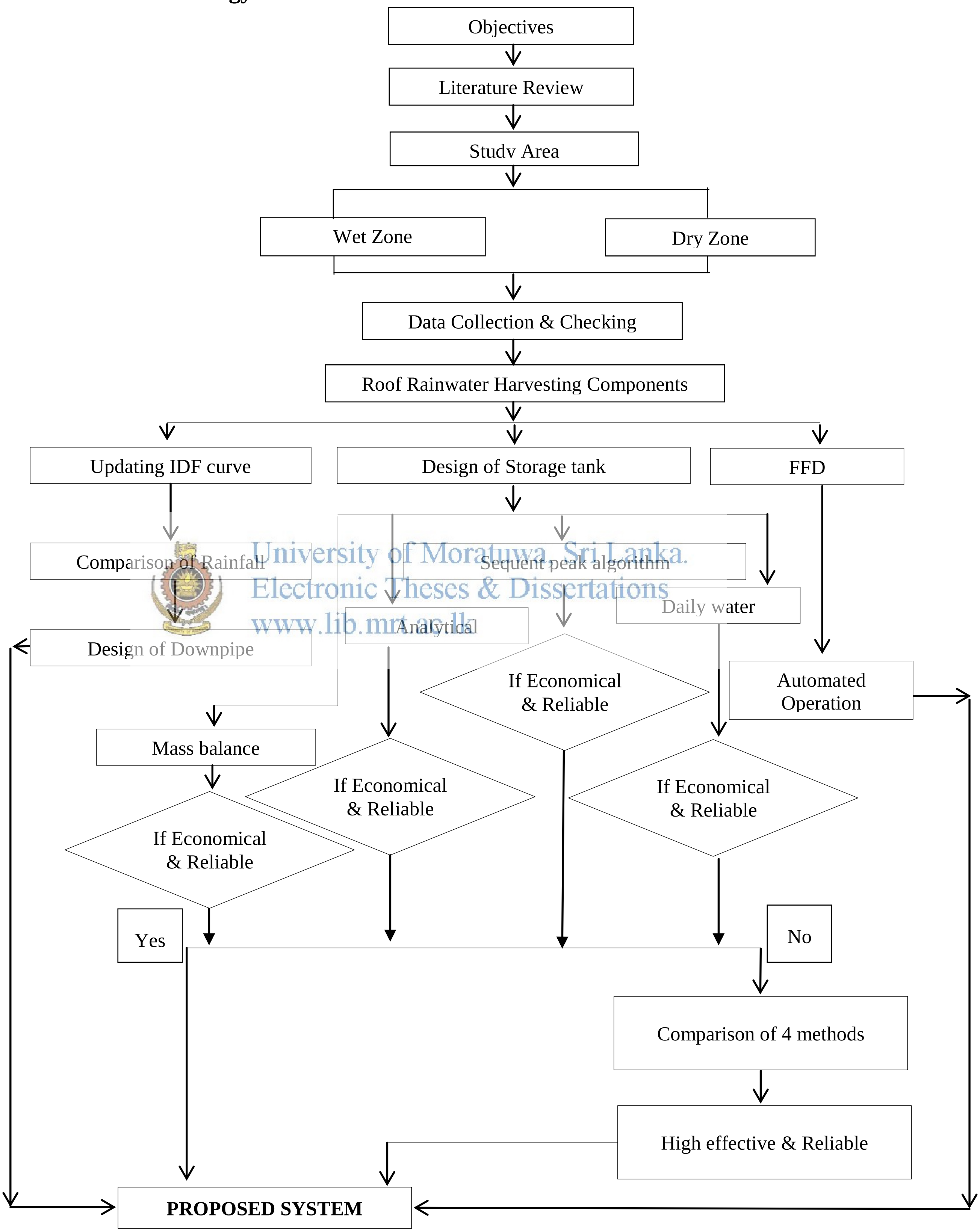

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Figure 3-1: Methodology Flowchart

In the proposed Methodology, the analysis of the optimal storage tank size, conveyance system, quality system of RRWH design components are considered. Under the proposed tank size analysis, the existing practices are compared, contrasted and investigated in an attempt to identify the most effective system with the highest reliability, while proposing further improvements to enhance the effectiveness and reliability of the current practices. Under the conveyance system analysis, the adequacy of the present practices are studied and the need of updating rainfall intensity values in each selected area is investigated based on available more recent rainfall data from relevant gauge stations. The advantages and disadvantages of automatic and manual working mechanism are considered under the proposed methodology for water quality systems.

3.2 Study Area

The main objective of this study covers an investigative study of the present rainwater harvesting practices in Sri Lanka, and therefore Puttalam, Trincomalee from dry zone and Colombo from wet zone were representatively chosen as study area for the present study.

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3.2.1 Climate

The location of Sri Lanka is within the tropics between 5^{o} 55' to 9^{o} 51' North latitude and between 79^{o} 42' to 81^{o} 53' East longitude and the climate of Sri Lanka is characterized as tropical (Department of Meteorology Sri Lanka [DMSL], 2014).

3.2.2 Topography

The central part of the southern half is mountainous, with the core regions of the central highlands containing many complex topographical features. The remaining parts of the country are practically flat except for several small hills that rise abruptly in the lowlands. These topographical features strongly affect the spatial patterns of winds, seasonal rainfall, temperature, relative humidity, etc. (DMSL, 2014).

3.2.3 Temperature

The mean annual temperature in Sri Lanka shows largely homogeneous temperatures in the lowlands and rapidly decreasing temperatures in the highlands. The coldest month with respect to mean monthly temperature is January, and the warmest months are April and August (DMSL, 2014).

3.2.4 Rainfall

Rainfall variation of Sri Lanka is shown in Figure 3.2. There are four seasonal rainfall periods in Sri Lanka and they are;

- North East Monsoon from December to February
- 1st inter monsoon period from March to April
- South West Monsoon from May to September
- 2nd Inter Monsoon period from October to November.

Based on rainfall, Sri Lanka is commonly divided into three climatic zones, namely;

- Wet zone
- Intermediate zone
- Dry zone

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Wet zone mainly consists of the south west and the central hills of the country and it receives over 2500 mm of annual rainfall distributed throughout the year. Intermediate zone receives an annual rainfall between 1750 - 2500 mm. Dry zone receives an annual rainfall of less than 1750 mm (DMSL, 2014).

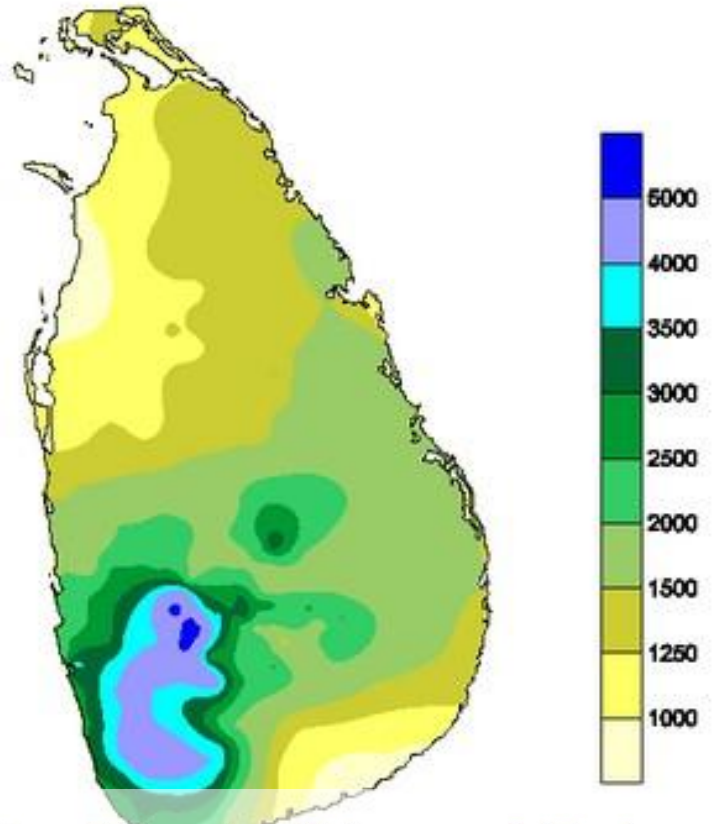

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Figure 3-2: Annual Average Rainfall (mm) of Sri Lanka

Source: (Department of Meteorology Sri Lanka, 2012)

3.2.5 Population

Sri Lanka has a land extent of nearly 65,610 square kilometres and the country's total population is approximately 20.328 million people (Department of Census and Statistics of Sri Lanka [DCS], 2014). The annual growth rate of about 1.2% and average population density is approximately 310 persons / km^2 (Central Bank of Sri Lanka [CBSL], 2012).

By considering the above climate, rainfall, and population characteristics, the study area is chosen to include two locations from the dry zone and one location from the wet zone. The reason to include locations from both dry and wet zones in this study is the distinct differences of climate, rainfall, population, and water demand characteristics with one region with those of the other.

3.2.6 Dry zone

Puttalam and Trincomalee are chosen from the dry zone of the country for the analysis of the storage tank size and rainfall intensity values.

Puttalam

The daily rainfall data for Puttalam (Station ID: S343424; Location: Latitude 08°02'N, Longitude 079°50'E) are available from 1982 to 2010. The average population is 4.4 per household (National Water Supply & Drainage Board [NWSDB], 2014). The NWSBD water requirement per person per day is 112 litres (NWSDB, 2014).

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Figure 3-3: Map of Sri Lanka with the locations of Puttalam, Trincomalee and Colombo

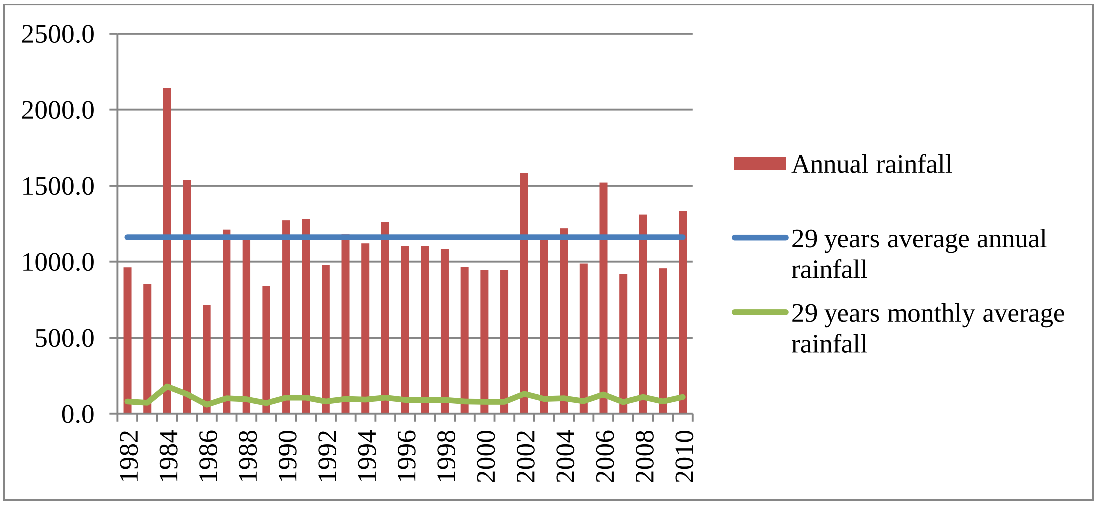

Figure 3-4: Puttalam rainfall data (1982-2010)

<u>Trincomalee</u>

The daily rainfall data for Trincomalee (Station ID: S343418; Location: Latitude 08°35'N, Longitude: 081°15'E) are available from 1982 to 2010. The average population is 4.4 per household (NWSDB, 2014). The NWSBD water requirement per person per day is 112 litres (NWSDB, 2014).The year considered for both study areas of dry zone are same due to availability of data. Based on NWSDB reference, all the above dry zone areas have an average population of 4.4 per household and water demand of 112 litres /day.

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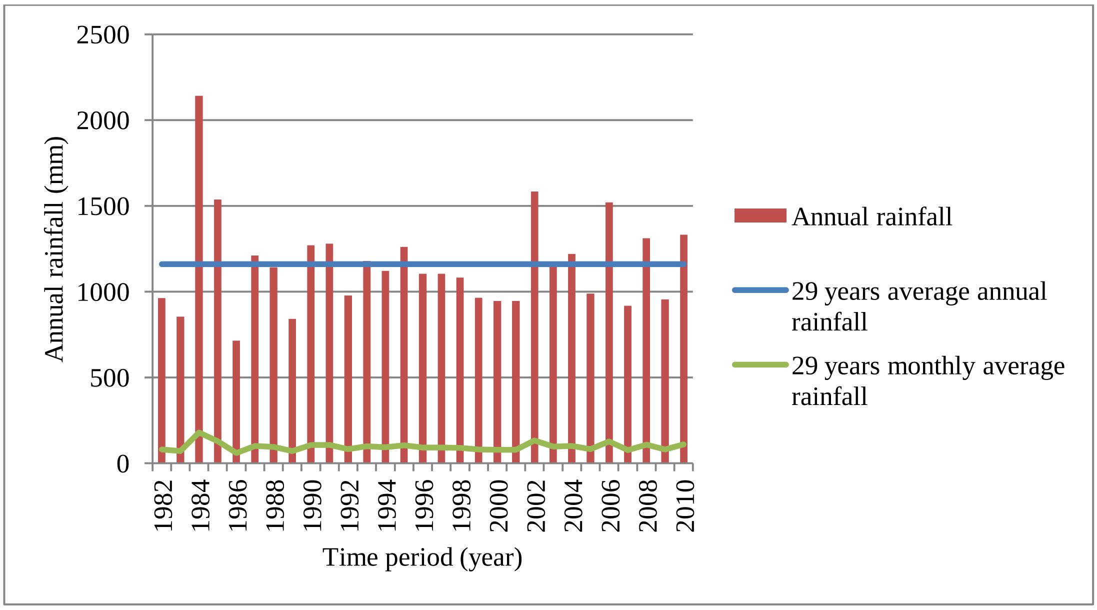

Figure 3-5: Trincomalee rainfall data (1982-2010)

3.2.7 Wet zone

Colombo is chosen from wet zone of the country for the analysis of the rainfall intensity values and storage tank size.

Colombo

The daily rainfall data for Colombo (Station ID: S343466; Location: Latitude 06°54'N, Longitude: 079°52'E) are available from 1972 to 2000. The average population is 4.2 per household (NWSDB, 2014). The NWSBD water requirement per person per day is 147 litres (NWSDB, 2014).

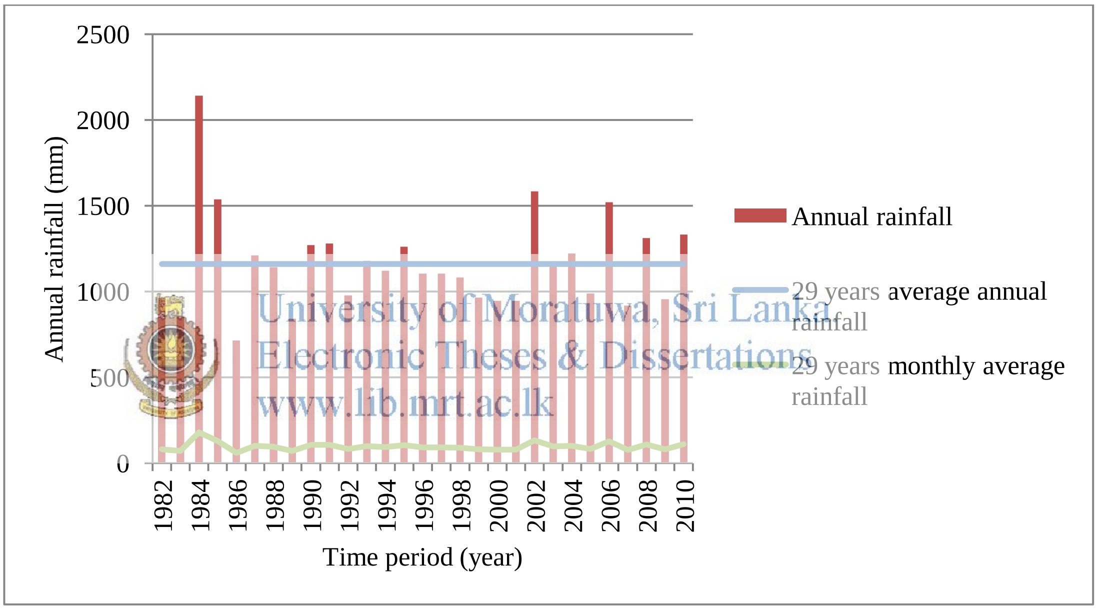

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Figure 3-6: Colombo rainfall data (1972-2000)

3.3 Field Study

Personal interviews were conducted with the officials from governmental and non-governmental organisations involved in RWH related matters in Sri Lanka to find details about the present practices of RWH systems with corresponding to the legislature, design guidelines and thumb rules, etc.,. These interviews and discussions were focused to cover the study related topics including design and sizing of storage tank, water quality system and downpipe sizing in accordance with rainfall intensity.

A brief summary of the findings of these personal surveys are included below.

Design of storage tank

- The unit cost of the storage tank is Rs. 4500/m^3It is relatively a high cost for the middle and low income people where the monthly income of low income groups of the country is Rs. 10,000/month. Further research is required to minimize the storage tank cost.
    - Ariyananda, T. (Personal communication, December 12, 2013).

Water quality system

- In most households, every one of the house goes out for work especially during daytime, leaving no one at home to operate the manual first flush diverter to wash out the first flush volume of an initial rainfall. Hence, the quality of water is affected, and this shortcoming minimizes the people's interest on this system.
    - Ariyananda, T. (Personal communication, December 12, 2013).

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Rainfall Intensity

- Due to climate change as well as long term seasonality and trends, rainfall distributions and patterns are changing thus affecting the established IDF curves and associated rainfall intensities. For effective design of RRWH systems, it is required to update IDF curves with more recent rainfall data.
    - Hettiarachchi, P. (Personal communication, January 13, 2014).

3.4 Data Collection

Daily rainfall data for over the period of 29 years from 1982 to 2010 is used for Puttalam and Trincomalee, while daily data from 1972 to 2000 is used for Colombo, for all analysis purposes. Rainfall data is collected from the Department of Meteorology, Sri Lanka. Population data is collected from the report of Central Bank of Sri Lanka (Central Bank of Sri Lanka, 2013). Daily water requirement for dry and wet zone is collected from the report of National Water Supply & Drainage Board (National Water Supply & Drainage Board, 2012).

3.5 Data Checking

The investigative evaluation of existing RRWH practices and developing recommendations for further improvements targeting effective design calculations required accurate rainfall data. The raw series consisting of historical daily rainfall values were analysed using standard data checking procedures and the missing data in the series were replaced with estimated values based on regression analysis method while the data values lesser than 0.3 mm were considered as zero (DMSL, 2014).

Double mass curve analysis was used to find the consistency of annual time series daily rainfall data. Co-efficient of determination (R^2) values for all the years were in acceptable range for all three study areas (Table 3-1 to 3-3).

Table 3-1: Co-efficient of determination (R^2) values for Puttalam data

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Year	R^2 for Puttalam	Year	R^2 for Puttalam
1982	0.97	1997	0.95
1983	0.89	1998	0.97
1984	0.83	1999	0.97
1985	0.97	2000	0.96
1986	0.99	2001	0.91
1987	0.95	2002	0.97
1988	0.92	2003	0.96
1989	0.97	2004	0.99
1990	0.95	2005	0.98
1991	0.97	2006	0.95
1992	0.95	2007	0.98
1993	0.97	2008	0.97
1994	0.97	2009	0.95
1995	0.96	2010	0.92
1996	0.96		

Table 3-2: Co-efficient of determination (R^2) values for Trincomalee data

Year	R^2 for Trincomalee	Year	R^2 for Trincomalee
1982	0.87	1997	0.97
1983	0.93	1998	0.95
1984	0.84	1999	0.95
1985	0.98	2000	0.97
1986	0.96	2001	0.96
1987	0.91	2002	0.97
1988	0.95	2003	0.97
1989	0.93	2004	0.97
1990	0.97	2005	0.96
1991	0.95	2006	0.81
1992	0.95	2007	0.96
1993	0.96	2008	0.92
1994	0.96	2009	0.91
1995	0.95	2010	0.93
1996	0.97		

Table 3-3: Co-efficient of determination (R^2) values for Colombo data

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Year	R^2 for Colombo	Year	R^2 for Colombo
1972	0.98	1987	0.94
1973	0.97	1988	0.98
1974	0.95	1989	0.99
1975	0.99	1990	0.94
1976	0.96	1991	0.97
1977	0.98	1992	0.97
1978	0.96	1993	0.99
1979	0.98	1994	0.98
1980	0.99	1995	0.96
1981	0.99	1996	0.96
1982	0.98	1997	0.97
1983	0.93	1998	0.98
1984	0.94	1999	0.98
1985	0.98	2000	0.97
1986	0.98		

4. ANALYSIS

In this chapter, the present design practices and procedures followed to determine the effective storage tank size are analysed based on reliability and economic considerations. The requirement for updating the existing intensity-duration-frequency (IDF) curves for establishing rainfall intensity values by comparing and contrasting the existing IDF curves with those after incorporating more recent (1982 to 2010) daily rainfall data and the distinct advantages of using self-regulated/automatic first flush diverter were considered in detail.

4.1 Storage Tank Size

The below mentioned four methods widely used in practice for determining the required storage tank size in RRWH systems were chosen following the literature review, and cost and reliability assessments were attempted for each method based on their distinct characteristics.

- Based on the annual water demand
- Based on maximum deficiency
- Based on maximum net rain volume
- Based on daily water balance

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For the specific calculations carried out, the following data were either assumed or extracted based on the guidelines/standards available from the present practices worldwide.

Include a list of all such values here with the related references.

<u>Actual data</u>

Wet zone, average person per household	=	4.2
Dry zone, average person per household	=	4.4
Wet zone, per person daily water consumption from NWSDB	=	147 litres
Dry zone, per person daily water consumption from NWSDB	=	122 litres
Cost of storage tank (LKR)	=	4500/m^3

Assumed data

Roof Runoff Co-efficient = 0.9

Area of Roof 1, Roof 2, Roof 3 = 100 m^2, 150 m^2, 200 m^2

Cost of Pipe-borne Water based on NWSDB Tariff Structure

The present NWSDB water tariff structure in 2014 for the domestic water supplies is presented in Table 4-1 (National Water Supply & Drainage Board, 2012). The rate is revised approximately every two years on average to compensate for increasing operational and maintenance costs.

Table 4-1: Present NWSDB water tariff structure (Source: (National Water Supply & Drainage Board, 2012))

No: of units	Usage charge Rs./Unit	Monthly service charge. Rs
0 - 5	12	50
6 - 10	16	65
11 - 15	20	70
16 - 20	40	80

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4.1.1 Mass balance method

In this method, the required storage tank size is estimated based on the total demand of the past years with available historical data, and for the present analysis, average monthly rainfall data over a period of 29 years were used. According to the design procedure adopted herein, any month having a rain volume higher than the monthly water demand for household is considered a wet month and the months having a lower rain volume than the demand is termed dry months. The required tank size is estimated by subtracting the total runoff volume over the period from the sum of total demand in dry months. Estimates of the required storage tank sizes based on this Mass balance method was carried out for Puttalam, Trincomalee and Colombo study sites with the assumed roof sizes, as presented in Appendix – A.

4.1.2 Analytical method

In this method, the required storage tank size is estimated based on the maximum cumulative deficiency and in the present study, average monthly rainfall data over a period of 29 years were used. Deficiency and surplus for each month of past 29 years were calculated and once the deficient value was zero, the cumulative of deficiency was refreshed and adjusted to zero. The maximum cumulative deficiency was then chosen for each year. From all 29 years maximum cumulative deficiency data, the maximum value was considered to be the required tank size. Estimates of the required storage tank sizes based on this Analytical method was carried out for Puttalam, Trincomalee and Colombo study sites with the assumed roof sizes, as presented in Appendix – B.

4.1.3 Sequent peak algorithm method

In this method, the required storage tank size is estimated based on the maximum cumulative net flow with respective to the time period under study and in the present study average monthly rainfall data over a period of 29 years were used. As per the analysis procedures, a graph is drawn for the time period versus cumulative net flow. For any given peak P_1, the next following P_2 which is higher than P_1 is named as the sequent peak, P_i. The lowest point between these two peaks is termed as trough, T_i. The required tank size is estimated based on the maximum of (P_i-T_i). Estimates of the required storage tank sizes based on this Sequent peak algorithm method was carried out for Puttalam, Trincomalee and Colombo study sites with the assumed roof sizes, as presented in Appendix – C.

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4.1.4 Daily water balance equation method

In this method, the required storage tank size is estimated based on the daily water balance equation and in the present study, daily rainfall data for the past 29 years, tank volume, daily runoff, and daily demand data were used in an excel spreadsheet model. The tank size is initially assumed to be as 1, 3, 5, 8, 10, 15, 20, and 25 m^3 and the first day tank volume (initial storage) is also taken to be zero. Subsequently, data for daily rain volume inflow from the roof entering into the tank, and daily consumption quantity from the tank are worked out in the Excel worksheet model. The initial tank storage volume for the second day will be the remaining volume of balance water in the tank at the end of the previous (first) day. In case of an overflow, the volume of the tank is calibrated to represent the assumed tank size. The percentage of reliability is calculated as the number of days in which the daily demand is consumed from the tank against the total number of days in the period under consideration. Based on the reliability percentage, one can select the tank size in this model. Estimates of the required storage tank sizes based on this Daily water demand method was carried out for Puttalam, Trincomalee and Colombo study sites with the assumed roof sizes, as presented in Appendix – D.

4.2 Intensity Duration Frequency (IDF) Curve

Proper sizing of downpipe allows harvesting the rainwater from roof catchment without any losses and avoiding damages to the surrounding area. To find the effective downpipe size, rainfall intensity value is required for using in rationale formula. At present in Sri Lanka, rainfall intensity values for all regions are available in the Irrigation Department guidelines (Ponrajah, 1984), however in this study, the IDF curves are developed based on historical rainfall data for the period of recent 29 years (1984 onwards) for all three regions where the study sites are located. The predictive steps of developing IDF curves are explained for Puttalam, Trincomalee and Colombo study sites, as presented in Appendix – E.

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4.3 First Flush Diverter

As highlighted in the literature review part, most authors prefer to install a first flush diverter as a component in the water quality improvement device of RRWH systems because of low additional cost, ease of use and relatively high reliability. By installing a first flush diverter in RRWHS supplies, good quality of collected water in terms of physicochemical parameters can be attained, however, the probable microbial contamination in the stored water cannot be controlled (Gikas & Tsihrintzis, 2012). First flush diversion volume is usually decided based on the water quality requirement (Aftab, Hasnain, & Iqbal, 2012). Meera & Ahammed (2006) listed the required values of first flush volume based on microbial contamination, average rainfall period, and preceding dry period, etc.

First flush diverter method has been found to be cost effective than the other water quality improvement devices and systems of RRWHS (Vieira, Weeber, & Ghisi, 2013). From the literature review part, it is noted that first flush diverters which are used in practice to wash out the contaminated water from the roof can be categorised into three different types based on their working principles. They are namely;

- Manual system
- Fixed volume system
- Flow rate system

4.3.1 Manual system

In the Manual system, a valve is placed between the diverter pipe and the pipe line conveying water to the storage tank. The diverter pipe line is terminated connecting to a first flush diverter tank to collect the diverted water. The size of the first flush diverter tank is decided based on the roof environment pollution factor and required water quality. If the water is already clean before the first flush storage tank becomes full, an operator can close the valve diverting the flow towards the main storage tank. If the environment has remained dry for a longer period prior to the rainwater reaching the roof surface, the operator has to wait until the roof gets fully washed with oncoming rain drops and then close the valve once the first flush tank gets full.

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4.3.2 Fixed volume system

The Fixed volume system is more or less similar to the manual system, except for the absence of a valve in the latter. Instead, it contains an extended pipe in which the diameter is larger than that of the down pipe. The extended pipe ends with a small cap and a floating ball is placed inside the extended pipe. Once the roof water flows into the extended pipe, the ball starts floating and eventually reaches the top of the extended pipe, acting as a barrier for incoming roof water. Therefore, the roof water incoming beyond this point onwards is automatically diverted into the storage tank.

In this case, the volume of the extended pipe is decided upon based on the roof environment pollution factor. When it rains after a long dry spell, it is required to remove the end cap to take out the water from the end cap, but it is not necessary during continuous rainy days as no dry matter or pollutant accumulation is envisaged.

4.3.3 Flow rate system

This system requires identification of the rainfall rate by means of an instrument or eye observation. Once there is enough water flow from the roof to wash out the accumulated dry matter completely, a person requires to divert the valve thus directing the flow into the main storage tank.

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5. RESULTS AND DISCUSSION

Results of analyses carried out based on above four identified design methods to determine the most effective storage tank size under the conditions of economical and reliability constraints, the effect of updated IDF curves based on rainfall intensity values and subsequent influence on required downpipe size in the conveyance system, and distinct advantages of automatic operation of first flush diverter are discussed herein.

5.1 Storage Tank Size

The estimated required storage tank sizes based on the Mass balance method, Analytical method and Sequent peak algorithm method are listed below in Table 5.1.

Table 5-1: Calculated tank sizes for all regions

Method	Required Tank Size (m^3)								
	Puttalam			Trincomalee			Colombo		
	Roof 1	Roof 2	Roof 3	Roof 1	Roof 2	Roof 3	Roof 1	Roof 2	Roof 3
Mass Balance Method	56	38	25.3	44.2	25.5	14.3	29.4	12.2	7.4
Analytical Method	84.3	72.6	66.6	97.1	83.7	70.2	51.4	51.1	50.9
Sequent Peak Algorithm Method	89.6	74.7	65.8	76.1	63.1	57.9	39.7	40.4	53.7

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Daily water balance equation method used an assumed storage tank size to determine the required reliability percentage of the system. Reliability percentage value for the assumed tank sizes of 1, 3, 5, 8, 10, 15, 20 and 25 m^3 are tabulated in Table 5.2.

Table 5-2: Reliability percentage based on tank size assumption

Method	Reliability (%)									
	Tank size, (m^3)	Puttalam			Trincomalee			Colombo		
		Roof 1	Roof 2	Roof 3	Roof 1	Roof 2	Roof 3	Roof 1	Roof 2	Roof 3
Daily water balance analysis	1	18.74	22.04	24.22	20.64	24.03	26.12	28.68	33.71	36.52
	3	32.92	38.76	42.53	36.87	42.95	46.5	48.63	56.83	60.77
	5	39.7	47.56	52.06	44.89	53.01	57.8	58.23	67.75	72.03
	8	45.67	55.24	60.51	51.03	60.73	65.87	66.2	76.13	80.44
	10	48.71	58.8	64.56	53.49	63.69	69.25	69.93	79.85	83.81
	15	54.55	66.12	72.23	57.65	68.95	75.46	77.12	86.24	89.29
	20	58.17	72.02	78.35	61.28	73.02	80.01	82.96	90.61	92.54
	25	61.42	76.75	83.67	64.71	76.69	83.9	87.89	93.58	95.25

Due to lack of data and discrepancies in collected and available data on cost of tank construction, a unit cost was assumed as the construction cost of storage tank. Therefore, the construction cost was found to be linearly increasing with increasing storage tank size, as shown in Fig. 5.1.

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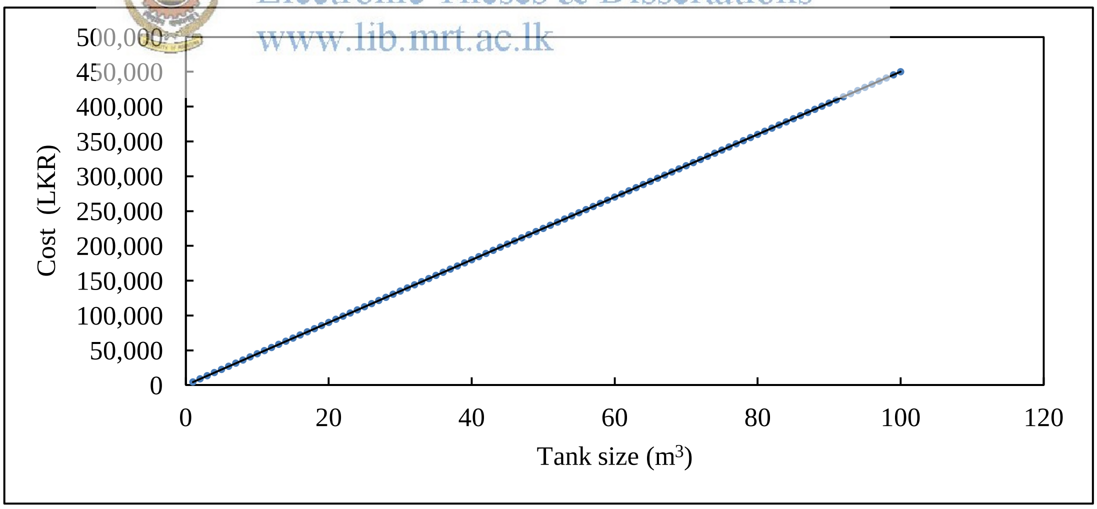

Figure 5-1: Cost of Storage Tank

In order to check and compare the reliability percentage values for the storage tank sizes estimated based on mass balance, analytical and sequent peak algorithm methods, the results were analysed in an Excel spreadsheet model. The corresponding reliability percentages thus identified are listed below in Table 5.3.

Table 5-3: Reliability percentage for storage tank sizes estimated based on Mass balance, Analytical and Sequent peak algorithm methods

Method	Roof size (m^2)	Puttalam		Trincomalee		Colombo	
		Tank size (m^3)	Reliability (%)	Tank size (m^3)	Reliability (%)	Tank size, (m^3)	Reliability (%)
Mass balance	100	56	69.64	44.2	76.41	29.4	91.26
	150	38	86.24	25.5	76.99	12.2	82.74
	200	25.3	83.9	14.3	74.76	7.4	79.15
Analytical	100	84.3	70.44	97.1	90.09	51.4	97.42
	150	72.6	96.73	83.7	97	51.1	99.02
	200	66.6	98.68	70.2	98	50.9	99.13
Sequent peak algorithm	100	89.6	70.58	76.1	87.37	39.7	95.41
	150	74.7	96.88	63.1	95.82	40.4	98.5
	200	65.8	98.66	57.9	97.5	53.7	99.2

Screened out 70% above percentage of reliability values because the reliability of tank increases with tank size. Selection of effective tank size with high reliability is considered in this study. For screening rainfall data of each region and corresponding analysis tank size are used in the excel model.

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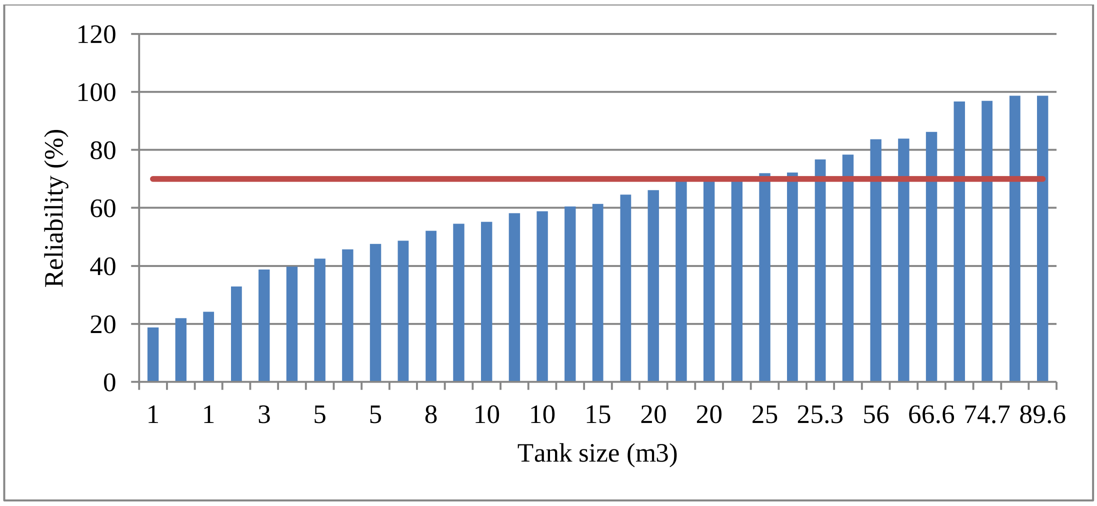

Figure 5-2: Reliability percentage cross checking of Puttalam result

In Fig 5.2, it is clear that around 20 m^3 of tank size is adequate to achieve a 70 % reliability level for all Roof 1, Roof 2, and Roof 3 types and to attain the 100% reliability (i.e. to increase reliability by another 30%), it is noted that the tank size has to be increased by a whopping 80 m^3.

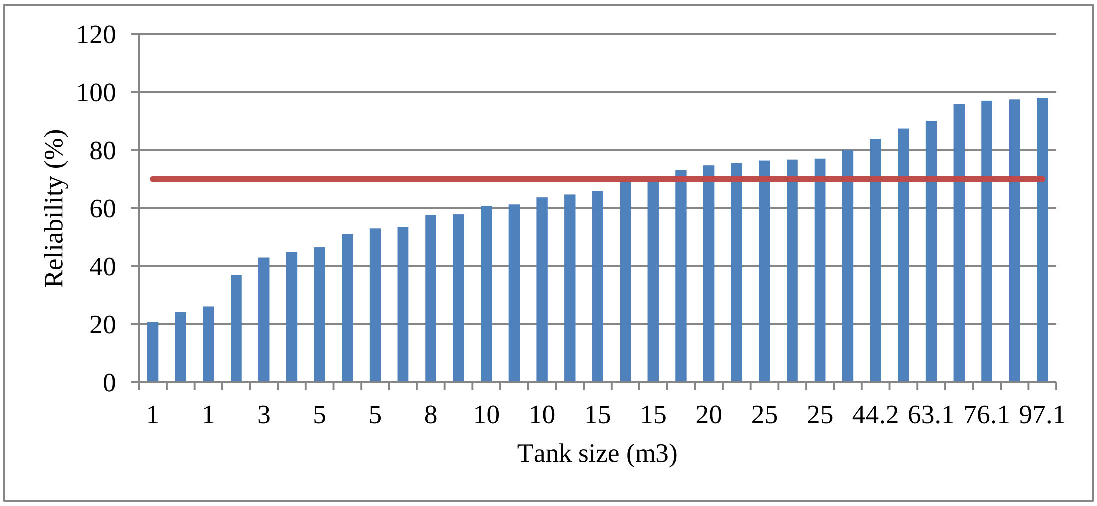

Figure 5-3: Reliability percentage cross checking of Trincomalee result

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From the above graph, it is clear that around 15 m^3 of tank size is adequate to achieve 70 % reliability level for all Roof 1, Roof 2, and Roof 3 types and to attain the 100% reliability (i.e. to increase reliability by another 30 %), it is noted that the tank size has to be increased by a 60 m^3. Increasing the tank size beyond this size was found to be not effective as the associated reliability does not improve any further.

From the above graph, it is clear that around 7 m^3 of tank size is adequate to achieve 70 % reliability level for Roof 1,Roof 2, and Roof 3 types and to attain the 100% reliability (i.e. to increase reliability by another 30 %) it is noted that the tank size has to be increased by a 44 m^3.

Above analyses show that 4 times of 70% reliability tank size is required to achieve the balance 30 % reliability of the RRWHS. The required storage tank size from Mass balance, Analytical, and Sequent peak algorithm methods were mostly above the 70% of reliability capacity tank size which required a higher cost to install the system, but the tank size estimate derived based on the Daily water balance equation method could supply rainwater for 70% of the period by using tank size of 10 m^3. Therefore, under the economical and reliability concerns, the daily water balance equation method using excel worksheet model is preferred for identifying an optimal size for the tank size in the proposed RRWH system.

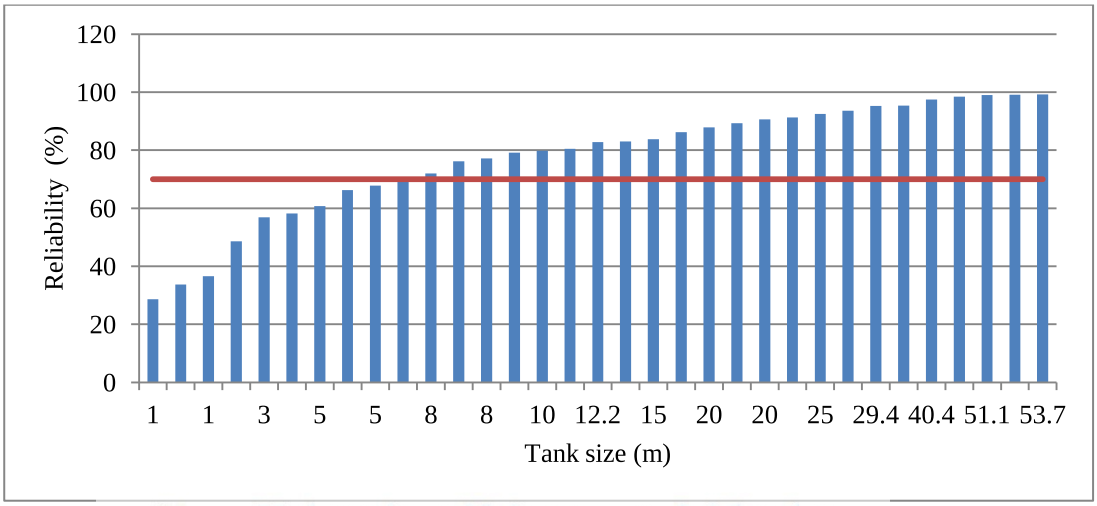

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Figure 5-4: Reliability percentage cross checking of Colombo result

<u>Benefits</u>

Consider that RRWHs are implemented in Puttalam, Trincomalee and Colombo with 70% of reliability. Analysis of the cost saved from the water bill by using this rainwater harvesting practices is carried out to understand the benefits of the system (Table 5.4~5.6).

Table 5-4: Benefits of roof rainwater harvesting – A house with Type 1 Roof in Puttalam

Puttalam: Roof Type 1 - Water requirement of NWSDB / month / household (m^3)			16.104	
Water charges (Rs./month)			724.16	
Rainwater requirement /month / household (m^3)			11.273	
Tank size (m^3)	Rainwater Consumption (m^3/month)	Balance water consumption from NWSDB (m^3/month)	Costs for NWSDB consumption (Rs./month)	Cost saved (Rs./month)
1	2.113	13.991	349.83	374.33
3	3.711	12.393	317.86	406.30
5	4.475	11.629	302.57	421.59
8	5.148	10.956	289.11	435.05
10	5.491	10.613	282.26	441.90
15	6.149	9.955	224.28	499.88
20	6.557	9.547	217.75	506.41
25	6.924	9.180	211.88	512.28

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Table 5-5: Benefits of roof rainwater harvesting – A house with Type 1 Roof in Trincomalee

Trincomalee: Roof Type 1 - Water requirement of NWSDB / month / household (m^3)			16.104	
Water charges (Rs/month)			724.16	
Rainwater requirement /month / household (m^3)			11.273	
Tank size, (m^3)	Rainwater Consumption (m^3/month)	Balance water consumption from NWSDB (m^3/month)	Costs for NWSDB consumption (Rs/month)	Cost saved (Rs/month)
1	2.327	13.777	345.55	378.61
3	4.156	11.948	308.95	415.21
5	5.060	11.044	290.87	433.29

8	5.753	10.351	277.03	447.13
10	6.030	10.074	271.48	452.68
15	6.499	9.605	218.68	505.48
20	6.908	9.196	212.14	512.02
25	7.295	8.809	205.95	518.21

Table 5-6: Benefits of roof rainwater harvesting – A house with Type 1 Roof in Colombo

Colombo: Roof 1 - water requirement of NWSDB / month / household in m^3)		18.522		
Water charges (Rs/month)		820.88		
Rainwater requirement /month / household (m^3)		12.9654		
Tank size, (m^3)	Rainwater Consumption (m^3/month)	Balance water consumption from NWSDB (m^3/month)	Costs for NWSDB consumption (Rs/month)	Cost saved (Rs/month)
1	3.718	14.804	366.07	454.81
3	6.305	12.217	314.34	506.54
5	7.550	10.972	289.44	531.44
8	8.583	9.939	224.02	596.86
10	9.067	9.455	216.28	604.60
15	9.999	8.523	201.37	619.51
20	10.756	7.766	189.25	631.63
25	11.395	7.127	179.03	641.85

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For all three regions, it is observed that a minimum of 40 % of monthly water bill reduction is possible with 1 m^3 size of RRWHS storage tank. The Cost column of the each table shows that there are only benefits and no losses are incurred from this system to the investors.

5.2 Updating of IDF Curves

For effective functioning of a RRHWS, the rainwater which falls on to the roof catchment should be collected without any water loss, no wastage and no damage by proper sizing of the conveyance system. The rainfall intensity values estimated based on presently used IDF curves of Irrigation Department, Sri Lanka were compared with the IDF curves developed based on historical rainfall data for the period of recent 29 years (1982 - 2000 for Dry zones, 1972 – 2010 for wet zone) for regions where the study sites are located.

The comparison of rainfall intensity values thus estimated for Puttalam site is presented in Table 5.7.

Table 5-7: Comparison of IDF curves – Puttalam

Return period	Data Hour, X	Present study		Previous study	
		Rainfall Intensity, mm/hr	Rainfall Depth, mm	Rainfall Intensity, mm/hr	Rainfall Depth, mm
25		$Y=97.639*X^{-0.731}$		$Y=150.95*X^{-0.859}$	
	24	9.57	229.56	9.85	236.29
	48	5.76	276.62	5.43	260.55
50		$Y=111.36*X^{-0.732}$		$Y=176.74*X^{-0.863}$	
	24	10.87	260.99	11.38	273.16
	48	6.55	314.27	6.26	300.38

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The comparison of rainfall intensity values thus estimated for Trincomalee site is presented in Table 5.8.

Table 5-8: Comparison of IDF curves - Trincomalee

Return period	Data Hour, X	Present study		Previous study	
		Rainfall Intensity, mm/hr	Rainfall Depth, mm	Rainfall Intensity, mm/hr	Rainfall Depth, mm
25		$Y=102.21*X^{-0.779}$		$Y=73.75*X^{-0.712}$	
	24	8.57	205.66	7.65	183.6
	48	4.99	239.53	4.67	224.02
50		$Y=121.64*X^{-0.801}$		$Y=88.91*X^{-0.721}$	
	24	9.51	228.22	8.96	215.1
	48	5.45	261.8	5.43	260.82

The comparison of rainfall intensity values thus estimated for Colombo site is presented in Table 5.9.

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Table 5-9: Comparison of IDF curves - Colombo

Return period	Data Hour, X	Present study		Previous study	
		Rainfall Intensity, mm/hr	Rainfall Depth, mm	Rainfall Intensity, mm/hr	Rainfall Depth, mm
25		$Y=139.98*X^{-0.787}$		$Y=146.26*X^{-0.844}$	
	24	11.48	275.46	10.01	240.13
	48	6.65	319.28	5.57	267.55
50		$Y=162.95*X^{-0.798}$		$Y=167.77*X^{-0.844}$	
	24	12.9	309.64	11.48	275.44
	48	7.42	356.18	6.39	306.89

The above analyses indicate that the rainfall intensity values estimated based on updated IDF curves with more recently historical rainfall data are differed by a minimum of 5% up to a maximum 20% incrementally, except for 24 hour duration intensity data in Puttalam where a marginal decrease of 2% ~ 5% is observed. Therefore, it is strongly recommended to design the conveyance systems of RRWHS with rainfall intensity values from the updated IDF curves.

5.3 First Flush Diverter

It is envisaged that a RRWH system should only supply good quality water for the people invested in the system. For better quality water, the system mainly depends on the first flush diverter. A prioritisation table (Table 5.10) is prepared to analyse the most efficient system which is both economical and user friendly among the three different types of first flush diverters. The present RRWHS practice in Sri Lanka requires a person to be in field to operate the manual first flush diverter system.

Table 5-10: Prioritisation table for first flush diverter

System method	Tank required	Person in field	Periodic maintenance
Manual system	Yes	Yes	No
Fixed volume system	Yes	No	Yes
Flow rate system	No	Yes	Yes

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Out of the three different types considered, the fixed volume first flush diverter method does not require a person in the field. Even though, this the system requires a first flush storage tank separately, it further helps to keep the surrounding environment clean and the stored water can be used for gardening or other similar purposes. Therefore, it is considered to be an effective system to supply good quality water, also without requiring a person in the field during the time of operation.

5.4 Proposed System

Accordingly, the most efficient RRWH system is proposed based on the above analyses, considering both economical and reliability concerns for an optimum outcome.

Catchment surface

The roof material and roof type should be chosen based on higher runoff coefficient values. If the catchment is located closer to an area with high pollutants, regular maintenance is required to avoid an increased volume of first flush quantity. Types and constituent material of the roof result in variation in the run-off co-efficient as presented in Table 5-11 (Farreny, et al., 2011) and should be incorporaed in \design estimates.

Table 5-11: Run-off Co-efficient values

Roof type	Roof material	Run-off co-efficient
General		0.85
Sloping roofs	Concrete asphalt	0.9
	Metal	0.95
		0.81-0.84
	Aluminium	0.7
Flat roofs	Bituminous	0.7
	Gravel	0.8-0.85
	Level cement	0.81

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Conveyance system

The conveyance system should be designed based on the rainfall intensity values from updated IDF curves, so that there will not be any spillage losses or damages.

Water Quality system

The Fixed volume first flush diverter method does not contaminate the water volume entering the storage tank and also does not require a person to to be in the field to handle the system during the time of operation.

Storage tank

The required tank size is recommended to be chosen based on the reliability percentage, which is pre-determined based on economical constraints.

Routine Maintenance

Even though first flush diverter removes the dirt particles and other pollutant materials from the roof runoff, the whole system required to be regularly cleaned and maintained properly for ensuring high durability and increased safe water quality, as presented in Table 5.11.

Table 5-12: Routine maintenance of RRWH system

S.No	Component	Maintenance Activity	Duration
1	Catchment surface	Roof cleaning	Frequently
2	Conveyance system	Checking the system	Prior to rain
3	Quality system	First flush	Based on rain period
		Cleaning	Prior to rain
		Checking the system	Prior to rain
4	Storage tank	Cleaning	Frequently

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6. CONCLUSION

The present practice of designing rainwater harvesting systems in Sri Lanka was studies in detail in the present study. The system or the practice is declared as a sustainable technology by the Sri Lankan government (GOSL) and relevant authorities. Hence further to the relevant governmental organizations, several Non – Governmental Organisations (NGO) are also involved in popularising and promoting this system by consulting, constructing, demonstrating and campaigning for the system all over Sri Lanka targeting both rural and urban communities using various means and fora. In the present day global context, impending Climate change scenarios (CC) have pointed out possible changes in long term rainfall patterns and increase in global temperatures leading to large extents of densely populated urban regions and rural/urban locale situated within the bounds of low-lying floodplains highly vulnerable to a vast range of recurrent extreme events probably triggered at an increased frequency over the recent years. To address the adverse direct and indirect impacts of such climatic variations and also to overcome the issues pertaining to ever growing future demand for already scarce traditional water resources, rainwater harvesting system should be developed with the introduction of more effective, sustainable and innovative means than the existing present practices. With the above perspectives, the design and practical aspects of the four main components of a rainwater harvesting system, i.e. catchment area, conveyance system, water quality system and storage tank, were extensively studied in the present study in an attempt to identify the shortcomings hindering adopting and popularising of the rainwater harvesting systems amongst both rural and urban population masses and while the possibility of incorporating more recent data and available advanced technology to enhance the present practices were also investigated.

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Daily rainfall data of past 29 years, average daily water demand, and average population of the households were collected from the selected study areas; i.e. Puttalam, Trincomalee and Colombo. The missing data in the collected 29 years daily rainfall data of all the three study areas were filled by regression analysis method and valuated by co-efficient of determination value through double mass curve analysis.

The collected data were used for the analysis of design practices available for estimating storage tank, further including cost and reliability as additional constraints. The reliability of the storage tank was compared based on the estimated tank sizes derived from mass balance method, analytical method, sequent peak algorithm method, and daily water balance equation method, and it was reasonably justified that the daily water balance equation method is more effective and can produce better results when combined with cost and area requirements.

Therefore, 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 updated rainfall Intensity – Duration – Frequency (IDF) curves for the three regions were compared with the values derived based on the IDF curves in the Irrigation Department guidelines and found to be vary in the range of minimum of 5% up to a maximum 20% positive increment. Therefore, 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.

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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 selection of roof type and roof material of the catchment surface was found to influence the quantity and quality of water harvested through the system and could also be considered as the basis of the effective rainwater collection. Therefore it was noted that based on the roof type and roof material, one can better benefit from the system.

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 and calculating the cost recovery period for the RRWH systems.

Based on the findings of the present study, it was noted with proper operation and maintenance, rooftop rainwater harvesting in conjunction with first flush diversion has the potential to provide relatively clean, reliable water to people in need and the adapting of optimised design procedures will lead reducing associated costs, thus help popularising the systems among needy communities.

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Appendix A: Mass Balance Method

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Appendix A: Mass Balance Method

This method analyses minimum the volume of water (storage) required to maintain an uninterrupted supply during subsequent dry months based on past 29 years of average monthly data. A month having a volume of runoff higher than the volume of household demand is considered a wet month and a volume of runoff lower than the volume of household demand is considered a dry month. The wet month demand is not considered for the storage tank size calculation and the dry month demand is considered by subtracting the respective runoff volume of the month from the remaining storage. The mass balance method of analysis for Puttalam data of Roof 1 type houses is presented in Table A1.

Table A1: Mass balance method: Puttalam – Roof 1

Months	29 years data of average monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	% of total runoff	Cummu. % of runoff	Required tank capacity (m^3)
Jan	61.107	5.500	11.273	5.267	5.267	5.773
Feb	41.524	3.737	11.273	3.579	8.847	7.536
Mar	63.007	5.671	11.273	5.431	14.278	5.602
Apr	180.321	16.229	11.273	15.544	29.822	0.000
May	80.534	7.248	11.273	6.942	36.764	4.025
Jun	33.748	3.037	11.273	2.909	39.673	8.235
Jul	17.693	1.592	11.273	1.525	41.199	9.680
Aug	18.769	1.689	11.273	1.618	42.816	9.584
Sep	69.817	6.284	11.273	6.018	48.835	4.989
Oct	222.090	19.988	11.273	19.144	67.979	0.000
Nov	252.817	22.754	11.273	21.793	89.772	0.000
Dec	118.648	10.678	11.273	10.228	100.000	0.594
		104.407				56.019

The sum of dry month demand from the above table is 56.019 m^3 which is the required storage tank size for Roof 1 type houses in Puttalam. The mass balance method of analysis for Puttalam data of Roof 2 type houses is presented in Table A2.

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Table A2: Mass balance method: Puttalam – Roof 2

Months	29 years data of average monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	% of total runoff	Cummu. % of runoff	Required tank capacity (m^3)
Jan	61.1	8.249	11.273	5.267	5.267	3.023
Feb	41.5	5.606	11.273	3.579	8.847	5.667
Mar	63.0	8.506	11.273	5.431	14.278	2.767
Apr	180.3	24.343	11.273	15.544	29.822	0.000
May	80.5	10.872	11.273	6.942	36.764	0.401
Jun	33.7	4.556	11.273	2.909	39.673	6.717
Jul	17.7	2.389	11.273	1.525	41.199	8.884
Aug	18.8	2.534	11.273	1.618	42.816	8.739
Sep	69.8	9.425	11.273	6.018	48.835	1.847
Oct	222.1	29.982	11.273	19.144	67.979	0.000
Nov	252.8	34.130	11.273	21.793	89.772	0.000
Dec	118.6	16.018	11.273	10.228	100.000	0.000
		156.610				38.045

The sum of dry month demand from the above table is 38.045 m^3 which is the required storage tank size for Roof 2 type houses in Puttalam. The mass balance method of analysis for Puttalam data of Roof 3 type houses is presented in Table A3.

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Table A3: Mass balance method: Puttalam – Roof 3

Months	29 years data of average monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	% of total runoff	Cummu. % of runoff	Required tank capacity (m^3)
Jan	61.1	10.999	11.273	5.267	5.267	0.274
Feb	41.5	7.474	11.273	3.579	8.847	3.798
Mar	63.0	11.341	11.273	5.431	14.278	0.000
Apr	180.3	32.458	11.273	15.544	29.822	0.000
May	80.5	14.496	11.273	6.942	36.764	0.000
Jun	33.7	6.075	11.273	2.909	39.673	5.198
Jul	17.7	3.185	11.273	1.525	41.199	8.088
Aug	18.8	3.378	11.273	1.618	42.816	7.894
Sep	69.8	12.567	11.273	6.018	48.835	0.000
Oct	222.1	39.976	11.273	19.144	67.979	0.000
Nov	252.8	45.507	11.273	21.793	89.772	0.000
Dec	118.6	21.357	11.273	10.228	100.000	0.000
		208.814				25.253

The sum of dry month demand from the above table is 25.253 m^3 which is the required storage tank size for Roof 3 type houses in Puttalam. The mass balance method of analysis for Trincomalee data of Roof 1 type houses is presented in Table A4.

Table A4: Mass balance method: Trincomalee – Roof 1

Months	29 years data of average monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	% of total runoff	Cummu. % of runoff	Required tank capacity (m^3)
Jan	154.7	13.922	11.273	10.286	10.286	0.000
Feb	76.5	6.888	11.273	5.089	15.376	4.385
Mar	48.2	4.336	11.273	3.203	18.579	6.937
Apr	54.3	4.884	11.273	3.608	22.187	6.389
May	71.6	6.441	11.273	4.759	26.946	4.832
Jun	11.4	1.030	11.273	0.761	27.707	10.243
Jul	57.0	5.134	11.273	3.793	31.500	6.139
Aug	76.9	6.924	11.273	5.116	36.616	4.349
Sep	114.5	10.304	11.273	7.613	44.229	0.969
Oct	171.5	15.433	11.273	11.403	55.632	0.000
Nov	352.4	31.702	11.273	23.430	79.062	0.000
Dec	314.9	28.339	11.273	20.938	100.000	0.000
		135.347				44.242

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The sum of dry month demand from the above table is 44.242 m^3 which is the required storage tank size for Roof 1 type houses in Trincomalee. The mass balance method of analysis for Trincomalee data of Roof 2 type houses is presented in Table A5.

Table A5: Mass balance method: Trincomalee – Roof 2

Months	29 years data of average monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	% of total runoff	Cummu. % of runoff	Required tank capacity (m^3)
Jan	154.7	20.883	11.273	10.286	10.286	0.000
Feb	76.5	10.332	11.273	5.089	15.376	0.941
Mar	48.2	6.503	11.273	3.203	18.579	4.770
Apr	54.3	7.325	11.273	3.608	22.187	3.947
May	71.6	9.662	11.273	4.759	26.946	1.611
Jun	11.4	1.545	11.273	0.761	27.707	9.728

Jul	57.0	7.701	11.273	3.793	31.500	3.572
Aug	76.9	10.386	11.273	5.116	36.616	0.887
Sep	114.5	15.456	11.273	7.613	44.229	0.000
Oct	171.5	23.150	11.273	11.403	55.632	0.000
Nov	352.4	47.568	11.273	23.430	79.062	0.000
Dec	314.9	42.508	11.273	20.938	100.000	0.000
		203.020				25.455

The sum of dry month demand from the above table is 25.455 m^3 which is the required storage tank size for Roof 2 type houses in Trincomalee. The mass balance method of analysis for Trincomalee data of Roof 3 type houses is presented in Table A6.

Table A6: Mass balance method: Trincomalee – Roof 3

Months	29 years data of average monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	% of total runoff	Cummu. % of runoff	Required tank capacity (m^3)
Jan	154.7	27.844	11.273	10.286	10.286	0.000
Feb	76.5	13.776	11.273	5.089	15.376	0.000
Mar	48.2	8.671	11.273	3.203	18.579	2.602
Apr	54.3	9.767	11.273	3.608	22.187	1.506
May	71.6	12.883	11.273	4.759	26.946	0.000
Jun	11.4	2.059	11.273	0.761	27.707	9.213
Jul	57.0	10.268	11.273	3.793	31.500	1.005
Aug	76.9	13.848	11.273	5.116	36.616	0.000
Sep	114.5	20.608	11.273	7.613	44.229	0.000
Oct	171.5	30.867	11.273	11.403	55.632	0.000
Nov	352.4	63.424	11.273	23.430	79.062	0.000
Dec	314.9	56.677	11.273	20.938	100.000	0.000
		270.693				14.325

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The sum of dry month demand from the above table is 14.325 m^3 which is the required storage tank size for Roof 3 type houses in Trincomalee. The mass balance method of analysis for Colombo data of Roof 1 type houses is presented in Table A7.

Table A7: Mass balance method: Colombo – Roof 1

Months	29 years data of average monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	% of total runoff	Cummu. % of runoff	Required tank capacity (m^3)
Jan	47.7	4.290	12.965	2.28	2.28	8.676
Feb	55.1	4.961	12.965	2.64	4.92	8.005
Mar	109.2	9.826	12.965	5.23	10.16	3.139
Apr	220.1	19.807	12.965	10.54	20.70	0.000
May	298.0	26.824	12.965	14.28	34.98	0.000
Jun	163.4	14.704	12.965	7.83	42.81	0.000
Jul	103.8	9.341	12.965	4.97	47.78	3.624
Aug	95.1	8.562	12.965	4.56	52.34	4.403
Sep	181.2	16.312	12.965	8.68	61.02	0.000
Oct	345.6	31.108	12.965	16.56	77.59	0.000
Nov	341.4	30.729	12.965	16.36	93.94	0.000
Dec	126.4	11.374	12.965	6.06	100.00	1.591
		187.839				29.438

The sum of dry month demand from the above table is 29.438 m^3 which is the required storage tank size for Roof 1 type houses in Colombo. The mass balance method of analysis for Colombo data of Roof 2 type houses is presented in Table A8.

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Table A8: Mass balance method: Colombo – Roof 2

Months	29 years data of average monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	% of total runoff	Cummu. % of runoff	Required tank capacity (m^3)
Jan	47.7	6.434	12.965	2.28	2.28	6.531
Feb	55.1	7.441	12.965	2.64	4.92	5.524
Mar	109.2	14.739	12.965	5.23	10.16	0.000
Apr	220.1	29.710	12.965	10.54	20.70	0.000
May	298.0	40.236	12.965	14.28	34.98	0.000
Jun	163.4	22.056	12.965	7.83	42.81	0.000
Jul	103.8	14.012	12.965	4.97	47.78	0.000
Aug	95.1	12.844	12.965	4.56	52.34	0.122
Sep	181.2	24.469	12.965	8.68	61.02	0.000
Oct	345.6	46.663	12.965	16.56	77.59	0.000
Nov	341.4	46.094	12.965	16.36	93.94	0.000
Dec	126.4	17.061	12.965	6.06	100.00	0.000
		281.759				12.177

The sum of dry month demand from the above table is 12.177 m^3 which is the required storage tank size for Roof 2 type houses in Colombo. The mass balance method of analysis for Colombo data of Roof 3 type houses is presented in Table A9.

Table A9: Mass balance method: Colombo – Roof 3

Months	29 years data of average monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	% of total runoff	Cummu. % of runoff	Required tank capacity (m^3)
Jan	47.7	8.579	12.965	2.28	2.28	4.386
Feb	55.1	9.922	12.965	2.64	4.92	3.044
Mar	109.2	19.652	12.965	5.23	10.16	0.000
Apr	220.1	39.613	12.965	10.54	20.70	0.000
May	298.0	53.648	12.965	14.28	34.98	0.000
Jun	163.4	29.408	12.965	7.83	42.81	0.000
Jul	103.8	18.683	12.965	4.97	47.78	0.000
Aug	95.1	17.125	12.965	4.56	52.34	0.000
Sep	181.2	32.625	12.965	8.68	61.02	0.000
Oct	345.6	62.217	12.965	16.56	77.59	0.000
Nov	341.4	61.459	12.965	16.36	93.94	0.000
Dec	126.4	22.748	12.965	6.06	100.00	0.000
		375.679				7.430

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The sum of dry month demand from the above table is 7.430 m^3 which is the required storage tank size for Roof 3 type houses in Colombo. Sum up the required tank size for Puttalam, Trincomalee and Colombo of Roof 1, Roof 2 and Roof 3 values are presented in Table A10.

Table A10: Results of Mass balance method

Method	Roof size (m^2)	Required tank size (m^3)		
		Puttalam	Trincomalee	Colombo
Mass balance	100	56.019	44.242	29.438
	150	38.045	25.455	12.177
	200	25.253	14.325	7.430

Appendix B: Analytical Method

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Appendix B: Analytical Method

This analysis is carried out based on the maximum value of monthly cumulative deficient from past 29 years of monthly data. A month which meets the monthly demand from runoff results the deficient to be set to zero. A month which does not meet the monthly demand from the runoff results in a deficient value which is equal to the balance quantity required to supply the monthly demand. It is assumed that the next value starts with new cumulative series, once the cumulative deficient becomes zero. The estimations carried out based on the analytical method for the analysis of Puttalam data for Roof 1 type houses is presented in Table B1.

Table B1: Analytical method for Puttalam Roof 1

Month	1982 monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	Surplus (m^3)	Deficient (m^3)	Cum. Surplus (m^3)	Cum. Deficient (m^3)
Jan	0.0	0.000	11.273	0.000	11.273	0.000	11.273
Feb	0.0	0.000	11.273	0.000	11.273	0.000	22.546
Mar	24.9	2.241	11.273	0.000	9.032	0.000	31.577
April	88.3	7.947	11.273	0.000	3.326	0.000	34.903
May	100.6	9.054	11.273	0.000	2.219	0.000	37.122
June	120.6	10.854	11.273	0.000	0.419	0.000	37.541
July	9.8	0.882	11.273	0.000	10.391	0.000	47.932
Aug	3.2	0.288	11.273	0.000	10.985	0.000	58.916
Sep	20.1	1.809	11.273	0.000	9.464	0.000	68.380
Oct	289.7	26.073	11.273	14.800	0.000	14.800	0.000
Nov	238.5	21.465	11.273	10.192	0.000	24.992	0.000
Dec	67.1	6.039	11.273	0.000	5.234	0.000	5.234

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The maximum cumulative deficient for this month is 68.38 m^3 which is the required storage tank size for Roof 1 type houses in Puttalam.

The estimations carried out based on the analytical method for the analysis of Puttalam data for Roof 2 type houses is presented in Table B2.

Table B2: Analytical method for Puttalam Roof 2

Month	1982 monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	Surplus (m^3)	Deficient (m^3)	Cum. Surplus (m^3)	Cum. Deficient (m^3)
Jan	0.0	0.000	11.273	0.000	11.273	0.000	11.273
Feb	0.0	0.000	11.273	0.000	11.273	0.000	22.546
Mar	24.9	3.362	11.273	0.000	7.911	0.000	30.457
April	88.3	11.921	11.273	0.648	0.000	0.648	0.000
May	100.6	13.581	11.273	2.308	0.000	2.956	0.000
June	120.6	16.281	11.273	5.008	0.000	7.964	0.000
July	9.8	1.323	11.273	0.000	9.950	0.000	9.950
Aug	3.2	0.432	11.273	0.000	10.841	0.000	20.791
Sep	20.1	2.714	11.273	0.000	8.559	0.000	29.350
Oct	289.7	39.110	11.273	27.837	0.000	27.837	0.000
Nov	238.5	32.198	11.273	20.925	0.000	48.761	0.000
Dec	67.1	9.059	11.273	0.000	2.214	0.000	2.214

The cumulative deficient for this month is 30.457 m^3 which is the required storage tank size for Roof 2 type houses in Puttalam.

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The estimations carried out based on the analytical method for the analysis of Puttalam data for Roof 3 type houses is presented in Table B3.

Table B3: Analytical method for Puttalam Roof 3

Month	1982 monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	Surplus (m^3)	Deficient (m^3)	Cum. Surplus (m^3)	Cum. Deficient (m^3)
Jan	0.0	0.000	11.273	0.000	11.273	0.000	11.273
Feb	0.0	0.000	11.273	0.000	11.273	0.000	22.546
Mar	24.9	4.482	11.273	0.000	6.791	0.000	29.336
April	88.3	15.894	11.273	4.621	0.000	4.621	0.000
May	100.6	18.108	11.273	6.835	0.000	11.456	0.000
June	120.6	21.708	11.273	10.435	0.000	21.892	0.000
July	9.8	1.764	11.273	0.000	9.509	0.000	9.509
Aug	3.2	0.576	11.273	0.000	10.697	0.000	20.206
Sep	20.1	3.618	11.273	0.000	7.655	0.000	27.860
Oct	289.7	52.146	11.273	40.873	0.000	40.873	0.000
Nov	238.5	42.930	11.273	31.657	0.000	72.530	0.000
Dec	67.1	12.078	11.273	0.805	0.000	73.336	0.000

The cumulative deficient for this month is 29.336 m^3 which is the required storage tank size for Roof 3 type houses in Puttalam.

The estimations carried out based on the analytical method for the analysis of Trincomalee data for Roof 3 type houses is presented in Table B4.

Table B4: Analytical method for Trincomalee Roof 1

Month	1982 monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	Surplus (m^3)	Deficient (m^3)	Cum. Surplus (m^3)	Cum. Deficient (m^3)
Jan	13.0	1.170	11.273	0.000	10.103	0.000	10.103
Feb	0.0	0.000	11.273	0.000	11.273	0.000	21.376
Mar	31.3	2.817	11.273	0.000	8.456	0.000	29.831
April	29.2	2.628	11.273	0.000	8.645	0.000	38.476
May	37.5	3.375	11.273	0.000	7.898	0.000	46.374
June	0.6	0.054	11.273	0.000	11.219	0.000	57.593
July	1.8	0.162	11.273	0.000	11.111	0.000	68.704
Aug	16.5	1.485	11.273	0.000	9.788	0.000	78.491
Sep	105.0	9.450	11.273	0.000	1.823	0.000	80.314
Oct	170.4	15.336	11.273	4.063	0.000	4.063	0.000
Nov	568.3	51.147	11.273	39.874	0.000	43.937	0.000
Dec	498.5	44.865	11.273	33.592	0.000	77.530	0.000

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The cumulative deficient for this month is 80.314 m^3 which is the required storage tank size for Roof 1 type houses in Trincomalee.

The estimations carried out based on the analytical method for the analysis of Trincomalee data for Roof 2 type houses is presented in Table B5.

Table B5: Analytical method for Trincomalee Roof 2

Month	1982 monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	Surplus (m^3)	Deficient (m^3)	Cum. Surplus (m^3)	Cum. Deficient (m^3)
Jan	13.0	1.755	11.273	0.000	9.518	0.000	9.518
Feb	0.0	0.000	11.273	0.000	11.273	0.000	20.791
Mar	31.3	4.226	11.273	0.000	7.047	0.000	27.838
April	29.2	3.942	11.273	0.000	7.331	0.000	35.169

May	37.5	5.063	11.273	0.000	6.210	0.000	41.379
June	0.6	0.081	11.273	0.000	11.192	0.000	52.571
July	1.8	0.243	11.273	0.000	11.030	0.000	63.601
Aug	16.5	2.228	11.273	0.000	9.045	0.000	72.646
Sep	105.0	14.175	11.273	2.902	0.000	2.902	0.000
Oct	170.4	23.004	11.273	11.731	0.000	14.633	0.000
Nov	568.3	76.721	11.273	65.448	0.000	80.081	0.000
Dec	498.5	67.298	11.273	56.025	0.000	136.106	0.000

The cumulative deficient for this month is 72.646 m^3 which is the required storage tank size for Roof 2 type houses in Trincomalee.

The estimations carried out based on the analytical method for the analysis of Trincomalee data for Roof 3 type houses is presented in Table B6.

Table B6: Analytical method for Trincomalee Roof 3

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Month	1982 monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	Surplus (m^3)	Deficient (m^3)	Cum. Surplus (m^3)	Cum. Deficient (m^3)
Jan	13.0	2.340	11.273	0.000	8.933	0.000	8.933
Feb	0.0	0.000	11.273	0.000	11.273	0.000	20.206
Mar	31.3	5.634	11.273	0.000	5.639	0.000	25.844
April	29.2	5.256	11.273	0.000	6.017	0.000	31.861
May	37.5	6.750	11.273	0.000	4.523	0.000	36.384
June	0.6	0.108	11.273	0.000	11.165	0.000	47.549
July	1.8	0.324	11.273	0.000	10.949	0.000	58.498
Aug	16.5	2.970	11.273	0.000	8.303	0.000	66.800
Sep	105.0	18.900	11.273	7.627	0.000	7.627	0.000
Oct	170.4	30.672	11.273	19.399	0.000	27.026	0.000
Nov	568.3	102.294	11.273	91.021	0.000	118.048	0.000
Dec	498.5	89.730	11.273	78.457	0.000	196.505	0.000

The cumulative deficient for this month is 66.800 m^3 which is the required storage tank size for Roof 3 type houses in Trincomalee.

The estimations carried out based on the analytical method for the analysis of Colombo data for Roof 1 type houses is presented in Table B7.

Table B7: Analytical method for Colombo Roof 1

Month	1972 monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	Surplus (m^3)	Deficient (m^3)	Cum. Surplus (m^3)	Cum. Deficient (m^3)
Jan	8.8	0.792	12.965	0.000	12.173	0.000	12.173
Feb	0.5	0.045	12.965	0.000	12.920	0.000	25.094
Mar	53.2	4.788	12.965	0.000	8.177	0.000	33.271
April	98.3	8.847	12.965	0.000	4.118	0.000	37.390
May	541.4	48.726	12.965	35.761	0.000	35.761	0.000
June	70.4	6.336	12.965	0.000	6.629	0.000	6.629
July	87.6	7.884	12.965	0.000	5.081	0.000	11.711
Aug	46.2	4.158	12.965	0.000	8.807	0.000	20.518
Sep	203.9	18.351	12.965	5.386	0.000	5.386	0.000
Oct	323.8	29.142	12.965	16.177	0.000	21.562	0.000
Nov	355.8	32.022	12.965	19.057	0.000	40.619	0.000
Dec	185.7	16.713	12.965	3.748	0.000	44.366	0.000

The cumulative deficient for this month is 33.390 m^3 which is the required storage tank size for Roof 1 type houses in Colombo.

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The estimations carried out based on the analytical method for the analysis of Colombo data of Roof 2 type houses is presented in Table B8.

Table B8: Analytical method for Colombo Roof 2

Month	1972 monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	Surplus (m^3)	Deficient (m^3)	Cum. Surplus (m^3)	Cum. Deficient (m^3)
Jan	8.8	1.188	12.965	0.000	11.777	0.000	11.777
Feb	0.5	0.068	12.965	0.000	12.898	0.000	24.675
Mar	53.2	7.182	12.965	0.000	5.783	0.000	30.459
April	98.3	13.271	12.965	0.305	0.000	0.305	0.000
May	541.4	73.089	12.965	60.124	0.000	60.429	0.000
June	70.4	9.504	12.965	0.000	3.461	0.000	3.461
July	87.6	11.826	12.965	0.000	1.139	0.000	4.601
Aug	46.2	6.237	12.965	0.000	6.728	0.000	11.329
Sep	203.9	27.527	12.965	14.561	0.000	14.561	0.000

Oct	323.8	43.713	12.965	30.748	0.000	45.309	0.000
Nov	355.8	48.033	12.965	35.068	0.000	80.376	0.000
Dec	185.7	25.070	12.965	12.104	0.000	92.480	0.000

The cumulative deficient for this month is 30.459 m^3 which is the required storage tank size for Roof 2 type houses in Colombo.

The estimations carried out based on the analytical method for the analysis of Colombo data for Roof 3 type house is presented in Table B9.

Table B9: Analytical method for Colombo Roof 3

Month	1972 monthly rainfall (mm)	Runoff (m^3)	Demand (m^3)	Surplus (m^3)	Deficient (m^3)	Cum. Surplus (m^3)	Cum. Deficient (m^3)
Jan	8.8	1.584	12.965	0.000	11.381	0.000	11.381
Feb	0.5	0.090	12.965	0.000	12.875	0.000	24.257
Mar	53.2	9.576	12.965	0.000	3.389	0.000	27.646
April	98.3	17.694	12.965	4.729	0.000	4.729	0.000
May	541.4	97.452	12.965	84.487	0.000	89.215	0.000
June	70.4	12.672	12.965	0.000	0.293	0.000	0.293
July	87.6	15.768	12.965	2.803	0.000	2.803	0.000
Aug	46.2	8.316	12.965	0.000	4.649	0.000	4.649
Sep	203.9	36.702	12.965	23.737	0.000	23.737	0.000
Oct	323.8	58.284	12.965	45.319	0.000	69.055	0.000
Nov	355.8	64.044	12.965	51.079	0.000	120.134	0.000
Dec	185.7	33.426	12.965	20.461	0.000	140.594	0.000

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The cumulative deficient for this month is 27.646 m^3 which is the required storage tank size for Roof 3 type houses in Colombo.

The past 29 years of cumulative deficient values for the different roof sizes are presented in Table B10.

Table B10: Maximum deficient of three regions of 29 years analysis

Year	Maximum Deficient (m^3)								
	Puttalam			Trincomalee			Colombo		
	Roof 1	Roof 2	Roof 3	Roof 1	Roof 2	Roof 3	Roof 1	Roof 2	Roof 3
1	68.380	30.457	29.336	80.314	72.646	66.800	37.390	30.459	27.646
2	84.333	72.606	66.566	76.080	37.801	35.371	24.388	18.951	16.625
3	45.020	33.711	16.606	23.851	12.812	11.273	25.567	22.151	20.891
4	33.976	31.712	31.010	49.772	31.902	27.505	23.506	15.811	11.453
5	49.875	46.631	43.386	33.467	17.416	15.706	31.264	27.448	23.699
6	36.802	32.658	28.513	65.761	33.575	33.494	24.212	23.352	22.493
7	28.612	22.235	18.374	24.060	19.306	18.226	32.800	24.924	21.539
8	49.191	45.605	42.018	51.365	43.229	25.489	17.804	13.740	12.731
9	44.560	44.295	44.029	22.991	18.671	17.380	31.912	28.420	25.661
10	34.012	30.902	29.930	48.467	35.898	32.833	19.501	13.605	9.497
11	70.612	33.076	32.828	64.739	36.964	34.255	25.913	25.904	25.895
12	67.300	36.789	34.021	61.225	18.820	17.578	51.385	51.146	50.908
13	47.090	31.335	26.366	52.121	28.486	26.708	17.521	12.898	12.875
14	45.384	41.311	40.051	51.361	39.746	20.422	12.548	7.282	5.387
15	26.641	21.439	14.428	34.125	21.034	16.772	21.802	13.551	9.425
16	38.224	34.791	31.730	54.722	48.264	41.807	30.409	26.166	21.922
17	34.251	28.284	22.681	74.042	55.420	32.846	13.655	12.965	12.965
18	45.339	39.827	34.314	50.456	33.441	29.557	29.050	24.127	21.431
19	46.163	32.550	31.478	57.629	29.309	27.806	35.293	24.216	23.645
20	54.686	48.210	41.735	28.617	20.548	19.882	17.584	12.755	11.003
21	44.970	41.595	40.429	71.422	33.603	31.298	42.484	38.181	37.942
22	34.602	27.176	24.962	48.827	39.422	21.439	29.185	24.330	23.141
23	30.664	26.785	24.440	34.993	29.944	24.895	21.541	11.669	11.237
24	51.990	49.803	47.616	40.398	22.249	19.846	27.565	21.900	16.234
25	42.446	32.158	31.604	97.120	83.679	70.238	23.965	17.709	14.969
26	44.763	38.963	33.162	31.704	20.423	17.380	28.381	12.695	12.605
27	43.539	28.999	27.392	33.895	28.297	17.542	35.152	33.280	31.408
28	47.225	26.528	24.098	47.733	43.418	39.102	14.587	8.659	7.223
29	32.540	31.901	31.262	68.807	59.848	53.494	9.716	8.092	6.467

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The maximum value of cumulative deficiency for Puttalam, Trincomalee and Colombo of Roof 1, Roof 2 and Roof 3 is presented in Table B11.

Table B11: Results of Analytical method

Method	Roof size (m^2)	Required tank size (m^3)		
		Puttalam	Trincomalee	Colombo
Analytical method	100	84.3	97.1	51.4
	150	72.6	83.7	51.1
	200	66.6	70.2	50.9

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Appendix C: Sequent Peak Algorithm Method

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Appendix C: Sequent Peak Algorithm Method

This method is used for estimating the storage tank size based on the graph of time period versus cumulative net flow. Past 29 years of monthly rainfall data was used to find the net flow. Sequent peak algorithm analysis for Puttalam Roof 1 type houses is presented in Table C1.

Table C1: Sequent peak algorithm table – Puttalam Roof 1

Number of months	Year	Month	Monthly rainfall (mm)	Runoff volume (m^3)	Demand (m^3)	Cumulative demand (m^3)	Net Flow Volume (m^3)	Cumulative Net Flow Volume (m^3)
1	1982	Jan	0.0	0.000	11.273	11.273	-11.273	-11.273
348	2010	Dec	330.0	29.700	11.273	3922.934	18.427	-895.136

The graph of time (months) versus cumulative net flow volume of Puttalam Roof 1 type houses is presented in Figure C1.

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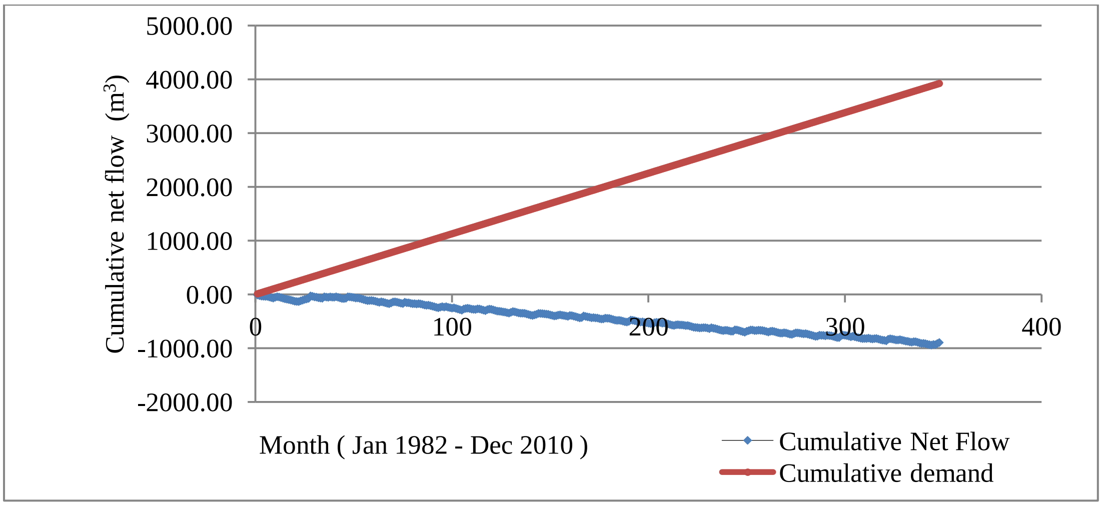

Figure C1: Sequent peak algorithm graph for Puttalam Roof 1

The required tank size calculated from maximum value of (P_i-T_i) is 89.560 m^3 for Roof 1 type houses in Puttalam.

Sequent peak algorithm analysis for Puttalam Roof 2 houses is presented in Table C2.

Table C2: Sequent peak algorithm table – Puttalam Roof 2

Number of months	Year	Month	Monthly rainfall (mm)	Runoff volume (m^3)	Demand (m^3)	Cumulative demand (m^3)	Net Flow Volume (m^3)	Cumulative Net Flow Volume (m^3)
1	1982	Jan	0.0	0.000	11.273	11.273	-11.273	-11.273
348	2010	Dec	330.0	44.550	11.273	3922.934	33.277	618.763

The graph of time (months) versus cumulative net flow volume of Puttalam Roof 2 type houses is presented in Figure C2.

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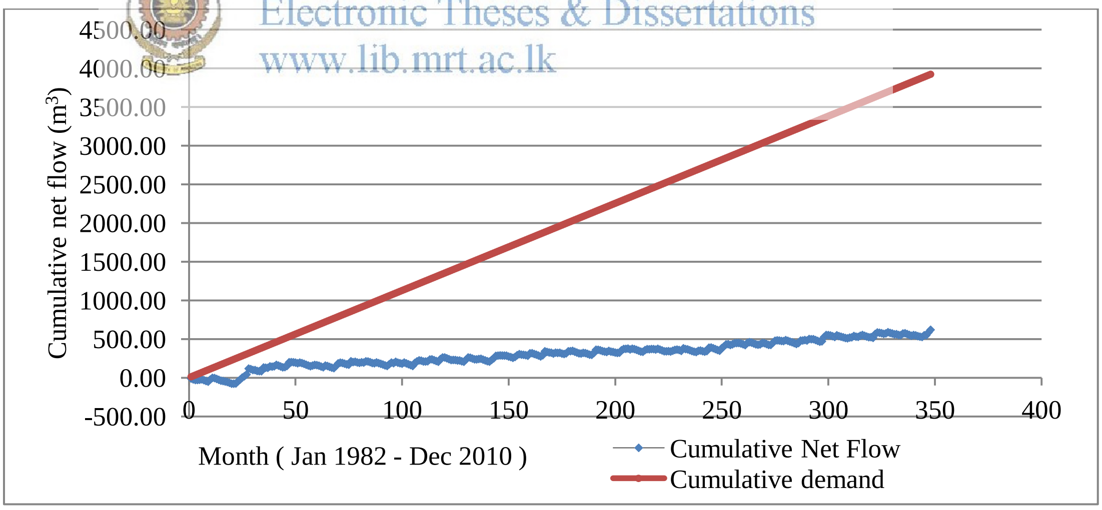

Figure C2: Sequent peak algorithm graph for Puttalam Roof 2

The required tank size calculated from maximum value of (P_i-T_i) is 74.69 m^3 for Roof 2 type houses in Puttalam.

Sequent peak algorithm analysis for Puttalam Roof 3 type houses is presented in Table C3.

Table C3: Sequent peak algorithm table – Puttalam Roof 3

Number of months	Year	Month	Monthly rainfall (mm)	Runoff volume (m^3)	Demand (m^3)	Cumulative demand (m^3)	Net Flow Volume (m^3)	Cumulative Net Flow Volume (m^3)
1	1982	Jan	0.0	0.000	11.273	11.273	-11.273	-11.273
348	2010	Dec	330.0	59.400	11.273	3922.934	48.127	2132.662

The graph of time (months) versus cumulative net flow volume of Puttalam Roof 3 type houses is presented in Figure C3.

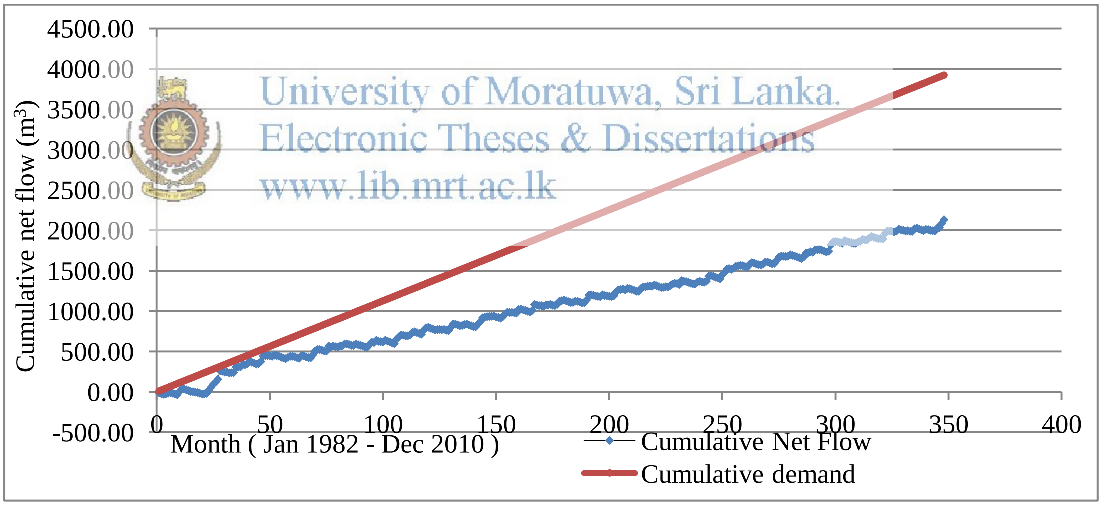

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Figure C3: Sequent peak algorithm method for Puttalam Roof 3

The required tank size calculated from maximum value of (P_i-T_i) is 65.77 m^3 for Roof 3 type houses in Puttalam.

Sequent peak algorithm analysis for Trincomalee Roof 1 houses is presented in Table C4.

Table C4: Sequent peak algorithm table – Trincomalee Roof 1

Number of months	Year	Month	Monthly rainfall (mm)	Runoff volume (m^3)	Demand (m^3)	Cumulative demand (m^3)	Net Flow Volume (m^3)	Cumulative Net Flow Volume (m^3)
1	1982	Jan	13.0	1.170	11.273	11.273	-10.103	-10.103
348	2010	Dec	621.5	55.935	11.273	3922.934	44.662	2.118

The graph of time (months) versus cumulative net flow volume of Trincomalee Roof 1 type houses is presented in Figure C4.

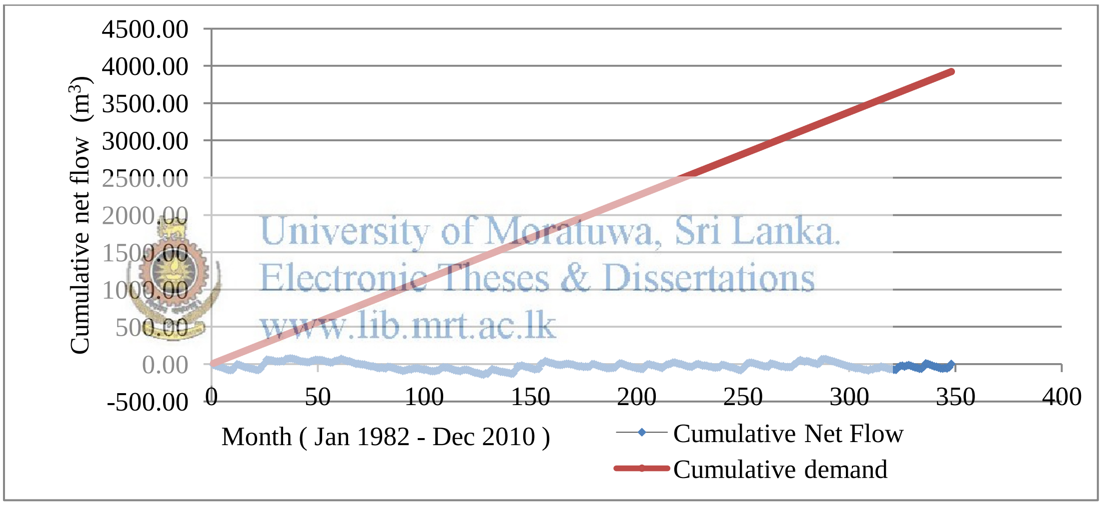

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Figure C4: Sequent peak algorithm method for Trincomalee Roof 1

The required tank size calculated from maximum value of (P_i-T_i) is 76.08 m^3 for Roof 1 type houses in Trincomalee.

Sequent peak algorithm analysis for Trincomalee Roof 2 type houses is presented in Table C5.

Table C5: Sequent peak algorithm table – Trincomalee Roof 2

Number of months	Year	Month	Monthly rainfall (mm)	Runoff volume (m^3)	Demand (m^3)	Cumulative demand (m^3)	Net Flow Volume (m^3)	Cumulative Net Flow Volume (m^3)
1	1982	Jan	13.0	1.755	11.273	11.273	-9.518	-9.518
348	2010	Dec	621.5	83.903	11.273	3922.934	72.630	1964.644

The graph of time (months) versus cumulative net flow volume of Trincomalee Roof 2 houses is presented in Figure C5.

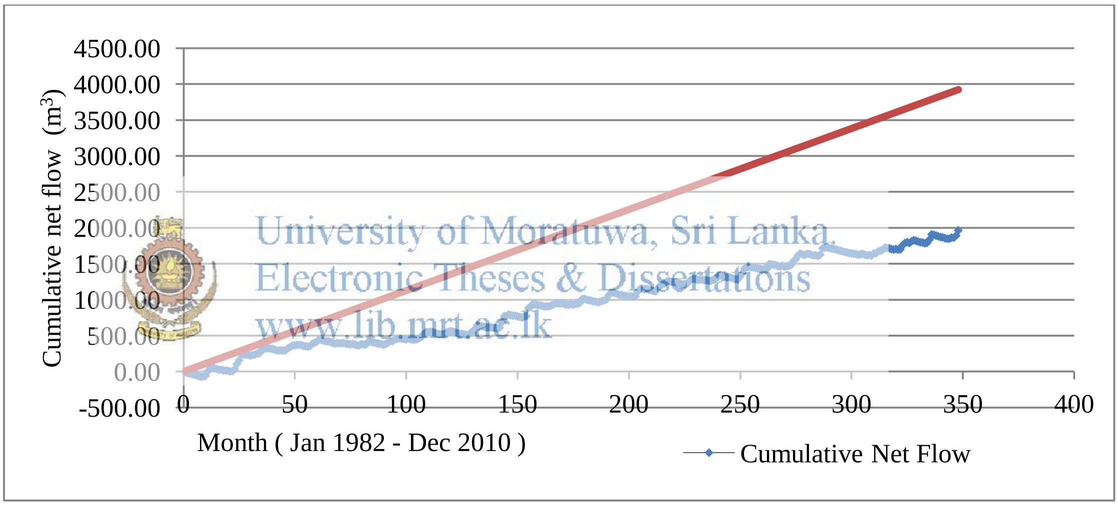

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Figure C5: Sequent peak algorithm method for Trincomalee Roof 2

The required tank size calculated from maximum value of (P_i-T_i) is 63.13 m^3 for Roof 2 type houses in Trincomalee.

Sequent peak algorithm analysis for Trincomalee Roof 3 type houses is presented in Table C6.

Table C6: Sequent peak algorithm table – Trincomalee Roof 3

Number of months	Year	Month	Monthly rainfall (mm)	Runoff volume (m^3)	Demand (m^3)	Cumulative demand (m^3)	Net Flow Volume (m^3)	Cumulative Net Flow Volume (m^3)
1	1982	Jan	13.0	2.340	11.273	11.273	-8.933	-8.933
348	2010	Dec	621.5	111.870	11.273	3922.934	100.597	3927.171

The graph of time (months) versus cumulative net flow volume of Trincomalee Roof 3 houses is presented in Figure C6.

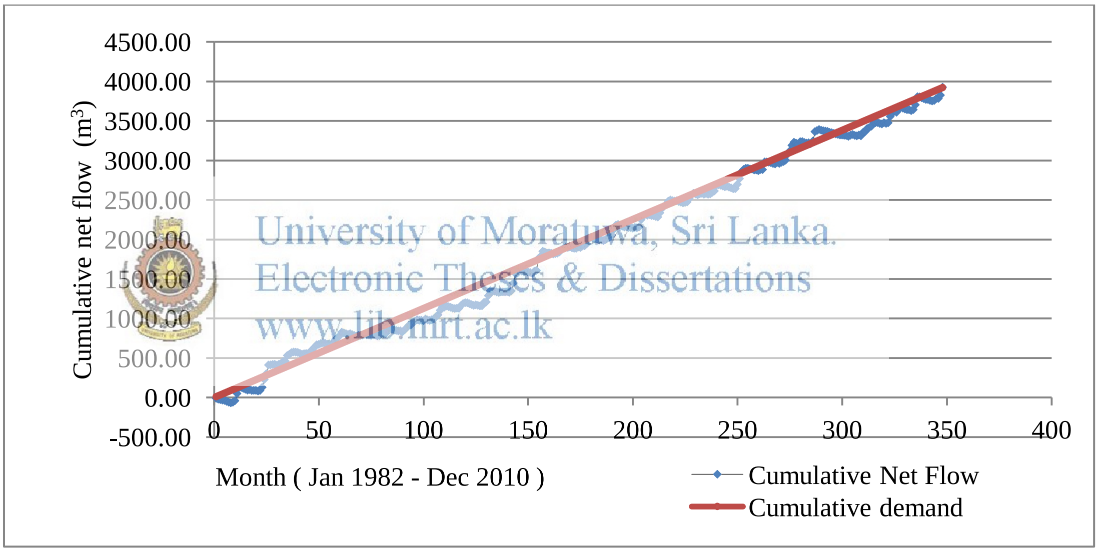

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Figure C6: Sequent peak algorithm method for Trincomalee Roof 3

The required tank size calculated from maximum value of (P_i-T_i) is 57.87 m^3 for Roof 3 type houses in Trincomalee.

Sequent peak algorithm analysis for Colombo Roof 1 type houses is presented in Table C7.

Table C7: Sequent peak algorithm analysis table - Colombo Roof 1

Number of months	Year	Month	Monthly rainfall (mm)	Runoff volume (m^3)	Demand (m^3)	Cumulative demand (m^3)	Net Flow Volume (m^3)	Cumulative Net Flow Volume (m^3)
1	1972	Jan	8.8	0.792	12.965	12.965	-12.173	-12.173
348	2000	Dec	122.4	11.016	12.965	4511.959	-1.949	935.386

The graph of time (months) versus cumulative net flow volume of Colombo Roof 1 houses is presented in Figure C7.

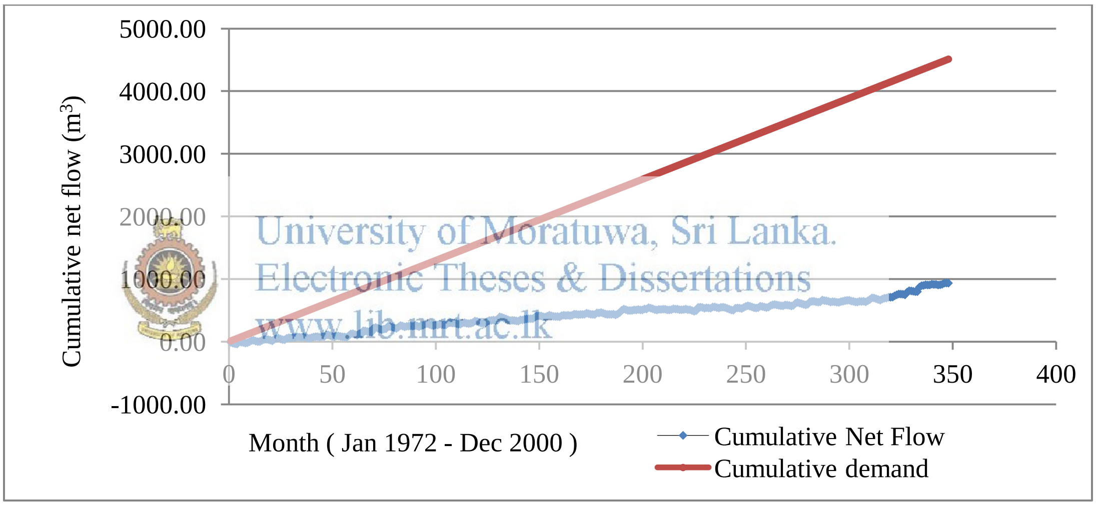

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Figure C7: Sequent peak algorithm method for Colombo Roof 1

The required tank size calculated from maximum value of (P_i-T_i) is 39.67 m^3 for Roof 1 type houses in Colombo.

Sequent peak algorithm analysis for Colombo Roof 2 type houses is presented in Table C8.

Table C8: Sequent peak algorithm analysis table - Colombo Roof 2

Number of months	Year	Month	Monthly rainfall (mm)	Runoff volume (m^3)	Demand (m^3)	Cumulative demand (m^3)	Net Flow Volume (m^3)	Cumulative Net Flow Volume (m^3)
1	1972	Jan	8.8	1.188	12.965	12.965	-11.777	-11.777
348	2000	Dec	122.4	16.524	12.965	4511.959	3.559	3659.058

The graph of Time (months) versus cumulative net flow volume of Colombo Roof 2 houses is presented in Figure C8.

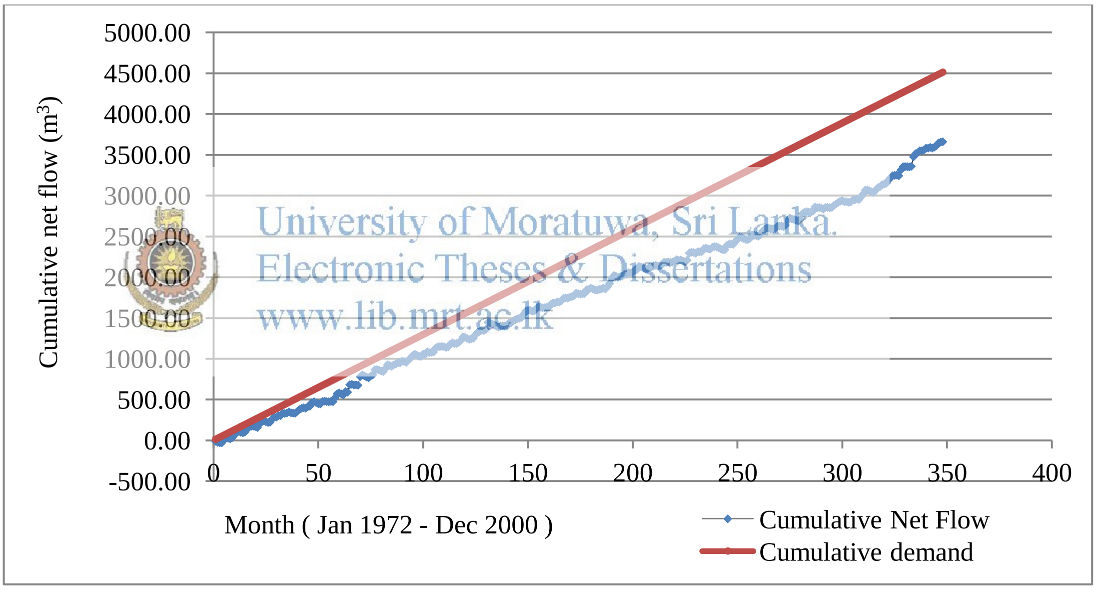

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Figure C8: Sequent peak algorithm method for Colombo Roof 2

The required tank size calculated from maximum value of (P_i-T_i) is 40.40 m^3 for Roof 2 type houses in Colombo.

Sequent peak algorithm analysis for Colombo Roof 3 type houses is presented in Table C9.

Table C9: Sequent peak algorithm analysis table - Colombo Roof 3

Number of months	Year	Month	Monthly rainfall (mm)	Runoff volume (m^3)	Demand (m^3)	Cumulative demand (m^3)	Net Flow Volume (m^3)	Cumulative Net Flow Volume (m^3)
1	1972	Jan	8.8	1.584	12.965	12.965	-11.381	-11.381
348	2000	Dec	122.4	22.032	12.965	4511.959	9.067	6382.730

The graph of time (months) versus cumulative net flow volume of Colombo Roof 3 houses is presented in Figure C9.

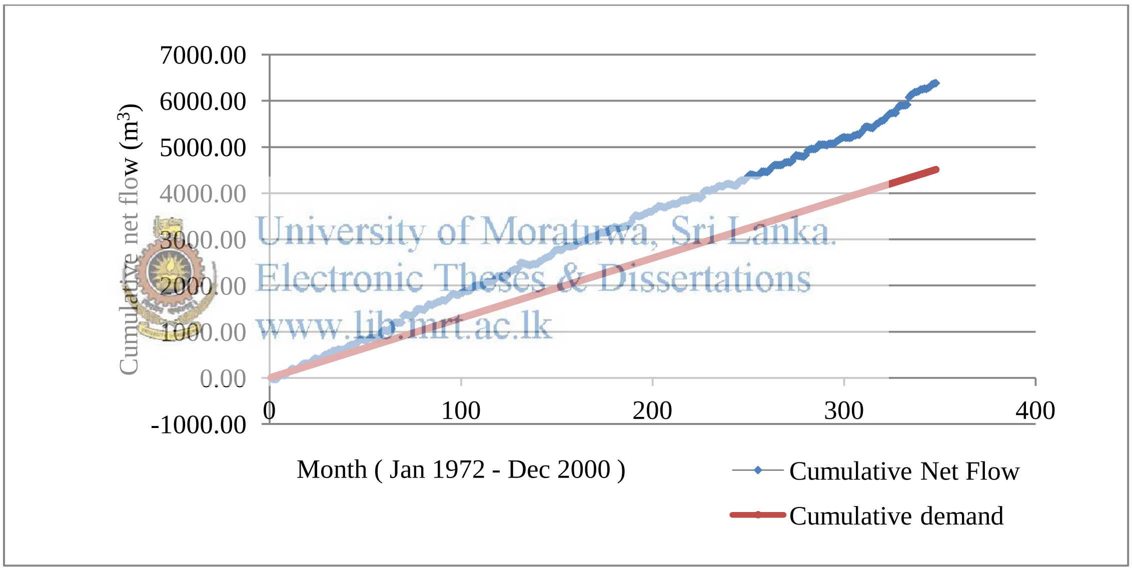

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Figure C9: Sequent peak algorithm method for Colombo Roof 3

The required tank size calculated from maximum value of (P_i-T_i) is 53.72 m^3 for Roof 3 type houses in Colombo.

Sum up the required tank size for Puttalam, Trincomalee and Colombo of Roof 1, Roof 2 and Roof 3 values are presented in Table C10.

Table C10: Results of Sequent peak algorithm method

Method	Roof size (m^2)	Required tank size (m^3)		
		Puttalam	Trincomalee	Colombo
Sequence peak algorithm	100	89.6	76.1	39.7
	150	74.7	63.1	40.4
	200	65.8	57.9	53.7

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Appendix D: Daily Water Balance Method

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Appendix D: Daily Water Balance Method

This method is carried out to for the analysis of required storage tank size based on the water balance equation of daily cycle i.e. tank inflow, tank outflow and storage at time‘t’. Tank inflow is the volume of runoff from the roof to the tank, tank outflow is the volume of water consumed from the tank and storage is the balance availability of water in the tank on a particular day. Assume that the first day initial storage of the tank is zero. The daily water balance method by assumed tank sizes of 1,3,58,10,15,20 and 25 m^3 are presented in Table D1.

Table D1: Excel worksheet format for daily water analysis method

	Average person	Daily demand/ person (litres)	Water demand (m^3)	Rainwater demand (m^3)	Roof size (m^2)	Runoff coeffient
Wet zone	4.2	147	0.617	0.432	100, 150, 200	0.9
Dry zone	4.4	122	0.537	0.376		
No:of days	Daily rainfall (mm)	Daily demand (m^3)	Tank size (m^3)	Daily runoff (m^3)	Initial tank storage (m^3)	Final tank storage (m^3)
			Assumed			
					Max.Final storage (m^3)	
					No:of days’ supply demand	
					Total no:of days	
					Reliability (%)	

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First day: Initial storage of tank is zero

Second day: Initial storage of tank is balance water in the tank on previous day

Final storage = Daily runoff + Initial storage – Daily demand

Tank overflows calibrate the final storage value into assumed tank size

Reliability is defined as the ratio of number of days the system can supply water for the daily demand to the total number of days. The reliability percentage is calculated for all three regions considering all 3 types of roofs to the specific tank size.

Reliability percentage for the assumed tank sizes of 1,3,5, 8, 10, 15, 20 and 25 is calculated from Excel worksheet model for Roof 1, Roof 2, Roof 3 houses in Puttalam, Trincomalee and Colombo are represented in Table D2.

Table D2: Reliability percentage for Puttalam, Trincomalee and Colombo of Roof 1, Roof 2 and Roof 3

Tank size	Reliability (%)								
	Roof 1	Roof 2	Roof 3	Roof 1	Roof 2	Roof 3	Roof 1	Roof 2	Roof 3
	Puttalam			Trincomalee			Colombo		
1	18.74	22.04	24.22	20.64	24.03	26.12	28.68	33.71	36.52
3	32.92	38.76	42.53	36.87	42.95	46.5	48.63	56.83	60.77
5	39.7	47.56	52.06	44.89	53.01	57.8	58.23	67.75	72.03
8	45.67	55.24	60.51	51.03	60.73	65.87	66.2	76.13	80.44
10	48.71	58.8	64.56	53.49	63.69	69.25	69.93	79.85	83.81
15	54.55	66.12	72.23	57.65	68.95	75.46	77.12	86.24	89.29
20	58.17	72.02	78.35	61.28	73.02	80.01	82.96	90.61	92.54
25	61.42	76.75	83.67	64.71	76.69	83.9	87.89	93.58	95.25

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Appendix E: Intensity Duration Frequency (IDF) Curve

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Appendix E: Intensity Duration Frequency (IDF) Curve

To establish updated IDF curves, the maximum rainfall is chosen from the available rainfall data from the past 29 years. In this study, the maximum rainfall of 24, 48 & 72 hours are used for Puttalam, Trincomalee & Colombo. The 24, 48 & 72 hours maximum rainfall data of Puttalam (1982-2010) are presented in Table E1.

Table E1: 24, 48 and 72 hour maximum rainfall for Puttalam

Year	Puttalam - Maximum rainfall (mm)		
	Duration (hr)		
	24	48	72
1982	72.2	73.7	106.3
1983	60.9	69.3	113
1984	275.7	410.9	410.9
1985	142.9	142.9	142.9
1986	94.8	94.8	116.2
1987	159.2	167.6	167.6
1988	82.1	123.5	123.5
1989	95.3	166.9	188.9
1990	122.3	163	205
1991	74.5	87.8	94
1992	101.8	114.3	127.4
1993	83.2	90.8	125.8
1994	114.2	114.2	114.2
1995	237.9	240.1	387.5
1996	134.4	134.4	134.4
1997	52.1	67.5	89.7
1998	164.1	180.8	188.7
1999	57.3	59.3	85.1
2000	117.1	131.3	131.3
2001	116	117.7	117.7
2002	88.5	94.2	94.7
2003	91.4	95.3	115.4
2004	73.2	93.2	101.9
2005	65.9	71.2	113.1
2006	72.5	105.5	105.5
2007	99.5	128.3	134.2
2008	81.1	126.1	147.5
2009	61.3	71.3	106.5
2010	174.5	192.6	199.5

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The 24, 48 and 72 hours maximum rainfall data of Trincomalee for the period of 1982-2010 are presented in Table E2.

Table E2: 24, 48 and 72 hour maximum rainfall for Trincomalee

Year	Trincomalee - Maximum rainfall (mm)		
	Duration (hr)		
	24	48	72
1982	161.6	195.1	221.8
1983	105	148.2	159.3
1984	206.2	224	250.2
1985	102.2	135.9	144.7
1986	80.3	101.4	111.4
1987	135.9	146.5	221.4
1988	103.2	106.7	133
1989	98	98	187.6
1990	86.2	119.4	150.7
1991	148.1	149.4	249.1
1992	118	172.5	199.9
1993	156.5	226.8	187.5
1994	158.8	192.1	199.9
1995	130.2	142.7	164.7
1996	78.3	137.9	138.3
1997	93.4	104.5	174.2
1998	162.8	231.3	258.4
1999	112.9	133.8	192.3
2000	160.3	181.5	208.8
2001	98.2	119.9	124.1
2002	98.4	139.2	182
2003	182.8	195.9	209.3
2004	92.7	136.4	229.1
2005	136.7	208.5	215
2006	35.9	41.1	37.8
2007	107.8	119.4	132
2008	159.8	206.5	215.8
2009	103.4	123.4	188.8
2010	89.7	157.5	161.5

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The 24, 48 and 72 hours maximum rainfall data of Trincomalee for the period of 1972-2000 are presented in Table E3.

Table E3: 24, 48 and 72 hour maximum rainfall for Colombo

Year	Colombo - Maximum rainfall (mm)		
	Duration (hr)		
	24	24	72
1972	99	146.9	153.7
1973	151.3	154.6	189.8
1974	133.3	145.2	179.2
1975	131	135	139.6
1976	80.7	110.1	120
1977	321.3	351	393.1
1978	127.2	152.6	193.9
1979	109.5	110.7	118.1
1980	148.9	185.2	174.4
1981	97.9	123.5	185.6
1982	161.8	165.2	168.3
1983	84.7	134.8	163
1984	142.5	179.4	197.3
1985	139.1	254.3	283.5
1986	140.2	145	161.1
1987	143.4	165.8	171.6
1988	116.3	125.3	140.1
1989	85.6	85.6	100.4
1990	137.1	160.1	297.2
1991	88.5	155.7	99.2
1992	113.6	207.2	233.3
1993	108.6	123.3	133.3
1994	167.3	192.8	196.3
1995	166.7	198.4	278.7
1996	244.5	244.5	275.7
1997	73	93.5	122
1998	213.5	230.1	240.7
1999	266.8	388.7	427.9
2000	181.8	234	234

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Gumbel (EV1) Distribution

Statistical analysis to find the reduced variant from the annual maximum rainfall of all regions using Gumbel (EV1) distribution are presented in Table E4, Table E5, Table E6.

Table E4: Statistical analysis using Gumbel (EV1) distribution for Puttalam

S.No	Year	Puttalam Maximum rainfall data			Descending order			P=m/(n+1)	T=1/P	Q=(1-P)	Y=-ln(-ln(Q))
		24 (hour)	48 (hour)	72 (hour)	24 (hour)	48 (hour)	72 (hour)				
1	1982	72.2	73.7	106.3	275.7	410.9	410.9	0	30	1	3.4
2	1983	60.9	69.3	113	237.9	240.1	387.5	0.1	15	0.9	2.7
3	1984	275.7	410.9	410.9	174.5	192.6	205	0.1	10	0.9	2.3
4	1985	142.9	142.9	142.9	164.1	180.8	199.5	0.1	7.5	0.9	1.9
5	1986	94.8	94.8	116.2	159.2	167.6	188.9	0.2	6	0.8	1.7
6	1987	159.2	167.6	167.6	142.9	166.9	188.7	0.2	5	0.8	1.5
7	1988	82.1	123.5	123.5	134.4	163	167.6	0.2	4.3	0.8	1.3
8	1989	95.3	166.9	188.9	122.3	142.9	147.5	0.3	3.8	0.7	1.2
9	1990	122.3	163	205	117.1	134.4	142.9	0.3	3.3	0.7	1
10	1991	74.5	87.8	94	116	131.3	134.4	0.3	3	0.7	0.9
11	1992	101.8	114.3	127.4	114.2	128.3	134.2	0.4	2.7	0.6	0.8
12	1993	83.2	90.8	125.8	101.8	126.1	131.3	0.4	2.5	0.6	0.7
13	1994	114.2	114.2	114.2	99.5	123.5	127.4	0.4	2.3	0.6	0.6
14	1995	237.9	240.1	387.5	95.3	117.7	125.8	0.5	2.1	0.5	0.5
15	1996	134.4	134.4	134.4	94.8	114.3	123.5	0.5	2	0.5	0.4

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S.No	Year	Puttalam Maximum rainfall data			Descending order			P=m/(n+1)	T=1/P	Q=(1-P)	Y=-ln(-ln(Q))
		24 (hour)	48 (hour)	72 (hour)	24 (hour)	48 (hour)	72(hour)				
16	1997	52.1	67.5	89.7	91.4	114.2	117.7	0.5	1.9	0.5	0.3
17	1998	164.1	180.8	188.7	88.5	105.5	116.2	0.6	1.8	0.4	0.2
18	1999	57.3	59.3	85.1	83.2	95.3	115.4	0.6	1.7	0.4	0.1
20	2001	116	117.7	117.7	81.1	94.2	113.1	0.7	1.5	0.3	-0.1
21	2002	88.5	94.2	94.7	74.5	93.2	113	0.7	1.4	0.3	-0.2
22	2003	91.4	95.3	115.4	73.2	90.8	106.5	0.7	1.4	0.3	-0.3
23	2004	73.2	93.2	101.9	72.5	87.8	106.3	0.8	1.3	0.2	-0.4
24	2005	65.9	71.2	113.1	72.2	73.7	105.5	0.8	1.3	0.2	-0.5
25	2006	72.5	105.5	105.5	65.9	71.3	101.9	0.8	1.2	0.2	-0.6
26	2007	99.5	128.3	134.2	61.3	71.2	94.7	0.9	1.2	0.1	-0.7
27	2008	81.1	126.1	147.5	60.9	69.3	94	0.9	1.1	0.1	-0.8
28	2009	61.3	71.3	106.5	57.3	67.5	89.7	0.9	1.1	0.1	-1
29	2010	174.5	192.6	199.5	52.1	59.3	85.1	1	1	0	-1.2

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Table E5: Statistical analysis using Gumbel (EV1) distribution for Trincomalee

S.No	Year	Trincomalee Maximum rainfall data			Descending order			P=m/(n+1)	T=1/P	Q=(1-P)	Y=-ln(-ln(Q))
		24 (hour)	48 (hour)	72 (hour)	24 (hour)	48 (hour)	72 (hour)				
1	1982	161.6	195.1	221.8	206.2	224	250.2	0	30	1	3.4
2	1983	105	148.2	159.3	182.8	195.9	209.3	0.1	15	0.9	2.7
3	1984	206.2	224	250.2	162.8	231.3	258.4	0.1	10	0.9	2.3
4	1985	102.2	135.9	144.7	161.6	195.1	221.8	0.1	7.5	0.9	1.9
5	1986	80.3	101.4	111.4	160.3	181.5	208.8	0.2	6	0.8	1.7
6	1987	135.9	146.5	221.4	159.8	206.5	215.8	0.2	5	0.8	1.5
7	1988	103.2	106.7	133	158.8	192.1	199.9	0.2	4.3	0.8	1.3
8	1989	98	98	187.6	156.5	226.8	187.5	0.3	3.8	0.7	1.2
9	1990	86.2	119.4	150.7	148.1	149.4	249.1	0.3	3.3	0.7	1
10	1991	148.1	149.4	249.1	136.7	208.5	215	0.3	3	0.7	0.9
11	1992	118	172.5	199.9	135.9	146.5	221.4	0.4	2.7	0.6	0.8
12	1993	156.5	226.8	187.5	130.2	142.7	164.7	0.4	2.5	0.6	0.7
13	1994	158.8	192.1	199.9	118	172.5	199.9	0.4	2.3	0.6	0.6
14	1995	130.2	142.7	164.7	112.9	133.8	192.3	0.5	2.1	0.5	0.5
15	1996	78.3	137.9	138.3	107.8	119.4	132	0.5	2	0.5	0.4

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S.No	Year	Trincomalee Maximum rainfall data			Descending order			P=m/(n+1)	T=1/P	Q=(1-P)	Y=-ln(-ln(Q))
		24 (hour)	48 (hour)	72 (hour)	24 (hour)	48 (hour)	72 (hour)				
16	1997	93.4	104.5	174.2	105	148.2	159.3	0.5	1.9	0.5	0.3
17	1998	162.8	231.3	258.4	103.4	123.4	188.8	0.6	1.8	0.4	0.2
18	1999	112.9	133.8	192.3	103.2	106.7	133	0.6	1.7	0.4	0.1
19	2000	160.3	181.5	208.8	102.2	135.9	144.7	0.6	1.6	0.4	0
20	2001	98.2	119.9	124.1	98.4	139.2	182	0.7	1.5	0.3	-0.1
21	2002	98.4	139.2	182	98.2	119.9	124.1	0.7	1.4	0.3	-0.2
22	2003	182.8	195.9	209.3	98	98	187.6	0.7	1.4	0.3	-0.3
23	2004	92.7	136.4	229.1	93.4	104.5	174.2	0.8	1.3	0.2	-0.4
24	2005	136.7	208.5	215	92.7	136.4	229.1	0.8	1.3	0.2	-0.5
25	2006	35.9	41.1	37.8	89.7	157.5	161.5	0.8	1.2	0.2	-0.6
26	2007	107.8	119.4	132	86.2	119.4	150.7	0.9	1.2	0.1	-0.7
27	2008	159.8	206.5	215.8	80.3	101.4	111.4	0.9	1.1	0.1	-0.8
28	2009	103.4	123.4	188.8	78.3	137.9	138.3	0.9	1.1	0.1	-1
29	2010	89.7	157.5	161.5	35.9	41.1	37.8	1	1	0	-1.2

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Table E6: Statistical analysis using Gumbel (EV1) distribution for Colombo

S.No	Year	Colombo -Maximum rainfall data			Descending order			P=m/(n+1)	T=1/P	Q=(1-P)	Y=-ln(-ln(Q))
		24 (hour)	48 (hour)	72 (hour)	24 (hour)	48 (hour)	72 (hour)				
1	1972	99	146.9	153.7	321.3	351	393.1	0	30	1	3.4
2	1973	151.3	154.6	189.8	266.8	388.7	427.9	0.1	15	0.9	2.7
3	1974	133.3	145.2	179.2	244.5	244.5	275.7	0.1	10	0.9	2.3
4	1975	131	135	139.6	213.5	230.1	240.7	0.1	7.5	0.9	1.9
5	1976	80.7	110.1	120	181.8	234	234	0.2	6	0.8	1.7
6	1977	321.3	351	393.1	167.3	192.8	196.3	0.2	5	0.8	1.5
7	1978	127.2	152.6	193.9	166.7	198.4	278.7	0.2	4.3	0.8	1.3
8	1979	109.5	110.7	118.1	161.8	165.2	168.3	0.3	3.8	0.7	1.2
9	1980	148.9	185.2	174.4	151.3	154.6	189.8	0.3	3.3	0.7	1
10	1981	97.9	123.5	185.6	148.9	185.2	174.4	0.3	3	0.7	0.9
11	1982	161.8	165.2	168.3	143.4	165.8	171.6	0.4	2.7	0.6	0.8
12	1983	84.7	134.8	163	142.5	179.4	197.3	0.4	2.5	0.6	0.7
13	1984	142.5	179.4	197.3	140.2	145	161.1	0.4	2.3	0.6	0.6
14	1985	139.1	254.3	283.5	139.1	254.3	283.5	0.5	2.1	0.5	0.5
15	1986	140.2	145	161.1	137.1	160.1	297.2	0.5	2	0.5	0.4

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S.No	Year	Colombo -Maximum rainfall data			Descending order			P=m/(n+1)	T=1/P	Q=(1-P)	Y=-ln(-ln(Q))
		24 (hour)	48 (hour)	72 (hour)	24 (hour)	48 (hour)	72 (hour)				
16	1987	143.4	165.8	171.6	133.3	145.2	179.2	0.5	1.9	0.5	0.3
17	1988	116.3	125.3	140.1	131	135	139.6	0.6	1.8	0.4	0.2
18	1989	85.6	85.6	100.4	127.2	152.6	193.9	0.6	1.7	0.4	0.1
19	1990	137.1	160.1	297.2	116.3	125.3	140.1	0.6	1.6	0.4	0
20	1991	88.5	155.7	99.2	113.6	207.2	233.3	0.7	1.5	0.3	-0.1
21	1992	113.6	207.2	233.3	109.5	110.7	118.1	0.7	1.4	0.3	-0.2
22	1993	108.6	123.3	133.3	108.6	123.3	133.3	0.7	1.4	0.3	-0.3
23	1994	167.3	192.8	196.3	99	146.9	153.7	0.8	1.3	0.2	-0.4
24	1995	166.7	198.4	278.7	97.9	123.5	185.6	0.8	1.3	0.2	-0.5
25	1996	244.5	244.5	275.7	88.5	155.7	99.2	0.8	1.2	0.2	-0.6
26	1997	73	93.5	122	85.6	85.6	100.4	0.9	1.2	0.1	-0.7
27	1998	213.5	230.1	240.7	84.7	134.8	163	0.9	1.1	0.1	-0.8
28	1999	266.8	388.7	427.9	80.7	110.1	120	0.9	1.1	0.1	-1
29	2000	181.8	234	234	73	93.5	122	1	1	0	-1.2

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To find the rainfall depth equation for 24, 48 and 72 hours data for all three regions, the graph is plotted for reduced variate (-Ln (-Ln (q))) versus maximum rainfall depths is drawn from statistical analysis tables. Rainfall depth equation from Puttalam – 24 hour data is represented in Figure E1.

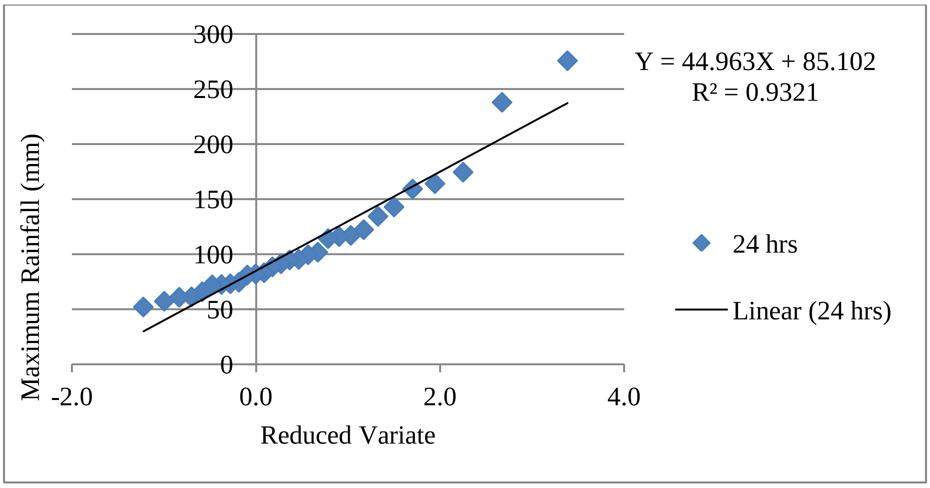

Figure E1: 24 hour data Gumbel Distribution for Puttalam

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Rainfall depth equation from Trincomalee – 24 hour data is represented in Figure E2.

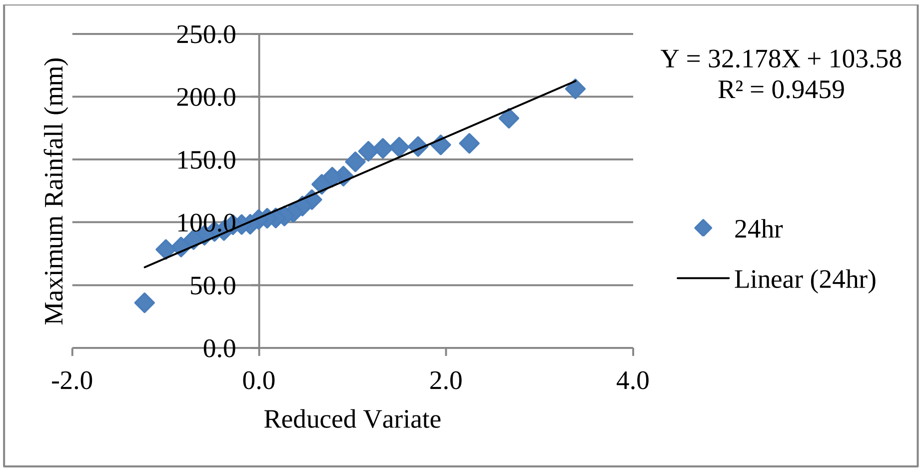

Figure E2: 24 hour data Gumbel Distribution for Trincomalee

Rainfall depth equation from Colombo – 24 hour data is represented in Figure E3.

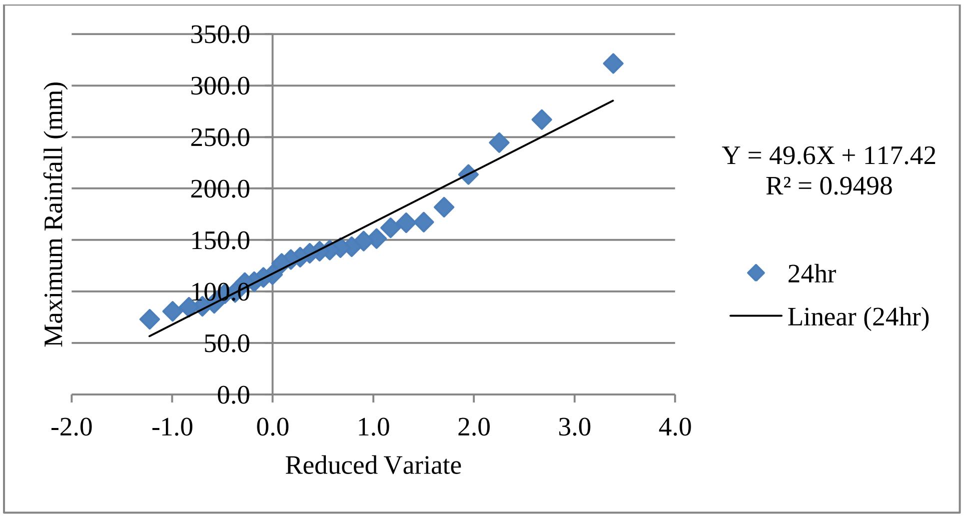

Figure E3: 24 hour data Gumbel Distribution for Colombo

Rainfall depth equation from Puttalam – 48 hour data is represented in Figure E4.

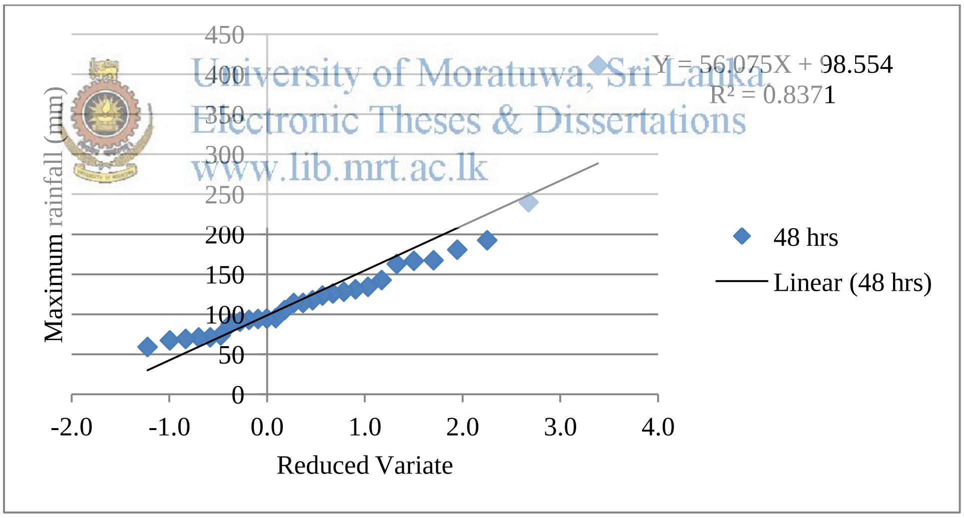

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Figure E4: 48 hour data Gumbel Distribution for Puttalam

Rainfall depth equation from Trincomalee – 48 hour data is represented in Figure E5.

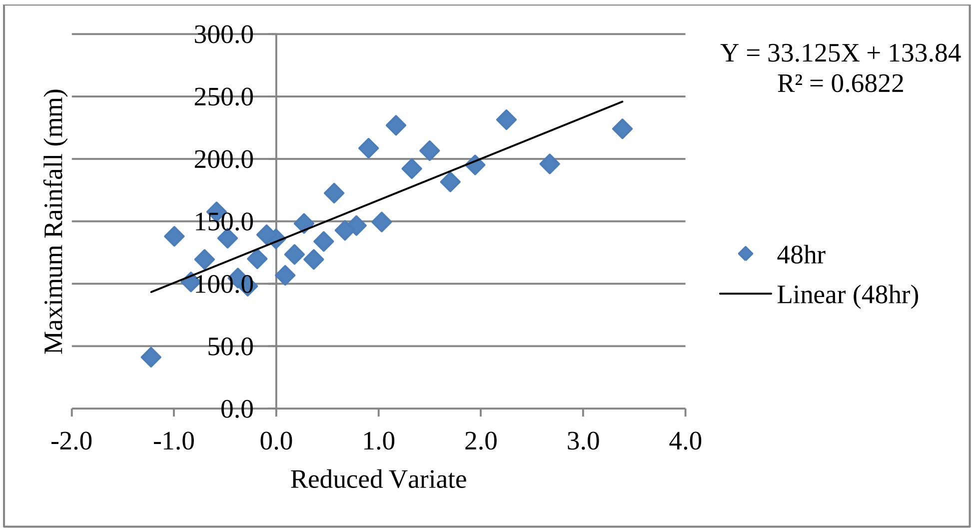

Figure E5: 48 hour data Gumbel Distribution for Trincomalee

Rainfall depth equation from Colombo – 48 hour data is represented in Figure E6.

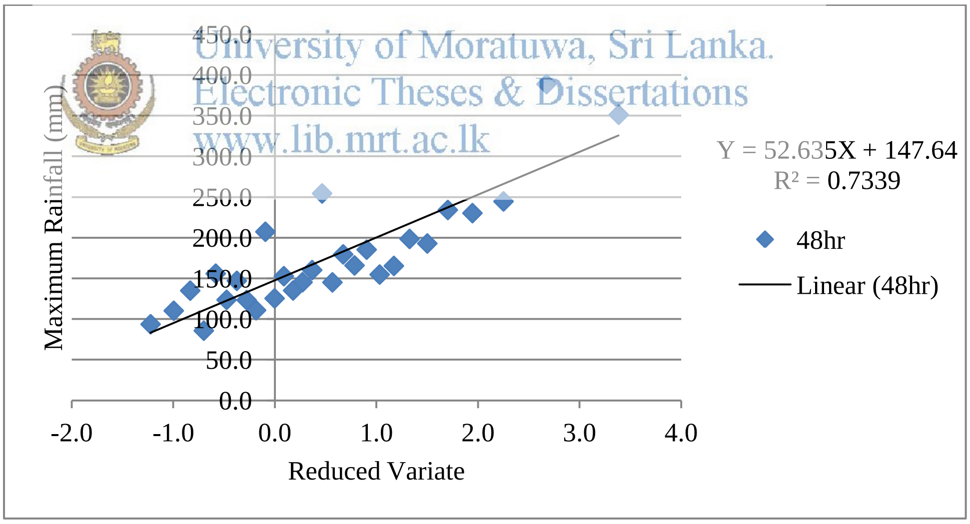

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Figure E6: 48 hour data Gumbel Distribution for Colombo

Rainfall depth equation from Puttalam – 72 hour data is represented in Figure E7.

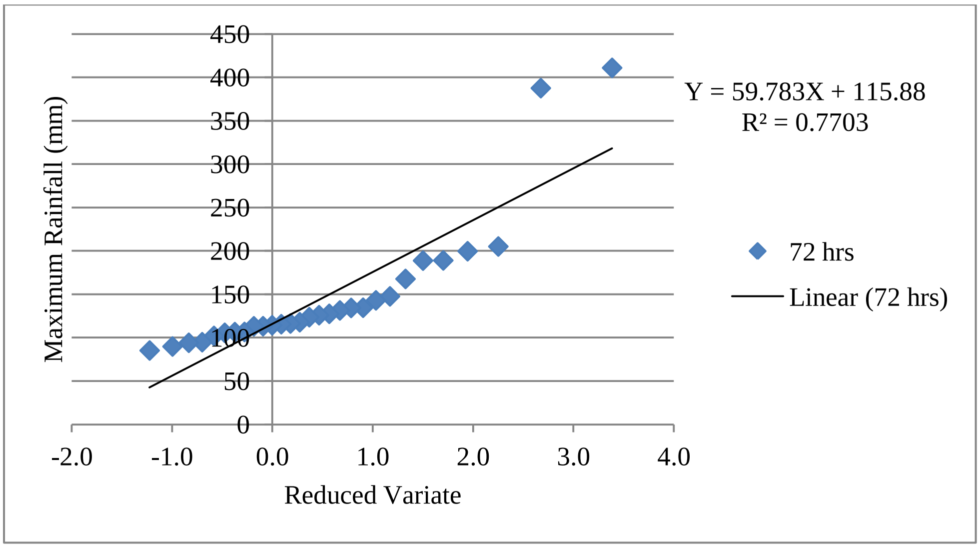

Figure E7: 72 hour data Gumbel Distribution for Puttalam

Rainfall depth equation from Trincomalee – 72 hour data is represented in Figure E8.

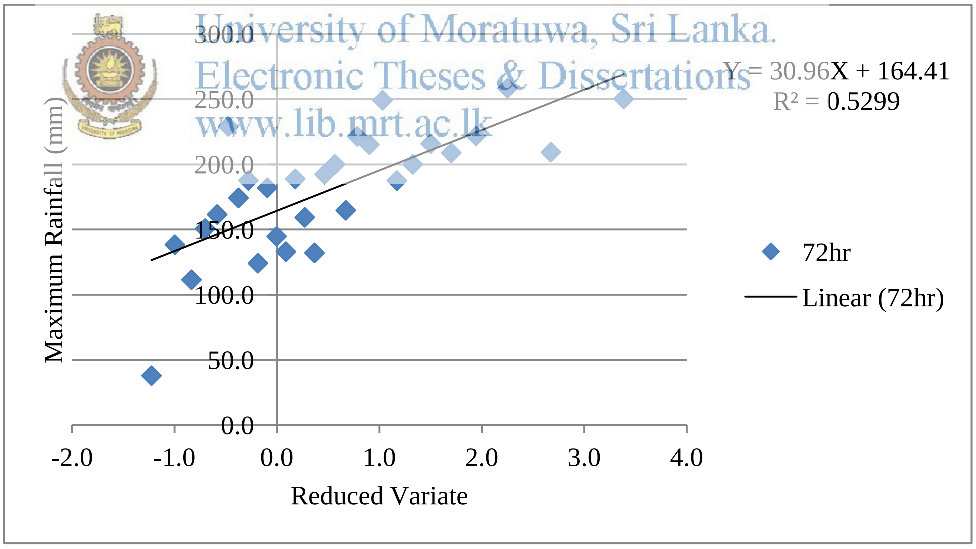

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Figure E8: 72 hour data Gumbel Distribution for Trincomalee

Rainfall depth equation from Colombo – 72 hour data is represented in Figure E9.

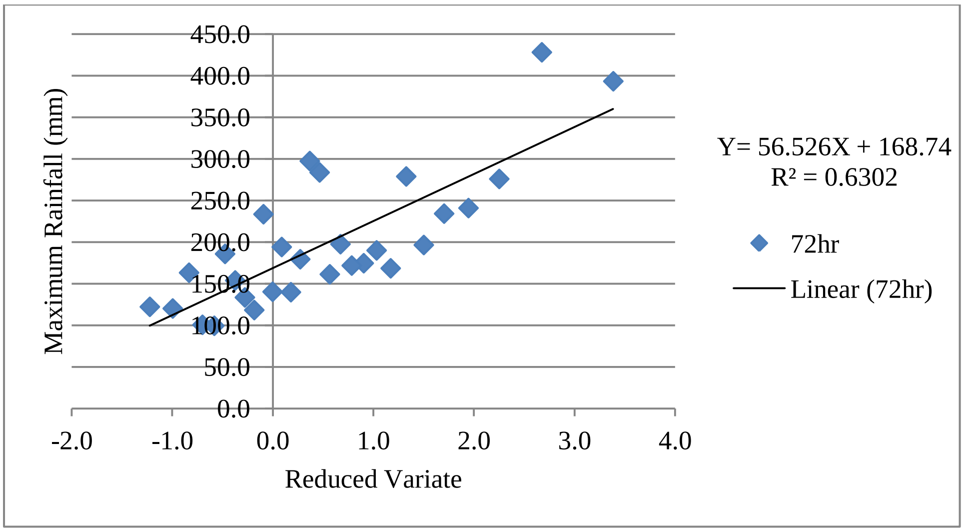

Figure E9: 72 hour data Gumbel Distribution for Colombo

Rainfall Depth

Rainfall depth equations of 24, 48, 72hours time period for Puttalam, Trincomalee and Colombo are summarized.

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Puttalam

Equation of trend line relevant to 24 hour duration:

$Y = 44.963 X + 85.102$ --------- (1a)

Equation of trend line relevant to 48 hour duration:

$Y = 56.075X + 98.554$ --------- (1b)

Equation of trend line relevant to 72 hour duration:

$Y = 59.783X + 115.88$ --------- (1c)

Trincomalee

Equation of trend line relevant to 24 hour duration:

$Y = 32.178 X + 103.58$ --------- (2a)

Equation of trend line relevant to 48 hour duration:

$Y = 33.125X + 133.84$ --------- (2b)

Equation of trend line relevant to 72 hour duration:

$Y = 30.96X + 164.41$ -------- (2c)

Colombo

Equation of trend line relevant to 24 hour duration:

$Y = 49.6\ X + 117.42$ -------- (3a)

Equation of trend line relevant to 48 hour duration:

$Y = 52.635\ X + 147.64$ -------- (3b)

Equation of trend line relevant to 72 hour duration:

$Y = 56.526X + 168.74$ -------- (3c)

Where Y = Rainfall in mm

X = Reduced variate = -Ln (-Ln (Q))

= -Ln (-Ln (1-P))

= -Ln (-Ln (1-1/T))

\

Computations relevant to 24 hour, 48 hour and 72 hour duration for Puttalam by using equations 1a, 1b, and 1c are represented in Table E7.

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Table E7: Rainfall Depth - Puttalam

Return period (T)	P	Q=1-P	Reduced Variate, X=-ln(-ln(q))	24 (hour)	48 (hour)	72 (hour)
				Rainfall Depth (mm)		
				Y=44.963X+85.102	Y=56.075X+98.554	Y=59.783X+115.88
2	0.5	0.5	0.37	101.58	119.11	137.79
5	0.2	0.8	1.5	152.54	182.66	205.55
10	0.1	0.9	2.25	186.29	224.74	250.41
25	0.04	0.96	3.2	228.92	277.91	307.1
50	0.02	0.98	3.9	260.54	317.36	349.15

Computations relevant to 24 hour, 48 hour and 72 hour duration for Trincomalee by using equations 2a, 2b, and 2c are represented in Table E8.

Table E8: Rainfall Depth - Trincomalee

Return period (T)	P	Q=1-P	Reduced Variate, X=-ln(-ln(q))	24 (hour)	48 (hour)	72 (hour)
				Rainfall Depth (mm)		
				Y=32.178X+103.58	Y=33.125X+133.84	Y=30.96X+164.41
2	0.5	0.5	0.37	115.38	145.99	175.77
5	0.2	0.8	1.5	151.86	183.54	210.86
10	0.1	0.9	2.25	176	208.39	234.09
25	0.04	0.96	3.2	206.51	239.8	263.45
50	0.02	0.98	3.9	229.15	263.1	285.22

Computations relevant to 24 hour, 48 hour and 72 hour duration for Colombo by using equations 3a, 3b, and 3c are represented in Table E9.

Table E9: Rainfall Depth - Colombo

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Return period (T)	P	Q=1-P	Reduced Variate, X=-ln(-ln(q))	24 (hour)	48 (hour)	72 (hour)
				Rainfall Depth (mm)		
				Y=49.6X+117.42	Y=52.635X+147.64	Y=56.526X+168.74
2	0.5	0.5	0.37	135.6	166.93	189.46
5	0.2	0.8	1.5	191.82	226.59	253.53
10	0.1	0.9	2.25	229.04	266.09	295.94
25	0.04	0.96	3.2	276.07	315.99	349.54
50	0.02	0.98	3.9	310.96	353.02	389.3

Rainfall Intensity

The above rainfall depths were converted into rainfall intensity and graphs are plotted for time period versus rainfall intensity for all three regions. Conversion of rainfall depth into rainfall intensity for Puttalam is represented in Table E10.

Table E10: Rainfall intensity for Puttalam

Return period (T)	P	Q=1-P	Reduced Variate	Rainfall Intensity		
			X=-ln(-ln(q))	24 (hour)	48 (hour)	72 (hour)
2	0.5	0.5	0.37	4.23	2.48	1.91
5	0.2	0.8	1.5	6.36	3.81	2.85
10	0.1	0.9	2.25	7.76	4.68	3.48
25	0.04	0.96	3.2	9.54	5.79	4.27
50	0.02	0.98	3.9	10.86	6.61	4.85

Graph of duration versus rainfall intensity for Puttalam is represented in Figure E10.

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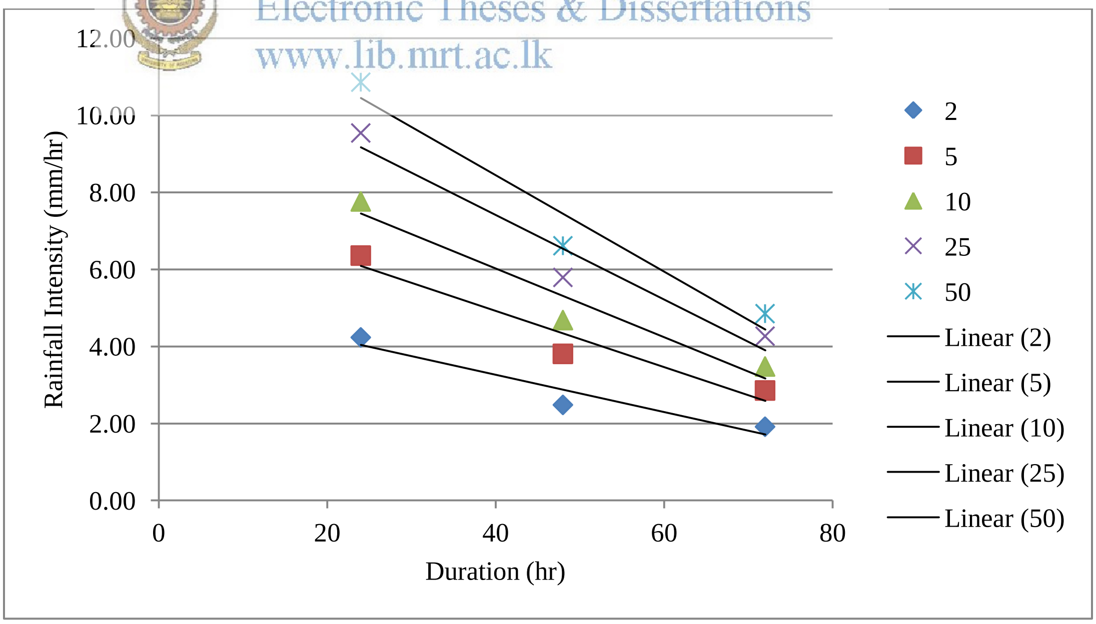

Figure E10: Rainfall Intensity Frequency curve - Puttalam

Conversion of rainfall depth into rainfall intensity for Trincomalee is represented in Table E11.

Table E11: Rainfall intensity for Trincomalee

Return period (T)	P	Q=1-P	Reduced Variate	Rainfall Intensity		
			X=-ln(-ln(q))	24 (hour)	48 (hour)	72 (hour)
2	0.5	0.5	0.37	4.81	3.04	2.44
5	0.2	0.8	1.5	6.33	3.82	2.93
10	0.1	0.9	2.25	7.33	4.34	3.25
25	0.04	0.96	3.2	8.6	5	3.66
50	0.02	0.98	3.9	9.55	5.48	3.96

Graph of duration versus rainfall intensity for Trincomalee is represented in Figure E11.

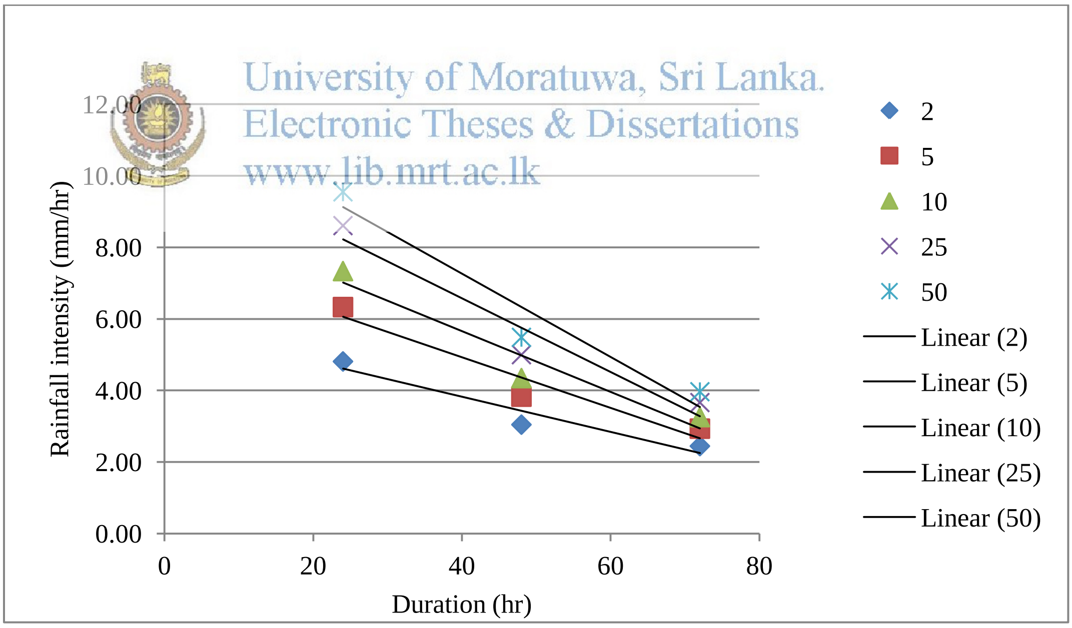

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Figure E11: Rainfall Intensity Frequency curve – Trincomalee

Conversion of rainfall depth into rainfall intensity for Colombo is represented in Table E12.

Table E12: Rainfall intensity for Colombo

Return period (T)	P	Q=1-P	Reduced Variate	Rainfall Intensity		
			X=-ln(-ln(q))	24 (hour)	48 (hour)	72 (hour)
2	0.5	0.5	0.37	5.65	3.48	2.63
5	0.2	0.8	1.5	7.99	4.72	3.52
10	0.1	0.9	2.25	9.54	5.54	4.11
25	0.04	0.96	3.2	11.5	6.58	4.85
50	0.02	0.98	3.9	12.96	7.35	5.41

Graph plotted against duration versus rainfall intensity for Colombo is represented in Figure E12.

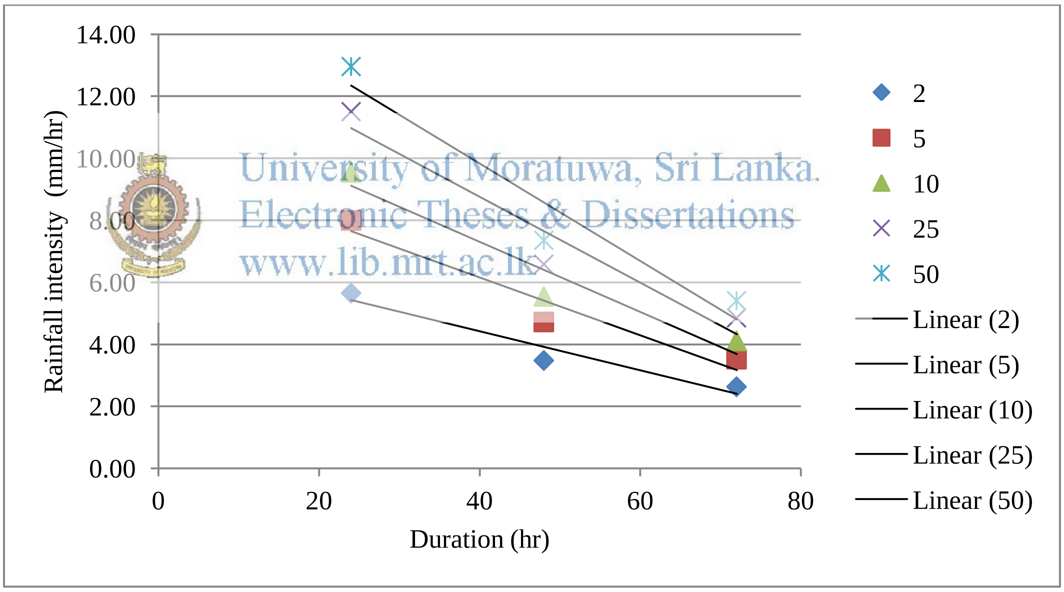

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Figure E12: Rainfall Intensity Frequency curve – Colombo

The same graphs were plotted in log scale for the purpose of approximating those curves to straight lines and deriving the equations of trend lines for interpolation and extrapolation are represented as Figure E13, Figure E14 and Figure E15.

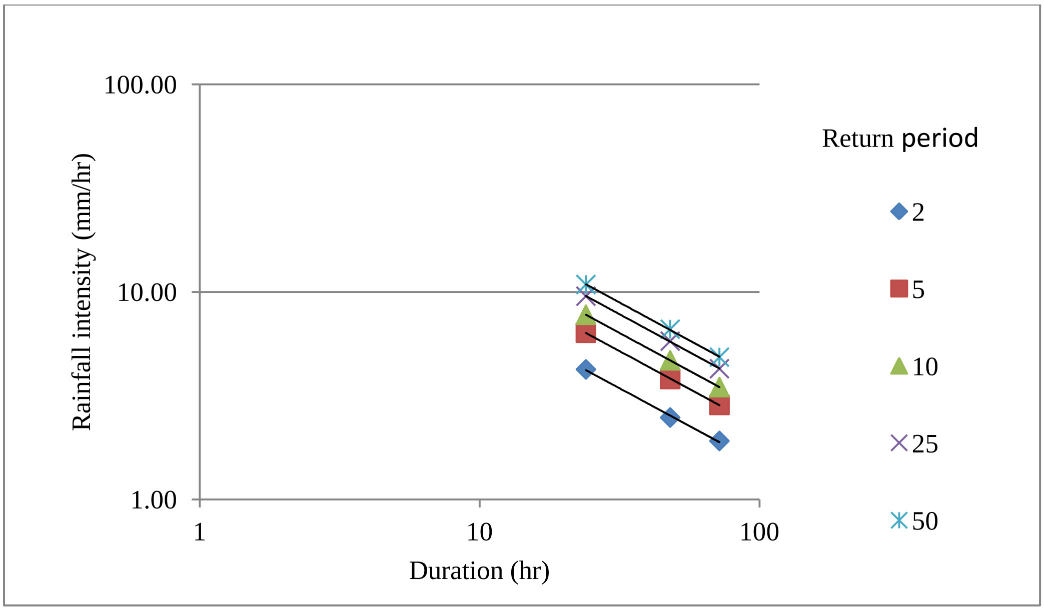

Figure E13: Logarithmic graph of Rainfall Intensity Frequency Curves - Puttalam

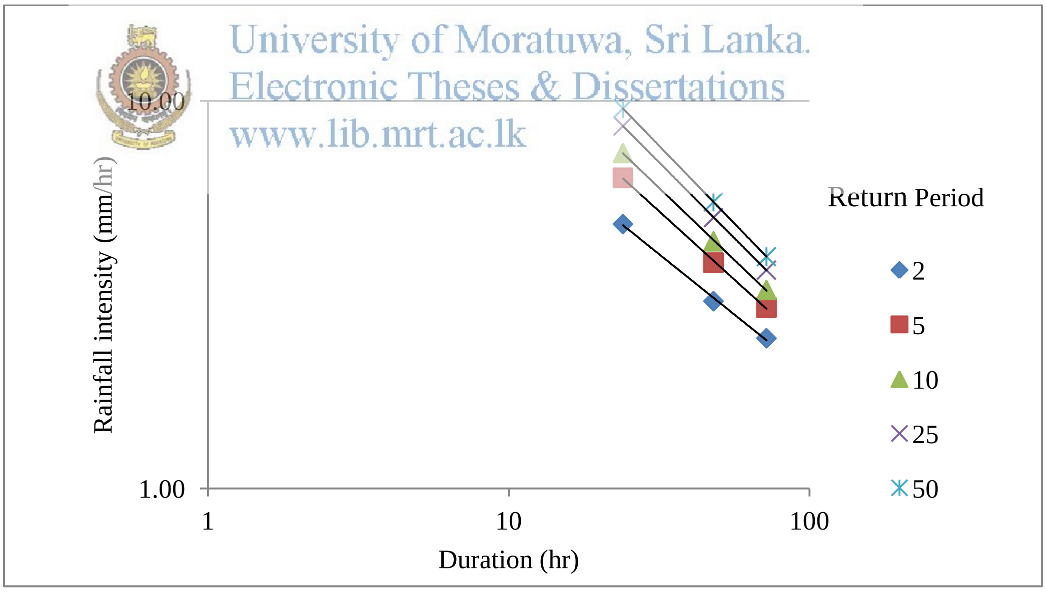

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Figure E14: Logarithmic graph of Rainfall Intensity Frequency Curves – Trincomalee

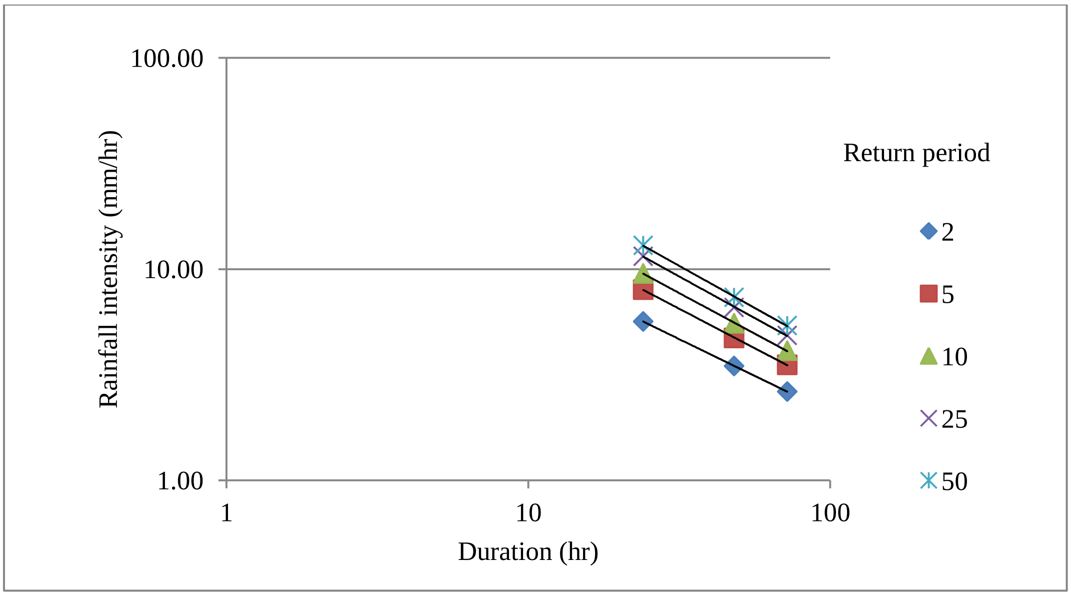

Figure E15: Logarithmic graph of Rainfall Intensity Frequency Curve – Colombo

The equation retrieved from the IDF curve of Puttalam for the return periods are

2 years return period, $Y = 42.407*X^{-0.728}$

5 years return period, $Y = 64.504*X^{-0.73}$

10 years return period, $Y = 79.141*X^{-0.731}$

25 years return period, $Y = 97.639*X^{-0.731}$

50 years return period, $Y = 111.360*X^{-0.732}$

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Rainfall depth of Puttalam calculated from the above equation of Rainfall intensity is represented in Table E13.

Table E13: Rainfall depth of Puttalam

Return period	Data Hour	Rainfall Intensity (mm/hr)	Rainfall Depth (mm)
25		$Y=97.639*X^{-0.731}$	
	24	9.57	229.56
	48	5.76	276.62
50		$Y=111.36*X^{-0.732}$	
	24	10.87	260.99
	48	6.55	314.27

The equation retrieved from the IDF curve of Trincomalee for the return periods are

2 years return period, $Y = 34.41X^{-0.622}$

5 years return period, $Y = 59.016X^{-0.704}$

10 years return period, $Y = 77.341X^{-0.742}$

25 years return period, $Y= 102.21X^{-0.779}$

50 years return period, $Y= 121.64X^{-0.801}$

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Rainfall depth of Trincomalee calculated from the above equation of Rainfall intensity is represented in Table E14.

Table E14: Rainfall depth of Trincomalee

Return period	Data Hour	Rainfall Intensity (mm/hr)	Rainfall Depth (mm)
25		$Y=102.21*X^{-0.779}$	
	24	8.57	205.66
	48	4.99	239.53
50		$Y=121.64*X^{-0.801}$	
	24	9.51	228.22
	48	5.45	261.8

The equation retrieved from the IDF curve of Trincomalee for the return periods are

2 years return period, $Y = 51.571^{-0.696}$

5 years return period, $Y = 85.803^{-0.748}$

10 years return period, $Y = 109.45^{-0.769}$

25 years return period, $Y = 139.98X^{-0.787}$

50 years return period, $Y = 162.95X^{-0.798}$

Rainfall depth of Colombo calculated from the above equation of Rainfall intensity is represented in Table E15.

Table E15: Rainfall depth of Colombo

Return period	Data Hour	Rainfall Intensity (mm/hr)	Rainfall Depth (mm)
25		$Y=139.98*X^{-0.787}$	
	24	11.48	275.46
	48	6.65	319.28
50		$Y=162.95*X^{-0.798}$	
	24	12.9	309.64
	48	7.42	356.18

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Rainfall intensity values for Puttalam, Trincomalee and Colombo from recent rainfall data were analysed based on daily rainfall data from the past 29 years.

The updated rainfall Intensity – Duration – Frequency (IDF) curves for the three regions were compared with the values derived based on the IDF curves in the Irrigation Department guidelines and found to be vary in the range of minimum of 5% up to a maximum 20% positive increment.

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