RAINWATER HARVESTING SYSTEMS

A THESIS SUBMITTED TO
THE FACULTY OF ARCHITECTURE AND ENGINEERING
OF
EPOKA UNIVERSITY

BY

EVA KOÇI

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
WATER RESOURCES ENGINEERING

JULY, 2022

Approval sheet of the Thesis

This is to certify that we have read this thesis entitled **"Rainwater harvesting systems"** and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

____

Dr. Erion Luga
Head of Department
Date: July, 14, 2022

Examining Committee Members:

Dr. Erion Luga	(Civil Engineering)	________________
Assoc. Prof. Dr. Mirjam Ndini	(Civil Engineering)	________________
Prof. Dr. Hüseyin Bilgin	(Civil Engineering)	________________

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Surname: Eva Koçi

Signature: ______________

ABSTRACT

RAINWATER HARVESTING SYSTEM

Eva Koçi
M.Sc., Department of Civil Engineering
Supervisor: Dr. Mirjam Ndini

Rainwater is a key component in the water cycle and the main cause of floods. With climate change, it has become more and more important not only to prevent the negative effect of the flood but to ensure a sustainable source of water. Therefore, several measures are being taken such as storm water management and identifying alternative water sources such as rainwater harvesting, greywater, and wastewater reuse and desalination. One of most profitable measures is rainwater (stormwater harvesting). Rainwater captured from roof catchments is the easiest and most common method used to harvest rainwater.

In this study will be explained what is rainwater harvesting, why is it important, what is the rainwater harvesting technology and its components and how the collected water can be used in case study in Tirana. For this scope, various literature and research papers are used as the base of this study and programs such as AutoCad and Excel.

As for the case study a perfect example is Air Albania stadium due its roof size and multipurpose use of its spaces.

Keywords: *Rain, Rainwater, Stormwater, Rainfall data, Harvesting rainwater, Drainage systems, Roof drainage, Water collection*

ABSTRAKT

SISTEMI I MBLEDHJES SE UJRAVE TE SHIUT

Koçi, Eva

Master Shkencor, Departamenti i Inxhinierisë së Ndërtimit

Udhëheqësi: Dr. Mirjam Ndini

Uji i shiut është një komponent kyç në ciklin e ujit dhe shkaku kryesor i përmbytjeve. Me ndryshimin e klimës, është bërë gjithnjë e më e rëndësishme jo vetëm parandalimi i efektit negativ të përmbytjeve, por sigurimi i një burimi të qëndrueshëm uji. Prandaj, po ndërmerren disa masa si menaxhimi i ujërave të shiut dhe identifikimi i burimeve alternative të ujit si mbledhja e ujërave të shiut, ujërat gri dhe ripërdorimi dhe shkripëzimi i ujërave të zeza. Një nga masat më fitimprurëse është uji i shiut (grumbullimi i ujërave të stuhisë). Uji i shiut i marrë nga ujëmbledhësit e çatisë është metoda më e lehtë dhe më e zakonshme që përdoret për të mbledhur ujin e shiut.

Në këtë studim do të shpjegohet se çfarë është mbledhja e ujit të shiut, pse është e rëndësishme, cila është teknologjia e grumbullimit të ujit të shiut dhe përbërësit e saj dhe si mund të përdoret uji i grumbulluar në nje rast rast konkret studimi në Tiranë. Për këtë qëllim, literaturë dhe punime të ndryshme kërkimore janë përdorur si bazë e këtij studimi dhe programe si AutoCad, Revit dhe Excel. Për sa i përket rastit të studimit, një shembull i përsosur është stadiumi Air Albania për shkak të sipërfaqes së madhe të çatisë dhe përdorimit shumëfunksional të hapësirave të tij.

Fjalët kyçe: *Shi, ujë shiu, ujë stuhish, të dhëna për reshjet, grumbullimi i ujërave të shiut, sistemet e kullimit, kullimi i çatisë, grumbullimi i ujit*

Dedicated to my family.

ACKNOWLEDGEMENTS

The realization of this thesis is the fruit of a wide collaboration of people without whom it would not be possible.

I would first like to thank my supervisor, Assoc. Prof. Dr. Mirjam Ndini, whose expertise was invaluable in formulating the research questions and methodology.Your advices, help and patience are the main pillars of this thesis. Thank you for everything.

I want to thank the colleagues of Gener 2 sh.p.k, in particular my colleague and good friend Eng. Klajd Bono for his continuous help and support.

And last but not least, I want to thank my family. You have been and are still the support and motivation to move forward.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF GRAPHS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Water is one of the most integral and important aspects of daily life for every human being, for example, food, clothing, and almost everything else humans interact with involves water. Therefore, water and water security are going to be a crucial focus for governments in the next few decades, especially since the population is expected to grow exponentially. Water, and specifically liquid water, is a key factor in the creation and sustenance of life. Mankind has been and remains connected to water and its resources. Since the beginning of civilization, man has built settlements near water sources, thus creating an inevitable dependence. But as the population has grown, the quality of life and industrialization is increased, the demand for water has increased to when at the same time its resources are reduced. As the global population is expected to keep growing in the coming decades, the negative impact that humans will have on earths finite resources, especially water, will become increasingly apparent as areas of the world will start to experience drastic shortages of water, leading to instability in food production, industry, etc.,

In order to meet the demand for water there is a need to find other water resources, to provide water management techniques, newer and more efficient technology to conserve as much water as possible as well as the management and reuse of existing ones.

Also one of the most important benefits of rainwater collection is the Environmental benefit. Rainwater harvesting is a great way to:

- Protect the local watershed
- Restore the hydrologic cycle
- Recharge groundwater
- Mitigate impacts of climate change

Rainwater collection and conservation for further use is one of the oldest and most economical forms of water source.

Further in this study will be examined the technology used for rainwater collection, the necessary calculations for estimating the volume of water and the ways of using the collected water.

1.2 Thesis Objective

Controlling and using in the best way possible the rainfall water is the main objective of this thesis. During thesis development will be introduced the technology used for rainwater harvesting, the elaboration of rainfall data, and the calculation steps for a rainfall harvesting system of the Air Albania stadium.

1.3 Scope of works

The scope of this study is to estimate the rainfall water quantity that can be collected from a roof and the use of it in irrigation of football pitch of Air Albania Stadium. Putting into practice the calculation methods for rainwater collection explained in various literature and studies done by researchers and engineers from different parts of the world have been used. The objective is not only to collect the rainwater but also to store it and use it in most efficient way to meet the needs and decrease the costs of irrigation. For this reason, the rainfall data in the area of Tirana city will be analyzed, an assessment will be made of the possible amount of water that can be collected and what needs this amount of water can meet.

Furthermore, a feasibility economical study will be presented to show in principle the benefit of this technology.

In simple and funny words, this thesis objective motto will be: *Slow it, Spread it, Sink it, Store it!* as the opposite of *Pump it, Pipe it, Pollute it!*

1.4 Organization of the thesis

This thesis is divided in 5 chapters. The organization is done as follows:

In Chapter 1, introduction, problem statement, thesis objective and scope of works is presented. Chapter 2, includes the literature review and basic guide line for planning and designing a rainwater harvesting system. Chapter 3, consists of the methodology followed in this study. In Chapter 4 are presented the experimental results and discussions. And finally in Chapter 5, conclusions and recommendations for further research are stated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Reducing the runoff from storm events via rainwater harvesting strategies provides benefits to property owners, including lower municipal fees and larger developable site area, and contributes to the big-picture goal of reducing the impact of urbanization on receiving water bodies. Rainwater collection is becoming one of the many tools used by sustainable design professionals.

The aim of rainwater harvesting is to concentrate runoff and collect it in a basin or cistern to be stored for future use. Rainwater captured from roof catchments is the easiest and most common method used to harvest rainwater. RWH primarily consists of the collection, storage and subsequent use of captured rainwater, either as the principal or supplementary source of water. It is applicable both for potable and non-potable purposes. Projects throughout the world are demonstrating that rainwater collection systems can solve some of our water-related problems. Rainwater systems are meeting the challenges of water conservation while demonstrating the effectiveness of alternative nontraditional water supplies.

By designing the site and building as a complete system for water storage and use, designers can conserve water resources, save energy, and reduce the cost to community treatment facilities.

New technologies and a better understanding of these “new water sources” allow the designer to use these natural resources as part of the integrated design of commercial buildings. India, Malaysia, Germany, Australia, New Zealand, Bermuda, and many countries in the Caribbean are and have been harvesting rainwater for both potable and non-potable water sources. [1]

2.2 Rainwater harvesting systems

Rainwater harvesting systems are systems divided in components and each of them plays specific role to serve the final goal. Further will be explained every component and guidelines for their calculation.

There are numerous identified benefits of water catchment from either rooftop or ground level:

- It provides a self-sufficient water supply located close to the user.
- It reduces the need for, and\ hence the cost of, pumping groundwater.
- It provides high-quality soft water that is low in mineral content.
- It augments the supply and improves the quality of groundwater when it reaches the aquifer after it has been applied to the landscape or crops.
- It reduces and may even eliminate soil salts as it dissolves and moves the salts down through the soil.
- It mitigates urban flooding and, as a result, reduces soil erosion in urban areas.
- Rooftop rainwater harvesting is usually less expensive than other water sources.
- Rooftop rainwater harvesting systems are easy to construct, operate, and maintain.
- In coastal areas where salt water intrusion into the aquifer is a problem, rainwater provides good quality water, and when recharged to groundwater, reduces groundwater salinity while helping to maintain a balance between the fresh and saline water interface.
- Occasionally, there are economic advantages such as rebates from municipalities for a reduction in use and dependency on municipal water (not in Albania). [2]

Rainwater harvesting consists in 6 (six) components depending on the required quality (fig 1)**.** [1]

1) Catchment area

The catchment area is the surface upon which the rain falls. It may be a roof or impervious pavement and may include landscaped areas.

2) Conveyance

Are channels or pipes that transport the water from catchment area to storage.

3) Filtration

Are the systems that filter and remove contaminants and debris. This includes first-flush devices

4) Storage

Are cisterns or tanks where collected rainwater is stored.

5) Distribution

Is the system that delivers the rainwater, either by gravity or pump.

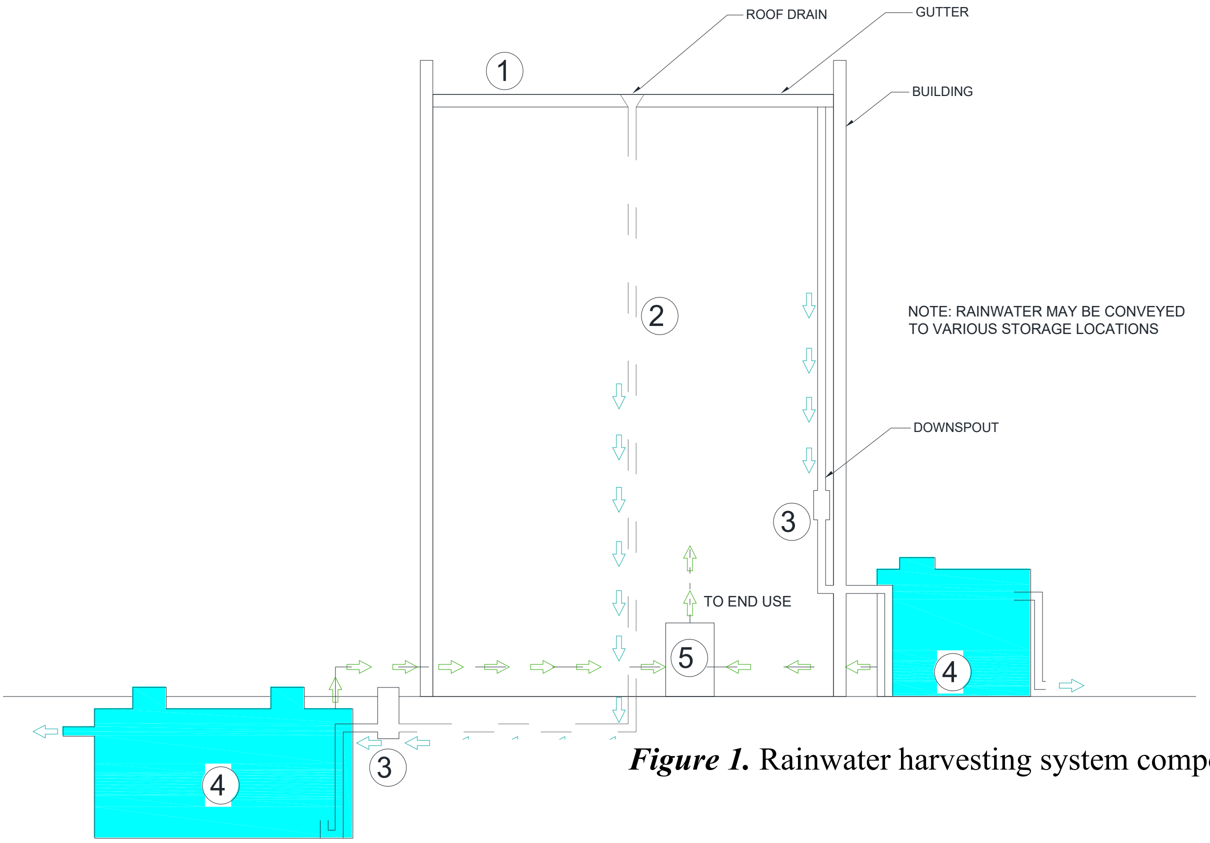


Figure 1. Rainwater harvesting system components

6) Purification

Purification includes filtering equipment, distillation, and additives to settle, filter, and disinfect the collected rainwater. Purification is only required for potable systems and would typically occur prior to distribution

2.2.1. Collection/Catchment Surface (Roof or Other)

The roof of the building is the primary collection surface and essentially serves to protect the building and its occupants from climatic factors. With rainwater harvesting systems, the roof can collect and utilize one of those factors (rain) as a valuable resource.

Typical roofing surfaces include the following:

- Metal (Steel: Galvanized, Painted, Stainless, Terne-Coated, Aluminum, and Copper)
- Membrane: Including modified bitumen, EPDM, PVC, polyester (some with insulation and aggregate ballast)
- Asphalt/fiberglass shingles (typically fine aggregate surface)
- Wood shingles
- Roll roofing (may have fine aggregate surface)
- Built-up roofing
- Slate
- Tiles: Clay and Concrete
- Glass/plastic/fiberglass panels
- Green roof: Typically membrane-covered with growing media and plant [1]

The total amount of water that is received in the form of rainfall over an area is called the rainwater **endowment** of that area. The actual amount of rainwater that can be effectively harvested from the rainwater endowment is called the **rainwater harvesting potential**. Rainwater yields vary with the size and texture of the catchment area. A maximum of 90 percent of a rainfall can be effectively captured through.

The quality of the captured rainwater depends, in part, upon catchment texture: the best water quality comes from the smoother, more impervious catchment or roofing materials. Captured rainwater quality is also determined by rainfall pattern and frequency. Both the greater the storm event, i.e., the rainfall extent and the quantity of rain that falls, and the shorter the time between storms influence the cleanliness of the catchment area. Greater rainwater volumes and frequencies will transport fewer pollutants to the first-flush device [2]

2.2.2. Conveyance (Gutters and Downspouts)

Rainwater is typically conveyed from the collection surface (roof) to a storage tank or cistern in two ways: [1]

1. A sloped roof typically drains to gutters and downspouts at the outer edges(s) of the building envelope. Scuppers, oversized gutters, and other methods are employed for overflow protection.

2. A flat or semi flat roof may use roof area drains that connect to leaders (downspouts).

These leaders penetrate the roof, and flow either overhead to the exterior or down and then under the floor to the building's exterior. Gravity-drained (fig.2) and siphonic pipes (fig.3) then convey the water down to the storage vessel. Scuppers or unobstructed roof edges are typically used for overflow protection.

Siphonic roof drains are carefully engineered systems that use a siphonic action to convey water instead of gravity. The siphonic action of a drainpipe running full of water is used to create suction that pulls the water into the storage tank.

The advantages of this type of roof drainage for flat or semi flat roofs are:

- Horizontal runs within the building envelope can be run with smaller-diameter pipes.
- These runs can be almost level until they are tied into the vertical leaders of the roof drain system.

Siphonic systems are usually preferred over gravity systems for roof areas of 500m² and above. The larger the roof area and the higher the roof, the bigger the advantages of siphonic systems. [3]

There are two types of conveyance systems, wet and dry. A wet system involves downspouts that lead to a storage system where standing water is maintained; downspouts run down the wall and underground and then up into the tank. In a dry system, the downspouts drain down into the storage system, thus eliminating any standing water in the conveyance system after a rain event [2]

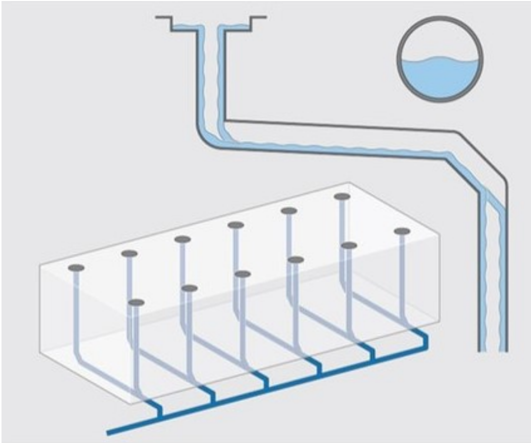


Figure 3. Gravity drained system

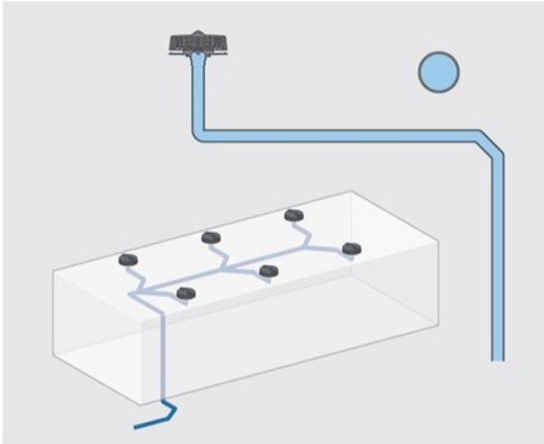


Figure 2. Siphonic system

2.2.3. Pre-storage Filtration and Debris Exclusion

Inlet filtration, pre-storage filtration is the element responsible for removing a number of contaminants from rainwater prior to storage.

Typical contaminants that cause problems include the following:

- Leaf litter, branches, other plant debris
- Bird, rodent, and insect droppings
- Bird, rodent, and insect carcasses
- Trash
- Dirt and pollen
- Pollution particulates
- Degrading roof materials

The primary types of devices include downspout filters, basket-type filters (Fig.4), centrifugal-type filters (Fig.5), and cascading-type filters (Fig.6)

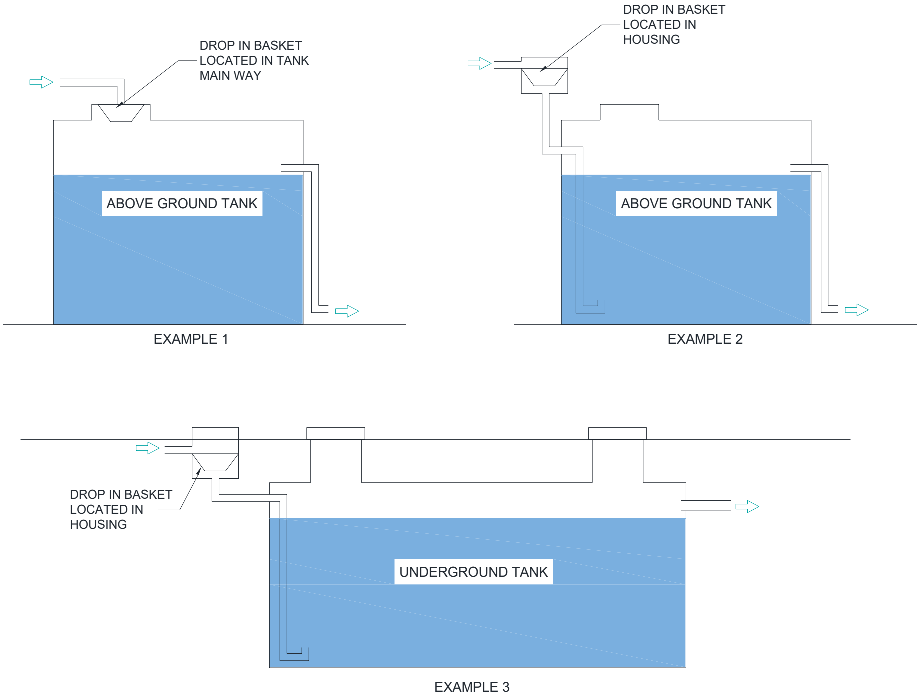
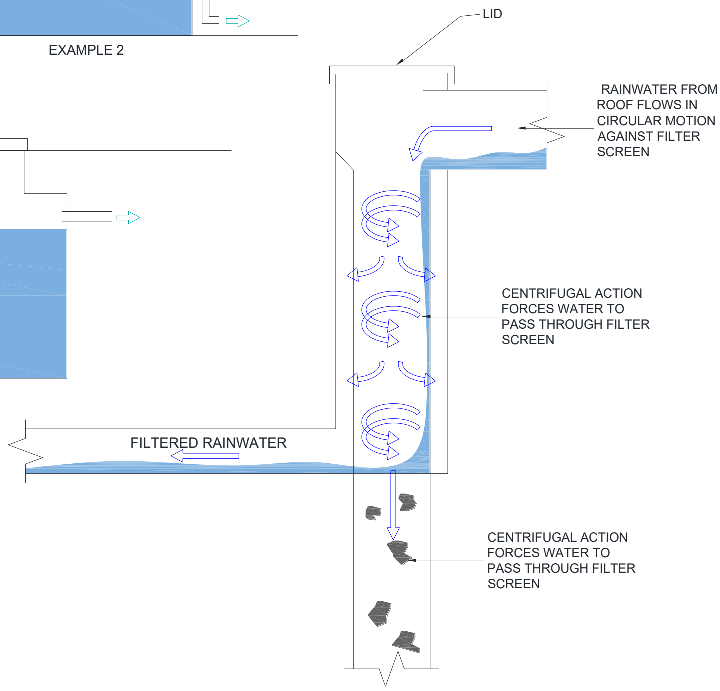
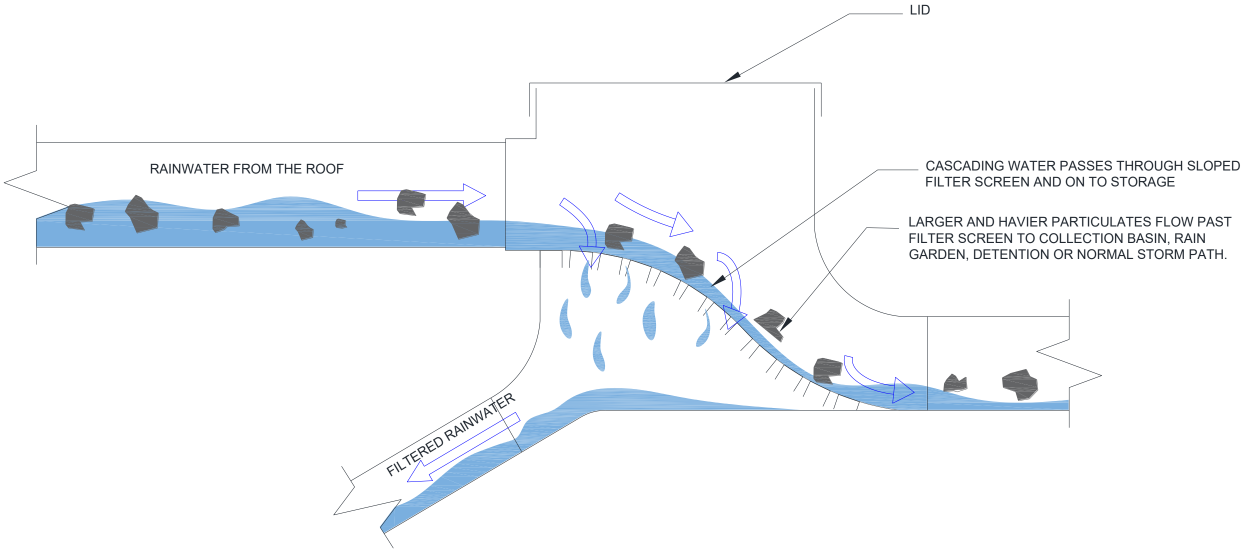


Figure 4. Basket-type filters





2.2.4. Storage

The terms "storage (unit)," "tank," and "cistern" refer to the same thing. While the tank is the largest component of storage, there are numerous supporting components that are fundamental to the functioning of this element. [1]

The components of a storage system include the following (Fig.7):

1. Tank
2. Rainwater Inlet from Conveyance

- May enter the tank from top, side, or bottom via riser

3. Calming Inlet

- Minimizes disturbance of sediment at bottom of tank by reducing agitation from the incoming water
- Incoming water provides aeration

4. Intake (Extractor)

- Provides extraction of water from a location below top surface. Generally, higher water quality is found below the top surface and above the very bottom of the tank. A floating screen inlet reduces vortexing and the introduction of air into the pumping system.
- An alternative is to provide a fixed intake with a screen (to reduce vortexing) placed a minimum of 6–8 inches above the bottom of the tank.

5. Water to Distribution

- Rainwater from storage flow to distribution
- Submersible pumps typically used in belowground tanks
- Flooded-suction pumps preferred in aboveground tanks

6. Water Level Indicator

- Device to monitor water level in tank and communicate with components in distribution
- Types include floating or electronic based

7. Overflow

- Excess water flows out of tank to grade, stormwater sewer, stormwater control devices, or other appropriate path per local requirements/system goals

8. Vent

- Provides ventilation for stored water and pressure relief from incoming water

9. Tank Access

- Should be secured to prevent unauthorized access
- Access from low ground tanks should be minimum 4 inches above surrounding grade

Figure 7. Components of a storage system

2.2.5. Distribution

Distribution is the element responsible for delivering water with the appropriate quality and pressure. [1]

Stored rainwater may be conveyed or distributed by gravity or by pumping [2].

Distribution is affected by factors such as location of the tank, location of the control station, and the water supply expected from the rainwater system.

Typical components of Distribution include:

1) Pressurization:

A pump provides pressurization on the downstream side of storage.

2) Filtration:

The main post-storage filter types used in rainwater harvesting systems are fine-mesh screen filters, bag filters, cartridge filters, and membrane filters. The purpose is to remove particles in the water including silts, clays, organic particles, microorganisms, and various compounds that may have formed in storage.

3) Disinfection:

Further improvement of water quality is provided through disinfection techniques.

4) Controller:

Multiple relationships between various components on the pressure side of storage must be managed in an operating rainwater system.

A program controller monitors and manages various functions such as:

- Water level in tank (supply)
- Demand from end use
- Backup/makeup supply
- Pressure differentials on filters that might indicate maintenance is needed
- Other maintenance data points

5) Automatic Protected Bypass

In the event of low cistern water levels or mechanical failure, a means of allowing water to flow from the backup source (usually the municipal cold-water supply) to the end use is mandatory.

6) Makeup Supply

The term “makeup supply” implies the refilling of a tank or vessel.

2.3. Calculation steps

In the first part it was explained what and how a rainwater harvesting system works and all its components. Further it is explained the according procedure of designing a rainwater harvesting system and all the calculation steps involved.

The main literature in which I’m based are [4] [5] and [6]

Design procedure should go through the following data calculation [6]

1) Rainfall data
2) Effective catchment area
3) Design flow loads
4) Capacity of freely-discharging gutters
5) Outlets from gutters
6) Rainwater pipes and drains inside building
7) Siphonic system (If used)

2.3.1. Rainfall data

The values of rainfall intensities ***r***, in EN 12056-3, are expressed in unit l/s per m² of effective catchment area on which the rain falls [7]

The value or r can be related to the corresponding rainfall intensity r_0 in mm/h by the formula:

$$r_0 = 3600r \qquad \text{(Equation 1)}$$

The design rainfall intensity to be used for sizing a rainwater system depends on three factors:

1. The duration of the rainfall event (D, in minutes)
2. The geographical location of the building
3. The return period of the event (T, in years)

Design of rainfall duration

Shorter the duration of the considered event the higher will be the value of the design rainfall intensity but it is necessary to consider also the time of concentration Tc of the drainage system.

Time of concentration is the time for rain falling on the most upstream of the roof to reach the outlet. If the time of concentration is greater than the design rainfall duration D the flow rate at the outlet will not reach the maximum value that can be produced. For design purposes the worst case is taken when D is equal to Tc.

Risk and return period

The degree of risk is defined as probability P_R that a particular design rainfall intensity will be exceeded in the life of the building. The value of P_R can vary from 0 to 1. The risk that the intensity of a storm with return period of T will be exceeded within the design life L_Y

$$\mathrm{T} = \frac{1}{1-(1-\mathrm{P_R})^{\alpha}} \qquad \text{(Equation 2)}$$

Where

$$\alpha = \frac{1}{\mathrm{L_y}} \qquad \text{(Equation 3)}$$

2.3.2. Effective catchment area

Effective catchment area

$$\boldsymbol{A} = \boldsymbol{A_H} + \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{A_V} \qquad \text{(Equation 4)}$$

Where:

A – Effective catchment area

A_H – Plan area

A_V – Exposed area in elevation

Complex roof layouts

If a gutter a gutter receives runoff from more than one side it is necessary to calculate the elevation areas of the contributing surfaces looking in four directions

$A_{V.0} - Viewed\ from\ one\ side\ of\ the\ gutter(defined\ as\ direction\ 0^o)$

$A_{V.90} - Viewed\ from\ one\ end\ of\ the\ gutter(in\ direction\ 90^o)$

$A_{V.180} - Viewed\ from\ the\ other\ side\ of\ the\ gutter(in\ direction\ 180^o)$

$A_{V.270} - Viewed\ from\ the\ other\ end\ of\ the\ gutter(in\ direction\ 270^o)$

The wind is assumed to come from all the directions and will maximize the rate of runoff into the gutter. If one surface is exposed to the wind the surface in the opposite direction will be sheltered.

The effective catchment area (A) of a complex roof is given by:

$$\mathrm{A} = \mathrm{A_H} + \frac{1}{2}\sqrt{\left[\left(\mathrm{A_{v,0}} - \mathrm{A_{v,180}}\right)^2 + \left(\mathrm{A_{v,90}} - \mathrm{A_{v,270}}\right)^2\right]} \qquad \text{(Equation 5)}$$

2.3.3. Design of flow loads

It is assumed that the flow conditions at all points in a roof drainage system (roof, gutter, outlet and rainwater pipe) have reached a steady state. [6]

Therefore, each component of the system should be designed to cater for the peak flow by multiplying the design rainfall intensity and the total effective catchment area to that point.

The design flow load Q (l/s) is determined as

$$\boldsymbol{Q} = \boldsymbol{r} * \boldsymbol{A} * \boldsymbol{C} \qquad \text{(Equation 6)}$$

C - runoff coefficient =1 for design

Division of flow load between outlets

The positions of outlets along the run of a gutter determine the direction in which water flows in each individual gutter length (L)

Gutter length L is defined as the distance between a downstream outlet and the upstream point of zero flow. For a roof with an irregular profile in plan or elevation, the point of zero flow between two adjacent outlets in a level or nearly level gutter should be identified as follows:

a) Calculate the flow load entering the gutter between tow outlets
b) The point zero flow will be located so that the flow load divides equally between the two outlets
c) The position of zero flow is therefore located by finding the position along the gutter run where the effective catchment area of that run is divided in half.

2.3.4. Capacity of freely-discharging gutters

Definitions: [6]

Eaves gutter – a gutter fixed externally to a building and located so that it collects runoff from the eaves of a roof and is able to overflow along its length away from the face of the building

Valley gutter – an internal gutter located along the valley formed by two roofs or catchment areas.

Parapet gutter – a gutter around the perimeter of the building either with a higher outer edge or located behind a parapet of fascia that prevents it from overflowing along its length

Boundary-wall gutter – similar geometrically to a parapet gutter but typically located across the width of a roof either side of a boundary wall between two adjacent properties.

Hydraulics of gutter flow

- The discharge capacity of a gutter is determined by its cross sectional geometry and is effectively independent of the gutter length
- A gutter will tend to overflow first at the zero flow point, where the water is deepest.

Calculations steps:

a) For a given gutter length Lm calculate the design low load Q from the roof

b) Choose or assume the size and cross sectional shape of the gutter

c) Determine the maximum allowable depth of flow in the gutter for safe operation without overflowing.

d) Calculate the discharge capacity Qc of the gutter

$$\mathrm{Qc} = 9.90 \times 10^{-5} \left(\frac{\mathrm{A_c^3}}{\mathrm{B_C}}\right)^{0.5} \qquad \text{(Equation 7)}$$

Where :

Bc (mm) is the surface width of flow and Ac (mm^2) is the cross sectional area of flow in the gutter corresponding to the critical depth Yc

e) If the discharge capacity Qc is equal or greater than the flow load Q the choice of gutter is satisfactory

f) If not we either use more outlets or we use a larger gutter and repeat the calculation steps to check whether Qc>Q

Eaves gutters

There are two categories of gutter profile

- Eaves gutters of semicircular shape
- Eaves gutters of rectangular, trapezoidal or similar shape

Calculation steps

Determine the maximum water depth W (mm) in the gutter above which the overtopping would occur.

Calculate the cross sectional area A_E(mm²) of the gutter corresponding to the water depth W.

Determine the nominal flow capacity Q_N(l/s)

If the gutter is semicircular shape $Q_N = 2.78 \times 10^{-5} A_E^{1.25}$ (Equation 8)

If the gutter is semicircular shape $Q_N = 3.48 \times 10^{-5} F_D F_S A_E^{1.25}$ (Equation 9)

Where $F_D = \left(\frac{W}{T}\right)^{0.25}$ (Equation 10)

$F_S = 0.8943 + 0.2013\left(\frac{S}{T}\right) - 0.0965\left(\frac{S}{T}\right)^2$ (Equation 11)

S (mm) – is the width of the flat sole of the gutter

T (mm) – is the top width of the gutter

The design flow capacity $Q_C = 0.9\, F_L\, Q_N$ (Equation 12)

Where:

$F_L = 1.0 - \frac{0.2}{150}\left[\frac{L}{W} - 50\right]$ ***for 50<L/W≤200*** (Equation 13)

Or:

$$F_L = 0.8 - \frac{0.2}{300}\left[\frac{L}{w} - 200\right] \quad \textbf{\textit{for 200<L/W≤500}} \qquad \text{(Equation 14)}$$

2.3.5. Outlets from gutters

Calculation steps

For a circular outlet with a top diameter D_o (mm), effective diameter D (mm) should be determined.

Determine the discharge capacity Q_C(l/s) of each gutter drained by a particular outlet assuming that the gutter is able to discharge freely

$$\textbf{\textit{Find the limiting depth}}\ h_L = F_h W \qquad \text{(Equation 15)}$$

$$\textbf{\textit{Where}}\ F_h = 0.6459 - 0.3084\left(\frac{S}{T}\right) + 0.1415\left(\frac{S}{T}\right)^2 \qquad \text{(Equation 16)}$$

Calculate the total flow rate Q_T(l/s) entering the outlet, the sum of Q_C for the individual gutter lengths that it drains

Calculate the flow rate Q_o(l/s) that can be accepted by the outlet with a head h (mm) equal to the limiting depth h_L

For circular outlet:

$$\textbf{\textit{Weir type flow}} \quad Q_0 = \frac{k_0 D h^{1.5}}{7500} \quad \textbf{\textit{for h ≤ D/2}} \qquad \text{(Equation 17)}$$

$$\textbf{\textit{Orifice type flow}} \quad Q_0 = \frac{k_0 D^2 h^{0.5}}{15000} \quad \text{for } h > D/2 \qquad \text{(Equation 18)}$$

For rectangular outlet

Weir type flow $Q_0 = \frac{k_0 L_W h^{1.5}}{24000}$ for h $\leq \frac{2A_0}{L_w}$ (Equation 19)

Orifice type flow $Q_0 = \frac{k_0 A_0 h^{0.5}}{12000}$ ***for h*** $> \frac{2A_0}{L_w}$ (Equation 20)

Where k_0 is the outlet coefficient $k_0 = 1\ for\ unobstructed\ outlet$

$k_0 = 0.5\ for\ outlets\ with\ strainers\ or\ gratings$

L_W is the wetted perimeter

A_0 is the plan area of the outlet

If the flow capacity Q_0 equals or exceeds the total flow rate Q_T, the gutter length will be able to discharge freely

If not, it is required to use a larger outlet and repeat the calculation steps

2.3.6. Rainwater pipes and drains

Calculation steps

Find the total design flow rate Q_T(l/s) entering the rainwater pipe

Determine the maximum flow capacity Q_{RWP}(l/s) of the vertical sections of rainwater pipe

$$Q_{RWP} = 5 \times 10^{-5} d_i^{2.667} \quad \text{(Equation 21)}$$

If $Q_{RWP} \geq Q_T$, the size of the rainwater pipe is satisfactory. If not it is necessary to increase the pipe diameter and repeat the steps

If the rainwater system contains sections of pipe that are flatter than 10° to the horizontal determine the maximum flow capacity Q_P (l/s) of the pipe when it is flowing at a depth equal to 70% of the pipe diameter.

$$Q_P = -2 \times {}^{10^{-6}}\sqrt{\frac{8giA_i^3}{P_i}} \log\left[\frac{14.84k_B P_i}{A_i} - \frac{6.275\times10^5 vP_i}{\sqrt{8giA_i^3/P_i}}\right] \qquad \text{(Equation 22)}$$

Where

g – acceleration due to gravity

i - fall or longitudinal gradient of pipe

Ai – cross sectional area of flow in pipe

Pi – wetted perimeter of pipe

kB – hydraulic roughness of pipe

v – kinematic viscosity of water

If $\boldsymbol{Q_P} \geq \boldsymbol{Q_T}$ the design is satisfactory. If not, it is necessary to increase the pipe size or gradient (or both) than repeat the last step

2.3.7. Siphonic roof drainage systems

A roof from which rainwater is drained by means of a siphonic system generally contains several roof outlets that are collected into a single down pipe. The Bernouli equation needs to be applied to every flow path from roof outlet (entry point) to the transition to partial filling (exit point). [8]

The purpose of the calculation is to keep the static residual pressure at the exit point of every flow path within ±100 mbar. The static residual pressure of a flow path is equal to the available pressure difference created by the height difference between the entry point and the exit point minus the pressure loss caused by the pipe friction in the auxiliary sections of the system.

$$\Delta p_{rest} = \Delta p_{available} - \Delta p_{loss} \qquad \text{(Equation 23)}$$

The available pressure difference is calculated as indicated in equation

$$p_{available} = \Delta h_a * g * p \qquad \text{(Equation 24)}$$

$\Delta h_a = available\ height\ from\ roof\ membrane\ to\ exit\ point$

$p = mass\ density\ of\ water\ at\ 10°\text{C}: 1000 kg/m^3$

$g = gravitational\ acceleration: 9.81\ m/s^2$

Pressure loss is calculated as specified in equation

$$\Delta \mathrm{p_{loss}} = \sum(\mathrm{l} * \ \mathrm{R} + \mathrm{Z}) \qquad \text{(Equation 25)}$$

l=pipe length (m)

R = pipe friction pressure loss (Pa/m)

Z = drag (Pa)

Calculating the pressure difference of a pipe section

The available pressure difference of a pipe section is computed by replacing the Δh_a of equation by the height difference of the pipe section.

$$\Delta \mathrm{p_{available,ls}} = \Delta \mathrm{h_{ls}} * \mathrm{g} * \mathrm{p} \qquad \text{(Equation 26)}$$

Calculating the pressure loss of a pipe section

The pressure loss of a pipe section is calculated by using equation

$$\Delta \mathrm{p_{loss,ls}} = \sum(\mathrm{l} * \ \mathrm{R} + \mathrm{Z}) \qquad \text{(Equation 27)}$$

l=pipe length (m) = the length of the pipe section

R = pipe friction pressure loss (Pa/m) = (λ/di) (0.5 . v2 x r) with:

λ= pipe friction factor

di=pipe section design diameter

v = flow velocity in flow path (m/s)=Qh/di

ρ= mass density of water at 10°C : 1.000kg/m³

Qh = rainwater load for the total roof section drained by the pipe

The flow path design diameter (di) is the only variable in the entire calculation (with the exception of down pipe diameter) that can be modified if the 100 mbar standard cannot be met.

$$\mathrm{Z} = \text{pipe friction (Pa)} = \sum \xi (0.5 v^2 \times \rho) \qquad \text{(Equation 28)}$$

Where:
ξ=pipe friction of fitting
v=flow velocity in flow path (m/s)
ρ=mass density of water at 10°C:1000 kg/m³

Table 1. Pipe friction of fitting for different angles

Fitting	*ξ*
Bend 15°	0.1
Bend 30°	0.3
Bend 45°	0.4
Bend 70°	0.6
Bend 90°	0.8
Branch 45°branch	0.6
Branch 45°through	0.3
Reduction	0.3
Transition to partial filling	1.8
Roof outlet	1.5

In contrast to a standard reduction, the exit point (transition to partial filling) has a larger pipe friction factor. This point can be incorporated in the down pipe but also in the underground pipe (horizontal).

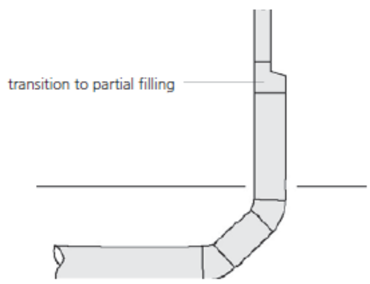


Figure 8. Transition to partial filling

The residual pressure is then determined by accumulating and offsetting the pressure differences and pressure losses of every pipe section.

$$\Delta \boldsymbol{p}_{\boldsymbol{res}} = \sum \Delta \boldsymbol{p}_{\boldsymbol{available}} - \sum \Delta \boldsymbol{p}_{\boldsymbol{loss}} \qquad \text{(Equation29)}$$

If the result of the residual pressure does not remain under the stated standard of ±100 mbar, the design diameters of one or more pipe section must be adjusted and retested.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Planning and designing a Rainwater harvesting system, which will be called abbreviated RHS, in one of the most important buildings in Tirana such is Air Albania stadium is a task that needs to be studied in each step of its design.

Arena Kombëtare, known for sponsorship reasons as the Air Albania Stadium, is an all-seater, multi-purpose football stadium located in the capital city of Tirana which was built on the ground of the former Qemal Stafa Stadium. The stadium has a seating capacity of 21,690 constituting the largest stadium in Albania. Designed by Marco Casamonti of Archea Associati, the structure of the stadium is a peculiar multi-faceted form (an 8-faceted rectangle) so that each side allows access to distinct functions. At one corner of the stadium structure is a 112-metre-tall tower (24 floors), which today is the tallest tower in Albania. Each facet accommodates different streams, thus identifying users of private areas, such as the hotel tower, shopping areas and stadium spectators.

In order to meet the required design standards, this study is going through a number of steps.

1. Identifying the purpose of use and site layout
2. Rainfall data analysis and estimating the amount of rainwater
3. Effective catchment area
4. Water balance analysis
5. Designing the collection pipes
6. Designing other components
7. Planning of rainwater storage, sizing of the storage tank

The new Albanian national stadium is a multifunctional building conceived as a mechanism capable of perfectly ‘working‘, ensuring in every circumstance the total separation of flow and activity, so that the coexistence and simultaneity of events is always guaranteed and safe in every situation. [9]

Figure 9. Air Albania Stadium

Due to its large top roof surface that has an area of 17,453.67 m², and the large amount of water required for football pitch irrigation at least 150000 l/week, is good reason to use rainwater harvesting as an alternative water source.

3.2. System planning

In order for the Rainfall Harvesting System to be reliable, first a water balance analysis should be made. A water balance analysis, typically referred to as a water budget, describes the amount of rainwater that can be collected in the project catchment area and determines if that amount will meet the user’s water demands. A water budget will provide a supply-and-demand analysis on a monthly basis and will help determine the size of the storage area. In addition, a water budget will determine how much, if any, supplemental water is needed to augment the intended use of the collected rainwater [2].

3.3. Water demand (Pitch irrigation)

The scope of Rainfall Harvesting System apart of controlling the stormwater on the building is to provide enough water for football pitch irrigation.

Football pitch has an area of 8030m² and needs an average 3-5 liters/m²/day (Table 1) [10]

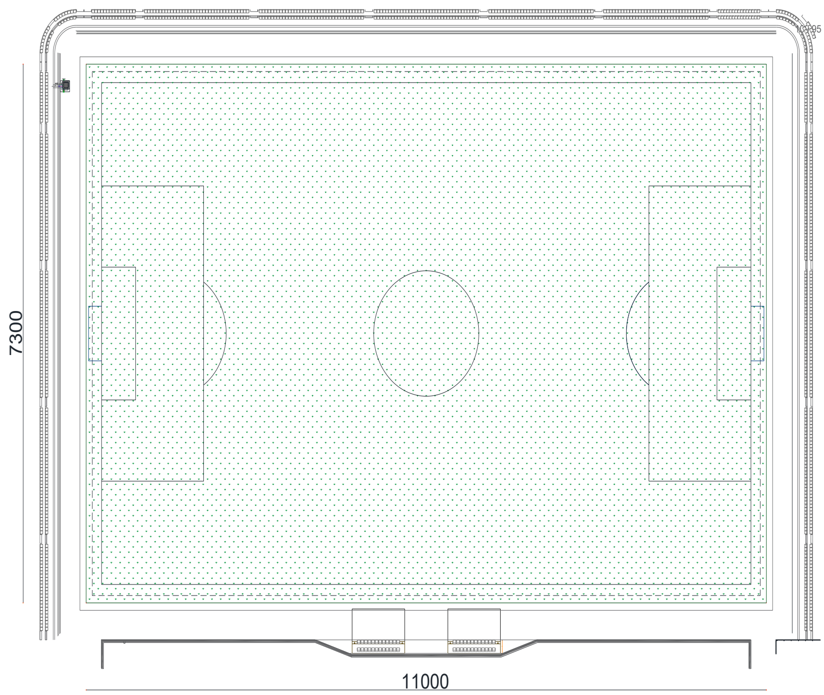


Figure 10. Football pitch

Table 2. Pipe friction of fitting for different angles

SI No.	*Purpose*	*Water requirement liters/m²/day*
1	Kitchen garden	1.4
2	Sports ground	3-5
3	Park and garden	2-3

In order to ensure a proper irrigation even in drought periods, maximum need is taken. So the football pitch irrigation need will be 8030m² * 5 l/m²/day = 41050 l/day

Air Albania stadium has a total roof surface of 17,453.67 m². The roof surface has a slope of 10% and it is covered with galvanized metal sheets. With these characteristics this roof is perfect for rainwater catchment.

3.4. Rainfall data analysis

A long period of 30 years daily observed rainfall records have been collected from Albanian Meteorological Institution (***Graph 1***). The concise information of rainfall stations considered for present analysis are presented in ***Table 3***. The rainfall data at each stations has undergone through preliminary data scrutiny for consistency.

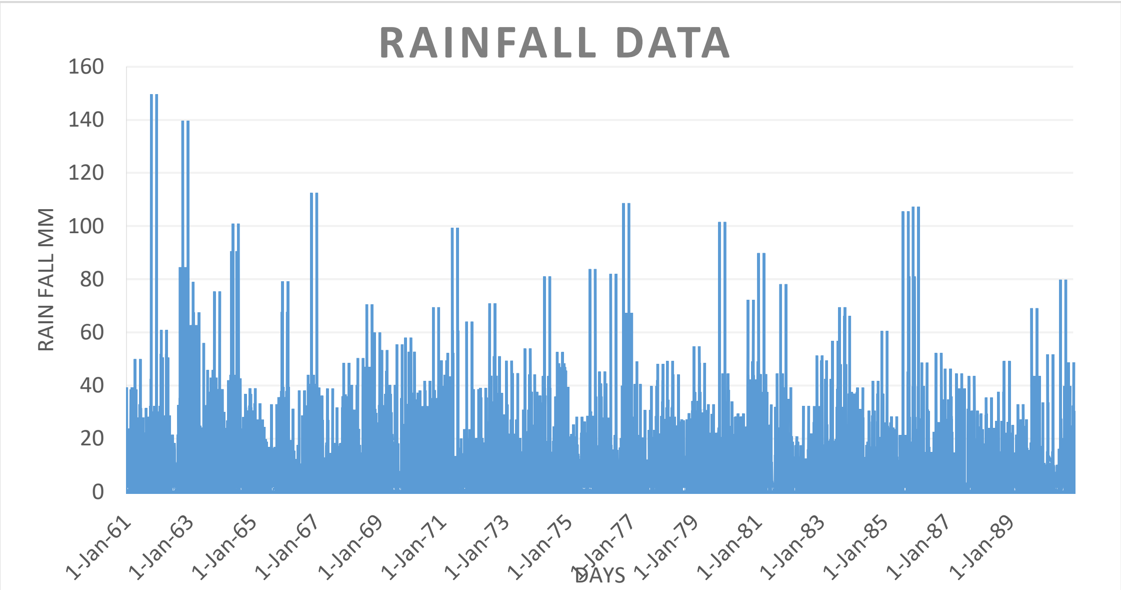
Two different analyses are done. The first one is a generic analysis to estimate the amount of rain water that can be collected and to evaluate if it satisfies the need.

The second analysis consist in determining the design rain intensity in order for roof to be drained properly and safely.

In order to estimate the quantity of rain water that can be collected, first the average rainfall intensity is needed.From the ***table 3*** below, where average monthly rainfall intensity is given for 30 years, we can get two important parameters.

Average rainfall intensity is 0.14 mm/h

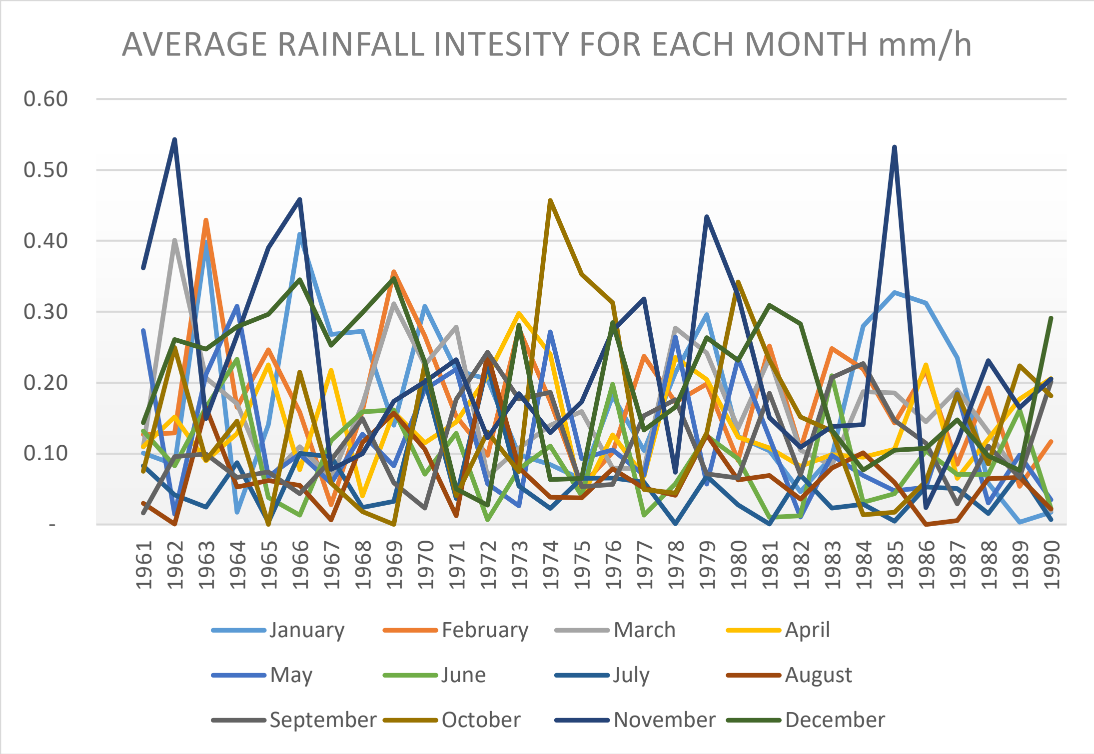
There are days without rain and they can last for 31 days as it is the case of August 1986. This is a very important clue for storage tank sizing.



Graph 1. Rainfall data from 1 January 1961 to 31 December 1991

Table 3. Monthly rainfall average intensity (mm/h)

Monthly rainfall intensity average (mm/h)												
Month Year	***January***	***February***	***March***	***April***	***May***	***June***	***July***	***August***	***September***	***October***	***November***	***December***
1961	0.10	0.13	0.11	0.11	0.27	0.13	0.08	0.03	0.02	0.08	0.36	0.14
1962	0.08	0.13	0.40	0.15	0.01	0.08	0.04	0.00	0.10	0.25	0.54	0.26
1963	0.40	0.43	0.21	0.09	0.21	0.17	0.02	0.16	0.10	0.09	0.15	0.25
1964	0.02	0.17	0.17	0.13	0.31	0.23	0.09	0.05	0.07	0.15	0.27	0.28
1965	0.14	0.25	0.06	0.23	0.07	0.04	0.00	0.06	0.07	0.00	0.39	0.30
1966	0.41	0.16	0.11	0.08	0.10	0.01	0.10	0.05	0.04	0.21	0.46	0.35
1967	0.27	0.03	0.07	0.22	0.06	0.12	0.10	0.01	0.09	0.06	0.08	0.25
1968	0.27	0.16	0.17	0.04	0.13	0.16	0.02	0.12	0.15	0.02	0.10	0.30
1969	0.14	0.36	0.31	0.16	0.08	0.16	0.03	0.16	0.06	0.00	0.17	0.35
1970	0.31	0.27	0.23	0.12	0.19	0.07	0.20	0.11	0.02	0.23	0.20	0.23
1971	0.22	0.15	0.28	0.14	0.22	0.13	0.04	0.01	0.18	0.04	0.23	0.05
1972	0.20	0.10	0.07	0.21	0.06	0.01	0.23	0.24	0.24	0.13	0.12	0.03
1973	0.10	0.28	0.11	0.30	0.03	0.08	0.05	0.08	0.18	0.07	0.18	0.28
1974	0.08	0.17	0.14	0.24	0.27	0.11	0.02	0.04	0.19	0.46	0.13	0.06
1975	0.06	0.05	0.16	0.04	0.09	0.04	0.07	0.04	0.05	0.35	0.17	0.06
1976	0.18	0.10	0.08	0.13	0.11	0.20	0.07	0.08	0.06	0.31	0.27	0.28
1977	0.10	0.24	0.08	0.07	0.07	0.01	0.06	0.05	0.15	0.05	0.32	0.13
1978	0.21	0.17	0.28	0.24	0.26	0.06	0.00	0.04	0.18	0.04	0.07	0.17
1979	0.30	0.20	0.24	0.20	0.06	0.13	0.07	0.13	0.07	0.13	0.43	0.26
1980	0.12	0.09	0.14	0.12	0.23	0.09	0.03	0.06	0.07	0.34	0.32	0.23
1981	0.10	0.25	0.23	0.11	0.12	0.01	0.00	0.07	0.19	0.23	0.15	0.31
1982	0.05	0.11	0.10	0.08	0.01	0.01	0.07	0.04	0.07	0.15	0.11	0.28
1983	0.10	0.25	0.08	0.10	0.10	0.21	0.02	0.08	0.21	0.13	0.14	0.13
1984	0.28	0.22	0.19	0.09	0.07	0.03	0.03	0.10	0.23	0.01	0.14	0.08
1985	0.33	0.14	0.19	0.11	0.05	0.04	0.00	0.06	0.15	0.02	0.53	0.10
1986	0.31	0.22	0.14	0.23	0.05	0.10	0.05	-	0.11	0.06	0.02	0.11
1987	0.24	0.09	0.19	0.07	0.19	0.07	0.05	0.01	0.03	0.18	0.12	0.15
1988	0.06	0.19	0.13	0.12	0.03	0.07	0.02	0.06	0.11	0.09	0.23	0.10
1989	0.00	0.05	0.07	0.18	0.10	0.16	0.07	0.07	0.07	0.22	0.16	0.08
1990	0.02	0.12	0.02	0.21	0.03	0.02	0.01	0.02	0.20	0.18	0.21	0.29
Averg.	***0.17***	***0.18***	***0.16***	***0.14***	***0.12***	***0.09***	***0.05***	***0.07***	***0.11***	***0.14***	***0.23***	***0.20***



Graph 2. Average rainfall intensity for each month

The second analysis that is done is more specific as it serves for designing of the rooftop drainage. In this case we need for the project to be safe for the worst case scenario. The main characteristics of a storm are its intensity, duration, total amount and frequency or recurrence interval.

The rainfall intensity is an important characteristic of rainfall storm and it is expressed as the rate of rainfall in inches or millimeter per hour. Similarly, rainfall duration is the period of time that rain falls at a particular rate or intensity. For the rainfall storm, the rainfall intensity may vary from high to very low; hence, the duration is how long time rainfall intensity lasts at a particular rate.

Frequency is how often a storm of specified intensity and duration may be expected to occur

Theoretical Extreme Value (EV) Distribution Approach

For this approach is selected the Gumbel (Type I) distribution as our EV distribution. The Gumbel Type I distribution is,

$$G(x; \mu; \beta) = 1/\beta e^{x-\mu/\beta} e^{-e^{x-\mu/\beta}} \quad \text{(Equation 30)}$$

Where μ is the location parameter and β is the scale parameter.

It can be shown that the value of the random variable XT associated with a given return period, T, may be obtained from the following expression,

$$X_T = \overline{X} + K_T S \qquad \text{(Equation 31)}$$

where $\bar{X}$ is the mean of the observations (arithmetic average of the observations), and S is the standard deviation of the observations. The frequency factor associated with return period T, K_T, is given by

$$K_T = -\frac{\sqrt{6}}{\pi}[0.5772 + \ln(\ln(\frac{T}{T-1}))] \qquad \text{(Equation 32)}$$

Equations (29), (30) are applied to each set of annual maxima corresponding to each duration.

For each duration (e.g., 5-min, 10-min …etc.), the mean sample mean and standard deviations sample of the series of annual maxima, (x1,…….,xm) are computed. (Table 4)

$$\overline{X} = \frac{1}{m}\sum_{i=1}^{m} x_i \qquad \text{(Equation 33)}$$

$$S = \frac{1}{m-1}\sum_{i=1}^{m}(x_i - \overline{X})^2 \qquad \text{(Equation 34)}$$

Than with the use of equation 31 are computed the precipitation intensity associated with each return period. (***Table 5***)

Table 4. Extreme value distribution for each duration time

Year	*Max*	*Time duration in minutes*									
		5.00	*10.00*	*15.00*	*20.00*	*60.00*	*120.00*	*180.00*	*240.00*	*300.00*	*360.00*
1961	*149.60*	*0.52*	*1.04*	*1.56*	*2.08*	*6.23*	*12.47*	*18.70*	*24.93*	*31.17*	*37.40*
1962	*139.70*	*0.49*	*0.97*	*1.46*	*1.94*	*5.82*	*11.64*	*17.46*	*23.28*	*29.10*	*34.93*
1966	*112.50*	*0.39*	*0.78*	*1.17*	*1.56*	*4.69*	*9.38*	*14.06*	*18.75*	*23.44*	*28.13*
1976	*108.60*	*0.38*	*0.75*	*1.13*	*1.51*	*4.53*	*9.05*	*13.58*	*18.10*	*22.63*	*27.15*
1986	*107.30*	*0.37*	*0.75*	*1.12*	*1.49*	*4.47*	*8.94*	*13.41*	*17.88*	*22.35*	*26.83*
1985	*105.50*	*0.37*	*0.73*	*1.10*	*1.47*	*4.40*	*8.79*	*13.19*	*17.58*	*21.98*	*26.38*
1979	*101.50*	*0.35*	*0.70*	*1.06*	*1.41*	*4.23*	*8.46*	*12.69*	*16.92*	*21.15*	*25.38*
1964	*101.00*	*0.35*	*0.70*	*1.05*	*1.40*	*4.21*	*8.42*	*12.63*	*16.83*	*21.04*	*25.25*
1971	*99.40*	*0.35*	*0.69*	*1.04*	*1.38*	*4.14*	*8.28*	*12.43*	*16.57*	*20.71*	*24.85*
1981	*89.80*	*0.31*	*0.62*	*0.94*	*1.25*	*3.74*	*7.48*	*11.23*	*14.97*	*18.71*	*22.45*
1975	*83.80*	*0.29*	*0.58*	*0.87*	*1.16*	*3.49*	*6.98*	*10.48*	*13.97*	*17.46*	*20.95*
1974	*81.00*	*0.28*	*0.56*	*0.84*	*1.13*	*3.38*	*6.75*	*10.13*	*13.50*	*16.88*	*20.25*
1990	*79.80*	*0.28*	*0.55*	*0.83*	*1.11*	*3.33*	*6.65*	*9.98*	*13.30*	*16.63*	*19.95*
1963	*79.00*	*0.27*	*0.55*	*0.82*	*1.10*	*3.29*	*6.58*	*9.88*	*13.17*	*16.46*	*19.75*
1980	*72.30*	*0.25*	*0.50*	*0.75*	*1.00*	*3.01*	*6.03*	*9.04*	*12.05*	*15.06*	*18.08*
1972	*70.90*	*0.25*	*0.49*	*0.74*	*0.98*	*2.95*	*5.91*	*8.86*	*11.82*	*14.77*	*17.73*
1968	*70.60*	*0.25*	*0.49*	*0.74*	*0.98*	*2.94*	*5.88*	*8.83*	*11.77*	*14.71*	*17.65*
1970	*69.50*	*0.24*	*0.48*	*0.72*	*0.97*	*2.90*	*5.79*	*8.69*	*11.58*	*14.48*	*17.38*
1983	*69.50*	*0.24*	*0.48*	*0.72*	*0.97*	*2.90*	*5.79*	*8.69*	*11.58*	*14.48*	*17.38*
1989	*69.10*	*0.24*	*0.48*	*0.72*	*0.96*	*2.88*	*5.76*	*8.64*	*11.52*	*14.40*	*17.28*
1969	*58.00*	*0.20*	*0.40*	*0.60*	*0.81*	*2.42*	*4.83*	*7.25*	*9.67*	*12.08*	*14.50*
1973	*53.90*	*0.19*	*0.37*	*0.56*	*0.75*	*2.25*	*4.49*	*6.74*	*8.98*	*11.23*	*13.48*
1982	*51.30*	*0.18*	*0.36*	*0.53*	*0.71*	*2.14*	*4.28*	*6.41*	*8.55*	*10.69*	*12.83*
1978	*49.20*	*0.17*	*0.34*	*0.51*	*0.68*	*2.05*	*4.10*	*6.15*	*8.20*	*10.25*	*12.30*
1988	*49.20*	*0.17*	*0.34*	*0.51*	*0.68*	*2.05*	*4.10*	*6.15*	*8.20*	*10.25*	*12.30*
1977	*49.10*	*0.17*	*0.34*	*0.51*	*0.68*	*2.05*	*4.09*	*6.14*	*8.18*	*10.23*	*12.28*
1967	*48.50*	*0.17*	*0.34*	*0.51*	*0.67*	*2.02*	*4.04*	*6.06*	*8.08*	*10.10*	*12.13*
1987	*46.30*	*0.16*	*0.32*	*0.48*	*0.64*	*1.93*	*3.86*	*5.79*	*7.72*	*9.65*	*11.58*
1984	*41.70*	*0.14*	*0.29*	*0.43*	*0.58*	*1.74*	*3.48*	*5.21*	*6.95*	*8.69*	*10.43*
1965	*37.90*	*0.13*	*0.26*	*0.39*	*0.53*	*1.58*	*3.16*	*4.74*	*6.32*	*7.90*	*9.48*

Table 5. Rainfall intensity for different duration and returning period

Duration	2 years	5 years	10 years	25 years	50 years	100 years	150 years	200 years	500 years
5 min	0.26	0.34	0.40	0.47	0.53	0.58	0.61	0.64	0.71
10 min	0.51	0.69	0.80	0.95	1.06	1.17	1.23	1.27	1.42
15 min	0.77	1.03	1.20	1.42	1.59	1.75	1.84	1.91	2.12
20 min	1.02	1.37	1.60	1.90	2.12	2.33	2.46	2.55	2.83
60 min	3.06	4.12	4.81	5.69	6.35	7.00	7.38	7.64	8.50
120 min	6.12	8.23	9.63	11.39	12.70	14.00	14.75	15.29	17.00
180 min	9.19	12.35	14.44	17.08	19.05	20.99	22.13	22.93	25.49
240 min	12.25	16.46	19.25	22.78	25.39	27.99	29.51	30.58	33.99
300 min	15.31	20.58	24.07	28.47	31.74	34.99	36.88	38.22	42.49
360 min	18.37	24.69	28.88	34.17	38.09	41.99	44.26	45.87	50.99

3.5. Sizing of the rainwater tank and reliability estimation

In order to size the water tank a water balance is made between water that can be harvested and water that is needed. The water balance equation used is:

$$V_t = V_{t-1} + Q_{in,t}\Delta_t - Q_{sup,t}\Delta_t - Q_{out,t}\Delta_t \qquad \text{(Equation 35)}$$

V_t is the cumulative water stored in the tank (m³) at time t.

V_{t-1} is the cumulative water stored in the tank (m³) at time t-1.

Δ_t is the time step (day).

$Q_{in,t}$ is the inflow rate of the rainwater tank (m³/h) at time t, which is the same as the runoff flow rate from the roof as in (***Equation 6***)

$$\boldsymbol{Q_t = C * A * I_{eff,t}} \qquad \text{(Equation 36)}$$

C is the runoff coefficient 0.95 in this case

A is the rainfall collection area (m²)

Ieff, t is the daily effective rainfall depth at the end of t^{th} day (m).

The daily effective rainfall is equal to the daily rainfall minus the first flush to cater for quality concerns from dust and bird droppings.

The first flush is assumed as 0.33 mm

3.6. Design rainfall intensity

The design rainfall intensity is calculated using equation 1

$$r = \frac{r_0}{3600} \left[\frac{\frac{l}{s}}{m^2}\right]$$

The design rainfall intensity depends from D – (duration of the event in minutes) and return period T in years.

For design purposes $D = T_C$ where Tc is time of concentration

In order to calculate Tc, Kirpich formula is used

$$\mathrm{T_c} = \frac{0.21*\mathrm{L}^{0.77}}{\mathrm{S}_0^{0.385}} \qquad \text{(Equation 37)}$$

Where

T_c= time of concentration in minutes

L = flow length in meters

S= average slope of flow m/m

From calculations Tc=10 min

From equation 2 the return period is calculated

$T = \frac{1}{1-(1-P_R)^{\alpha}}$ = 450 years

Where:

Pr = risk category as proposed in Clause NB.21.1 of BS EN 12056-3 is category 3 [11]

Pr=0.2 or T=4.5 Ly

For a design life L_y of 100 years;

$\alpha = \frac{1}{L_y}$=1/100=0.01

Now that we have the duration D= Tc=12 min from ***table 5*** for return period of T=500 years, which is the value nearest to T=450 years, we can obtain the design rainfall intensity r_0 =1.42 mm/h

3.7. Effective catchment area

Effective catchment area is calculated using equation 4

$$A = A_H + \frac{1}{2}A_V$$

Where:

A – Effective catchment area

A_H – Plan area

A_V – Exposed area in elevation

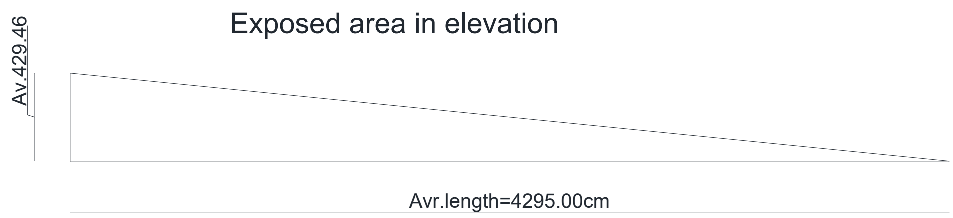


Figure 11. Exposed area in elevation of the roof

Exposed area in elevation is approximately 1488.32 m²

A= 17,453.67 +1488.32 = 18,941.99 m²

3.8. Design flow load

The design flow load is calculated using equation 6

Q=r *A* C= 1.42/3600 * 18,941.99 *0.95= 7.1l/s

Q – Flow load

A – Effective catchment area

C – Runoff coefficient

R – rainfall intensity

3.9. Design flow load for each surface

First the division of catchment surface needs to be done taking into account various factors such as draining pattern, geometry of the roof, and maximum allowed gutter dimensions fitting with the architecture of the building.

Entire roof surface is divided into smaller catchment areas and for each of them the design flow load is calculated.

It is assumed that flow conditions at all points in a roof drainage system have reached a steady state. Therefore each component of the system should be designed to cater for the peak flow rate obtained by multiplying the design rainfall intensity and the total effective catchment area draining to that point. [7]

Sloped roof typically drains to gutters and downspouts at the outer edges. [7] Due to the shape and inward slope of the roof the best choice of water collection is Parapet gutter (Figure 12) – a gutter around the perimeter of the building either with a higher outer edge or located behind a parapet of fascia that prevents it from overflowing along its length [7]

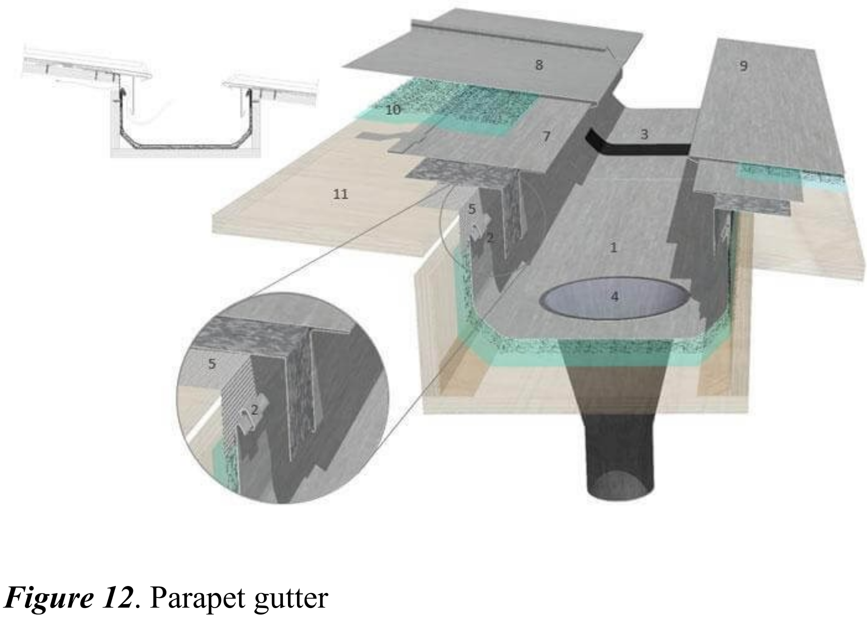


Figure 12. Parapet gutter

3.10 Performance efficiency of the system

A typical RHS for water supply generally consists of roof catchment area, screen filter, downpipe, storage tank, supply facility and overflow unit. The daily rainfall data of one average year is used for simulation.

The performance efficiency is simulated on the basis of a water balance equation. At each time-step, the roof runoff during that time-step is added to the volume (mass) in the tank and the user's consumption and overflow is subtracted. Tests and corrections are applied to cover the three cases – 'full tank', 'empty tank', and 'demand exceeds the available stored water.'

$$\boldsymbol{V_t = V_{t-1} + Q_{in,t}\Delta_t - Q_{sup,t}\Delta_t - Q_{out,t}\Delta_t} \qquad \text{(Equation. 38)}$$

V_t is the cumulative water stored in the tank (m³) at time t.

V_{t-1} is the cumulative water stored in the tank (m³) at time t-1.

Δ_t is the time step (day).

$Q_{in,t}$ is the inflow rate of the rainwater tank (m³/h) at time t, which is the same as the runoff flow rate from the roof as in (***Equation 6***)

$Q_{sup,t}$ is the water supply rate to the building from the rainwater tank (m³/day) at the t day. $Q_{sup,t}$ can be mathematically described as follows:

If $V_t \leq 0$, $Q_{sup,t} = 0$

If $V_t > 0$, the water supply is limited by the cumulative water stored and inflow in the tank.

$$\mathbf{V_{t-1} + Q_{in,t}\Delta_t < D\Delta_t \rightarrow Q_{sup,t}\Delta_t = V_{t-1} + Q_{in,t}\Delta_t} \qquad \text{(Equation 39)}$$

$$\boldsymbol{V_{t-1} + Q_{in,t}\Delta_t \geq D\Delta_t \rightarrow Q_{sup,t} = D} \qquad \text{(Equation 40)}$$

D is the daily demand (m³/day).

Outflow can be determined based on the water level in the RWH tank with respect to the High Water Level (H.W.L).

If $V_t \leq$ V, $Q_{sup,t}$ = 0

If V_t > V, the tank is full.

$$\mathrm{Q_{out,t}\Delta_t = V_{t-1} - V + Q_{in,t}\Delta_t - Q_{sup,t}\Delta_t} \qquad \text{(Equation 41)}$$

CHAPTER 4

RESULTS AND DISCUSSIONS

Following the analysis done for planning and designing the Rainfall harvesting system in Air Albania stadium I have reached in the following results.

4.1. Rainfall analysis

From the rainfall data of a period of 30 years daily observed rainfall records have been collected from Albanian Meteorological Institution two different analyses were done. In the first one, a generic analysis to estimate the amount of rain water that can be collected and to evaluate if it satisfies the need, the average rainfall intensity is 0.14 mm/h and the dry period without rain is 31 days in August 1986.

4.2. Water demand and storage tank sizing

The water demand for the football pitch irrigation was calculated and a total of 41050 liter/day or 41.05 m³ is required.

In order for football pitch to be irrigated properly this quantity of water needs to be provided even during non-raining days. The size of the catchment area and tank should be enough to supply sufficient water during the dry period. Assuming a full tank at the beginning of the dry season (and knowing the average length of the dry season and the average water use), the volume of the tank can be calculated

The tank volume is calculated as V_T= Water needed (l/day) * dry period (days) =41050 * 31= 1,272,550.00 liter $\simeq$ 1300 m³

The tank size satisfying this needs and the geometry of the building is a rectangular tank with a height of 3 m length of 31m and width of 14 m.

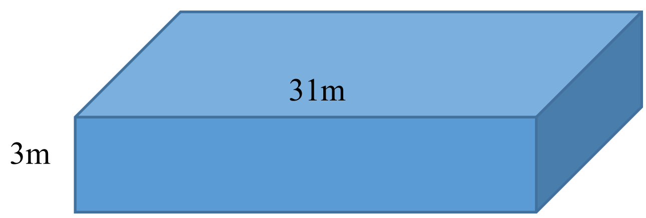


Figure 13. Storage tank

4.3. RHS components design

Rainwater Harvesting system components are designed taking into account the design rainfall intensity, the geometry of the rooftop catchment area and architecture of building. In the design of hydraulic structures and prediction of hydrological behavior, the most crucial task is to logically model the rainfall pattern, that is, to properly manage the time-rainfall intensity relationship at the design site.

4.3.1. Design rainfall intensity

For this reason a time distribution of rainfall data is done using the Gumbel (Type I) distribution as extreme values distribution. First the maximum values for each year are found. ***Table 6***

Table 6. Annual maxima

Year	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*	*Max*
1961	23.80	39.40	38.50	21.70	50.00	28.00	31.50	22.30	9.20	28.30	149.60	32.40	149.60
1962	25.90	24.60	60.90	28.70	8.00	18.40	21.50	0.30	32.70	84.60	139.70	60.70	139.70
1963	79.00	62.70	67.50	20.20	56.00	24.90	5.60	45.90	37.70	42.90	75.40	38.60	79.00
1964	7.60	26.80	30.00	42.00	90.60	101.00	42.70	23.80	21.50	28.10	36.80	39.00	101.00
1965	24.90	33.30	27.20	24.40	18.90	7.40	2.00	16.90	32.90	0.10	35.60	37.90	37.90
1966	79.30	19.40	31.30	12.30	17.70	3.40	38.10	28.70	10.80	32.50	44.00	112.50	112.50
1967	39.20	9.50	17.40	36.20	13.00	38.90	14.60	3.20	18.40	31.70	18.10	48.50	48.50
1968	36.70	30.90	40.20	10.70	50.30	23.70	14.70	47.00	70.60	7.70	19.00	59.90	70.60
1969	26.10	45.50	53.30	36.80	21.70	40.20	18.20	55.50	10.20	0.20	25.50	58.00	58.00
1970	52.70	37.30	33.70	17.00	38.10	32.20	41.70	27.30	12.80	69.50	38.20	44.00	69.50
1971	49.50	21.30	43.40	52.20	99.40	60.70	13.40	8.00	20.00	23.60	64.10	17.40	99.40
1972	38.60	20.20	20.30	39.10	18.50	1.90	26.50	70.90	51.00	37.20	29.10	9.90	70.90
1973	19.30	49.40	21.90	44.70	7.60	15.20	20.30	30.90	53.90	22.80	44.20	37.70	53.90
1974	20.30	33.70	36.20	43.60	81.00	24.60	10.80	13.10	52.60	48.40	39.50	18.50	81.00
1975	25.30	20.80	17.80	10.60	28.30	12.30	22.20	26.40	28.60	83.80	17.50	35.80	83.80
1976	45.20	40.80	27.90	17.70	21.40	82.00	16.70	20.20	11.80	108.60	61.90	67.30	108.60
1977	29.40	49.10	40.60	20.40	16.70	6.70	30.80	23.30	39.80	13.80	42.00	48.20	49.10
1978	34.60	27.40	49.20	28.20	44.20	15.00	0.30	26.50	27.30	13.60	29.60	27.60	49.20
1979	54.80	37.50	48.50	30.80	14.00	29.30	33.00	22.20	24.20	20.80	101.50	44.50	101.50
1980	24.80	34.00	19.40	21.80	28.40	29.50	19.40	16.00	24.50	72.30	42.20	49.10	72.30
1981	17.20	89.80	44.30	25.20	32.80	2.70	0.10	32.00	44.50	78.20	35.00	39.40	89.80

Year	January	February	March	April	May	June	July	August	September	October	November	December	Max
1982	12.80	20.90	18.80	17.50	4.30	5.80	32.30	12.60	19.80	22.00	32.20	51.30	51.30
1983	22.50	49.50	42.50	25.40	19.80	56.80	12.50	32.00	69.50	66.20	25.30	36.90	69.50
1984	37.50	31.10	39.20	27.90	17.70	10.60	18.80	30.60	41.70	4.00	36.90	20.70	41.70
1985	60.50	26.10	24.20	28.40	13.20	18.00	2.60	21.40	105.50	4.40	81.10	39.70	105.50
1986	107.30	23.70	39.80	48.60	15.00	22.60	16.90	-	52.20	26.20	8.50	34.80	107.30
1987	46.30	14.80	35.80	12.70	44.50	38.80	31.30	3.80	11.60	43.50	30.60	24.50	46.30
1988	15.70	29.00	29.40	35.50	7.50	24.00	11.50	26.70	37.60	15.00	49.20	22.20	49.20
1989	2.40	14.40	25.10	30.00	32.90	27.30	18.50	16.00	12.70	69.10	43.50	17.30	69.10
1990	5.10	33.70	10.30	51.70	10.20	10.00	5.00	16.20	79.80	39.80	32.50	48.80	79.80

In order to estimate the rainfall intensities for shorter periods of time an empirical reduction formula is used. Indian Meteorological Department (IMD) uses the empirical reduction formula (Equation 41) for estimation of various duration like 1-hr, 2-hr, 3-hr, 5-hr, 8-hr rainfall values from annual maximum values.

Chowdhury et al. (2007), used Indian Meteorological Department (IMD) empirical reduction formula to estimate the short duration rainfall from daily rainfall data.

$$\boldsymbol{P_t = P_{24}(\frac{t}{24})^{1/3}} \qquad \text{(Equation 42)}$$

Where Pt is the required rainfall intensity
P24 is rainfall intensity during 24 h period
t is the duration required of rainfall
For each of these duration Gumbel, distribution formulas are applied and the results are plotted in the ***table 4*** .

Than with the use of equation (31) are computed the precipitation intensity associated with each return period (***table 5*****).**

For a return period of 500 years and storm duration of 10minutes the deign rainfall intensity is 1.42mm/h

4.3.2. Effective catchment area

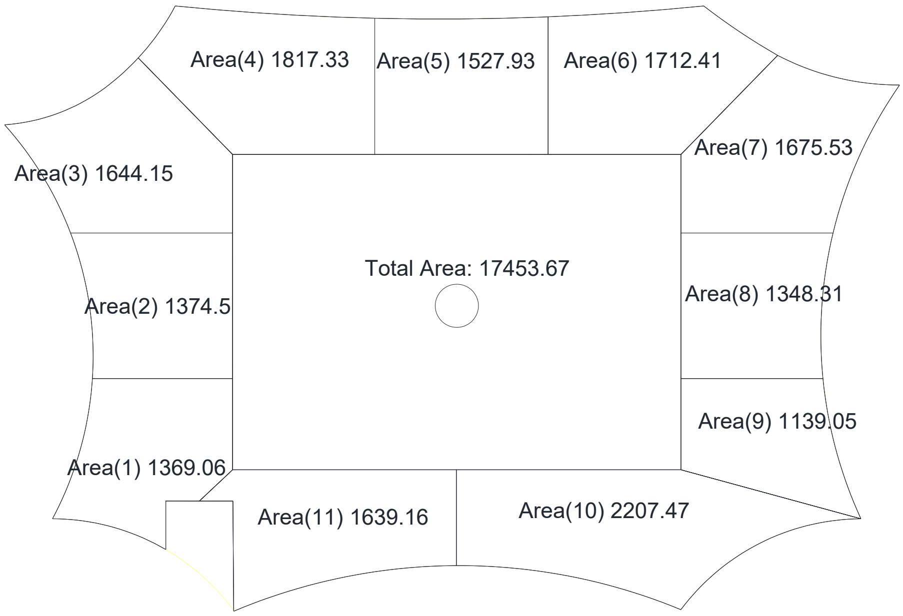


Figure 14. Plan area of the roof

Effective catchment area (A) = Plan area (A_H) + 1/2 Exposed area in elevation (A_V)

Where:

A – Effective catchment area

A_H – Plan area

A_V – Exposed area in elevation

Exposed area in elevation is approximately 1488.32 m² from figure 9

A= 17,453.67 +1488.32 = 18,941.99 m²

4.3.3. Conveyance

Design of flow loads

It is assumed that the flow conditions at all points in a roof drainage system (roof, gutter, outlet and rainwater pipe) have reached a steady state. [6]

Therefore, each component of the system is designed to cater for the peak flow by multiplying the design rainfall intensity and the total effective catchment area to that point.

The design flow load Q (l/s) is determined using equation 6

$$Q = r*A*C \ = 1.42/3600 * 18{,}941.99 *0.95= 7.1 l/s$$

Where :

A – Effective catchment area

r – design rainfall intensity

C – runoff coefficient

The positions of outlets along the gutters and the rainwater pipes are shown below.

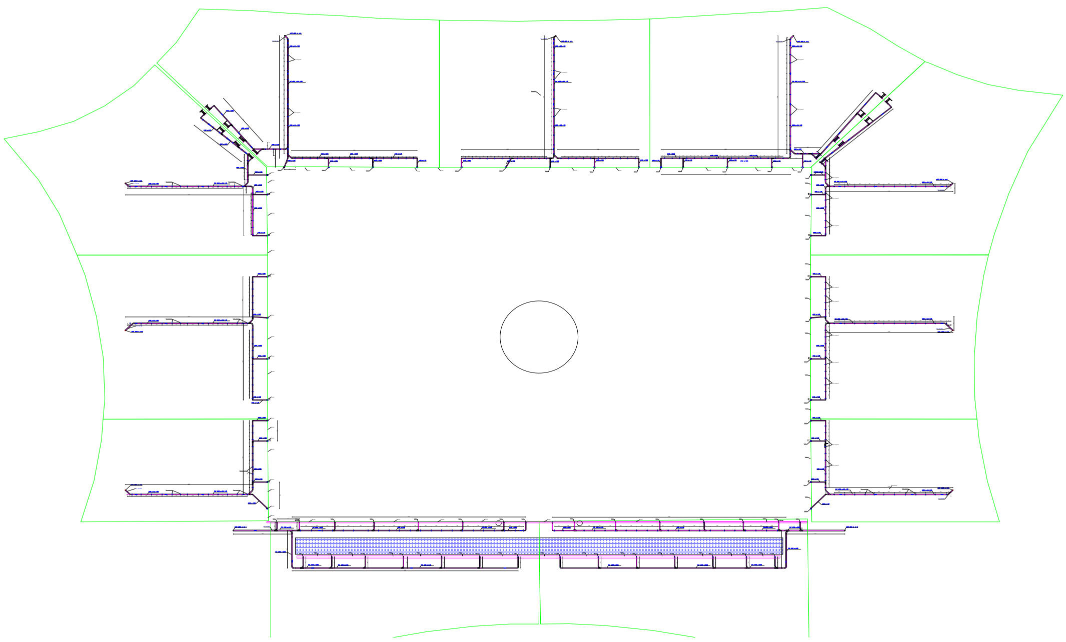


Figure 15. Rainwater pipes and outlets positioning

Sloped roof typically drains to gutters and downspouts at the outer edges. [7] Due to the shape and inward slope of the roof the best choice of water collection is Parapet gutter – a gutter around the perimeter of the building either with a higher outer edge or located behind a parapet of fascia that prevents it from overflowing along its length [7]

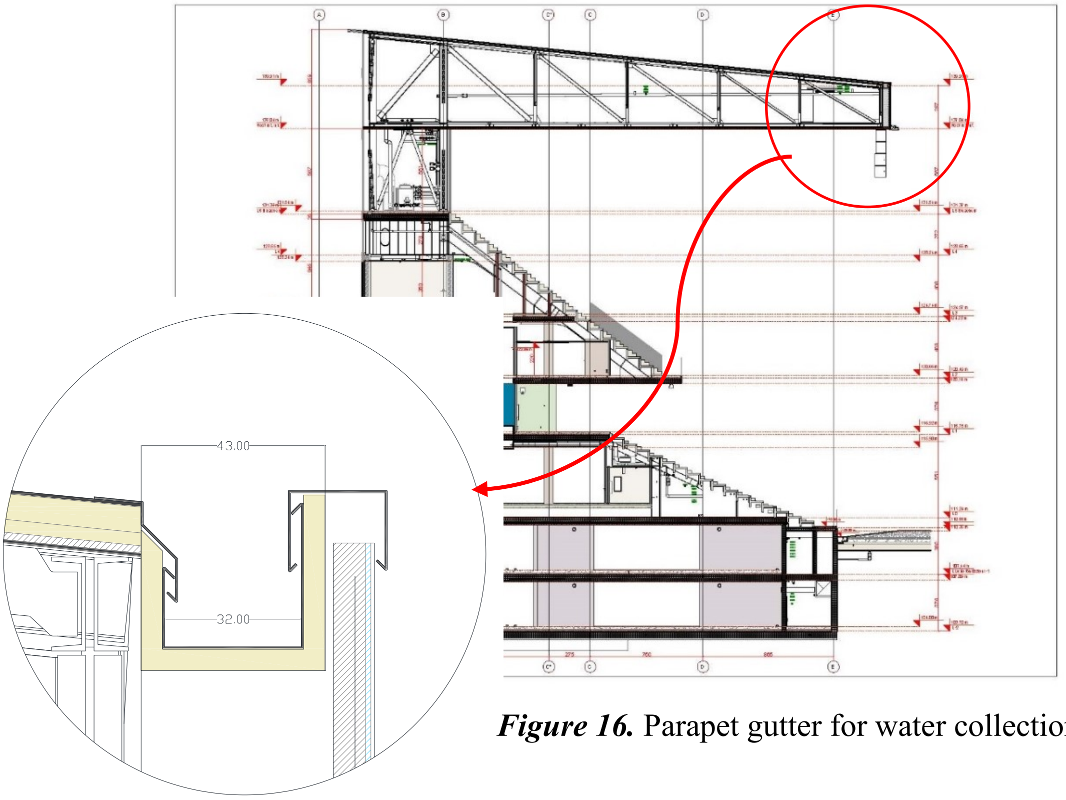


Figure 16. Parapet gutter for water collection

4.4 Viability analysis of the RHS system

In order to investigate the performance of a RWH system, a water balance analysis is done. For this analysis are taken into counts the water demand and the water availability from rainwater harvesting. Average rainfall data is used for this analysis (***Table 7***). From average rainfall intensities an estimation of harvested rainwater is done along with the water needed for irrigation every month. (***Table 8***)

As it can be seen both from the table and the graph no 3, the water harvested from the rain satisfies the needs of the football pitch for irrigation. So it can be said that RHS in this case study is a success.

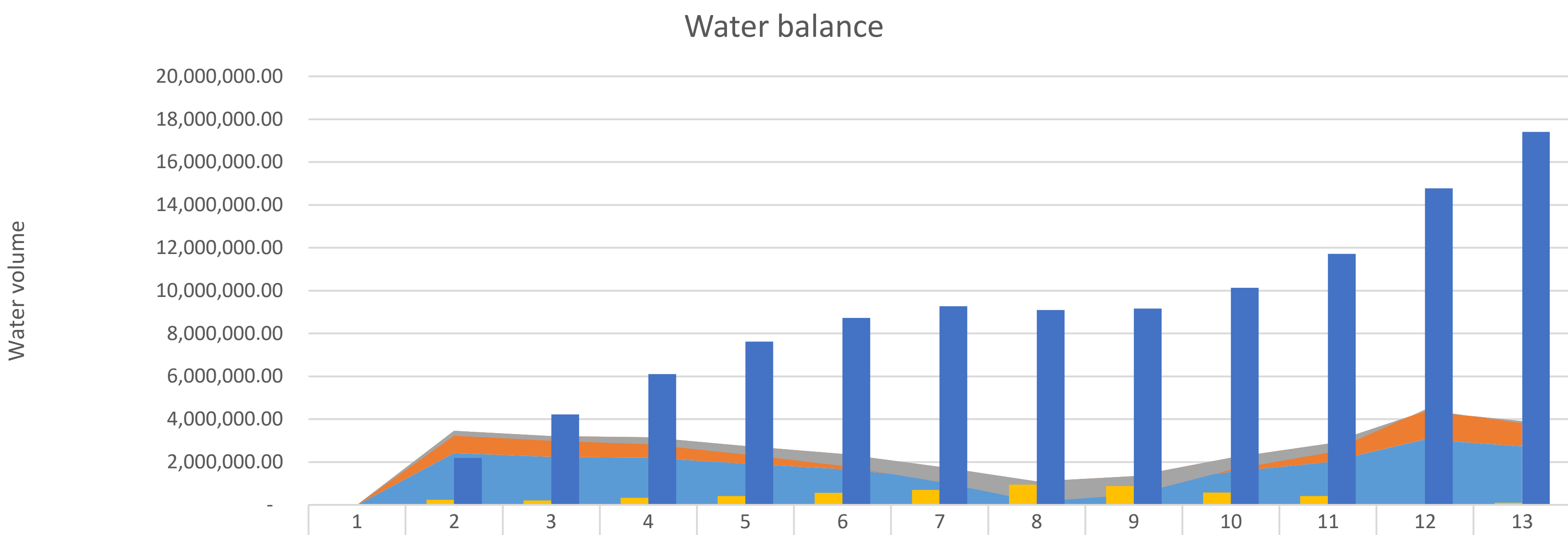
Table 7. Monthly rainfall intensity in average values

	Monthly rainfall intensity average (mm/h)											
Month Year	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
1,961	0.10	0.13	0.11	0.11	0.27	0.13	0.08	0.03	0.02	0.08	0.36	0.14
1,962	0.08	0.13	0.40	0.15	0.01	0.08	0.04	0.00	0.10	0.25	0.54	0.26
1,963	0.40	0.43	0.21	0.09	0.21	0.17	0.02	0.16	0.10	0.09	0.15	0.25
1,964	0.02	0.17	0.17	0.13	0.31	0.23	0.09	0.05	0.07	0.15	0.27	0.28
1,965	0.14	0.25	0.06	0.23	0.07	0.04	0.00	0.06	0.07	0.00	0.39	0.30
1,966	0.41	0.16	0.11	0.08	0.10	0.01	0.10	0.05	0.04	0.21	0.46	0.35
1,967	0.27	0.03	0.07	0.22	0.06	0.12	0.10	0.01	0.09	0.06	0.08	0.25
1,968	0.27	0.16	0.17	0.04	0.13	0.16	0.02	0.12	0.15	0.02	0.10	0.30
1,969	0.14	0.36	0.31	0.16	0.08	0.16	0.03	0.16	0.06	0.00	0.17	0.35
1,970	0.31	0.27	0.23	0.12	0.19	0.07	0.20	0.11	0.02	0.23	0.20	0.23
1,971	0.22	0.15	0.28	0.14	0.22	0.13	0.04	0.01	0.18	0.04	0.23	0.05
1,972	0.20	0.10	0.07	0.21	0.06	0.01	0.23	0.24	0.24	0.13	0.12	0.03
1,973	0.10	0.28	0.11	0.30	0.03	0.08	0.05	0.08	0.18	0.07	0.18	0.28
1,974	0.08	0.17	0.14	0.24	0.27	0.11	0.02	0.04	0.19	0.46	0.13	0.06
1,975	0.06	0.05	0.16	0.04	0.09	0.04	0.07	0.04	0.05	0.35	0.17	0.06
1,976	0.18	0.10	0.08	0.13	0.11	0.20	0.07	0.08	0.06	0.31	0.27	0.28
1,977	0.10	0.24	0.08	0.07	0.07	0.01	0.06	0.05	0.15	0.05	0.32	0.13
1,978	0.21	0.17	0.28	0.24	0.26	0.06	0.00	0.04	0.18	0.04	0.07	0.17
1,979	0.30	0.20	0.24	0.20	0.06	0.13	0.07	0.13	0.07	0.13	0.43	0.26
1,980	0.12	0.09	0.14	0.12	0.23	0.09	0.03	0.06	0.07	0.34	0.32	0.23
1,981	0.10	0.25	0.23	0.11	0.12	0.01	0.00	0.07	0.19	0.23	0.15	0.31
1,982	0.05	0.11	0.10	0.08	0.01	0.01	0.07	0.04	0.07	0.15	0.11	0.28
1,983	0.10	0.25	0.08	0.10	0.10	0.21	0.02	0.08	0.21	0.13	0.14	0.13
1,984	0.28	0.22	0.19	0.09	0.07	0.03	0.03	0.10	0.23	0.01	0.14	0.08
1,985	0.33	0.14	0.19	0.11	0.05	0.04	0.00	0.06	0.15	0.02	0.53	0.10
1,986	0.31	0.22	0.14	0.23	0.05	0.10	0.05	-	0.11	0.06	0.02	0.11
1,987	0.24	0.09	0.19	0.07	0.19	0.07	0.05	0.01	0.03	0.18	0.12	0.15
1,988	0.06	0.19	0.13	0.12	0.03	0.07	0.02	0.06	0.11	0.09	0.23	0.10
1,989	0.00	0.05	0.07	0.18	0.10	0.16	0.07	0.07	0.07	0.22	0.16	0.08
1,990	0.02	0.12	0.02	0.21	0.03	0.02	0.01	0.02	0.20	0.18	0.21	0.29

Table 8. Rainwater Harvesting System viability

Average mm/h	0.17	0.18	0.16	0.14	0.12	0.09	0.05	0.07	0.11	0.14	0.23	0.20
Rain (m^3/h)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rain l/m^2/h	0.17	0.18	0.16	0.14	0.12	0.09	0.05	0.07	0.11	0.14	0.23	0.20
Catchment area (m^2)												
18,742.11												
Rain from catchment l/h	3,253.42	3,282.33	2,965.24	2,676.48	2,235.62	1,724.62	1,029.89	1,263.25	2,145.71	2,683.93	4,247.26	3,679.99
Rain from catchment l/day	78,082.05	78,775.95	71,165.81	64,235.46	53,654.83	41,390.91	24,717.42	30,317.88	51,497.07	64,414.42	101,934.17	88,319.67
Days	31.00	28.50	31.00	30.00	31.00	30.00	31.00	31.00	30.00	31.00	30.00	31.00
Rain from catchment l/month	2,420,543.51	2,245,114.59	2,206,140.02	1,927,063.75	1,663,299.79	1,241,727.26	766,239.93	939,854.34	1,544,912.13	1,996,846.87	3,058,025.14	2,737,909.90
Pitch Area (m^2)	Water need (l/day)											
8,030.00	41,050.00											
Water from rain (l/h)	1,393.92	1,406.30	1,270.45	1,146.73	957.84	738.91	441.25	541.23	919.32	1,149.92	1,819.72	1,576.68
Water from rain (l/day)	33,454.02	33,751.32	30,490.77	27,521.49	22,988.25	17,733.81	10,590.10	12,989.60	22,063.76	27,598.16	43,673.39	37,840.30
Water from rain (l/month)	1,037,074.50	961,912.51	945,213.98	825,644.60	712,635.73	532,014.27	328,293.17	402,677.73	661,912.90	855,542.97	1,310,201.57	1,173,049.17
Monthly difference	(235,475.50)	(208,012.49)	(327,336.02)	(405,855.40)	(559,914.27)	(699,485.73)	(944,256.83)	(869,872.27)	(569,587.10)	(417,007.03)	78,701.57	(99,500.83)
Water absence	235,475.50	208,012.49	327,336.02	405,855.40	559,914.27	699,485.73	944,256.83	869,872.27	569,587.10	417,007.03	-	99,500.83
Water remaining	2,185,068.01	4,222,170.11	6,100,974.10	7,622,182.45	8,725,567.97	9,267,809.50	9,089,792.60	9,159,774.67	10,135,099.70	11,714,939.54	14,772,964.68	17,411,373.75

Graph 3.Water balance



	1	2	3	4	5	6	7	8	9	10	11	12	13
Monthly difference		(235,475	(208,012	(327,336	(405,855	(559,914	(699,485	(944,256	(869,872	(569,587	(417,007	78,701.5	(99,500.
Water from rain (l/month)		1,037,07	961,912.	945,213.	825,644.	712,635.	532,014.	328,293.	402,677.	661,912.	855,542.	1,310,20	1,173,04
Rain from catchment l/month		2,420,54	2,245,11	2,206,14	1,927,06	1,663,29	1,241,72	766,239.	939,854.	1,544,91	1,996,84	3,058,02	2,737,90
Water absence		235,475.	208,012.	327,336.	405,855.	559,914.	699,485.	944,256.	869,872.	569,587.	417,007.	-	99,500.8
Water remaining		2,185,06	4,222,17	6,100,97	7,622,18	8,725,56	9,267,80	9,089,79	9,159,77	10,135,0	11,714,9	14,772,9	17,411,3

Months

4.5 Economic analysis of the RHS system

Now that is known that RHS satisfies the need for irrigation of the pitch, another important aspect of this system is the economic impact.

Water needed = 41050 l/day=41.05m³/day

Cost of 1m³ water from local water supplier = 155 leke/m³ (***Table 9***)

The total cost in one year of football pitch irrigation

= 41.05*155*365=2,322,403.75 leke

This is considerable amount of money that can be saved if the RHS is implemented.

Table 9. Water supply costs from municipality

CLİENT CATEGORİES	WATER SUPPLY COST *(LEKË/M³)*
Family Customers	65
Public Clients	140
Private Clients	155
Special customers (Production of alcoholic beverages, swimming pools)	170
Bakery	95
Wholesale water sales	12
HEC Lanabregas	5

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

Recently, the interest in RHS as an alternative water source has increased, due to their economic and environmental advantages. Indeed, these systems can provide a supplementary water supply in urban areas when integrated with an existing conventional water supply system, or the main water supply in rural areas affected by water scarcity.

In the context of climate change, the installation of RHS tanks could represent a valuable adaptation measure against the reduction of water availability.

In this case study it was designed a Rainfall Harvesting system in one of the most important buildings in Tirana such is Air Albania Stadium.

Along with the design a viability analysis of the system was done and the results are satisfactory. From the analysis done it was made clear that rainfall harvesting is possible in Tirana and it could easily be implemented in any building. The benefits of RHS are not just in controlling stormwater and minimizing its effects on environment but it lowers cost in municipal fees for water supply at least 2,322,403.75 leke .

In summary, the analysis highlighted that the RHS can play a considerable role as an additional water supply system. For this reason, the installation of a RWH system in residential urban areas should be encouraged by incentives and government supports

5.2 Recommendations for future research

A recommendation for future research in this study might be and related to the impact that a Rainfall Harvesting System would have in urban flood mitigation.

REFERENCES

[1] Celeste Allen Novak, G. Edward Van Giesen,Kathy M. DeBusk,, Designing Rainwater Harvesting Systems, Hoboken, New Jersey: John Wiley & Sons, Inc., 2014.

[2] Kinkade-Levario, Heather, Design for Water, Canada: New Society Publishers, 2007.

[3] WRB-Wavin, QuickStream Technical Manual, 2015.

[4] John Swaffield with Michael Gormrley, Grant Wright and Ian McDougall, Transient free surface flows in building drainage systems, Abingdon, Oxon: Routledge, 2015.

[5] W.Mays, Larry, Stormwater Collection Systems Design Handbook, Tempe, Arizona, 2004.

[6] May, RWP, "Manual for the design of roof drainage systems/BS EN 120056-3:2000," 2003.

[7] May, RWP, "Manual for the design of roof drainage systems/BS EN 120056-3:2000," 2003.

[8] Akatherm, *Applications and design guidelines for siphonic drainage systems.*

[9] Progetti, AEI, "aeiprogetti.com," 2018. [Online]. Available: https://www.aeiprogetti.com/en/projects/air-albanian-stadium/. [Accessed 27 May 2022].

[10] Syed Azizul Haq, PEng, Harvesting Rainwater from Buildings, Switzerland: Springer International Publishing, 2017.

[11] British Standard BS EN 12056-3:2000,, Gravity drainage systems inside buildings. Part 3: Roof drainage, layout and calculation.

[12] "WISY," [Online]. Available: https://wisy-water.com/en/magazine/maracana.

[13] Winterbottom, Daniel, Rainwater harvesting, an ancient technology—cisterns—is reconsidered., 2000.

[14] W.Davies, David Butler and John, Urban drainage 2nd edition, 2004.

[15] board, Texas water development, "The Texas manual on Rainwater Harvesting," 2005.

[16] Gould, John and Erik Nissen Petersen., Rainwater Catchment Systems for Domestic Supply, Design,Construction and Implementation., London: Intermediate Technology Publications Ltd, 1999.

[17] John Swaffield with Michael Gormrley, Grant Wright and Ian McDougall, Transient free surface flows in building drainage systems, Abingdon, Oxon: Routledge, 2015.

[18] Akatherm, *Applications and design guidelines for siphonic drainage systems.*

[19] W.Mays, Larry, Stormwater Collection Systems Design Handbook, Tempe, Arizona, 2004.