FATİH SULTAN MEHMET VAKIF ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ
MİMARLIK ANABİLİM DALI
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PROPOSAL MODEL FOR RAINWATER HARVESTING IN RESIDENTIAL BUILDINGS IN PALESTINE

YÜKSEK LİSANS TEZİ

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(180202033)

Danışman

(Dr. Öğr. Üyesi, Hakkı Can ÖZKAN)

İSTANBUL, 2021

FATİH SULTAN MEHMET VAKIF ÜNİVERSİTESİ
TEZ ONAY FORMU

06/ 07/2021

LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ MÜDÜRLÜĞÜNE

Mimarlık Anabilim Dalı'nda 180202033 numaralı Mohammad Alı Yousef ALLABADI'nın hazırladığı "Palesrıne's Independency'ın Water Vıa Sustaınable Archıtecture/ Sürdürülebilir Mimarlık Üzerinden Filistinin Su Bağımsızlığı " konulu Mimarlık İngilizce Tezli Yüksek Lisans tezi ile ilgili Tez Savunma Sınavı, 06/07/2021 Salı günü saat 11:00 'da yapılmış, sorulara alınan cevaplar sonunda adayın tezinin **KABULÜNE** karar verilmiştir.

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Tez Adı Değişikliği Yapılması Halinde: Tez adının "Proposal Model For Raınwater Harvestıng In Resıdentıal Buıldıngs In Palestıne / Filistin'deki Konut Yapılarında Yağmur Suyu Hasadı İçin Model Önerisi" şeklinde değiştirilmesi uygundur.

Jüri Üyesi	Tarih	İmza
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BEYAN/ ETİK BİLDİRİM

Bu tezin yazılmasında bilimsel ahlak kurallarına uyulduğunu, başkalarının eserlerinden yararlanılması durumunda bilimsel normlara uygun olarak atıfta bulunulduğunu, kullanılan verilerde herhangi bir tahrifat yapılmadığını, tezin herhangi bir kısmının bağlı olduğum üniversite veya bir başka üniversitedeki başka bir çalışma olarak sunulmadığını beyan ederim.

MOHAMMAD ALI YOUSEF ALLABADI

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"Say:" Are those equal, those who know and those who do not know? It is those who are endued with understanding that receive admonition." (The Qur'an, 39:9)

"Seeking knowledge is a duty upon every Muslim." (Prophet Muhammad, Peace be upon him).

Thanking God comes first for the blessings and opportunities I was given. To my supportive family, simple gratitude is not near enough to suffice, but thank you for everything you have done. To give thanks where thanks are due, I would like to appreciate Asst. Prof. Dr. Hakkı Can ÖZKAN for his supervision and help throughout my thesis journey. And finally, I am grateful to my teachers of Fatih Sultan Mehmet Vakif University, colleagues, and my friends.

MOHAMMAD ALI YOUSEF ALLABADI

FİLİSTİN'DEKİ KONUT YAPILARINDA YAĞMUR SUYU HASADI İÇİN MODEL ÖNERİSİ

Mohammad Ali Yousef ALLABADI

ÖZET

Yaz ayları başta olmak üzere Filistin su kıtlığıyla karşı karşıyadır. Bu kıtlığın tek sebebi yağış rejiminin yetersiz olması değil, bölgedeki siyasal güç dengesizliğidir. İsrail'in bölgedeki su kaynaklarını kontrolü altında tutuşu, 30 yılı aşkın süredir iki ülke arasındaki krizlerin/müzakerelerin başlıca konusu olmuştur. Araştırma iki ülkenin arasındaki siyasal çatışmalardan uzak, bağımsız ve bireysel çözümlerle su krizini aşmanın yollarını incelemektedir.

Bu araştırma, su kıtlığı ve çözümlerini Antik Roma kentlerinden başlayarak, benzer nitelikteki coğrafyalarda arar. Ardından yine bölgedeki İslam dönemi eserlerini inceleyerek su yönetimi hakkında bilgi verir. Sonraki bölümde su yönetiminde yağmur hasadının önemi ve benzer krizler karşısında bu yöntem ile çözüm arayan örnek uygulamalar incelenmektedir. Ayrıca bu bölümde yağmur hasadının teknik uygulama prensiplerinden kapsamlı bir şekilde bahsedilecek, tek tek sistemin ögeleri açıklanmaktadır.

Son kısımda, Filistin'in yıllık yağmur rejimine göre bilgiler içermekte, yine bu kentlerde bulunan yapı stoğunun yağmur hasadına uygunluğu sorgulanmaktadır. Bireysel olarak Filistin'de yaşayanların kurabilecekleri yağmur hasadı sistemleri hakkında bir model önerisi geliştirilmiştir.

Anahtar Kelimeler: Filistin su kaynakları, Filistin-İsrail su çatışması, şebeke dışı su sistemleri, yağmur suyu hasadı.

PROPOSAL MODEL FOR RAINWATER HARVESTING IN RESIDENTIAL BUILDINGS IN PALESTINE

Mohammad Ali Yousef ALLABADI

ABSTRACT

Water shortages in Palestine are regularly occurring year-round and more in the summer. The main causality is the Palestinian-Israeli conflict, control over natural resources is essential in controlling the region, and as for water being the source of life, it has been one of the main points in political discussions and negotiations, and it has been a crisis for the Palestinians for more than 3 decades. To avoid the complexity of the political aspect in searching for an applicable solution, the idea of a decentralized approach is preferable for an independent potable water provider.

Steps of approaching this research will begin in discussing Palestine's water issues through previous civilizations in the same region, beginning with Roman ancient cities, following it with examples across various Islamic periods reaching to the current situation. Moving forward a description of Palestine's water sources and data regarding them, and the political aspects that revolved around them. The next step will be focussed on rainwater harvest. Starting with previous trials by countries that face a similar crisis, discussing the elements used, how they were used and their results. Moving on to the study of rainwater harvest systems, this section will thoroughly layout rainwater harvest systems elements and specifications in current times and technologies.

Finally, a series of collecting data regarding rain and general statistics concerning buildings' types, areas floors and dwellings in Palestine will be utilized and analysed in the process of figuring out Palestinian governorates' ability in rainwater harvest.

Keywords: Palestinian water, Palestinian-Israeli water conflict, Decentralized water systems, Off-grid water systems, Rainwater harvest.

PREFACE

The idea of this thesis is the product of my previous experiences living in Palestine in three different houses in two different cities and water shortage was common in all of them and cities. The shortage of water demanded the municipalities to provide water to each different district in the city one or two days a week, the rest of the week's supply needed is to be stored in rooftop tanks.

Living without water is life paralyzing, especially for today's lifestyle, where most of the needs are dependent on fast accessed piped water for washing machines, dishwaters, toilets, showers, etc. A more and bigger concern is the idea of needing approval or waiting for the mercy of a third party that forbids what is a nation's basic right and even their own property from consuming it to have power leverage over the Palestinians. Therefore, the need for an off-grid water supply will ensure survival in case of water cuts.

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SYMBOLS

mm	: Millimetres
cm	: Centimetre
m	: Metre
m^2	: Square metre
m^2	: Cubic metre
Km	: Kilometre
Psi	: Pound per square inch
kPa	: Kilopascal
pH	: A measure of the acidity or alkalinity of a fluid
MCM	: Million cubic metres

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ABBREVIATIONS

B.C.	**:** Before Christ
A.D.	**:** The birth of Christ
B.C.E.	**:** Before common era
C.E.	**:** Common era
UNRWA	**:** United Nations Relief and Works
UNESCO	**:** United Nations Educational, Scientific and Cultural Organization
UNEP	**:** United Nations Environment Programme
UNICEF	**:** United Nations Children's Emergency Fund
PCBS	**:** Palestinian Central Bureau of Statistics
MFA	**:** Israel Ministry of Foreign Affairs
IRC	**:** International rescue committee
CRR	**:** Coefficient of Rolling Resistance
PHG	**:** Palestinian Hydrology Group
IAPMO	**:** International Association of Plumbing and Mechanical Officials

INTODUCTION

Throughout history, Palestine has been accommodation for civilizations due to its location strategically and religiously. Therefore, it has been witnessing conflicts between nations millenniums ago as mentioned in some biblical stories as in The Old Testament and Quran. After the British Mandate, Palestine was divided into Jewish and Arab-Palestinian States in 1948. Now Palestine of 1967 consisting of the West Bank, Gaza Strip and East Jerusalem is under Israeli occupation as defined by the United Nations (United Nations, 1980). During times of war and conflict, water control by one party is a key for submitting the other. The first prime minister of Israel David Ben-Gurion in 1955 said that Israel is in a water war with the Arabs, and the fate of Israel depends on the results of this war (Nabil & Fua'd, 1998).

Palestine's water sources come from 2 types, the first is surface water consists of rivers, lakes, and valley streams. The second and the main source is groundwater and springs (Palestinian Water Authority, 2018). However, in the current situation Palestine suffers a major water crisis, with only 15% access to water sources (Alatili, 2004), they are forced to buy water from Mekerot (the national water company of Israel). Groundwater extraction is not allowed as set by the Israeli Water and Energy ministry under the pretext of damaging the aquifer according to the chief of staff of the Israeli energy and water department (Adam, 2012).

One of the questions that emerged by previous scholars is which approaches are better in terms of centralizing or decentralizing water management within a country, should it be managed by a certain ministry in the government, or some aspects could be centralized locally and some decentralized (Brooks, 2000).

With the previous introduction, this thesis's statement is adopting rainwater harvesting in current Palestinian architecture will minimize Palestine's reliance on importing water from Israel and may lead to its water independence.

0.1. LITERATURE REVIEW

Rainwater harvesting has been utilized since the early forms of human settlements for potable and agricultural use. The concept of rainwater harvesting is thought to appear in China 6000 years ago (Battenberg, 2009). As settlements evolved into populated cities, rainwater harvesting catchments were placed outside of the cities and were created to supply it by channels and aqueducts, which occurred in Greek cities as their population increased (Cook, Sharma, & Gardner, 2016). Another example is some Middle eastern settlements managed to provide a stable water supply even with the absence of a near-direct water source like a river by rainwater harvesting (AbedelKhaleq & Ahmed, 2007). Being a very ancient practice some of the systems used back then to this day are still applied, like catching runoff water with rock catchments (Barnbrah, 1994). Since the 1850s networks have become centrally managed and became more reliable as a water source (Cook, Sharma, & Gardner, 2016).

For the last 5 decades, water networks in cities changed from developing rainwater harvesting systems to more focus on groundwater and river basins with the use of pipes networks. However, this approach suited developed countries but not as much to developing countries due to the complexity of high scale water projects. Another issue that leads to more focus on rainwater harvesting system development is the attempt of minimizing damage to the Ecosystems (Barnbrah, 1994).

Great literature researched and published on rainwater harvesting by United Nations agencies (UNESCO, WHO, UNICEF), which coincides with their projects and interest in minimizing water shortage worldwide and especially in African countries, some of these researches are partnered with other parties, as observed in the case of "Water Harvesting in Five African Countries" report which was done by IRC International Water and Sanitation Centre on request of UNICEF in 1990. Other rich sources are manuals considering rainwater harvesting in rural areas done by local municipalities or water ministries.

In the case of the Middle Eastern and Palestinian-Israeli water management affairs, it has been studied and discussed excessively as a major Israeli-Palestinian conflict point. Some previous studies, reports and discussions about this subject mainly focused on it politically and geographically. In other literature water issues were addressed as the Eastern Mediterranean water crisis and deviated from the fact that it is just political or an Arab-Israeli Problems as addressed by Prof. Ozay Mehmet; therefore as a Mediterranean region problem, attaching it to just politics will not solve the problem on the long term, with this approach solutions suggested involves coordination between multiple nations (Mehmet, 2000). However, some scholars as David B. Brooks said, the Palestinian-Israeli water conflict resolve depends on political resolution between the two sides and only that, not necessarily ending the conflict fully, but focussing on water management as it concerns both parties (Brooks, 2000), otherwise, each country or side will have to deal with this crisis on its own. Dr. Samer Alatout considers the political side in this water conflict is rarely mentioned in literature and requires more attention, as for water sources in the region are shared by multiple countries political resolve is necessary (Alatout, 2000).

0.2. RESEARCH QUESTIONS HYPOTHESIS AND OBJECTIVES

Questions:

Some important questions that are risen on this matter are:

- Is the water crisis in Palestine strictly for political reasons or the whole region eventually is going to face it as well?
- Can former methods done by previous civilizations in the area be applicable in today's problems and circumstances? Or would some ideas be taken from them, and then be adapted to today's situation?
- Does rain precipitation in Palestine reach the required amounts for a sufficient rainwater harvesting? And will it suffice the complete Palestinian need?

Hypothesis:

Palestine’s water crisis cannot be solved by governmental proposals, but by the sum of initiative small-scale projects. Rainwater harvesting is a key player in water crisis solving, by collecting water before it reaches aquifers, which is under Israel's jurisdictions. Application of sustainable elements (e.g., rainwater catchments) in the current Palestinian architecture could become a convention method for future Palestinian architecture. By conducting this research, Palestinian individuals can have more control over their water affairs or even reach water independence from Israel.

Objectives:

To study and observe how water was managed during the previous periods and how cities survived at those periods. To calculate rain precipitation on Palestinian lands, and according to it the better method of rainwater harvesting it will be studied.

Studying the results of rainwater harvesting ineffectiveness costs, design problems and how could it be merged with Palestinian architecture.

0.3. RESEARCH SCOPE AND METHODOLOGY

Scope:

The main scope is regional. Historical and water sources data will be limited in the area of historical Palestine. However, the current rain precipitation, buildings and different statistics, and future suggestion are limited to the West Bank and Jerusalem (district J2); which is under the Palestinian authority, different from district J1 which was joined to the occupied lands in 1967 (Palestinian Central Bureau Statistics, 2018). The other limitation is buildings' purpose, the focus of this thesis will be on residential buildings, other types will be mentioned however during the study overall, but the final model is for the residential.

Methodology:

This thesis will adopt a descriptive approach of qualitative secondary data in studying examples from the past to present of water management in Palestine, moving to describe the current Palestinian water situation politically and environmentally, with the mention of how rainwater harvesting methods are applied in the current time worldwide accepted by the sustainability architecture community. By the third chapter a more specific secondary quantitative data of Palestine's buildings, rain and population then will be allocated for primary calculations done by the researcher and an analytical approach will take place of the results. In the final chapter a model of a list of suggestions for what the Palestinian community should consider in designing architecture that will help to solve the water crisis.

Figure 0.1: Map of current Palestine which is the West Bank and Gaza Strip **(Url-1)**.

0.4. FINDINGS

Results of this thesis as presented in the last chapter are concluded through data collection of Palestinian governorates regarding rain annual precipitation, building types, areas, and percentages of the previous. This data will then be analysed and utilized in a series of simple math equations that will show in numbers the possibility of roof catchment rainwater harvesting in each governorate.

The initial results varied between the governorates, if there were no malfunction in the design of the roof system, some can reach an independent off-grid water supply. However, in few governorates roof catchment by itself is not sufficient, the need for other methods like utilizing yards and parking areas as an extra catchment area, with maybe the recycling of used water. The results of this will vary according to each household capability whether financially or location area and specifications, which must be calculated individually for each design. If still not sufficient there will still be reliance on municipalities' water networks. However, collected rainwater will help during dry seasons or water cuts.

1. WATER MANAGEMENT FROM THE PAST TO PRESENT IN PALESTINE

To understand water obstructions and how they originate, whether its political causes, regional, financial, etc. Civilizations that pre-existed in Palestinian lands should be examined on how water affairs were managed as great societies had flourished there from Roman cities and cases from different Islamic periods will be demonstrated in this chapter.

1.1. WATER MANAGMENT IN THE ROMAN PERIOD

The city of Masada will be presented as prime examples of Roman architecture and water engineering at their time.

1.1.1. Masada

Masada was built by Herod the Great (37- 4 B.C.). Isolated on top of a hill in the Naqab Desert (Judean Desert), looking over the Dead Sea. Originally it was a palace complex but acted as a fortress for Herod against two threats, the Jewish rebellion, and the Egyptian threat of Queen Cleopatra (Flavius, 78 A.D.). Masada city went through three Herodian phases, Early, Main Herodian, and Late Herodian. before its fall in 73 A.D., Early Roman characteristics of architecture is seen in its architecture (UNESCO, 2001). As a fortress, providing the city with water was essential for its survival due to its location and in case of siege. The city has no springs nor rivers, the only source of water was shy rain, and floods that ran from areas with higher rain ratios. Rain in Masada was only a fifth of Jerusalem, just 100 mm, but the cisterns that were established were able to gather over 40,000 m^3.

During the Early phase, small cisterns were dug for collecting rainwater running off the summit. In the Main phase, 2 rows of cisterns were made. At 130m from the top, the first rows of four cisterns with a capacity of 4000 m^3, the second row with eight cisterns each with a capacity of 3000m^3, these rows were fed by dams created in the valise collecting water run from areas with higher altitudes. and by aqueducts reaching the cisterns., another way of feeding the cisterns, Herod ordered his slaves to bring water from dams on foot, to have a reserve in case of aqueducts demolition by his enemies.

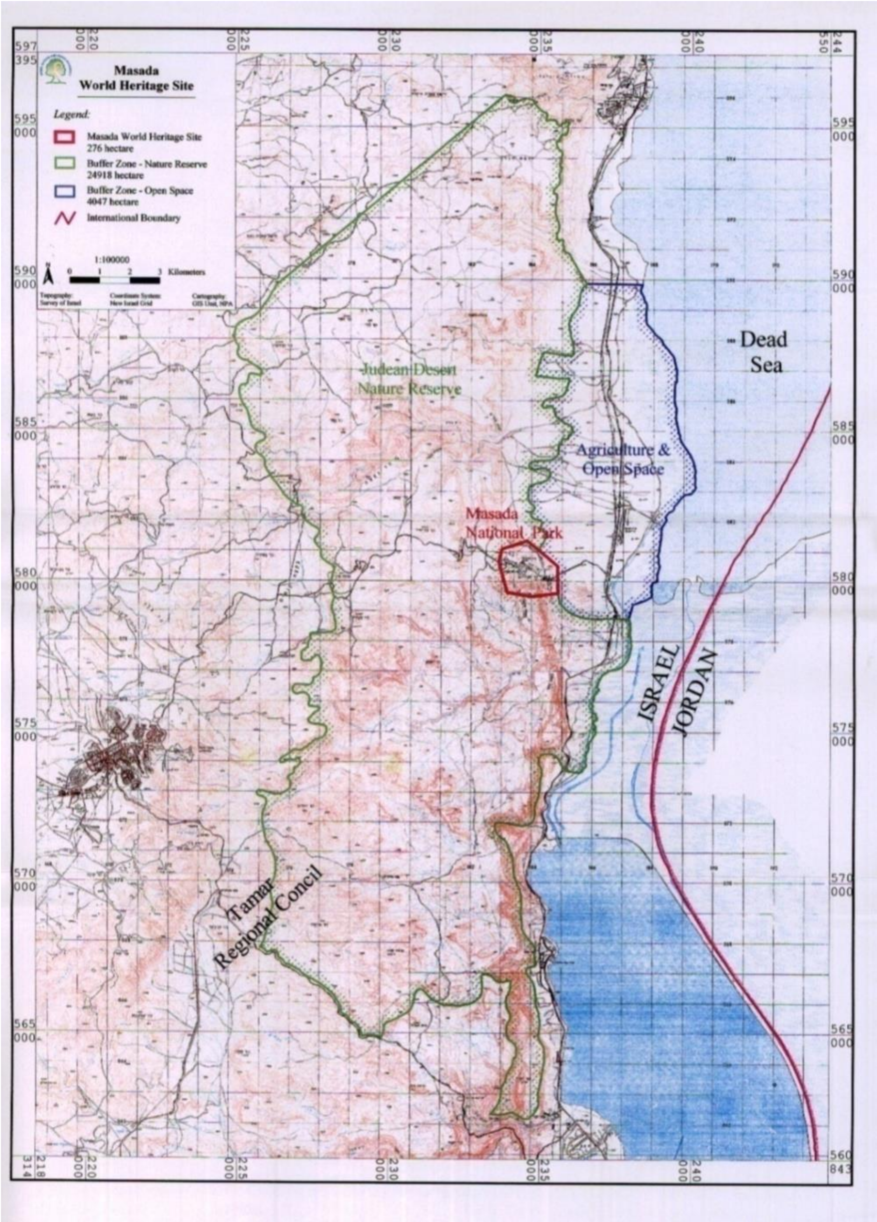


Figure 1.1: Map of Masada city, which is now converted to a national park (UNESCO, 2001).

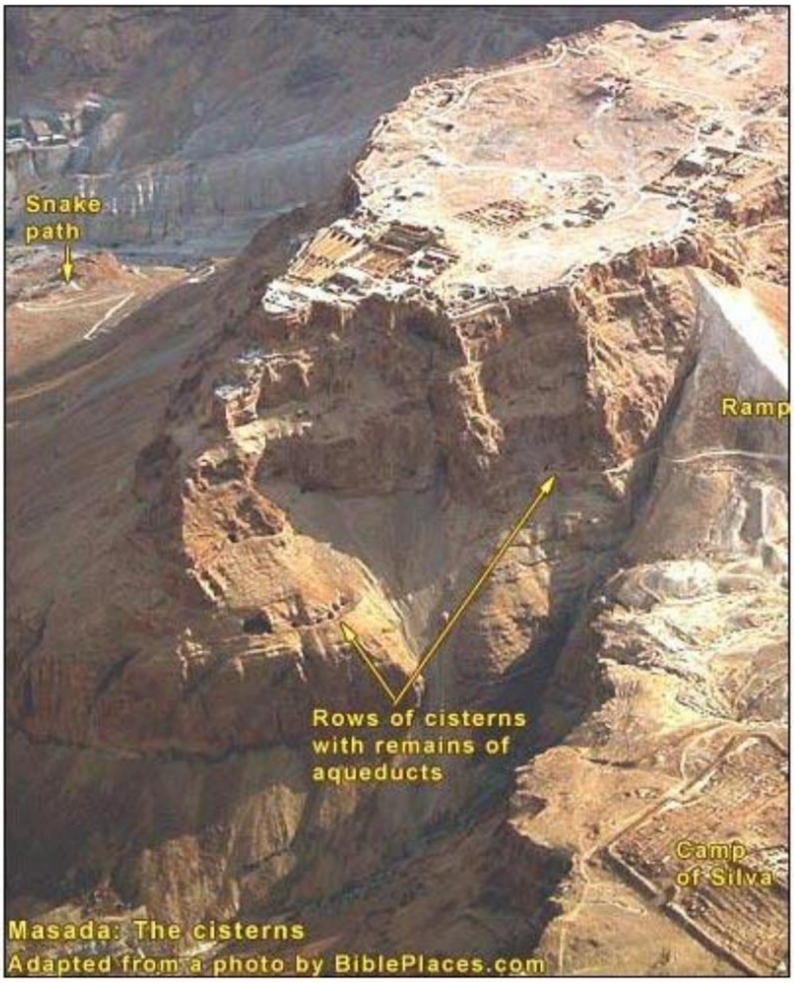


Figure 1.2: Air photo of Masada showing cisterns and aqueduct ruins **(Url-2)**.

1.1.2. Solomon's Pools And Its Aqueducts

A system that was built to provide the city of Jerusalem with water from the southern springs of the city, it is thought to be established during the First Temple period, some may label the system as Hasmonean, and some as a nearly Roman (Gibson and Amit, 2014). The difference with these views is due to multiple civilizations that used, restored, and improved this water system. It is consisted of 4 aqueducts and 3 collecting pools. The Arrub and Biyar aqueducts each brought water from southern water sources to be collected in Solomon's Pools, The Lower and Upper aqueducts resend water from the pools to Jerusalem. Each element will be described separately.

Figure 1.3: Ottoman map of the Solomon Pools and the aqueducts heading from south of Bethlehem to Jerusalem (T.C. Republic of Turkey General Directorate Of State Archives, 2009).

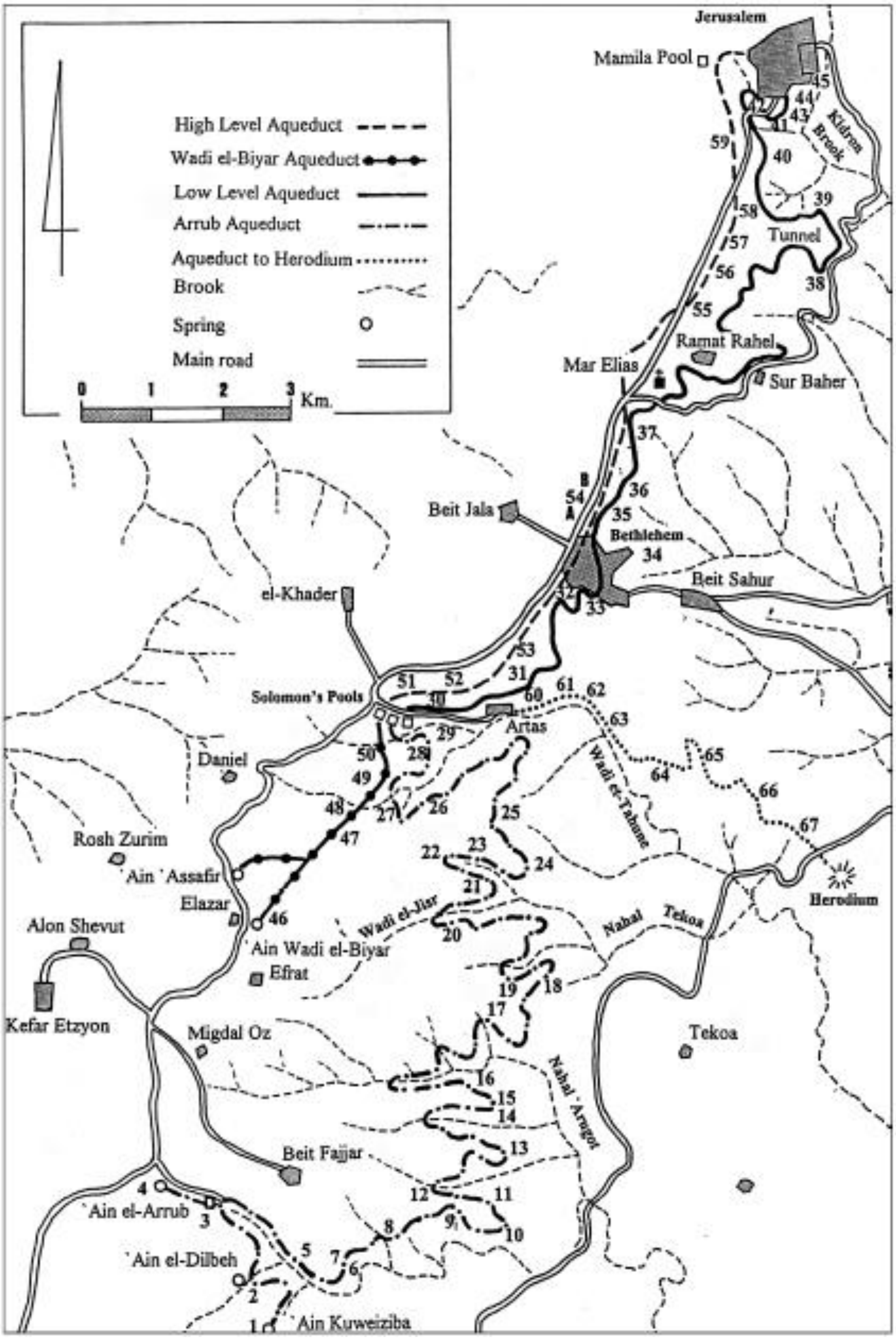


Figure 1.4: Map of the Solomon Pools and the aqueducts (Gibson and Amit, 2014).

1.1.2.1. The Arrub Aqueduct

With a length of 39 km south of Solomon's Pools, Arrub aqueduct derived water from Ein Elarrub, Ein Eldilbehand Ein Kuweiziba springs. It is said that the earliest part of the aqueduct was built during the Second Temple period (538 B.C.-70 A.D.) (Shalem, 1997). In a section of the aqueduct with multiple layers of plaster, some referred to Late Roman or Byzantine period, other was identified as Medieval and one as Ottoman, the latest did major work on the aqueduct to improve its water supply.

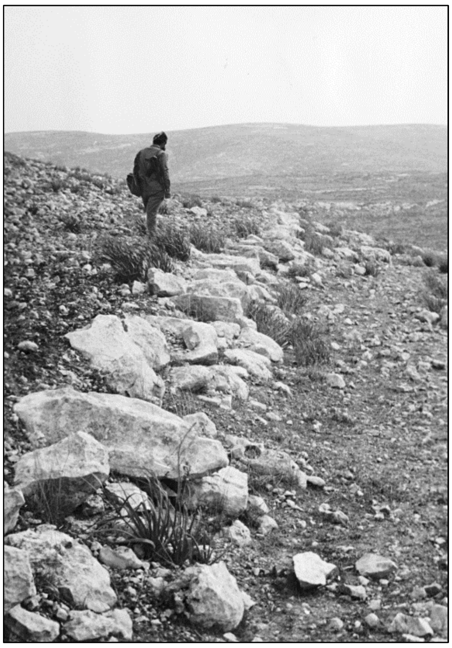


Figure 1.5: The Arrub Aqueduct (Gibson and Amit, 2014).

1.1.2.2. The Biyar Aqueduct

Its source of water is Ein Eldaraj, at an elevation of 870 m it derived water from the aquifer by a rock cut tunnel at the back of a roofed chamber, another rock-cut is tunnel found at an elevation of 860-800 m with 2.8 km long, collected ground and surface water, with 80 shafts, one every 35 m at depth varies from 5-23 m, they were used for ventilation and maintenance. A pool collects the water from the tunnel by a dam. another tunnel will be found with 11 shafts for 0.5 km, the water then goes through an open channel reaching Solomon's pools. The aqueduct was restored by the Ottomans and during the British mandate period.

Figure 1.6: The Biyar Aqueduct (Gibson and Amit, 2014).

1.1.2.3. Solomon’s Pools

3 pools at the southwest of Bethlehem. 2 pools originally built during the early periods, the third and lowest pool was built by the Mamluks during the rule of the Sultan Qaytby, rebuilt afterward by Suleiman the Magnificent (1541-1568 A.D.), which got named after him. The purpose of the pools is to gather water transferred from Arrub and Biyar aqueducts and some near springs to send it via the Lower and Upper aqueducts to Jerusalem.

Figure 1.7: One of Solomon's Pools **(Url-3)**.

Solomon's Pools Capacity

POOL NAME	L * W * H (m)	CAPACITY m^3
Upper Pool	71 * 118 * (9.5-11.0)	85,000
Middle Pool	135 * 50 * (10-12)	90,000
Lower Pool	179 *(46-81) * (8-16)	113,000

Table 1.1: Dimensions and capacities of Solomon's Pools (Mazar, 2002).

1.1.2.4. The Upper Aqueduct

Starts at the level of the middle pool, 13 km long, parallel to the lower aqueduct. Heading north from the east of Bethlehem at an elevation of 790 m, built with limestone. A reverse siphon system was used in the canal to move water through valleys and from low to high elevations. An older arcaded bridge system built by Herod the great is found next to it. Only ruins can be found from this aqueduct due to the agriculture and new cities.

Figure 1.8: The inverted siphon of the Upper-Level aqueduct (Gibson and Amit, 2014).

1.1.2.5. Lower Aqueduct

The first aqueduct to reach Jerusalem before the establishment of the pools fed by Spring Atan, after that it was fed by the Lower pool at an elevation of 765 m and a length of 21.5 km. It is believed by Prof. Amihai Mazar that it was established during the Hasmonean period and restored by the byzantine, the Mamluks had their part as shows in some of the inscriptions on a stone in 1320-1321 A.D., Suleiman the Magnificent restored it and added ceramic pipes to the system. The aqueduct starts with a rock-cut tunnel that reaches a vaulted settling tank, the rest of the aqueduct continues a free-standing wall of stone and mortar. Reaching Jerusalem in Sur Baher at an elevation of 745 m heading northwest for 150m long-reaching elevation of 740.10 m the ruins show six types of construction, Early Roman, Byzantine, Medieval and Ottoman, which is seen from the ceramic pipes and openings for maintenance, then reaching Tel-Byut by a tunnel with 6 shafts cutting through Mukaber Mountain, which shortened the aqueduct by 3.5 km.

Figure 1.9: The Lower-Level aqueduct in the Jewish Quarter (Gibson and Amit, 2014).

1.2. WATER MANAGEMENT IN ISLAMIC PERIODS

Water in Islam has a significant place, other than it being considered as the source of all life, it is also important in different worship rituals and prayers to be on Tahara "purity" which requires washing some parts of the body or whole, ablution facilities are an example of this which is seen in most of mosques. It is also reflected on Islamic culture and facilities in their cities like public Baths "Hammam" which the city residence went to for their regular wash and body treatment.

Under this title the old city of Jerusalem and the Aqsa Mosque water matters, and facilities will be described since this area went under the rule of multiple Islamic rulers which each one had it's on print on for managing water matters, to provide Jerusalem with enough water for daily uses and religious rituals. Elements of this kind of architecture will be described with a brief history each.

1.2.1. Old City Of Jerusalem And Al-Aqsa Mosque

As it was mentioned in the description of Solomon pools, Jerusalem has low rain rates and low springs, therefore it relied heavily on springs around the city and water gathering wells. since the Aqsa Mosque is the heart of the old city of Jerusalem, wells and water facilities existed in it or near it, their purpose was not just to service the mosque and its visitors, the residents of the city used to take their need of water from them as well, As seen in Figure 1.10, 1.11.

Figure 1.10: Shows the reliance of people on the Aqsa Mosque wells in 1918 image by the Palestinian National Archive **(Url-4).**

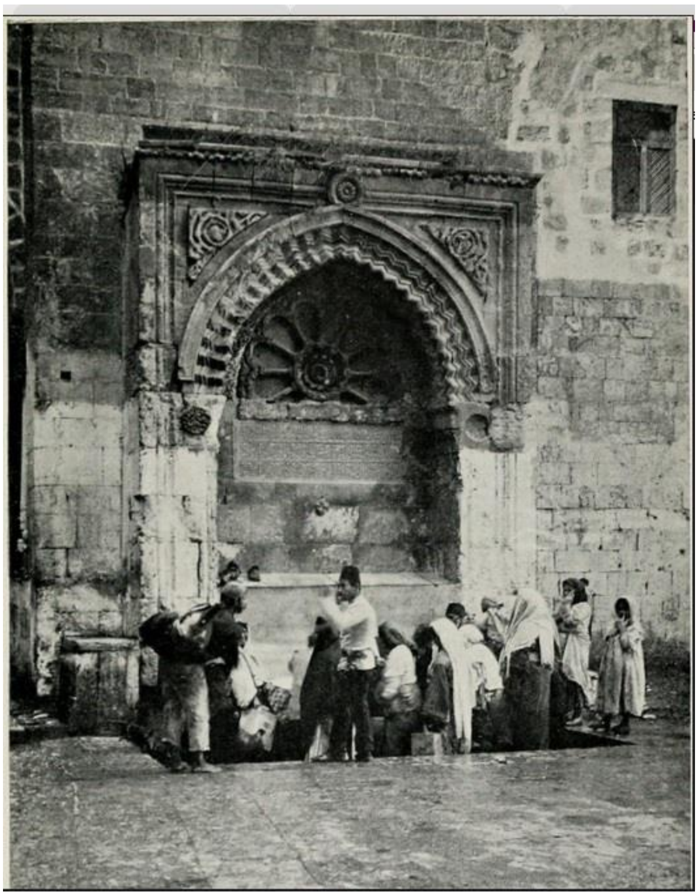


Figure 1.11: Showing residents of the old city of Jerusalem in 1913 supplying from Chain gate's water fountain one of the Aqsa mosque main gates (Goodrich-freer, 1913).

1.2.1.1. Al- Aqsa Fountains (Sabil) And Pools

Sabil is an Arabic word that according to Alwasit dictionary means sweet water easy to the throat, or sweet rapid springs. Al- Aqsa Mosque has 16 Sabils in its yards from multiple different eras, and 6 in the old city built by Suleiman the Magnificent.

- Qaytbay’s Sabil

Was built in 1455 A.D. by Mamluks King Al-Ashraf Abu Annasr Inal. After it was destroyed it was restored and built again by Mamluks King Al-Ashraf Qaytby in 1482 A.D. Then restored again by the Ottoman Sultan Abdul Majeed the second in 1912 A.D. It is on the western side of Al Aqsa’s yard. A Tall building with onion shaped dome, built over a 28m long, 6m wide and 11.5m deep well full of gathered water. Recently a water cooler was added inside the Sabil to cool down extracted water (Marouf & Marie, 2010).

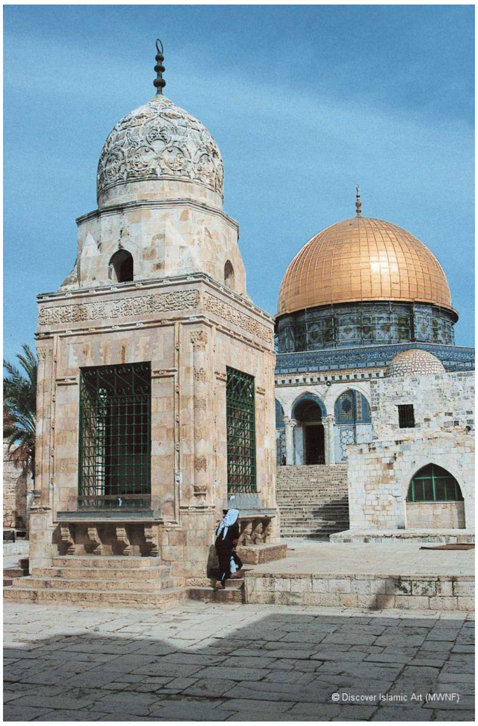


Figure 1.12: Qaytbay’s Sabil in Al Aqsa Mosque **(Url-5).**

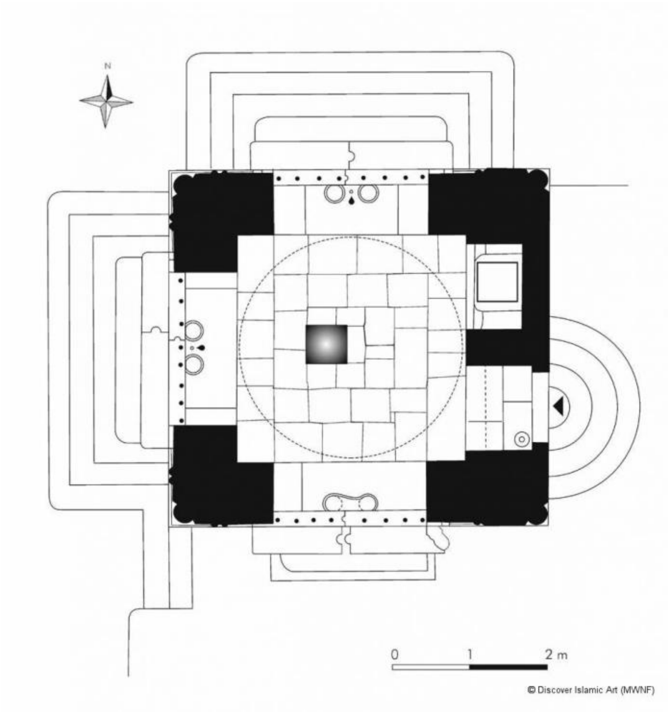


Figure 1.13: Qaytbay's Sabil Plan **(Url-5).**

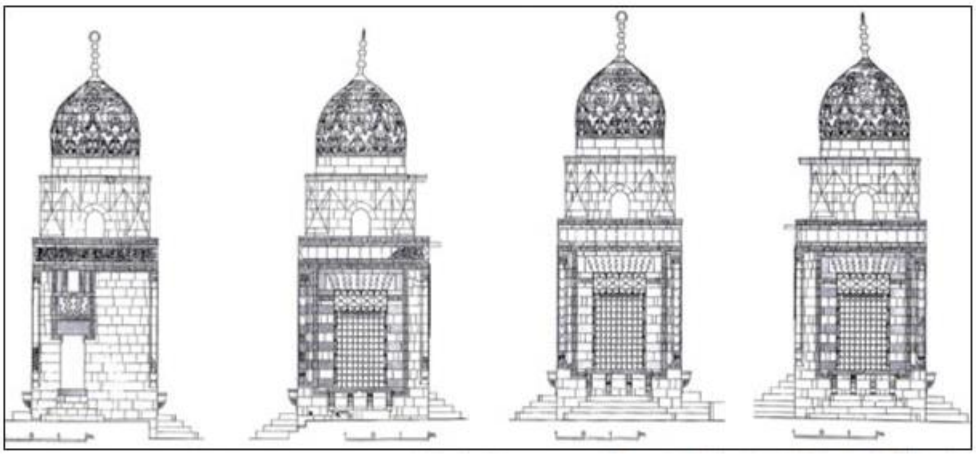


Figure 1.14: Qaytbay's Sabil 4 elevations **(Url-5).**

- Al-Ka's Sabil

Ka's is Arabic for cup, given to it for its cylinder shape with a fountain in the middle, 20 water taps and marble seats surrounding it used for ablution (Figure 1.15). Built between the southern mosque and Dome of the rock. The current structure was built during the Ayyubid period by Abu Baker bin Ayyub in 1193 A.D and renewed by Mamluks. Near it is a well with the same name 10m long, 6 m in width and 20 m deep (Khalifa, 2001).

Figure 1.15: Al Ka's Sabil **(Url-6).**

- Annarenj Pool

A 7 by 7 m Marble pool. Built by Mamluks during the reign of Qaytby in 1482 A.D.

- King Eisa's cistern

Built by the Ayyubid sultan Eisa in 1210 A.D. Built on the west Al Aqsa's yard as a water cistern. The building contains 3 arcades with different entrances, now it is used as a medical clinic and offices for Waqif (Islamic endowment) (Marouf & Marie, 2010).

Figure 1.16: King Eisa’s cistern **(Url-7).**

- Albasiry Sabil

Initiated during the time of Mamluks sultan Al-Ashraf Barsbay in 1436 A.D. After recently being restored, a water cooler was added with water taps (Marouf & Marie, 2010).

Figure 1.17: Albasiry Sabil **(Url-8).**

- Sha’lan Sabil

Built by the Ayyubid sultan Eisa in 1216 A.D. It was restored twice, the first time by Mamluks sultan Al-Ashraf Barsbay in 1429 A.D and the second by Bayram Pasha in 1627 A.D.

- Burhan Eddin’s minbar Sabil

A new Sabil was built in 1998 with 24 taps by the reconstruction committee from Islamic Waqif.

- Suleiman’s Sabil

Established in 1536 A.D. by Suleiman the Magnificent which it was named after. Then in 1997 34 water taps for ablution were added.

- Kasim Pasha’s Sabil

Was built by Jerusalem’s magistrate Kasim Pasha during the rule of Suleiman the Magnificent in 1527 A.D. Water source for this Sabil came from Solomon’s pools until the British mandate, after that it was supplied from the Israeli Municipality.

Figure 1.18: Kasim Pasha’s Sabil **(Url-9).**

- Mustafa Agha’s Sabil

Built-in 1740 A.D in the time of Sultan Mahmud I, and supervised Mustafa Agha the surrogate of Jerusalem by the order of magistrate Osman Bek. Now it is out of service (Marouf & Marie, 2010).

- Arrahma Sabil

Built-in 1995 by the Islamic Heritage Committee.

- Azzytona Sabil

Azzytona means the olive in Arabic. initiated by the Islamic Heritage Committee by adding a water cooler next to an olive tree called The Prophet tree, covered in a cylindered shaped stone pot with seven water taps.

Figure 1.19: Azzytona Sabil **(Url-10).**

- Alghadirye School Sabil

Set in front Alghadirye school in Alaqsa yards, was used by students of the school. currently out of service.

- Hutta Gate Sabil

Built-in the eastern wall of Hutta Gate during the ottoman period, currently out of service.

- Alasbat Gate’s minaret Sabil

Small water fountain, out of service today.

- Almaghariba Gate Sabil

Lays at the east of Almaghariba Gate, built in the Ottoman period, but out of service today.

1.2.1.2. Wells

Al-Aqsa Mosque is estimated to have 25 to 27 gathering wells, the narrations differ due to the different types of wells it has, some wells has two openings which some counted as 2 wells, according to Dr. Najeh Dweikat the previous manager of Al-Aqsa Mosque, it has 25 wells, 8 in Dome of the Rock yard and the rest spread in Al-Aqsa yards containing about 32 million m^3 of water (Dweikat, 2019). In the ninth Palestinian seminar of chemistry in November the 2nd 2019, Prof. Mutaz Qotub presented research on the quality of historical wells of Al-Aqsa Mosque, according to him after testing for PH, minerals, nitrates, etc. it appeared that most of the wells are within the World Health Organization's criteria, some of them needs Chloride for more sterilization, but two of them showed high numbers of Lead poisoning due to their position near historical buildings with domes and roofs covered with Lead (Qotub, 2019).

1.3. WATER MANAGEMENT UNDER THE OCCUPATION OF PALESTINE

Researching the water situation in Palestine by including the political aspect of it, is a key for its problem. Unfortunately, the political aspect of the middle east water crisis is rarely addressed in research, to approach a solution for it, politics must be addressed (Alatout, 2000).

1.3.1. Beginning Of Occupation And Oslo Accords

Before the year 1948 A.D., the ratio of water for agriculture and residential consumption was equal for Palestinian and the Israeli individual, after the Armistice Line Agreement in 1949, Israel started laying obstacles restricting development on wells and springs (Alatili, 2004). in 1964, Israel initiated National Water Carrier to pump 450 MCM/year (Million Cubic Meters) from Jordan River (a shared natural border between Palestine and Jordan) to the southern Naqab desert. After the Arab loss in 1967 against Israel, Israel has occupied Golan, The West Bank and Gaza strip led to more water sources falling under its control and more control over the southern part of Jordan River, destroying water pumps feeding agricultural lands alongside the river. Moving to the year 1978, after the war of Lebanon, Israel controlled over an area that named it Security Zone, then dominated water sources in Lebanon and sources that feed Jordan River. Afterward, colonies were built over Palestinian aquifers, withdrawing water on high levels which caused a negative impact not just on water consumption, but also on polluting water sources with colonies' waste (Alatili, 2004). after the occupation, the ratio of water consumption became 3-4 times for the Israeli to the Palestinian.

Oslo Accords were a changing point for the water situation in Palestine in 1993-1995. According to Dr. Abdulrahaman Altamimi, the general director of the Palestinian Hydrology Group (PHG). Oslo accords had many legal gaps that Israel used to change the water situation in its favour (Altamimi, 2020). the 40th article in the agreement is responsible for water and sewage (MFA, 2013), some of these gaps are:

- In the first Item of the article, it is written that Israel admits that Palestine has water rights, but in the fifth item the right of ownership will be negotiated in the final negotiations, by that it admits the right of Palestinians to use water not owning it.
- The water relationship was set to be between the Palestinian authority and Mekorot (the national water company of Israel) not the Israeli government, therefore the relationship is between buyer and seller, prices of water were and still controlled and sold to Palestinians.
- Water sources stayed under the control of Israel, and water is given to Palestinians for distribution.
- Jordan River was not mentioned in the agreement.

According to Shaddad Alatili, the share of the Palestinian individual in Oslo's Agreement was set to be 75 litres/day, compared to 1000 litres/day for the Israeli colonizer, and the share of groundwater was set to be 118 MCM, it was supposed to be raised to 200 MCM in the year of 2000. The water deficit is 130-200 MCM/year for household use and 250 MCM/year for agriculture and industrial use (Alatili, 2018).

1.3.2. Palestine's Water Sources

Water sources can be divided into 2 types, surface sources and groundwater. For groundwater Historical Palestine has 6 aquifers:

1. Mountain aquifer, it's the main water source in the area with the highest basin capacity and its high permeability with high recharge rate (UNEP, 2003).
2. Western aquifer, in 1971 Israel withdrawn 450MCM water by 400 wells exceeding its recharging amount (UNEP, 2003).
3. Northern aquifer.
4. Eastern aquifer.
5. Galilee aquifer.
6. Coastal aquifer.

The annual recharging of these aquifers is 2000-2200 MCM, but only 624 MCM is in the West Bank area .and the use of the Palestinians is only 14 % of water sources gross (Alatili, 2004). Aquifers are easily endangered of pollution due to the bad agricultural practices and salinity from over-extraction of water (UNEP, 2003).

Figure 1.20: Aquifers of the West Bank with groundwater flow (UNEP, 2003).

Springs provide around 60 MCM/year with over 300 springs in the West Bank which makes springs a very important source of water; however, a study in 1997 took 400 samples of springs in the West Bank came out with 50 % of the sample were infected with faecal and Coliform bacteria, therefore it can't be consumed without treatment (UNEP, 2003) of and 40 municipal wells with 30 MCM/year (Figure 1.21). Rain cisterns gather around 6.6 MCM/year from roofs. this is not sufficient therefore buying water from Mekorot is needed, in comparison of the years 2006, 2007 and 2008 water from Mekorot changed from 43.9 to 49.4 to 52.8 MCM which shows the increasing need for water from the Israeli side (Palestinian Central Bureau of Statistics, 2008). 75 litre/day is the average use per individual. 88% in the West Bank has access to piped water and 95% in Gaza, but the infrastructures needed major maintenance in the 2000s, the loss of transferred water was approximately 30-40% (UNEP, 2003).

Re-used water in the West Bank and Gaza is 40 MCM/ year; however, it is mostly used for agriculture and without treatment (UNEP, 2003).

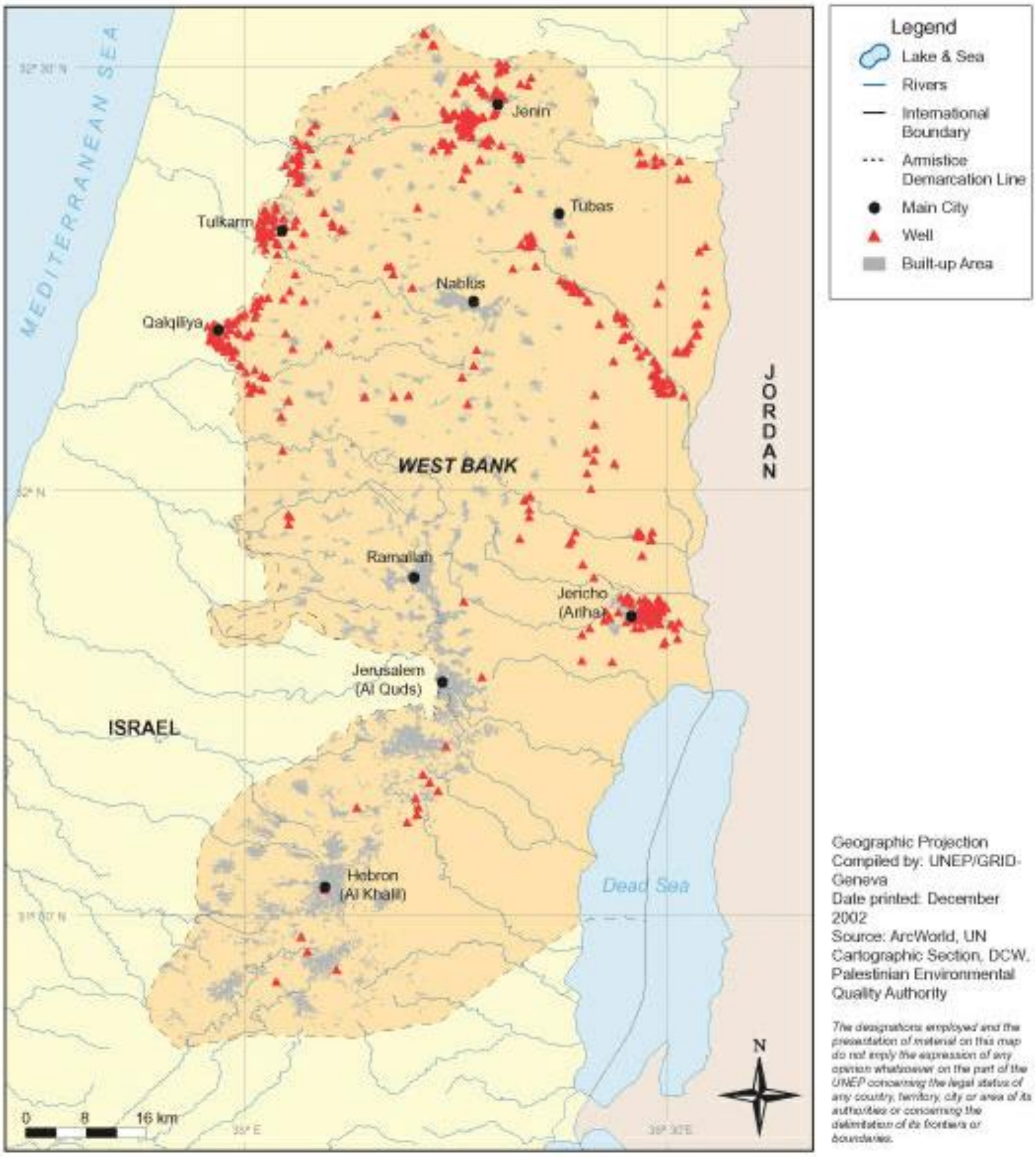


Figure 1.21: Well distribution in the West Bank (UNEP, 2003).

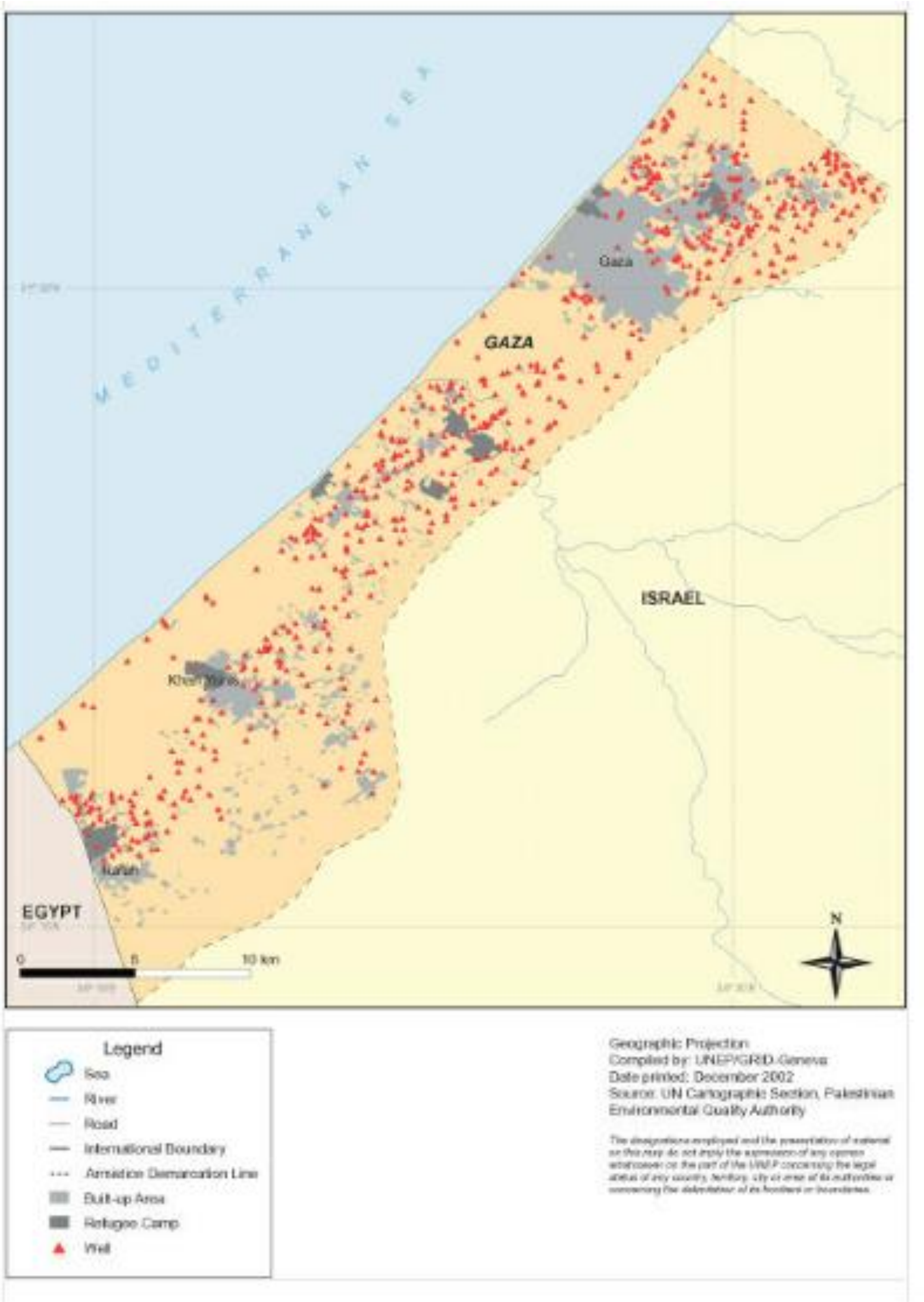


Figure 1.22: Well distribution in Gaza (UNEP, 2003).

The averages rain precipitation in the West Bank is 450 mm/year which is equivalent to 2600 MCM/year to its area of 5,879 km^2, 325 mm/year in Gaza is around 40 MCM/year to its area of 378 km^2 (Figure 1.23) (UNEP, 2003).

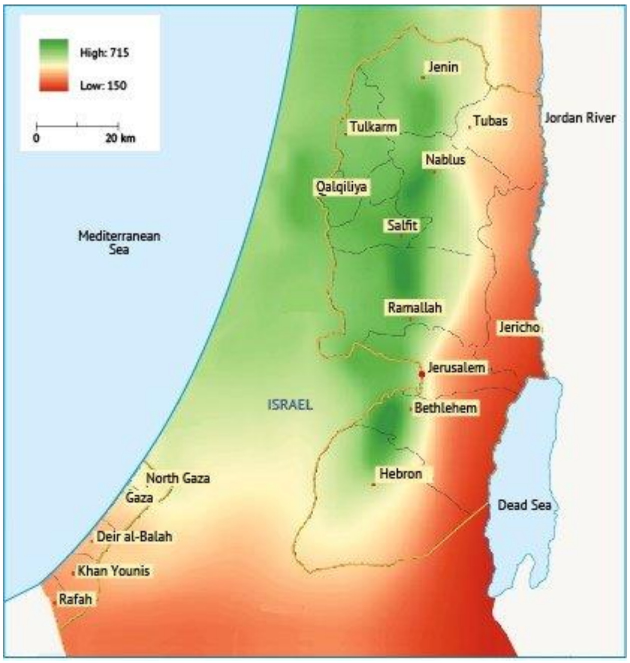


Figure 1.23: Rainfall average levels in Palestine **(Url-11).**

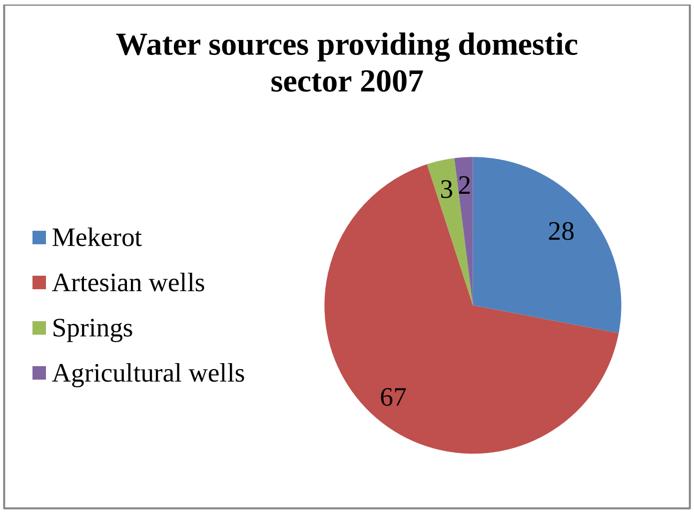


Figure 1.24: Showing the different water sources for domestic use **(Palestinian Central Bureau of Statistics, 2008)**.

1.3.3. Water Elements And Tools Used In Residential Buildings

Due to the shyness of water in cities, Municipalities set water schedules for different regions in each governorate, during the week, which means that water reaches some areas one day per week. This was observed by the researcher during his life living in 2 different cities in Palestine through the past decade, therefore in Palestine the use of roof tanks became essential to have regular water usage for basic needs, roof tanks are part of every city's skyline in Palestine.

Figure 1.25: A Palestinian building's roof showing water tanks **(Url-12).**

Figure 1.26: 30,000 litre water tank **(Url-13).**

2. RAINWATER HARVESTING ATTEMPTS IN OTHER COUNTRIES

In this chapter studies of countries that have similar water crisis and conditions of Palestine's will be examined to extract data from previous experiences within the same current period of the Palestinian crisis, after that, building types and areas in Palestine will be studied to flesh out the capability of applying rainwater harvesting, how efficient it may be, and which cities can be better than others.

Rainwater harvesting has many reasons for being a good candied of solving water crises, they are:

- Rainwater is free, costs are limited to the materials used in harvesting systems.
- Can be a convenient replacement for groundwater when it is unavailable.
- Rainwater has low to no sodium ratios.
- Rainwater is efficient for landscape irrigation.
- Rainwater harvesting helps reducing water demand in the summer and (Texas Water Development Board, 2005).
- Gathered water storage is close to the residential area which eliminates complex and big scale infrastructures that can be more convenient and acceptable for distribution (IRC International Water and Sanitation Centre, 1990).

2.1. RAINWATER HARVESTING IN BOTSWANA, KENYA, MALI, TANZANIA, AND TOGO

(IRC International Water and Sanitation Centre, 1990)

Groundwater is the main source of water in the countries of this study, extracted by hand pumps or in some areas by motor pumps like in Tanzania and more known and used in Botswana. In areas like Tanzania where there is a shortage of saline in groundwater, a search for more sustainable systems is sought for by the government, for example, gravity-based water pipes and manly rainwater harvesting which has been a common practice in the country areas but was being avoided by planners due to capital costs, working on a small scale, quality control, etc. In Togo rainwater harvesting became a choice in the 80s since 30- 40% of groundwater drillings and 15-20 % of villages could not be provided by reliable water wells.

Rainwater harvesting was used for drinking, irrigation, and cattle by building small dams. Rainwater harvesting has been adopted more by planners in these areas but at different rates, for example, In Kenya, it is more sources supported than in Tanzania which was in its beginning stages. Rainwater harvesting design depends on many factors which are:

1. The necessity of rainwater harvesting for people.
2. Rainfall amount and variation annually.
3. Dry seasons consideration.
4. Catchment surface type.
5. Number of consumers per tank.
6. Purpose of stored water (farming, household, etc.).
7. Local labour skills.
8. Material availability and supplying.
9. Affordability of components 'prices.
10. The lifespan of the tanks.
11. Maintenance.
12. Contamination prevention and safety.

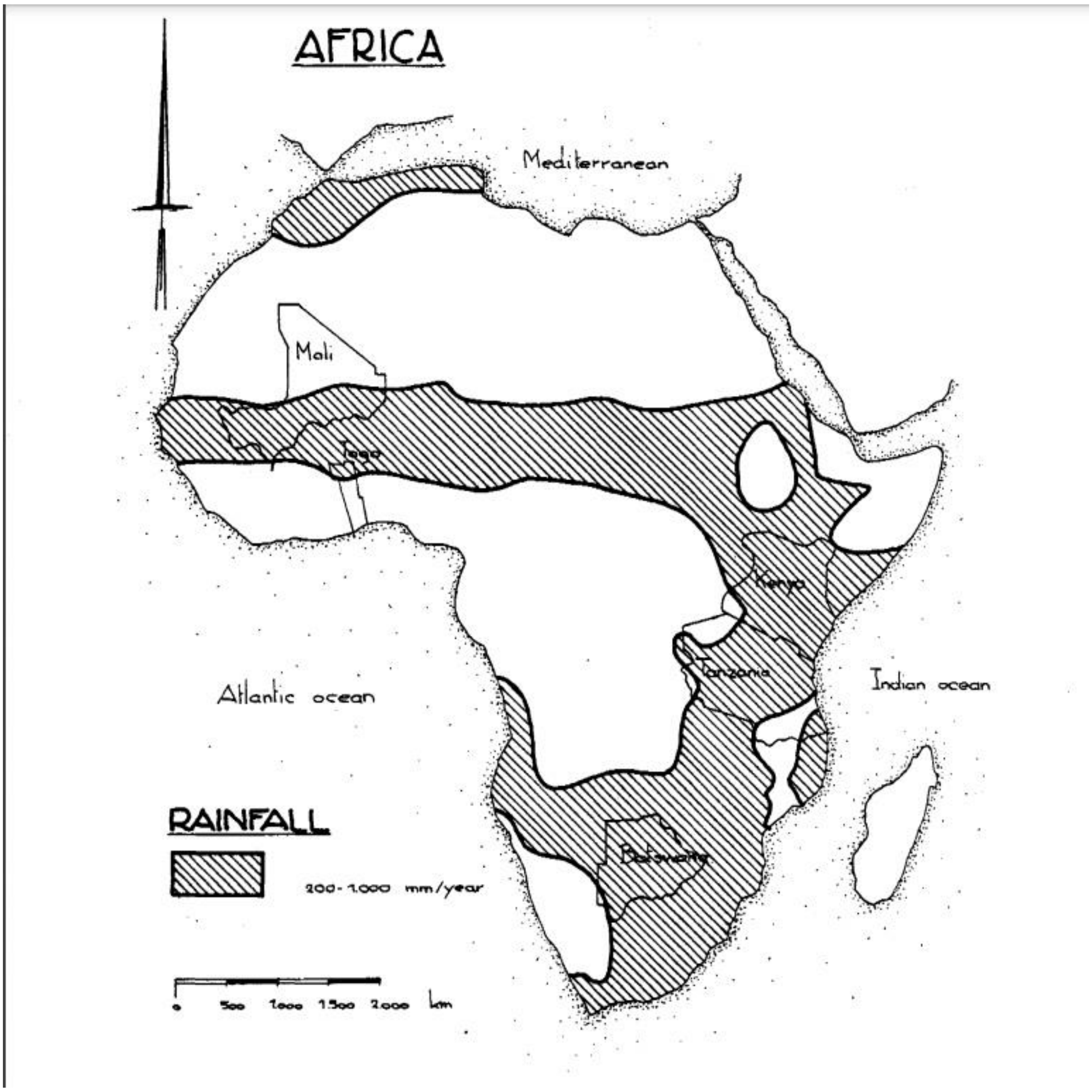


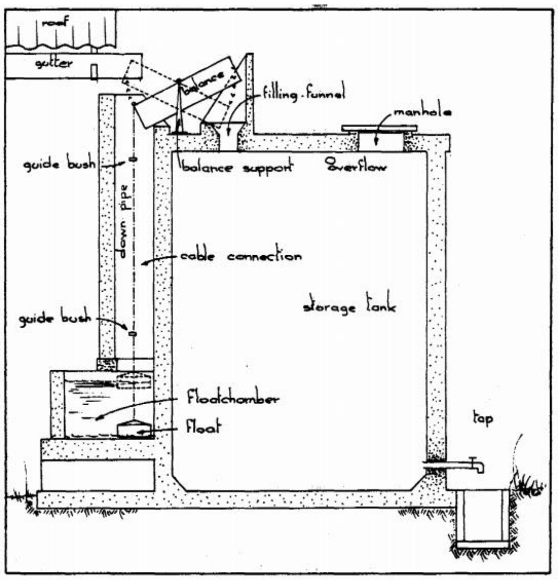
Figure 2.1: Map of Africa shows areas with relatively higher annual rainfall (IRC International Water and Sanitation Centre, 1990)

2.1.1. Methods Of Rainwater Harvesting Applied

Three methods were used in these 5 countries for rainwater harvesting which are:

2.1.1.1. Rooftop Rainwater Harvesting

Rooftop harvesting consists of 3 elements, water gathering surface, gutters and storing places. Roof surfaces are traditionally made of thatch or mud, but since they are not efficient in water gathering a lot of the residences switched to iron sheet roofing. Gutters are suspended by the eaves of the roof with roughly 1cm slope per meter. First flush system is a downpipe filled with first rainwater to keep it from contaminating storage tanks (Figures 2.2, 2.3). For storing water different ways has been used which are:



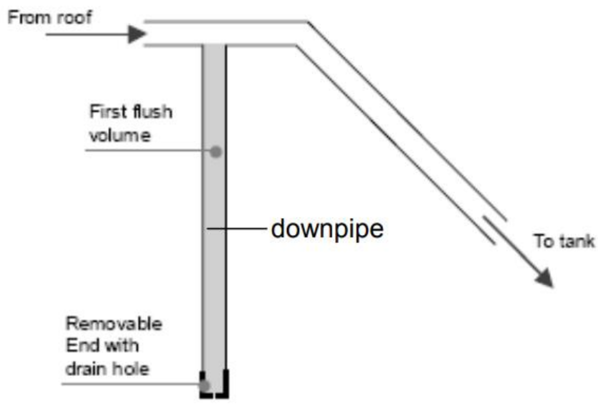


Figure 2.2: First flush system applied in Togo (IRC International Water and Sanitation Centre, 1990)
Figure 2.3: First flush system in Tanzania (Samsam water foundation, 2009).

- Cement jars with 0.5-2.0m^3 capacity plastered baskets (4-10 m^3) but have a short life span which led to it not being used in 1987's project.
- Underground tanks built with mortar and enforced with wires and mesh, with more reinforcement it could reach higher capacities up to 163 m^{3}that is used for large family grouping, health centres and schools. The capacity of underground tanks varied in each country, in Botswana it is 8-29 m3, Kenya 60-80m^3, Tanzania and Togo 80-110 m^3.

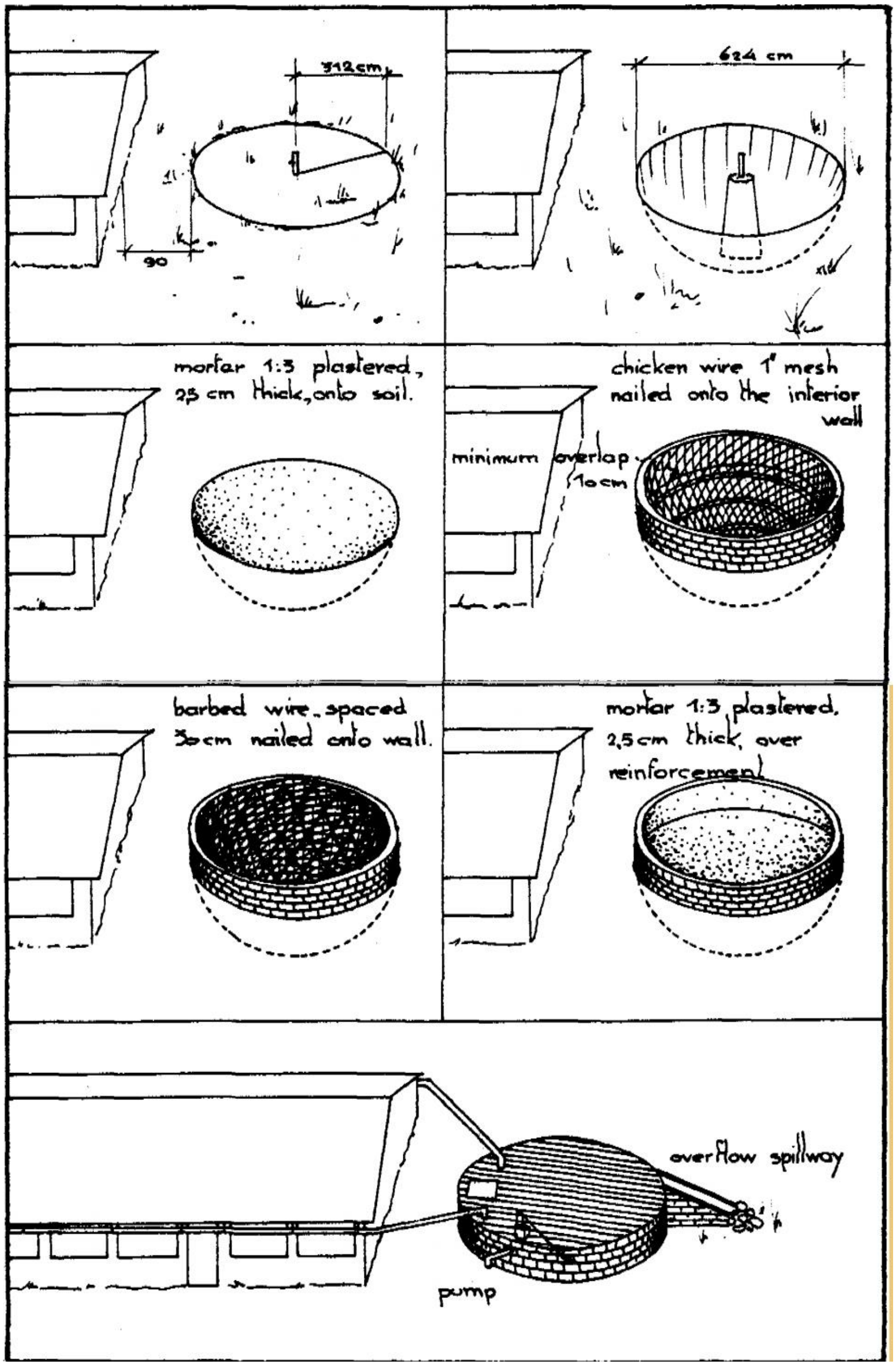


Figure 2.4: A 78m^3 underground tank construction, Lee, M.D. and Nissen-Petersen, E. (1989). The use of low-cost, self-help rainwater harvesting systems for community water supply in southern Kenya (IRC International Water and Sanitation Centre, 1990).

- Above-ground tanks come in two types, factory-made tanks, and constructed tanks. Constructed tanks sizes vary according to the reinforcement type it has. The first is 4-13.5 m^3 cylindrical tank made of ferrocement (wires and mortar) or cement blocks. The second is 20-40 m^3 reinforced by rigid iron mesh, which is of good quality and minimum repairs. Figure 3.5 shows the stages of constructing an above-ground tank.

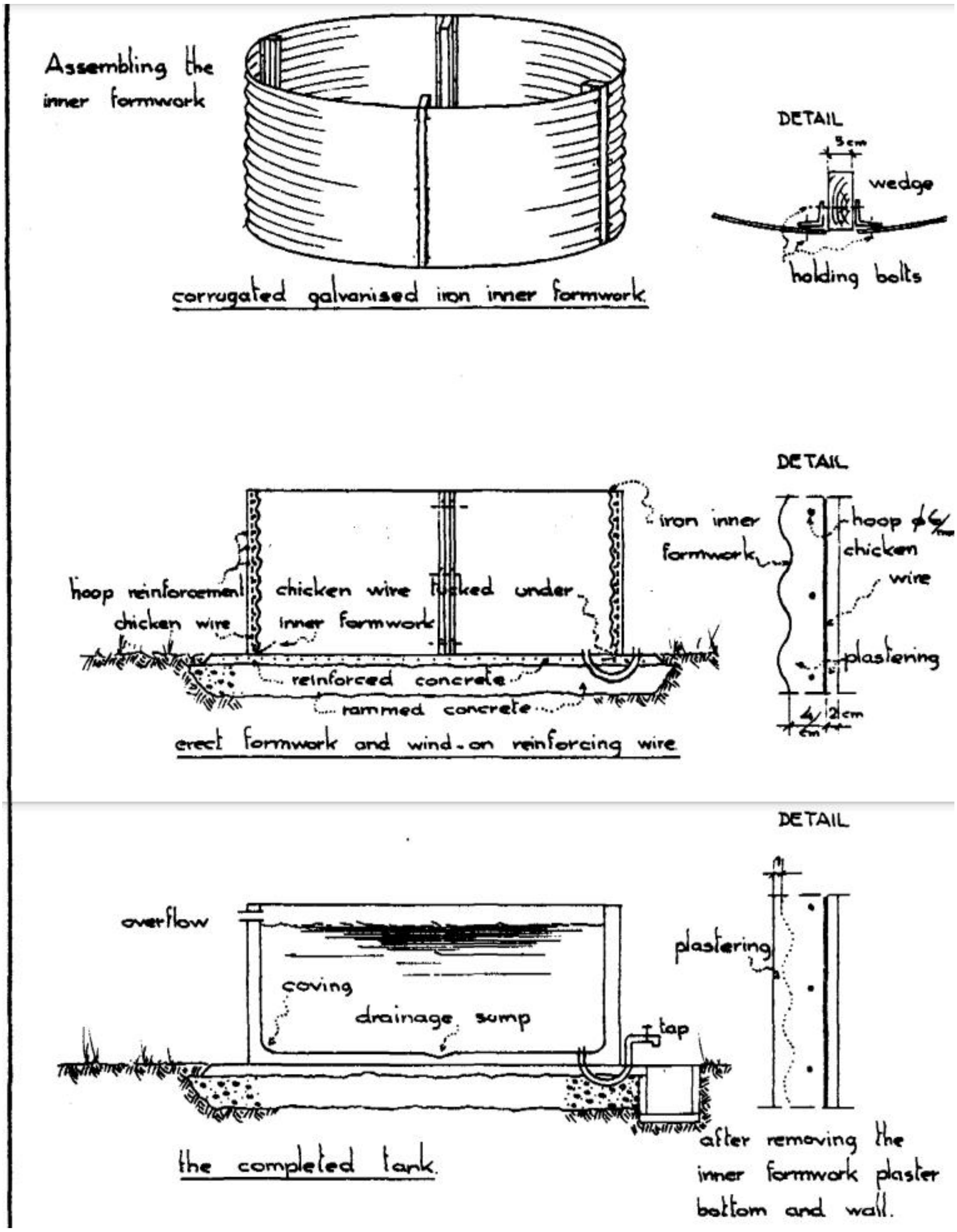


Figure 2.5: Watt, S.B. (1978). Ferrocement water tanks and their construction (IRC International Water and Sanitation Centre, 1990).

- Pre-made factory tanks out of galvanized iron are expensive and have short lifespan with a capacity of 5-7 m^3, In Botswana, 7 m^3 polyethylene tanks were considered by the Ministry of Agriculture for harvested water in which will be utilized for farming.

2.1.1.2. Surface Catchments

It comes in 4 types which are:

- Rock catchments, most known in Kenya, are walls constructed in valleys and low areas. Made of rock masonry. Gutters are placed to transfer gathered water.
- Underground cisterns, which are dug and plastered to reserve a large amount of runoff water used in Togo and Tanzania. Or underground tanks- not connected to roofs-used in Kenya and Botswana.
- Earth dams, made of clay and earth in small valleys for collecting runoff water for local use and for cattle.
- Under surface dams.

2.1.1.3. Farming Systems

Farming systems can be divided into runoff area which is the catchment area, and run-on area which is the planted area. Most of the countries have the potential for runoff farming systems except for Togo to improve farming areas. The negative side of these systems is the acceptance and applicability of them is very slow in Mali and Kenya because of the high labour need in construction and annual maintenance. System types are:

- Micro pits and micro catchments

Micro pits are small dug area that is planted at the end of a diamond-shaped slope (micro catchment), water run-off and gathers in the pits.

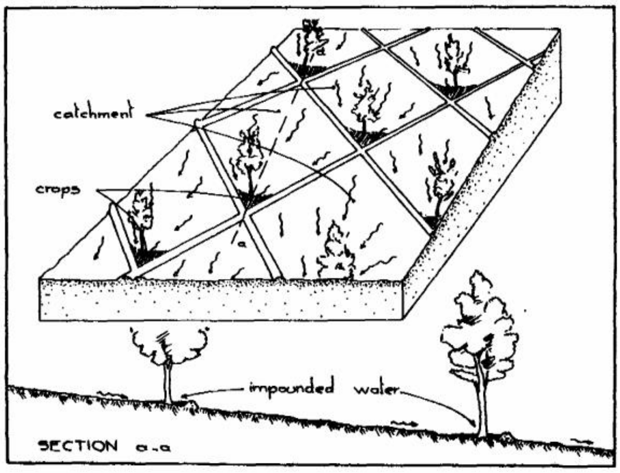


Figure 2.6: Micro catchment, Rainwater harvesting: the collection of rainfall and runoff in rural areas (IRC International Water and Sanitation Centre, 1990).

- Small check barriers

Ditches dug down the contour of a slope creating a low point and a higher point about 30cm high stacked the dug dirt with stones right behind the ditches to block slow runoff water and in the case of a strong runoff, allowing water to pass by the sides, 5 to 20m between ditches, the CRR -ratio for the planted (cultivated) area to catchment area- is 2-3 for 1%-3% slopes.

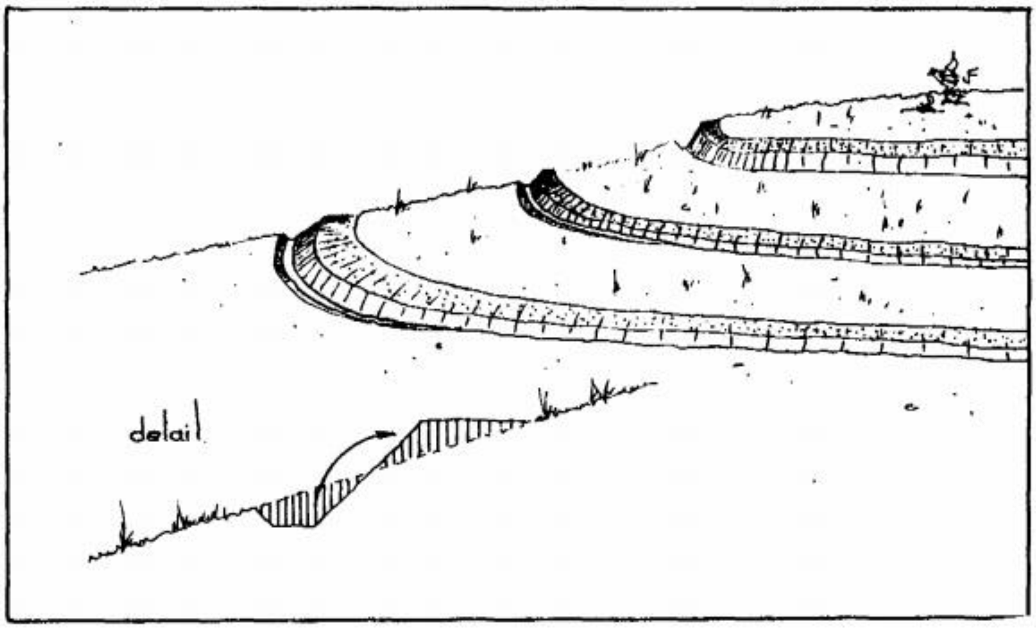


Figure 2.7: Contour small check barriers, Rainwater harvesting: the collection of rainfall and runoff in rural areas (IRC International Water and Sanitation Centre, 1990).

- Medium check barriers

A semi-circular or half-moon or U-shaped ditches along contours down a slope with the opening of the semi-circles facing the top of the slope and the end of its side by another circle. with CRR of 3 in half-moon shaped and 5 for 0.5 to 2 % slopes.

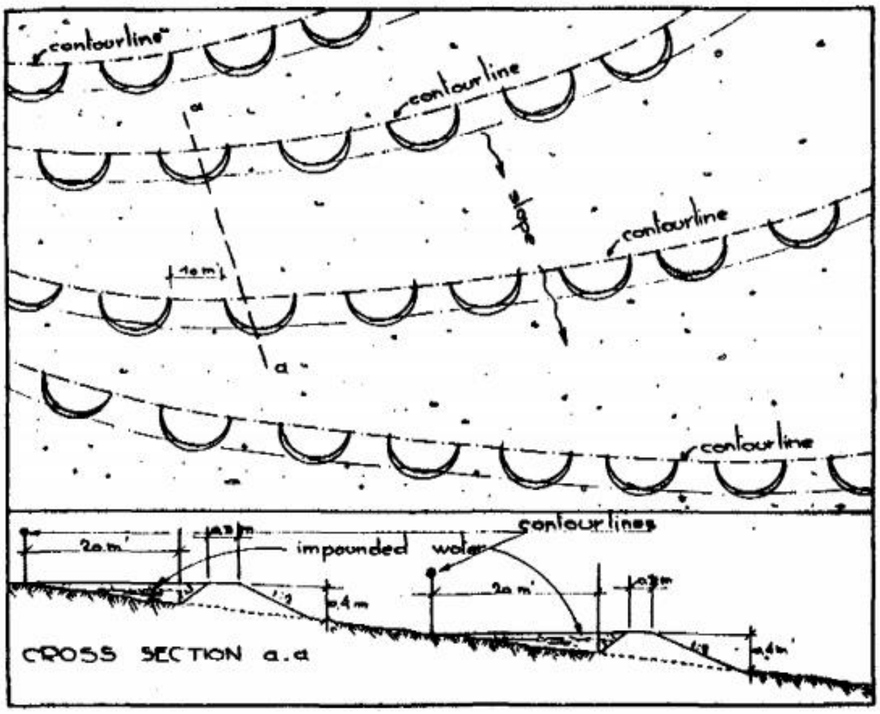


Figure 2.8: Half-moon check barriers, Report on water harvesting in Turkan, Kenya (IRC International Water and Sanitation Centre, 1990).

- Large check barriers

Large porous stone placed at the bottom of an alluvial valley to slow water runoff and water spread and disperse. Used in Mali but it was not widespread and adopted much.

2.1.2. Rainwater Harvesting Systems Criteria

1. Design is based on the average conditions of the area, dry season, rainy seasons, annual rain amount, average water consumption per individual.
2. Designed to use the maximum potential of the site.
3. Designed on decisive preferences for the pacific project like funding, managing preferences, available technologies, what communities dictate, etc.
4. Designed based on the models of needed size and density of run-off systems.

2.1.3. Rainwater Harvesting Systems Quality

According to a study in Batswana, water harvested from rooftops has Coliform bacteria in an acceptable range according to WHO's (World Health Organization). In the absence of tanks sanitary extraction, filters, first flush system, and surface catchments tanks water quality is low. For unclean roofs by birds' faecal residue, there is a risk of high levels of streptococci. Open stored water types have more potential of being a suitable habitat for mosquitoes carrying Malaria and other diseases. Earth dams and open reservoir in West Africa are habitable by Bilharzias and worms' contamination.

2.1.4. Accomplishments And Results

Water systems were focused on structure effectiveness neglecting local skills development and finance capability. Projects were in early stages therefore they have not always well reached their goals. In Kenya, school rooftop systems were applied and provided safe and clean water, but tanks were too small, and the reservoirs were empty earlier in dry seasons.

Other effects occurred on the social side; the first problem was water ownership conflict when a communal system is applied in a divided community. Another issue was a change in natural hydrology causing a drop in groundwater count, floods in some farming lands, and shortage of supply in others. Excluding a fraction of the community was also a problem, which can occur when only part of the community is targeted or treated preferably. forcing or not including communities with decision making, neglecting the possibility of newcomers to a community with the same water supplied before.

2.1.5. Maintenance For Roof Rainwater Harvesting Tanks

Maintenance steps relate to rain periods, before during, and after the rain season. Before rain season, water tanks, roofs, mesh filters, gutter and first flush system should be cleaned. During the rainy season, first flush system should be emptied from the first rainwater and repeating the first steps for the rest of the components except for the tank. After the end of the season, water tanks should be closed preventing light insects, etc. (Samsam water foundation, 2009).

2.1.6. Costs Review

Costs are affected by variable causes which leads to the fact that it is not effective to calculate costs based on different experiences' calculations, which

Kenya's project managers advice not to use pre-estimated and calculated costs[1]. Those variables are:

1. Currency exchange variations.
2. Economy inflammation changes through the years.
3. The purpose of the project, whether it is for research purposes, trial, or a real application.
4. Countries price differences for example labour wages.
5. Local materials, transportation, labour skills and utilized machines.

Rooftop system prices for $5m^3$ small rooftop according to more recent projects in Rundugai area, Tanzania (Samsam water foundation, 2009).

Description	Cost in €
Bricks	71
Reinforcement bars 1/2"	33
reinforcement bars 5/8"	11
reinforcement wire mesh	49
reinforcement bars (walls)	41
sand and gravel (foundation + roof)	97
sand and gravel (walls)	71
cement (wall + foundation)	98
cement, waterproof	14
Pvc pipes, gutters, and pieces	141
transport	44
Framework	29
tools, materials etc.	59
labour	47
Total	**805**

Table 2.1: System prices for $5m^3$ Rooftop system prices small rooftop according to more recent projects in Rundugai area, Tanzania (Samsam water foundation, 2009)

2.1.7. Rainwater Harvesting Methods Evaluation

In order to choo7se which method is best or more suitable for the current situation in Palestine according to multiple factors which are implemented by

[1]For more details on the prices of the components used in the five countries case study in 1989 pp 11-14

governments or individuals, area size needed, projects that are allowed to be constructed in Palestine, cost and suitability for Palestine's climate.

- Rooftop rainwater harvesting has wide options and choices for component types and materials, which can be chosen according to which is available or preferred costs, which makes it more flexible in design. This method also depends on the owner of the roof surface owner to implement it without interference from governments neither the Palestinian nor the Israeli, this leaves the freedom for the individual of taking the initiative of adopting rainwater harvesting. It is restricted by catchment area size its catchment effectiveness depends on it. This method is the best solution for urban areas.
- Surface catchment methods vary from type to type, but the need for vast open areas is in common with each one, moreover, good engineering is essential for these methods to succeed. Funding is also needed since the costs of these projects with the regular maintaining are high (IRC International Water and Sanitation Centre, 1990). Another downside to this type of project is the size of them, as previously mentioned large water projects are exposed to vandalism or demolition by Israel. However, if applied as part of certain built areas like schoolyards, parking lots, courtyards, etc., as an extra catchment area for water that can be used for multiple functions other than human consumption.

2.2. FACTORS THAT SET THE POSSIBLITY OF RAINWATER HARVESTING

Rainwater harvesting depends on 5 factors to succeed they are:

- Obtainable water amount

Water quantity that is obtainable by rainwater harvesting systems meets a household's requirement of water.

- System costs

Compared to other water sources - if available - rainwater harvesting systems expenses should not be drastically higher than other available options.

- Water quality

Water must be potable and consumable by people without health risks.

- Cultural acceptance

Systems that are considered better through time, are accepted by the culture of implementers and consumers.

- Regulations and policies

Sets of regulations and guides should be available to assist implementers to maximize systems efficiency (World Health Organization, 2009).

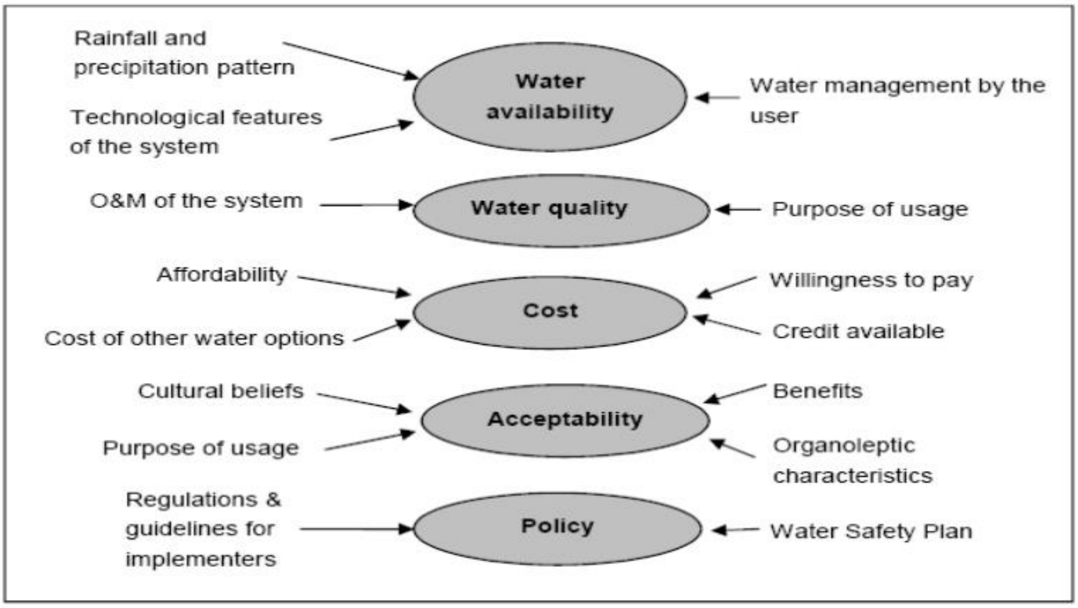


Figure 2.9: Rainwater harvesting feasibility factors (World Health Organization, 2009)

2.3. ROOFTOP RAINWATER HARVESTING COMPONENTS AND DESIGN CONCERNS SUITABLE FOR URBAN AREAS

Rooftop rainwater harvesting as mentioned in the case studies before consists of some elements, it will be discussed here in more detail and technicality aspects of it (Figure 2.10).

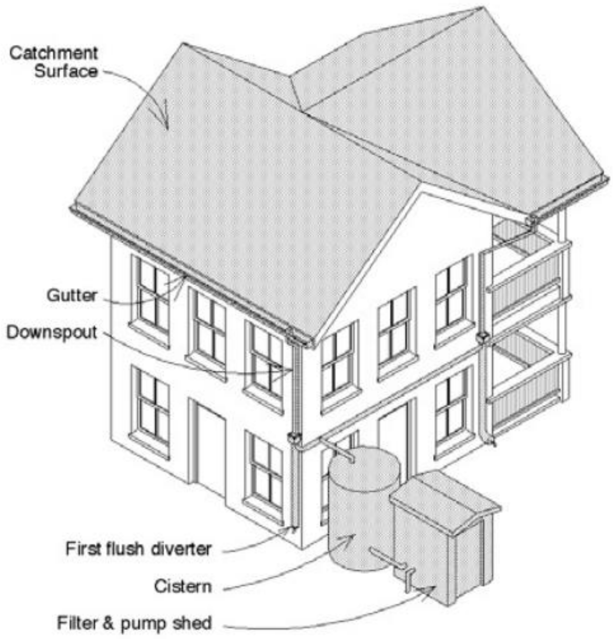


Figure 2.10: Standard roof rainwater harvesting system components (Texas Water Development Board, 2005).

2.3.1. Catchment Surfaces

Catchment surface is the roof of the building itself and other roofs can be added over a parking area, barn, patio, and porches. The shape of a roof affects the water amount it can catch, the more annual rain, more acute the roof shape should be as seen in (Figure 2.11) (Mou & Wang, 1994).

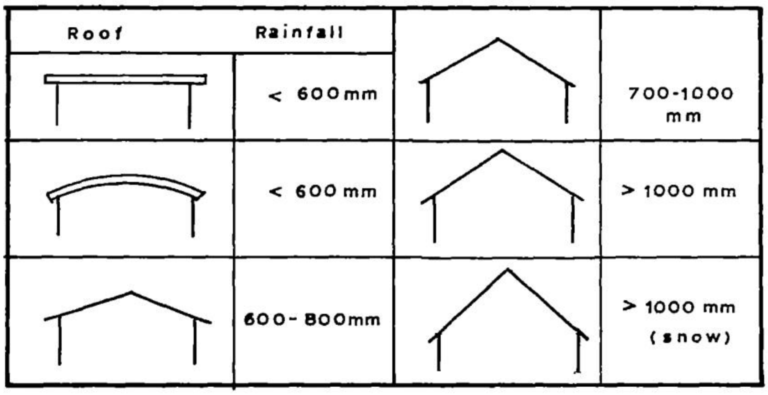


Figure 2.11: Roof shape differences and its relationship with annual rain (Mou & Wang, 1994).

Materials usage in rainwater harvesting is important for the efficiency of the system. Concrete and ceramic tiles are suitable for water-related work but due to their porous nature there is about 10% of water loss, which can be solved by painting the surface with a nontoxic sealer (Texas Water Development Board, 2005).

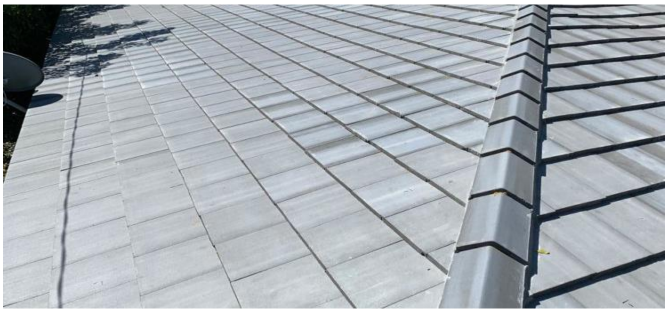


Figure 2.12: Concrete roof tiles (Url-14).

Metal roofs are a common use for rainwater harvesting, a common material used is made of 45% zinc and 55% aluminium called steel tile (Texas Water Development Board, 2005). Lead as mentioned in a previous chapter causes water to be toxic, which can cause poisoning (Qotub, 2019). Slate roofing which is a naturally mined stone is also a good material for rainwater harvesting because of the smoothness of the surface (Texas Water Development Board, 2005).

Asphalt roofing leaches toxins to water which makes it usable for irrigation but not for human consumption, the same applies to Wood and gravel roofs due to the rough surface objects and dirt leaches to it (Texas Water Development Board, 2005).

2.3.2. Gutters, First Flush Systems and Roof Washers

Gutters are the component that receives water from the roof and sends it to first flush system and the reservoir. Gutters are made from PVC, Aluminium, Galvanized steel, and Vinyl. Old gutters were made from Lead which should be avoided for the reasons explained before. The size of the gutter depends on the size, plan, and sloppiness of the roof, the plan of the roof determines the existence of valleys (the connection point of two roof slopes (eaves)), valley collects water more than other places of the roof which needs to be considered and calculated. Leaf screens and guards are used to prevent gutters and pipes clog, and to keep water quality from contamination, which is a mesh covering gutters. A series of filters along the gutters and in downspouts is needed to collect any debris (Texas Water Development Board, 2005).

Figure 2.13: Guttering system components **(Url-15).**

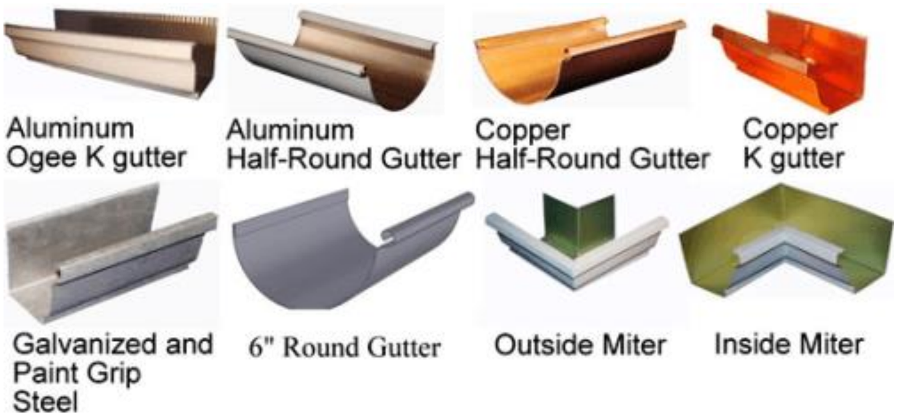


Figure 2.14: Gutters sections and materials **(Url-15).**

First flush system or diverter is a downpipe that collects the first rain wash, which prevents collected dust and small objects that pass from the previous filters from entering the tank, after it is filled, a lock mechanism diverts water to the tanks, an example of such mechanism is a floating ball that plugs pipe entrance when it is full

(Figures 2.15, 2.16). Collected water should be emptied after every rainfall and during it, water is drained continuously by a faucet or a small hall replacing dirty water. Calculation of diverter size depends on the volume intended to collect. For every 100 feet^2 (about 9.2 m^2) of catchment surface, 1 gallon (3.785 litres) is the estimated amount of water that should be diverted, another equation can be used which is that required volume of diverted water (Litres) = house length (m) * house width (m) * 0.5 (mm) (Mosley, 2005).

First flush diverters are made from PVC, Volume = radius^2 * π (3.14) ***** length of the PVC pipe, for example, 3 inches pipe needs 33 inches in length for a gallon (3.785 litres) (Texas Water Development Board, 2005).

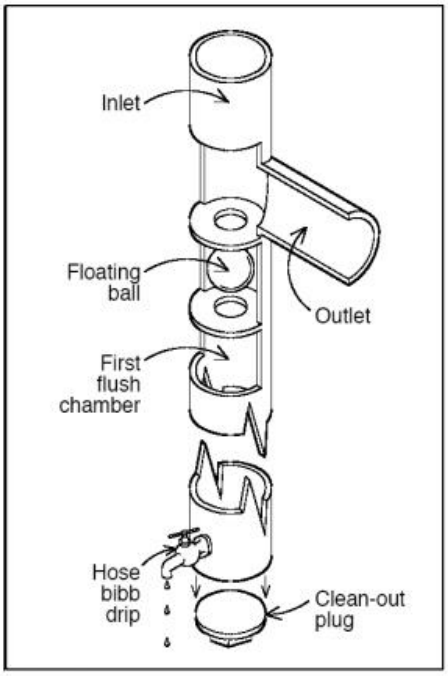


Figure 2.15: First flush diverter with floating ball mechanism (Texas Water Development Board, 2005).

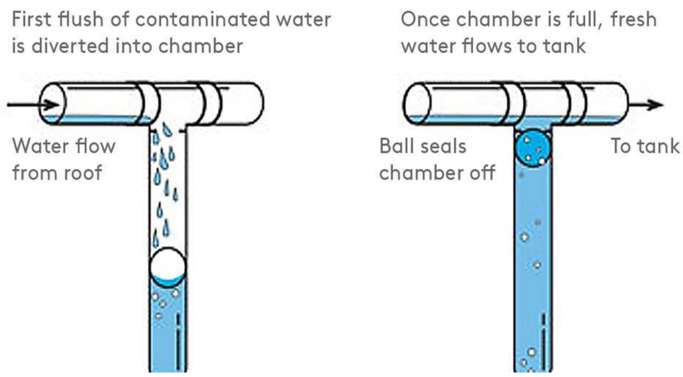


Figure 2.16: First flush system, floating ball mechanism **(Url-16).**

Roof washers are a type of water filtration placed before water tanks. It is a small tank commercially made of fibreglass with leaf screens, and a micron filter and an example of it is 30-micron filters which are commonly used (Figure 3.17). Roof washers should be cleaned regularly, or it will become a fitting environment for microbes and diseases (Texas Water Development Board, 2005).

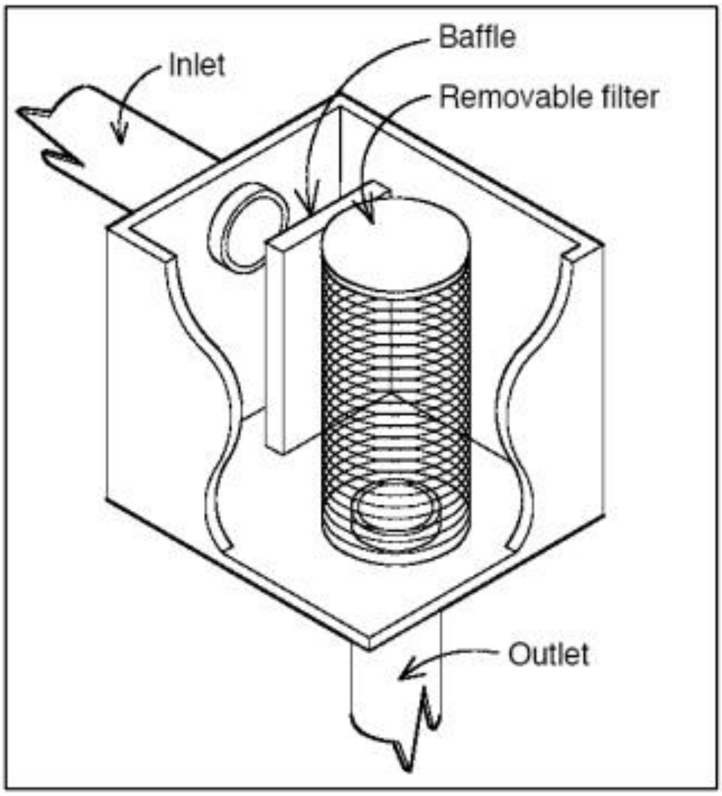


Figure 2.17: Roof washer's components (Texas Water Development Board, 2005).

2.3.3. Tanks

Tanks are fundamental in roof rainwater harvesting. tank type and size depend on:

1. Roof area size.
2. Rainfall precipitation annually.
3. Dry season length.
4. Budget.
5. Preference of the user.
6. Aesthetics of the tank.

2.3.3.1. Tanks Requirements

To provide safe water for household use, first tanks should not allow sunlight, it should be opaque, which prevents the growth of algae. The second is tanks should be accessible for cleaning. The third point is water reservoir must be covered to keep way insects and entrance of pollutants. In addition, tanks should not be second used after any storage of toxic materials. Tanks' placement is important to be near of water supplier and the supplied area and high as possible without exceeding gutters height, in order not to overpower water pumps and reduce energy by using gravity. In case of an overflow, a secondary tank should receive water that must be drained away from any near structures (Texas Water Development Board, 2005). Tanks' output should not be at the bottom of it, it should be a little higher to avoid any possible residue.(Mosley, 2005).

2.3.3.2. Tank Types

Tanks are manufactured and structured by many different materials and methods; each has its qualities which will be examined.

- Polypropylene (Plastic)

Considered inexpensive, has a long-life span, lightweight and durable. Capacity ranges from 50 gallons - 10,000 gallons (about 190 - 37,800 litres) (Texas Water Development Board, 2005). Can be found over ground and enforced tanks for underground. Plastic tanks come in dark opaque colours which is effective in blocking sun rays (Mosley, 2005).

- Fibreglass

Fibreglass tanks are high in cost, fittings of the tank are done in the manufacturing Phase, which minimizes leakage problems that can occur with plastic tanks. For human consumption, tanks should be lined with food-grade liner. Sizes vary from 50 - 15,000 gallons (about 190 - 57,000 litres) (Texas Water Development Board, 2005).

- Metal

Galvanized steel covered with zinc prevents corrosion. Suitable for suburban gardens and urban areas. capacity ranges from 150 - 2500 gallons (about 570 - 9460 litres) (Texas Water Development Board, 2005).

- Concrete

Concrete tanks can e precast or structured on-site above ground or under. On-site poured tanks or cisterns are recommended if they are well structured and steel reinforced by an engineer. The inner surface of concrete cisterns should be plastered with materials compatible with potable use. They prone to crack and fixing it requires draining the water it contains.

- Wood

Wooden tanks are made of Cypress, Pine, or Cedar staves wrapped in galvanized steel rods and bands. For potable use, the inside is lined with plastic (Polyethylene, Polypropylene, Polyvinyl). Wood tanks are used for their aesthetic appeal. Capacity varies from 700 - 37,000 gallons (about 2650 - 140,000 litres). Downside of wood tanks is cost (Texas Water Development Board, 2005).

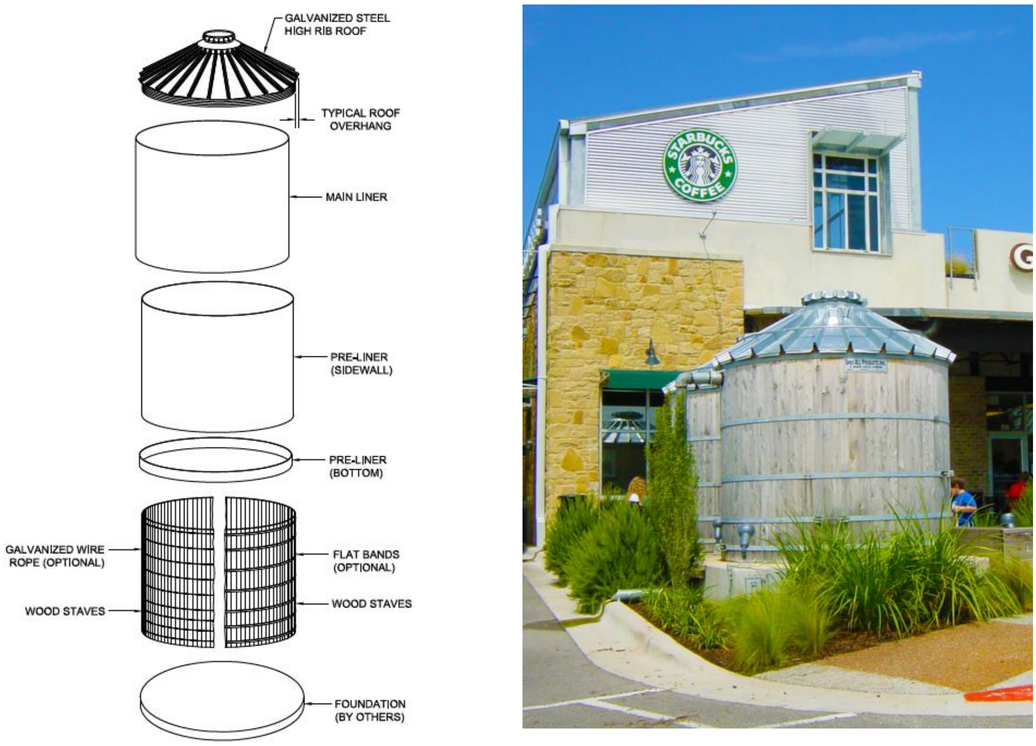


Figure 2.18: On the left is wood tank components. On the right a real example of a wooden tank **(Url-17).**

- Ferrocement

Ferrocement is mortar (concrete and sand mixture) sprayed by a gun called Gunite, this method uses dry mortar mixes with water the moment it's sprayed out over a structure of steel grids of rods tied with wires, another method is almost the same, but the difference is the mortar is in clay form, this method called Shotcrete. From the outside tanks are painted to reflect the sun. These methods are cost-efficient for larger size cisterns which is why it is used in 3rd world countries similar to the case studies mentioned in the previous doors (Texas Water Development Board, 2005).

- Rain drum or barrel

Rain barrels are 50 -75 gallons (about 189 - 284 litres) capacity. Some barrels are specially designed for rain, they have an outlet to connect with an extra barrel if needed.

2.3.4. Water Pumps

Municipal water pressure standard is 40 - 60 psi (275-414 kPa)[2]. Elevation change should be accounted, for every 1 vertical foot changes 0.433 psi (1 m changes9.79 kPa), the same is applied to gravity-based systems, to increase the pressure the tank is placed at a higher altitude. Pumps should not exceed 80 psi if does a reducing valve should be installed, 15 psi is the minimum for supplying water to water closets toilets, urinals, etc. Pipe size is determined by the height of the supplied outlet in the buildings and calculated accordingly (IAPMO, International Association of Plumbing and Mechanical Officials, 2015).

Pressure tank pump mechanism is to get water from rain cisterns, pressurizing it in a tank through a one-way valve, which is then sent through a check pressure valve to the household. When the pressured tank is full which is typically about 150 litres, the power shuts off from the pump, when it drops it comes back on supplying the tank with needed water to reach its threshold (Figure 2.19). On-demand pumps however eliminate pressure tanks as a separated unit and joints it to one unit with a pump, check valve, motor, controller (Texas Water Development Board, 2005).

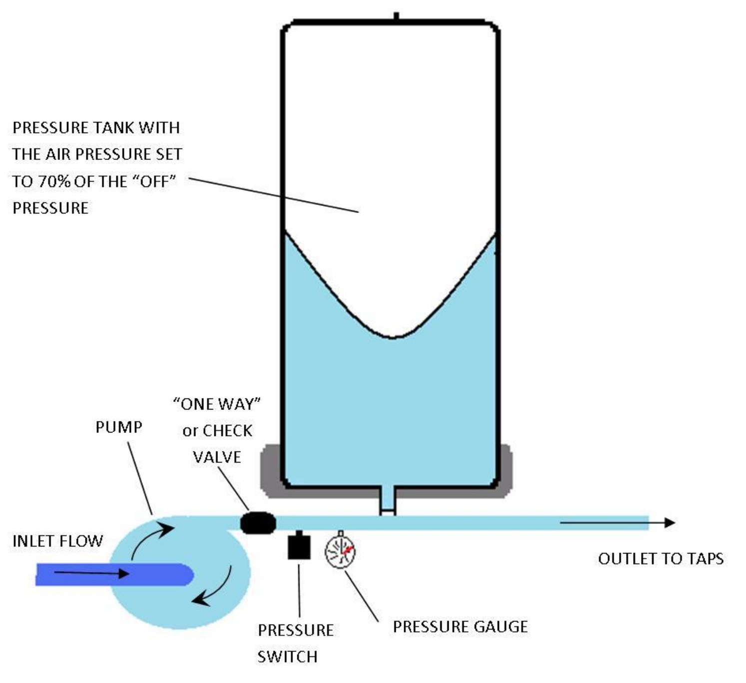


Figure 2.19: Pressure tank pump **(Url-18).**

[2]1 pound per square inch = 0.6895 Kilo Pascal

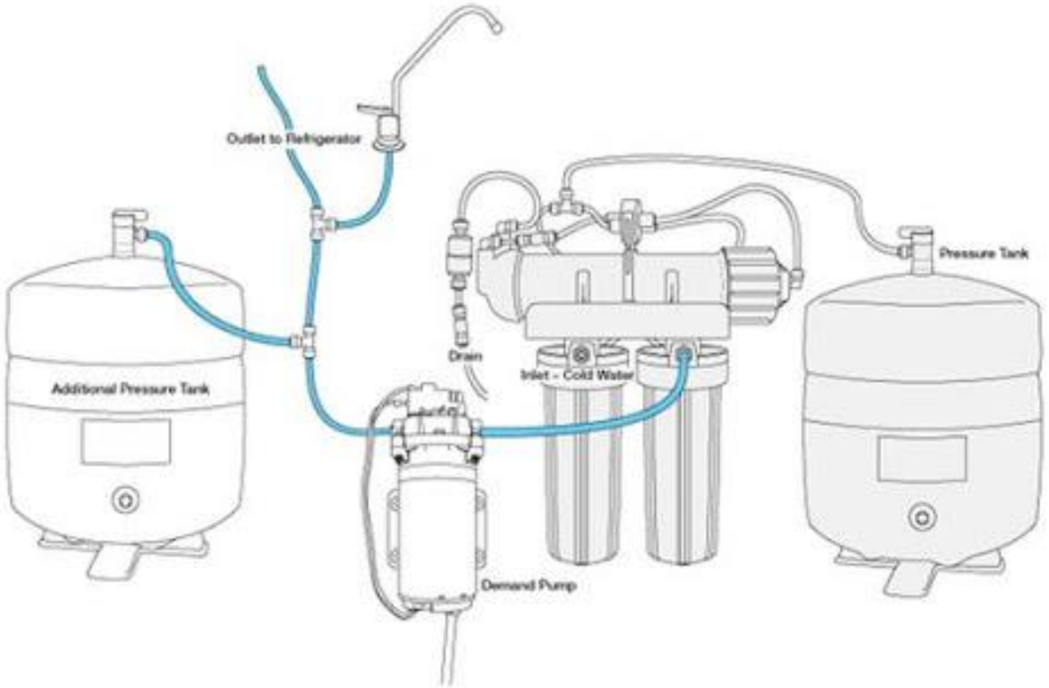


Figure 2.20: On demand pump **(Url-19).**

2.3.5. Water Treatment

Some factors should be considered that could contaminate or affect water's quality. Rain acidity is one of these factors, rain acidity occurs when rain particles contact carbon dioxide particles, distilled water pH[3] is natural 7.0, but rainwater is 5.7, it can be altered by adding 1 tablespoon of baking powder or an equivalent basic compound for every 100 gallons (378.5 litres) of water. For agricultural purposes screens on gutters and roof washers are sufficient by themselves. but for potable use, more disinfection and filtration are needed for the water stored in the tanks (Texas Water Development Board, 2005). Many methods are possible to use they are they are:

- Chlorination
- Ozone
- Cartridge Filters and Ultraviolet (UV) Light
- Membrane Filtration

2.3.6. Design Considerations

Some elements should be well considered during planning a rainwater harvesting system they are:

- Amount of rainwater that could be harvested is calculated by the amount of water available (litres) = rainfall (m/year) x roof area (m^2) x 1000 (Samsam water foundation, 2009).
- Straight gutters with no slope cause about 50% loss of water.
- Placing gutters on one side of the roof leads to 50 %.
- Overflow pipe on the tank placed on a low spot can reach a 25% water loss.
- Tank’s outlet placed on a high place may lead to 25% water loss (Mou & Wang, 1994).

[3]PH is the scale to measure acidic or basic water, or a solution is, ranges from 0 (acidic) -14 (basic). water is 7.0 which is neutral (Url-20).

2.4. SURFACE RAINWATER HARVESTING METHODS SUITABLE FOR URBAN AREAS

Surface rainwater harvesting can be a good use for gathering more water from schoolyards, open parking lots, gardens, building's yards, etc. By using more surface area more water can be used for multiple uses other than human consumption, which minimizes use from water gathered from rooftops and saves it for potable use.

Surface types and how impervious they are affects heavily rain circulation. Rain after precipitation is either evaporated, runoff, or infiltrated in the ground (Figure 2.21).

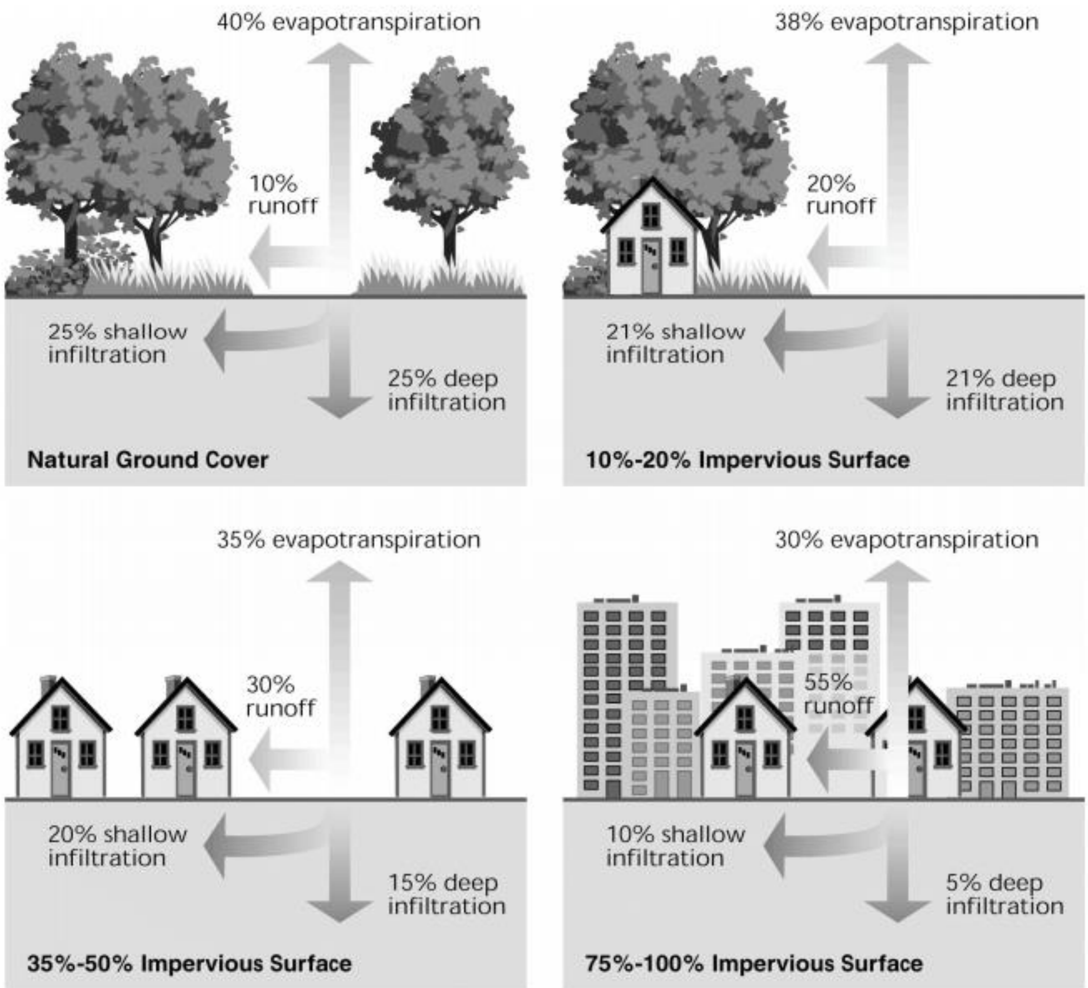


Figure 2.21: Surface differences and its impact on rain circulation (United States Enviromental Protection Agency, 2006).

2.4.1. Methods Of Harvesting Surface Water For Urban Sectors

- Permeable Surfaces

Permeable surfaces are porous surfaces the allow precipitation and runoff water to infiltrate the under surface which can then gather into a reservoir (Selbig & Beur, 2018).

Permeable surfaces can be pavements, concrete, or asphalt, (Figure 2.22).

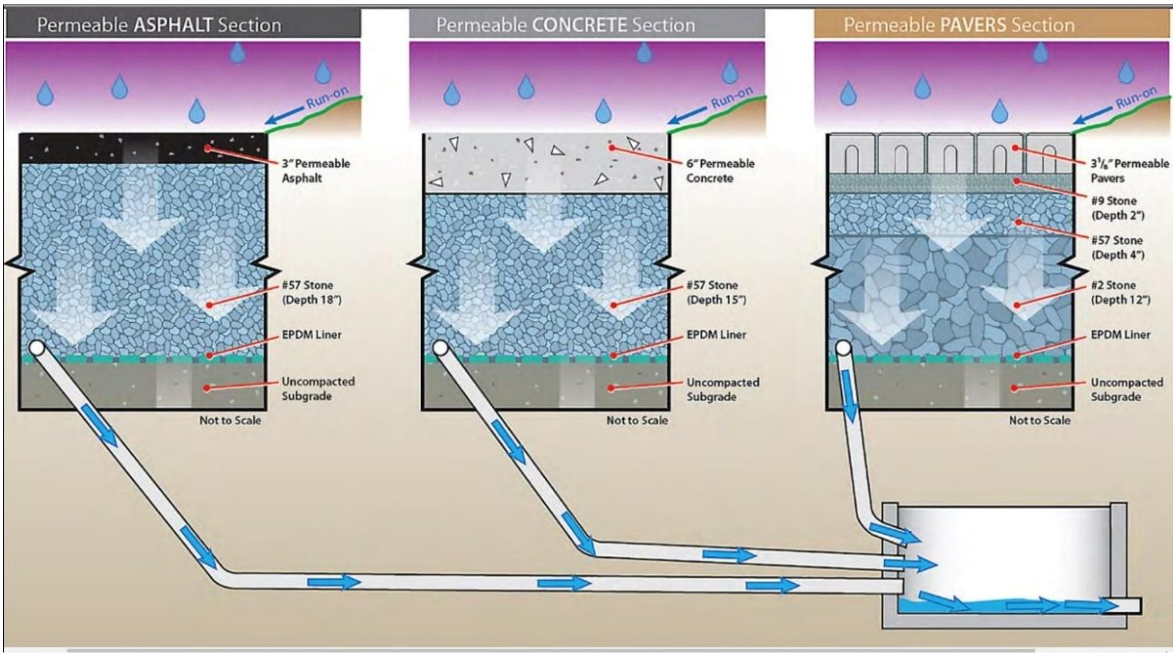


Figure 2.22: Asphalt, concrete, and pavers permeable surfaces (Selbig & Beur, 2018).

- Sloped Surface with Drain

It is an open field sloped to one or multiple filtered drains connected with a water reservoir.

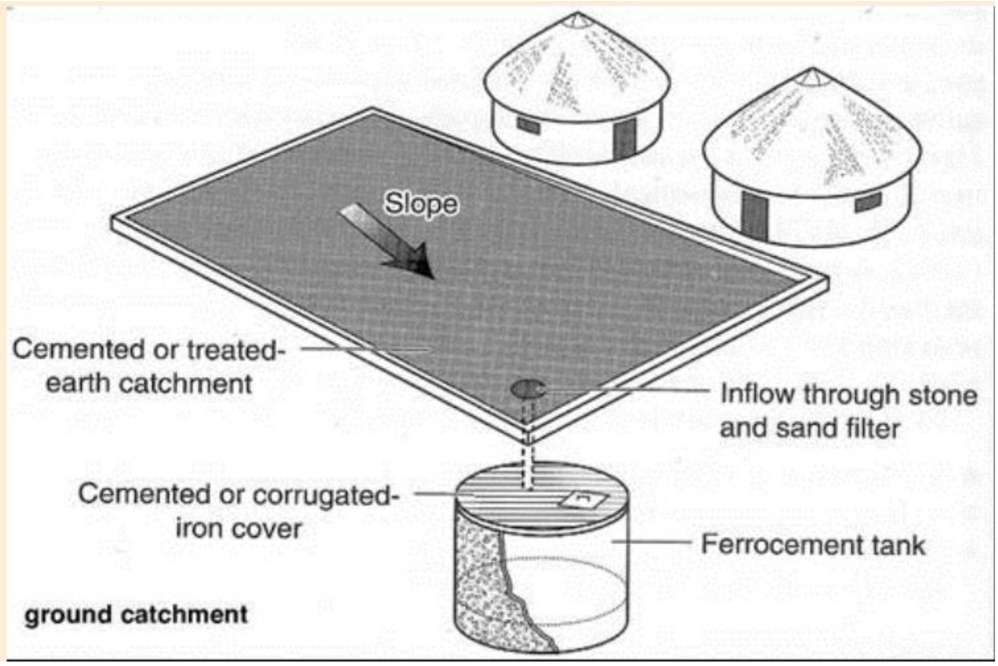


Figure 2.23: Sloped surface with filtered drain connected to a tank (Saleh, Taher, & Noaman, 2017).

3. CASE STUDY: RAINWATER HARVESTING APLICATION IN PALESTINE

To study rainwater harvesting in Palestine, the understanding of current architecture types, styles and statistics are important to figure out how much rainwater is possible to harvest, if it's enough to create water sufficiency year-round, and what methods can be adopted.

3.1. CURRENT ARCHITECTURE CLASIFICATIONS BASED ON FUNCTION IN PALESTINE

- Residential Buildings

Residential consists of single homes, villas, and apartments. A house according to Palestinian Central Bureau Statistics is built for a single-family, 1-2 storeys and if it was split into two apartments it is still counted as one house building (Palestinian Central Bureau Statistics, 2018). Villas are occupied by richer families, areas are around 200 - 500 m^2 (Hadid, 2002), they consist of 2 wings whether it is 1 storey or 2 storeys. Outside walls are covered with white stone(Palestinian Central Bureau Statistics, 2018). Single homes have flat concrete roofs in general and villas have red ceramic roofs.

Apartment buildings in Palestine are three types, first type is Low-Apartment buildings, apartment area varies from 80-180 m^2, every floor can have 1, 2, or 3 apartments. The second type is Block-apartments, which have a similar layout to the previous type but is repeated and connected by joints and has multiple stairwells which are suitable for housing. The third type is tower apartments which can reach up to 15 stories, layouts vary depending on apartments and stairwells counts. A dwelling is the living place of one family, the average family's individuals in the West bank is 4.6 and in Gaza's strip is 5.7 in 2018 (Palestinian Central Bureau of Statistics, 2019).

- Commercial Buildings

Commercial buildings are two types in Palestine, Linear shop buildings which are aligned with the main street creating a chain of shops with streets. In general, they are up to 2 floors with an elevation of 6 m. The second type is Office buildings, they contain offices and shops. The layout of these buildings generally contains courtyards open to a skylight to the roof or opened on the first floors.

- Multifunctional Buildings

Multifunctional buildings are stores on the street level. The upper floors are apartments which can also be offices. This type of buildings is common due to their return value.

- Public buildings

Public buildings come in rectangular or L shape, the function of the building is considered whether it is educational, governmental, or health in general in the design process, Built with stone and concrete.

- Religious buildings

Consisting of mosques and churches, design characteristics vary according to the period of the structure and plot shapes.

- Industrial buildings

Located outside of the cities and some villages. The building materials is concrete, exterior walls are either plastered concrete blocks, stone, or aluminium sheets (Hadid, 2002).

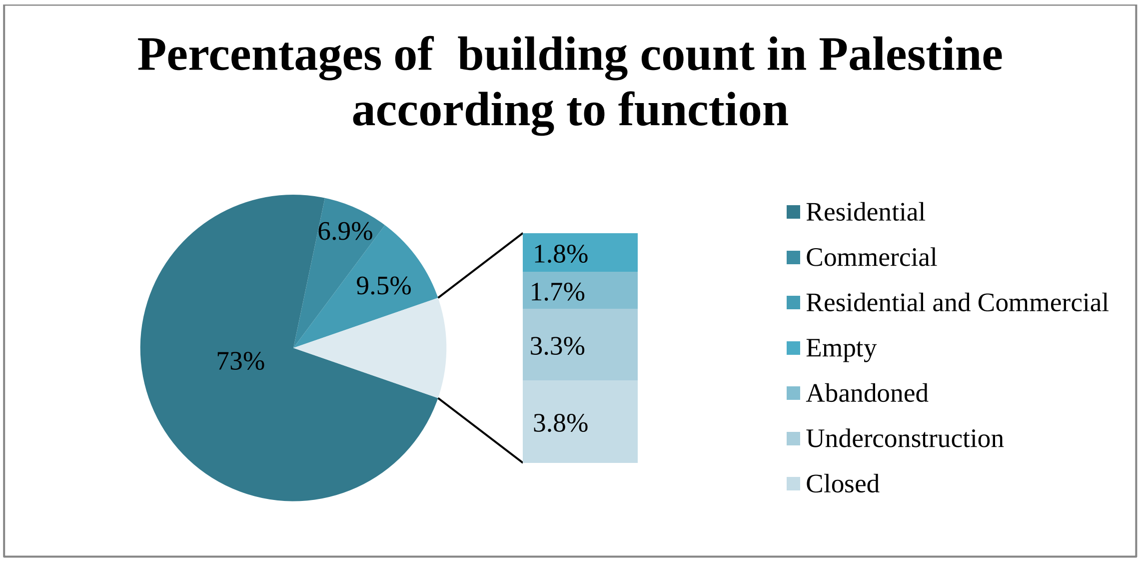


Figure 3.1: Percentages of buildings count in Palestine according to function (Palestinian Central Bureau Statistics, 2018).

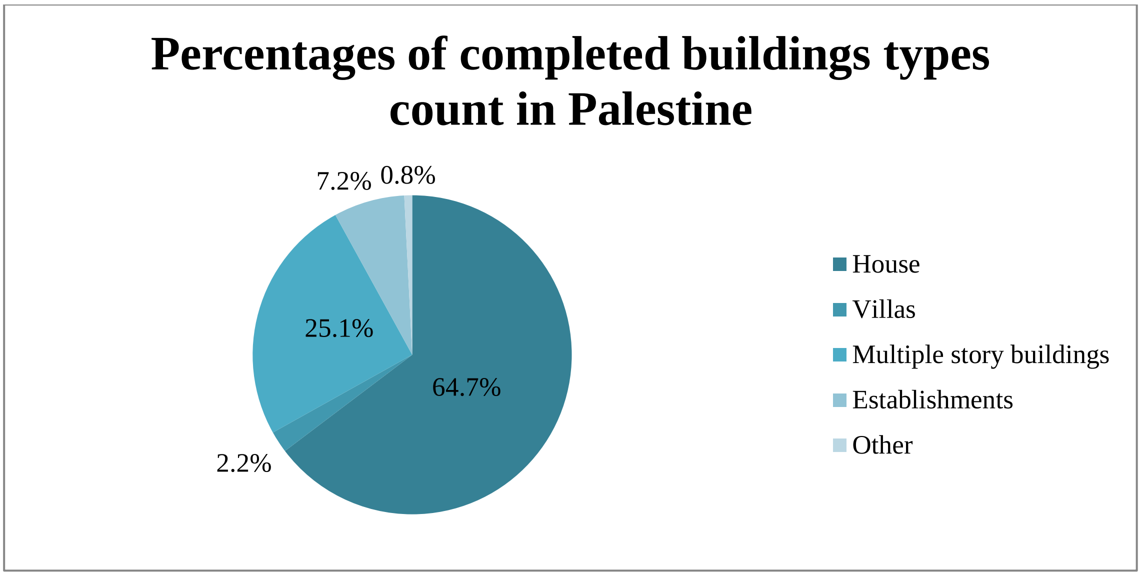


Figure 3.2: Percentages of complete building types in Palestine (Palestinian Central Bureau Statistics, 2018).

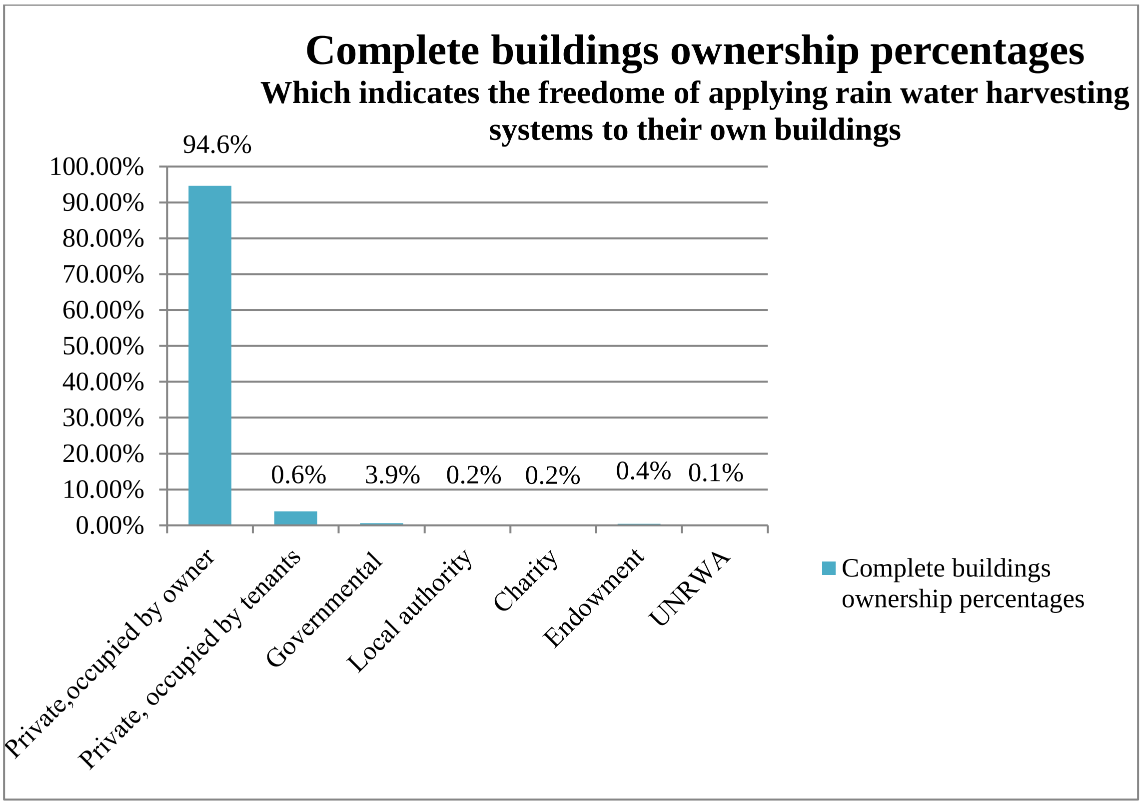


Figure 3.3: Complete buildings ownership percentages (Palestinian Central Bureau Statistics, 2018).

3.2. TYPES OF BUILDINGS AND NUMBERS IN PALESTINIAN GOVERNORATES

Governorate	**Total**	**Type of building**						
		Villa	House	Residential Building	Establishment	Under construction	Other*	Not Stated
West Bank	441,280	11,653	276,358	94,949	31,520	22,120	3,385	1,295
Jenin	59,284	1,071	42,672	8,256	4,430	2,487	73	295
Tubas & Northern Valleys	11,131	217	7,847	1,664	677	342	342	42
Tulkarm	32,253	570	21,834	5,837	2,389	1,596	11	16
Nablus	57,083	1,368	34,349	13,511	4,296	3,194	185	180
Qalqiliya	17,553	388	11,054	3,586	1,548	837	79	61
Salfit	15,488	685	10,852	1,802	1,234	831	35	49
Ramallah & Al-Bireh	52,021	2,949	28,713	12,833	4,028	2,947	379	172
Jericho & Al Aghwar	11,317	645	8,005	832	736	636	366	97
Jerusalem	40,745	639	19,167	17,469	1,661	633	1,037	139
Bethlehem	33,915	524	18,661	9,849	2,488	2,168	150	75
Hebron	110,490	2,597	73,204	19,310	8,033	6,449	728	169
Gaza Strip	186,103	1,693	111,213	55,416	11,855	4,218	1,390	318
North Gaza	33,290	356	18,702	10,919	2,073	723	470	47
Gaza	47,762	402	20,697	21,750	3,608	998	220	87
Dier Al-Balah	30,840	242	20,851	7,258	1,819	447	173	50
Khan Younis	45,962	492	31,445	9,470	2,849	1,295	314	97
Rafah	28,249	201	19,518	6,019	1,506	755	213	37

Table 3.1: Types and numbers of buildings in each governorate in Palestine, (Palestinian Central Bureau Statistics, 2018).

3.3. AREAS OF RESEDINTIAL BUILDINGS IN PALESTINE AND THEIR STATISTICS FOR EACH QUARTER OF 2018

From this table each housing area and their average dwellings will be used in testing the amount of harvested rainwater and its sufficiency to the individuals of the dwellings.

Areas of buildings permits in 2018	No. of Licenses in each quarter of 2018				Total No. of Dwellings in each quarter of 2018				Average No. of Dwellings in each quarter of 2018				Average No. of Floors in each quarter of 2018			
60 & less m^2	20	15	21	19	15	9	21	19	0.8	0.6	1.0	1.0	1.0	0.8	1.0	1.0
Total	75				64				0.85				0.95			
60-119 m^2	144	146	157	163	143	146	158	166	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	610				613				1.0				1.0			
120-199m^2	391	366	382	394	419	406	404	420	1.1	1.1	1.1	1.1	1.0	1.2	1.1	1.1
Total	1533				1649				1.1				1.1			
200-499 m^2	565	512	555	561	962	903	959	1000	1.7	1.8	1.7	1.8	1.4	1.8	1.9	1.8
Total	2193				3824				1.75				1.725			
500-1999 m^2	236	195	211	230	909	742	858	960	3.9	3.8	4.1	4.2	2.4	3.1	3.1	3.2
Total	872				3469				4.0				2.95			
2000 &over m^2	44	50	66	67	671	786	1243	1178	15.3	15.7	18.8	17.6	4.6	6.5	7.7	7.1
Total	227				3878				16.85				6.457			

Table 3.2: Information about residential building permits in the quarters of 2018 (Palestinian Central Bureau of Statistics, 2018), (Palestinian Central Bureau of Statistics, 2018), (Palestinian Central Bureau of Statistics, 2018), (Palestinian Central Bureau of Statistics, 2019).

3.4. NEW HOUSING UNITS' AREA SIZE AVERAGE IN PALESTINIAN GOVERNORATES IN 2019

Governorate	Average unit's area size in 2019
West Bank	161.3
Jenin	164.0
Tubas & Northern Valleys	143.7
Tulkarm	144.8
Nablus	158.0
Qalqiliya	149.2
Salfit	144.1
Ramallah & Al-Bireh	182.7
Jericho & Al Aghwar	148.3
Jerusalem	168.1
Bethlehem	161.4
Hebron	164.6
Gaza Strip	150.6
North Gaza	136.4
Gaza	151.9
Dier Al-Balah	144.6
Khan Younis	-
Rafah	-

Table 3.3: Housing area units averages in Palestine's governorates (Palestinian Central Bureau of Statistics, 2020).

3.5. RAIN STATISTICS IN PALESTINIAN GOVERNORATES

West bank's governorates	Annual rainfall quantity (mm)in2018
Nablus	873.0
Jenin	763.0
Tulkarm	877.0
Ramallah	804.0
Jericho	213.0
Bethlehem	518.0
Hebron	621.0
Gaza's governorates	**Annual rainfall quantity in 2020 (mm)**
Khanyunus	397.3
Rafah	280.9
Der Albalah	343.3
North Gaza	421
Gaza	436.1

Table 3.4: Rain statistics for major Palestinian governorates (Meteorological General Directorate, 2020), (Meteorological General Directorate, 2018)

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3.6. ROOF CATCHMENT RAINWATER HARVESTING POSIBILITY

In this section the previous data will be used to calculate the capacity of roof catchments rainwater harvesting in 4 major governorates in Palestine of different buildings' areas and rain ratios. These governorates are Hebron with the highest buildings number, Nablus with medium buildings count and high annual rainwater (660.1mm), Jericho which has low buildings count and low annual rainwater (166mm) and Gaza as an example from Gaza strip. According to the previous chapter amount of water available (litres) = rainfall (mm/year) * roof area (m2).[4]

The highest of building areas is in the range of 200-499 m^2, which is about 39.8%, followed by 120-199 m^2, about 27.8% of built areas in 2018.

- Hebron

Hebron's annual rainfall in 2018 is 621.0 mm. The areas that will be used for calculations are 120, 150, 200, 300, 400 and 450 m^2.

120-199m^2 which according to the previous PCBS stats the average number of dwellings is 1.1. and a dwelling is for one family.

-120 m^2 of built area

120 x 621= 74,520 litres/year. According to the previous information, the Palestinian individual consumes about 75 litres/day, which is 27,375 litres/year.

74,520 litres/year divided by 27,375 equals about 2.72, which is the individuals' number it can supply.

-150 m^2, with the same previous equation harvested rainwater is 93,150 litres/year, divided by the individual yearly water use, water amount can supply about 3.40 individual.

[4] In some sources like CuveWaters Integrated water resources management, in the calculation of rainwater harvest, catchment area has runoff coefficient depending on the surface material. For this chapter, the runoff coefficient will be discarded due to figure out the potential of rainwater harvest regardless of the material. Even though in the previous chapter’s rainwater harvest calculators sources, runoff coefficient was discarded as well by the authors of the reference.

200-499 m^2, average dwellings of this area are 1.75.

-200 m^2 roof can harvest 124,200 litres/year, divided by individual yearly use it can supply 4.54 individuals for a year.

-300 m^2 of roof area, can collect up to 186,300 litres/year. it provides for 6.8 ≈ 7 individuals.

-400 m^2 collects 248,400 litres/year. provides for 9 individuals.

-450 m^2 collects 279,450 litres/year. sufficient for 10.2 individuals for a year use.

As previously mentioned, a dwelling is for one family. The average of family members in the West Bank is 4.6, and in Gaza's strip is 5.7 in 2018. In the case of Hebron's house areas of 120-199m^2 with average dwellings of 1.1, for the area of 120 m^2, it is capable of harvesting rainwater for 2.72, which are mildly over half of an average family, or it can cover the whole average family for 60% of the year. For an area of 150m^2 harvested rainwater supplies 3.40 individuals which are about 74% of the average family size in the West bank. 200-499m^2 area average dwellings are 1.75, which is closer to 2 families. For an area of 200 m^2 supplies for 4.54 individuals, which provides for about one dwelling, or it can provide for 2 dwellings for a half year. Area of 300m^2 supplies for 6.8 individuals that is about 74% supply for 2 dwellings. 400m^2 provides for 9 individuals that are about 98% of 2 dwellings. 450m^2 area of roof collects water for 10.2 individuals, that is over the amount needed for 2 dwellings consumption for a year.

- Nablus

Nablus's annual rainfall in 2018 is 873 mm. The areas that will be used for calculations are 120, 150, 200, 300, 400 and 450 m^2. The previous method of analysis in Hebron is applied in a form of a table.

Building Area M^2	Average dwellings number	Annual harvested rainwater litres	Number of individuals supplied /year	Percentage to the required amount for average dwellings
120	1.1≈ 1	104,760	3.82	83%
150	1.1≈ 1	130,950	4.78	104%
200	1.1≈ 1	174,600	6.38	138.7%
300	1.75≈ 2	261,900	9.56	103.9%
400	1.75≈ 2	349,200	12.75	138.6%
450	1.75≈ 2	392,850	14.35	155.97%

- Jericho

Jericho's annual rainfall in 2018 is 213 mm. The areas that will be used for calculations are 120, 150, 200, 300, 400, and 450 m^2.

Building Area M^2	Average dwellings number	Annual harvested rainwater litres	Number of individuals supplied /year	Percentage to the required amount for average dwellings
120	1.1≈ 1	25,560	0.93	20.2%
150	1.1≈ 1	31,950	1.16	25.2%
200	1.1≈ 1	42,600	1.55	33.7%
300	1.75≈ 2	63,900	2.33	25.3%
400	1.75≈ 2	85,200	3.11	33.8%
450	1.75≈ 2	95,850	3.50	38%

- Gaza

Gaza's annual rainfall in 2020 is 436.1 mm. The areas that will be used for calculations are 120, 150, 200, 300, 400, and 450 m^2.

Building Area M^2	Average dwellings number	Annual harvested rainwater litres	Number of individuals supplied /year	Percentage to the required amount for average dwellings
120	1.1≈ 1	52,332	1.91	41.5%
150	1.1≈ 1	65,415	2.39	51.95%
200	1.1≈ 1	87,220	3.18	69.1%
300	1.75≈ 2	130,830	4.78	51.95%
400	1.75≈ 2	174,440	6.37	69.24%
450	1.75≈ 2	196,245	7.17	77.3%

4. MODEL LIST OF DESIGN AND GENERAL RECOMMENDATIONS

In Introduction chapter few questions were addressed regarding Palestine's water situation, these questions as the study concluded have been answered as the following:

- As in the first question, Is the water crisis in Palestine strictly for political reasons? In chapter 1, explanation of Oslo Accords' effects on Palestinian water consumption and control, political influence is great, even if there was a general East Mediterranean water issues, politics is in the forefront as it directly affects Palestinians since the beginning of the occupation.
- Can former methods done by previous civilizations in the area be applicable or adapted to today's situation?
- And for the final question, does rain precipitations in Palestine reach the required amounts for a sufficient rainwater harvesting and fulfilling for their needs? Results of chapter 3 in the case study are the answer which will be explained thoroughly next.

4.1. DATA RESULTS

As data was collected and calculated in the previous chapter some results are observed. These results are based on the Palestinian individual daily usage of water, which means the current usage to have a relatively well satisfying water quantity. However, according to WHO 7.5 to 15 litres/day per person in extreme cases is enough for survival (World Health Organization and Water Engineering Development Centre, 2013). On that note, even Jericho at a roof catchment area of 120 m^2, can supply enough water for the survival of a family via roof rainwater harvesting for a whole year.

- According to the PCBS, 73% of the buildings are residential if multi-functional buildings (commercial and residential buildings) are included, it will increase to 82.5%. Of complete buildings, 95.2 % are private ownership, 94.6% of them are occupied by the owner, and the rest by tenants. As shown in the previous table houses is the highest number of completed buildings in every city except for the governorate Gaza, then followed by residential buildings followed by establishment buildings, then villas. This is an indication that there is a wide range of freedom in applying decentralized rainwater harvesting solutions supported by the owners themselves, and if applied the impact on solving the crisis of water for individual use can be major.

- According to the previous data, the amount of harvested rainwater in Palestinian cities varies, which occurs due to the changes of annual rain amount, different building areas and dwellings count in each building. Therefore, the results varied as well and will vary every year.
- Jericho had the lowest results due to its low annual rainfall as its special geographical location being the lowest city on earth (258m below the sea) (UNESCO, 2020). The rest of the West Bank governorates have closer annual numbers to each other. Gaza strip's numbers are low too as being on the coast of the Mediterranean in a separated region than The West Bank.
- In the West Bank governorates except of Jericho, the lowest roof area chosen of $120m^2$, rainwater harvesting capacity was over 50% of the annual requirement for the average household, or a for a half year if need of harvested correctly.
- Nablus has the highest harvested rainwater, as it has the highest annual rain count in 2018 from the chosen governorates. Areas above $150m^2$ are capable of harvesting enough and over the needed water for the average individuals of a household, and average dwellings of the building. Therefore, it is self-sufficient and independent from other sources.
- The previous data can be based to which how successful the other governorates are, for example, Tulkarm had a little more annual rain in 2018 than Nablus, therefore it will have similar results and it will be self-sufficient as well.

As was examined in the Introduction chapter of this thesis, a key point for promising solutions is being off-grid and independently used by individuals.

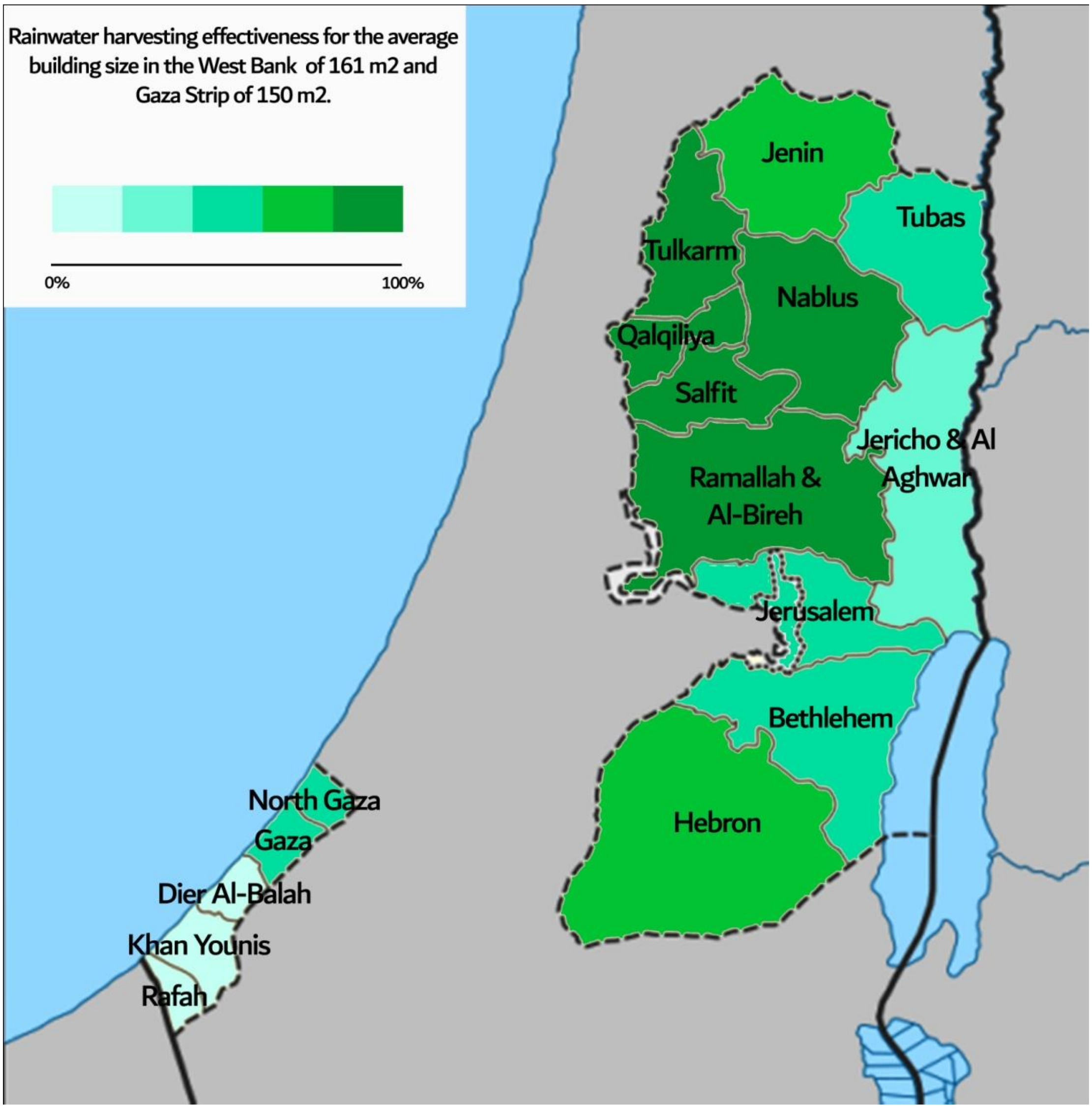

Figure 4.1: Rainwater harvesting effectiveness for the average building size in the West Bank of 161 m^2 and Gaza Strip of 150 m^2.

4.2. MODEL SUGGESTIONS

This section is a compilation of suggestions and a checklist forming a rainwater harvesting guide for residential buildings and houses in Palestine.

4.2.1. Water Tanks Positioning And Types

Tanks Positioning

As mentioned in previous chapters, tanks in Palestine are placed on buildings' rooftops, this measurement is relatively successful for receiving water that comes from the municipalities but is not however suitable for rainwater harvesting due to the receiving end being higher than the catchment area itself. Multiple options are available to solve this problem as shown in the following table. However, these options can still be employed by combining the municipality's water line and rainwater to maximize water gain.

TANKS POSTITIONING	PROS	CONS
Placed above ground backyard or basement	• Affective in rainwater harvesting. • Relatively as costly as rooftop tanks in terms of tanks type and plumbing. • Better aesthetics of buildings and cities skylines.	• The need of employing water pumps which increases expenses. • Larger space needed for municipality's water tanks and harvested rainwater tanks.
Buried underground Tank or well	• Affective in rainwater harvesting. • Being buried makes it affective in space management.	• Higher in construction and excavations costs. • Harder to maintain and clean. • Possibility of mixing with sewer water
A mix of one of the previous choices and rooftop tanks	• limiting the costs of changing the current roof tanks placements by utilizing it just for the municipality's line and adding the extra tanks for rainwater harvesting in one of the previous options. • Distributing the space needed for water storing.	• More complicated pluming networks needed. • Negatives of rooftop storing mentioned previously.

Table 4.1: Water storing options for the Palestinian residence buildings and homes with each its negatives and positives.

Tank Types

Tank types selection depends on the individual consumer preference and budget. However, Polypropylene (Plastic) tanks are very popular and more affordable for the average Palestinian individual as they are the most used in Palestine, therefore the continuation of using them is recommended. Constructed wells that are still used can be rehabilitated and used as buried tank types by applying disinfection measures as previously mentioned.

4.2.2. Roof Shape And Material

Rooftops in Palestine in general are flat, the ones covered with ceramic tiles are sloped (Hip or Gable shape). However, according to the average rainwater numbers of data collected, Sloped rooftops catchment areas are not a requirement for harvesting those numbers, for the governorates of over 600mm annual rain a sloped roof is preferable.

As mentioned previously concrete roofs are the main material of buildings and houses in Palestine, the other is red ceramic roof tiles used in villas generally. Both materials are compatible and efficient with rainwater harvesting therefore there is no need for a change of roof materials, although a rehabilitation of roofs in terms of cleanliness, slope calculation sending water to gutters.

4.2.3. Compliance with Rainwater Harvesting Factors

(As mentioned in Chapter 2)

- Obtainable water amount

The unique situation of Palestine's water scarcity is different from other cases because there is water provided, but not a reliable source as it is controlled by an outside party. For that reason, a different approach is needed. As of this, the first step recommended is the combined sources of rain and the current cities water network. By this, stored rainwater is always played as a reserve for any case of water shortage or seizing. However, this reserve of rainwater must be planned and designed as it is the only source since water cuts are a recurrent event. By this approach cities as Jericho can still be able to consume pipeline water, and when deprived of it reserved potable rainwater can take place.

- Water quality

Water quality can be verified after applying rainwater harvesting systems through lab testing by qualified parties; Nonetheless, if sanitation and overall hygiene procedures are applied, water quality is to be potable in theory.

- Cultural acceptance

As mentioned previously rainwater wells as part of the Palestinian culture were essential for cities' survival, still used till this day in some households in its basic form, therefore the concept of rainwater is culturally familiar in Palestine. However, the suggested upgraded rainwater harvesting systems feedbacks are still to be observed.

- Regulations and policies

Up to this date of this thesis a detailed Palestinian guide, regulations and policies considering rainwater harvesting isn't to be found in the hands of architects and individuals alike. One of the main purposes of this thesis can be an incentive for a more detailed and guide and policies specified for the Palestinian condition. Therefore, support and initiative of local Palestinian municipalities and Palestinian Engineering Syndicate pushing the ideology of rainwater harvesting to common individuals, also providing guidelines and courses to architects as well so they begin introducing roof rainwater harvesting in their designs eventually becoming a requirement or a standard in Palestinian residential buildings.

- System cost

System costs as mentioned vary according to the components chosen by architects or consumers. A defined price list is to be defined after the trials of local rainwater harvesting systems. In terms of tanks or reserve areas, the use of them is already necessary as previously discussed. By this, the costs of the reservoir could stay the same and may increase on the will of consumer or need. Extra cost will be invested in the pumping system and the price will vary according to the type of pumping system used. If the consumer considers rainwater reservoirs just for water shortages just as in emergency measures where water is obtained by a faucet, pumping costs can be avoided. Additional cost will be utilized in disinfection and maintenance, which is partially used in current water network tanks. Roof materials are already suitable in current Palestinian architecture, additional cost may be needed in the rehabilitation of surfaces.

4.3. DISCUSSION FOR FURTHER RESEARCH

Palestine's independence in water, as being the main end goal of this thesis, appears to be a very heavy subject to tackle or be solved in one thesis due to its complicated situation in many fields. It is dense in politics, economy, climatology, architecture, and even social behaviour. As the source of life, water is a big part of the agriculture, industrial sector, and daily human consumption. Therefore, a subject with this scale needs the focus of intellectuals, and experts from every division mentioned.

At the end of this thesis, it is fair to say that roof rainwater harvesting systems by themselves will not secure Palestine's way into water freedom as a total. However, in the housing and residential section according to the data and the results, its effectiveness is too big to ignore and not to invest more in it. In addition to roof catchment systems being the main go-to method, other methods can coexist with it like surface catchment as briefly mentioned in chapter 2. Apart from rain as a water source, water recycling in Palestine is not common and it is used generally in agriculture due to the heavy costs and complexity of such establishments. So, if in the near future, houses and residences lean to small scale and individual water recycling systems to reuse gathered rainwater for other than human consumption, which will give a good boost in cities with low rain precipitation amounts.

In conclusion, rainwater harvesting catchment systems show great potential in cities with high rainwater precipitation ratios, which will cause partial independence for Palestinian residences and houses. This thesis could hopefully have an impact to introduce others to participate in tackling this national matter with the goal of a complete independence Palestine in water.

REFERENCES

AbedelKhaleq, R., & Ahmed, I. A. (2007). *Rainwater harvesting in ancient civilizations in Jordan.* IWA Publishing.

Adam, S. B. (2012, July 02). A-Dik is drying out. (Y. B. Dalia Golomb, Interviewer) Israel Social TV.

Alatili, S. (2018, September 16). "Oslo"..How it changed geograghy and water to Israel's favor. (M. Omar, Interviewer)

Alatili, S. (2004, 10 3). *Palestinian water ... a crisis in reality and a problem in negotiations.* Retrieved June 20, 2020, from Aljazeera.

Alatout, S. (2000). *Water balances in the eastern mediterranean.* (D. B. Mehmet, Ed.) Ottawa, Canada: The International Development Research Centre.

Altamimi, A. (2020, July 28). how did Oslo agreenment neglected Palestinian water? (F. alsarfandi, Interviewer) Alalam.

Barnbrah, G. (1994). RAINWATER CATCHMENT SYSTEMS AND TECHNOLOGIES - AN OVERVIEW. *Proceedings of the Sixth International Conferenceon Rainwater Catchment systems* (p. 115). Nairobi: International Rainwater Catchment System, IRCS.

Battenberg, G. E. (2009, September 14). Flowing Issues A Brief History of Rainwater Harvesting. *Water Conditioning & Purification Magazine* .

Brooks, D. B. (2000). Keynote address: Access to water in the Eastern Mediterranean. *Water Balances in the Eastern Mediterranean* (pp. 1-12). International Development Research Centre.

Cook, S., Sharma, A., & Gardner, T. (2016). *Rainwater Tank Systems for Urban Water Supply.* Brisbane: IWA Publishing.

Dweikat, N. (2019). Masarat Maqdisye: Jerusalem Routs. *Al Aqsa Mosque Application*, Episode 22. Al Aqsa Mosque Application.

Flavius, J. (78 A.D.). *JEWISH WAR,Book 7,chapter 8.* (W. WHISTON, Trans.) The Roman Empire.

Gibson and Amit. (2014). Water to Jerusalem: the Route and Date of the Upper and Lower Level Aqueducts*Cura Aquarum in Israel II*9-42Siegburg

Goodrich-freer, A. (1913). *Things seen in Palestine.* London: Seeley, Service.

Hadid, M. (2002). *Architectural styles survey in Palestinian territories.*

IAPMO, International Association of Plumbing and Mechanical Officials. (2015). *Seatle plumbing code.* Seatle, Washington.

IRC International Water and Sanitation Centre. (1990). *Water Harvesting in Five African Countries.* The Hague.

Khalifa, A. (2001). *The first of the two Qiblas guide, دليل اولى القبلتين.* Jerusalem: Al-Aqsa Foundation for the Reconstruction of Islamic Sanctuaries.

Marouf, A., & Marie, R. (2010). *أطلس معالم المسجد الأقصى المبارك,Atlas of Masjid Al Aqsa Sites.* Amman: Al Fursan Est. for publishing and distribution.

Mazar, A. (2002). *A survey of the aqueducts to Jerusalem.*

Mehmet, O. (2000). Nature and scope of the workshop . *Water Balances in the Eastern Meditterranean* (p. vii). Ottawa: International Development Research Centre .

Meteorological General Directorate. (2018). *http://www.pmd.ps/.* Retrieved January 2021, from Meteorological General Directorate.

Meteorological General Directorate. (2020). *http://www.pmd.ps/.* Retrieved January 14, 2021, from Meteorological General Directorate.

MFA. (2013). *THE ISRAELI-PALESTINIAN INTERIM AGREEMENT-Annex III.* Retrieved August 16, 2020, from Israel Ministry of Foreign Affairs.

Mosley, L. (2005). *Water quality of rainwater harvesting systems.* SOPAC, South Pacific Applied geoscience Commission.

Mou, H., & Wang, H. (1994). Participation in rain water collection for low income communities and sustainable development. *Proceedings of the Sixth International Conferenceon Rainwater Catchment systems* (p. 69). Nairobi: International Rainwater Catchment System, IRCS.

Nabil, M., & Fua'd, M. (1998). *Water and peace negotiations in the Middle east, Third Annual Conference, Arab waters and challenges of the twenty-first century.*

Palestinian Central Bureau of Statistics. (2018). *Building licenses statistics first quarter,2018.* Ramallah.

Palestinian Central Bureau of Statistics. (2018). *Building licenses statistics second quarter,2018.* Ramallah.

Palestinian Central Bureau of Statistics. (2008). *Water Statistics in the Palestinian Territories.* Statistics.

Palestinian Central Bureau Statistics. (2018). *General census of population, housing and establishments,التعداد العام للسكان والمساكن والمنشآت.* Ramallah.

Palestinian Central Bureau of Statistics. (2019). *Building licenses statistics fourth quarter,2018.* Ramallah.

Palestinian Central Bureau of Statistics. (2018). *Building licenses statistics third quarter,2018.* Ramallah.

Palestinian Central Bureau of Statistics. (2019, 07 11). *http://www.pcbs.gov.ps/*. Retrieved 05 02, 2021, from Palestinian Central Bureau of Statistics.

Palestinian Central Bureau of Statistics. (2020). *The number and area of the licensed housing units in Palestine by governorate,2019.*

Palestinian Water Authority. (2018, January 17). *http://www.pwa.ps/.* Retrieved Febuary 1, 2021, from Palestinian Water Authority.

Qotub, M. (2019). The water quality of historical wells of Al-Aqsa Mosque. Beathlehem.

Saleh, S. A., Taher, T., & Noaman, A. (2017). *Manual for rooftop rainwater harvesting systems in the republic of Yemen.*

Samsam water foundation. (2009). *Construction of rainwater harvesting systems in Rundugai area, Tazania* . Rundugai.

Selbig & Beur, W. a. (2018). *Hydraulic, water-quality, and temperature performance of three types of permeable pavement under high sediment loading conditions.* Virginia.

Shalem, Y. (1997, March 10). *Bar-Ilan University.* Retrieved February 21, 2020, from https://www.biu.ac.il/JS/rennert/history_4.html.

T.C. Republic of Turkey General Directorate Of State Archives. (2009). *Palestine in Ottoman Documents.* Istanbul, Turkey.

Texas Water Development Board. (2005). *The Texas Manual on Rainwater Harvesting.* Austin.

UNEP, U. N. (2003). *Desk Study on the Environment in the Occupied Palestinian Territories.* Geneva.

UNESCO. (2001). *https://whc.unesco.org/en/list/1040/.* Retrieved march 29, 2020, from United Nations Educatinal, Scientific and Cultural Organization .

UNESCO. (2020, October 20). *Jericho Millenary City, Archaeological and Historical Urban Development*. Retrieved January 31, 2021, from http://whc.unesco.org/.

UNESCO. (2021). *Masada Proposed World Heritage Site By The State Of Israel.* UNESCO.

United Nations. (1980, January 01). The Palestine Question: A Brief History. New York.

United States Enviromental Protection Agency. (2006). *Protecting Water Resources with Higher-Density Development.*

World Health Organization and Water Engineering Development Centre. (2013). *How much water is needed in emergencies.*

World Health Organization. (2009). *Guidelines and Manual for Rain Water Harvesting in Maldives.* Male: Ministry of Housing Transport and Environment Government of the Republic of Maldives Technical Support.

Url-1 < *https://www.mapsofworld.com/answers/geography/what-are-the-key-facts-of-palestine/attachment/palestine-map/* >, Retrieved 05 02, 2021

Url-2 < *http://www.netours.com/content/view/133/26/1/1/* >, Retrieved 05 02, 2021

Url-3 < *https://www.bethlehem-city.org/en/jgytk* >, Retrieved 05 02, 2021

Url-4 < *https://www.facebook.com/pnac1/* >, Retrieved 05 02, 2021

Url-5
<*http://islamicart.museumwnf.org/database_item.php?id=monument;ISL;pa;Mon01;18;en* >, Retrieved 05 02, 2021

Url-6 < *https://alaqsa-archive.com/ar/?attachment_id=1586* >, Retrieved 05 02, 2021

Url-7 < *https://alaqsa-archive.com/ar/?page_id=457* >, Retrieved 05 02, 2021

Url-8 < *https://alaqsa-archive.com/ar/?page_id=459* >, Retrieved 05 02, 2021

Url-9 < *https://alaqsa-archive.com/ar/?page_id=483* >, Retrieved 05 02, 2021

Url-10 < *https://alaqsa-archive.com/ar/?page_id=473* >, Retrieved 05 02, 2021

Url-11 < *https://water.fanack.com/ar/palestine/climate-and-rainfall/* >, Retrieved 05 02, 2021

Url-12
<*https://www.aljazeera.net/news/miscellaneous/2012/3/22/%D8%BA%D8%A7%D9%84%D8%A8%D9%8A%D8%A9-%D9%81%D9%84%D8%B3%D8%B7%D9%8A%D9%86%D9%8A%D8%A9-%D8%AA%D8%B3%D8%AE%D9%86-%D8%A7%D9%84%D9%85%D9%8A%D8%A7%D9%87-%D8%A8%D8%A7%D9%84%D8%B7%D8%A7%D9%82%D8%A9* >, Retrieved 05 02, 2021

Url-13 < *http://emco.ps/?page_id=22* >, Retrieved 05 02, 2021

Url-14 < *https://www.roofrepairmiami.com/category/tile-roof/concrete-tile/* >, Retrieved 05 02, 2021

Url-15 < *https://www.bespokeguttering.co.uk/an-introduction-to-guttering/* >, Retrieved 05 02, 2021

Url-16 < *https://ecosustainablehouse.com.au/products/first-flush-downpipe-water-diverter.* Retrieved 05 02, 2021

Url-17 < *https://waterstoragetanksinc.com/water-tank-models/timbertanks-and-tinytimbers/#Components* >,Retrieved 05 02, 2021

Url-18 < *https://southernswater.com.au/pressure-tanks/* >, Retrieved 05 02, 2021

Url-19 < *http://www.purewateroccasional.net/hwdemandpump.html* >, Retrieved 05 02, 2021

Url-20 < *https://www.usgs.gov/special-topic/water-science-school/science/ph-and-water?qt-science_center_objects=0#qt-science_center_objects* >, Retrieved 05 02, 2021