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Rainwater Harvesting for Domestic uses in two Palestinian Rural Areas with Emphasis on Quality and Quantity

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Dedication

,In memory of my father
,To my precious mother

To my wife, Rana, for her love and support

To my daughters and son:
Dana, Lana, Sama and Saif Eddein

To my brothers and sisters

I love you all dearly

Mahmoud Abdul-Hamid
May, 2008

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Abstract

Rainwater harvesting becomes an appropriate solution to minimize the water shortage in Palestine, especially in rural areas where water networks are not available or supplied water is inadequate. The quality of roof-top harvested rainwater which is used for domestic and drinking purposes in the middle area of the West Bank and the factors affecting it were assessed through wet season surveillance (from Nov., 2005 to April, 2006). The study conducted in Kubar and Abu Shekheidim villages in Ramallah district. The quality of harvested rainwater was assessed for 7 cisterns. The quantity of harvested rainwater and run-off coefficient were determined for 5 cisterns. 72 rainwater samples were collected from ferroconcrete and rock with cement lining storage cisterns (48–114 m^3 capacity) tested in terms of physical, chemical and biological characteristics.

To assess the quality of rainwater (fresh and harvested), the following parameters were measured: a) Physical parameters: pH, Dissolved Oxygen (DO), Temperature (T), Electrical Conductivity (EC), Turbidity and Salinity. b) Chemical parameters: Total Hardness as ($CaCO_3$), Calcium (Ca^{++}), Sodium (Na^+), Chloride (Cl^-), nitrate (NO_3^-) as well as the heavy metals: lead (Pb), Chromium (Cr) and Zinc (Zn). C) Biological parameters: Fecal Coliforms (FC) and Total Coliforms (TC). Lab results on harvested and fresh rainwater samples showed that the samples were alkaline with pH values above 8. This is postulated to the alkaline dust from soil and rock type in this area which is mainly lime and delomite. Also, the results showed that rainwater have very low concentration of TDS of less than 68 mg/l for fresh water samples and below136 mg/l for harvested ones. The turbidity had varied remarkably for the same cistern over time. Some samples had turbidity above 10 NTU while its values went down after storage then raised again due to the nature of rainfall based on atmospheric conditions; Turbidity test showed that fresh and harvested rainwater mostly did not comply with the Palestinian standards and WHO guidelines (exceeds 5 NTU) due to debris from badly managed rooftops. Also most harvested rainwater samples were found aerobic with DO values range above 6 mg/l while fresh water was more aerobic with DO more than 8.5 mg/l. Total and fecal coliforms were absent in fresh rainwater but its detected respectively in 100% and 86% of the tested harvested rainwater samples; so that the pollution came after storage due to bad management of the whole system and/ or from leakage from nearest cesspits. Samples of harvested rainwater showed low concentration of ions as Ca^{++}, Na^+, Cl^- and total hardness while the results showed the NO_3 concentration varied from cistern to another. This is might be due to several factors like the status of rooftop and the distance from cesspits. In the cisterns which are closer than 10 m from cesspits, the NO_3 concentration was rather high probably due to ammonium leakage from these cesspits. Also, the results showed harvested rainwater is not contaminated with heavy metals like Cr, Zn and Pb as the measured values fell within the PS41 and WHO guidelines.

The Run-Off Coefficient (R) as an important design parameter was calculated based on the analysis of rainfall data and technical aspects for these systems. Results revealed that this coefficient is extending from 0.70 to 0.90 for Ferro-concrete catchments which considered the most common type of catchments in Palestine.

This study also highlights the uses of rainwater harvesting systems for providing an additional domestic water source from which to meet local water needs. To use rain water harvesting as a domestic source; systems must be well managed and disinfection should be applied into the cisterns but under direction of Ministry of Health or related institutions in order to avoid by-products formation.

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List of Abbreviations

ARIJ	Applied Research Institute- Jerusalem
Ca	Calcium
Cl	Chloride
Cr	Chromium
DO	Dissolved Oxygen
DRWH	Domestic Rain Water Harvesting
EC	Electrical Conductivity
FC	Fecal Coliform
IEWS	Institute of Environmental and Water Studies
JWU	Jerusalem Water Undertaking
MCM/yr	Million Cubic Meter per year
MEnA	Ministry of Environmental Affairs
Na	Sodium
NGO	Non-Governmental Organization
NO_3	Nitrate concentration
NTU	Nephelometric Turbidity Units
O&M	Operation and Maintenance
Pb	Lead
PEP	Polyethylene Pipe
PHG	Palestinian Hydrology Group

PNGO'S	Palestinian Non-Governmental Organizations
PNIC	Palestinien National Information Centre
PS41	Palestinian Standards No. 41
PVC	Polyvinyl chloride
PWA	Palestinian Water Authority
R	Run-Off Coefficient
RWH	Rain Water Harvesting
RWHC	Rain Water Harvesting Cisterns
RWHS	Rain Water Harvesting System
Sal	Salinity
T	Temperature
TC	Total coliform bacterial count
TDS	Total Dissolved Solids (mg/l)
TH	Total Hardness
WBWD	West Bank Water Department
WHO	World Health Organization
Zn	Zinc

Chapter One

Introduction

1.1 Background

Palestine is among the countries with the scarcest renewable water resources per capita due to both natural and artificial constraints. Today, efforts are being made to conserve and canalize water in the best possible direction, avoiding wastage as much as possible. As a result, there is an urgent need to find ways of saving, reusing and recycling water and to develop new technologies to improve and enhance water resource management. Rainwater harvesting systems (RWHS) are playing as an important role to meet the shortage in water demand for areas suffer from water scarce like the West Bank, Palestine. The rainwater harvesting alternative was considered an appropriate and possible solution for the shortage of water supply in Palestinian rural areas and they are looking for an option that seems feasible and acceptable to alleviate the gab between water demands and supply (See Table 1-1), these areas are suffering from limited water supply because of Israelis water polices; ground water sources are very restricted and controlled by the Israelis (more than 80% of ground water sources are controlled by the Israelis and expensive cost of wastewater reuse and seawater desalination.

Table 1.1: Water Supply-demand gap estimation in the West Bank

Year	Supply (Mcm/yr)	Demand (Mcm/yr)			Deficit (Mcm/yr)
		Municipal	Industrial	Agricultural	
2005	159	135	11	168	155
2010	159	156	25	190	212
2015	159	181	30	208	260

Source: UNESCO, 2005

Until now, the quality of rainwater harvesting is still an unanswered question because of the limited local studies were concentrating on this field. This study highlights the quality of rain water harvesting systems (RWHS) to use it as an important domestic water resource for Palestinians if these systems are well managed. Besides of the quality of RWHS, the Run-Off Coefficient (R) as the major design parameters to estimate quantity of water can be harvested was assessed based on the analysis of rainfall data and technical aspects for these systems. Catchment types, intensity of rainfall, conveyance systems status and the materials which used for cisterns structure are the main factors which affect the Run-Off Coefficient.

In the area of study, water scarcity is not described as the absence of available water, but the lack of sufficient amounts of clean and safe water. Rainwater harvesting can possibly be one of the solutions for the most vulnerable segment of society in terms of water supply. Past experiences show that rainwater harvesting techniques is an innovative approach for the integrated and sustainable development of the poorer areas, and where it is viable, it can be considered realistic to mainstream rainwater harvesting in the integrated water resources management (Zhu *et al.,* 2004). Rainwater collection can be thought of as involving a system whose components are identified as catchment surfaces, conveyance systems and storage tanks. Moreover, most components in this system must have associated means of protection against such hazards as contamination of water and mosquito breeding. Rainwater harvesting is an appropriate technology and effective tool to minimize the shortage of safe water for the Palestinians who live in the West Bank since rain is relatively abundant in the region (average rainfall about 686 mm/a), despite the fact that it is not well distributed over time. When rain is adequately harvested, it can be sufficient to fulfill the needs of households during critical periods of drought (on average, 51 days out of 365 days are rainy days (ARIJ, 2006). A storage tank with the capacity to hold 70m³ can provide a good complementary supply to other available water sources for the consumption of a family with 7 individuals during a period of 6 to 7 months. It would contribute with 50 liters per person per day, which is half of the recommended ideal per capita consumption per day (100 liters/day/person) according to Palestinian Standards. The availability of water through a cistern also liberates women and children from walking long distances to fetch water (local springs). Furthermore, access to harvested rainwater protects the family members against illnesses related to diseases through consumption of contaminated local spring's especially with high concentration of nitrates.

1.2 Problem definition

Shortage of safe water is among the most serious problems facing Palestine today. The problem is exacerbated by the deteriorating quality of much of its water resources due to industrial, agricultural and municipal pollution, as well as over-exploitation of its limited reserves and lack of control on main sources. Palestinians live in the West Bank have a very low water consumption rate ; on average the actual water consumption per capita amounts of 42 l/d generally using about one third of internationally daily amount of water for consumption, hygiene, and cleaning needs (Aliewi and Mimi, 2006).

Currently, ground water is considered the major source of water supply in the West Bank since 1967 when Palestinians have not had access to the Jordan River waters, besides small-scale rainwater harvesting in rural areas. There are three groundwater basins in the West Bank: the western, the northeastern, and the eastern basin. These basins are semi-completely controlled by the Israeli water supply company of Mekorot. Their approximate yields are: 350-360, 140-200, 100-130 Mm^3/a respectively; and the total recharges per Article 40 of the Oslo Agreement are as follows: 362 (abstraction: 22 for Palestinians and 389 for Israelis), 145 (62 and137) and 172 (36 and 146) (MCM/yr) respectively (Aliewi and Mimi, 2006).

Of the total population in the West Bank 10% has no access to piped water supply; while 90% are connected to piped system (PWA, 2005). The part that has no access to piped system depends mainly on rainwater harvesting from rooftops and on local springs. Many local studies in last years showed that many springs are polluted with high concentrations of NO_3. Even people who are connected to a water supply network are suffering continuously of shortage in quantity (ARIJ, 2006). Even though such a solution seems to be so attractive from an ecological point of view, potential health risks from ingestion of harvested rainwater related to microbiological and chemical contaminants should be taken into account. Microbial pathogens may originate in fecal contamination by birds, mammals and reptiles that have access to catchment areas or water storage tanks. Chemical contamination of the rainwater can occur due to traffic emissions and industrial pollution in urban areas or due to agricultural usage of fertilizers and pesticides in rural areas (Sazakli *et al*., 2007). As a result, Rainwater harvesting systems are classified as individual systems so that there are no public health concerns and regulations for testing the quality of the collected water and to use RWHS as a safe and additional water supply source for domestic uses, quality and quantity of these systems were analyzed. So that the most important questions that need to be addressed before harvesting rainwater are:

a. Is rainwater harvesting economically and technically feasible?
b. Does rainwater meet the quality for drinking water?

In this thesis, the quality and factors which affect rainwater quality were analyzed and the most important design parameter (run of coefficient) was evaluated to asses the technical feasibility of these systems.

1.3 Objectives

The general objective of the research was to investigate the applicability of rainwater harvesting in the Palestinian rural areas. One of the specific objectives of the research was to evaluate the quality of collected rainwater while the other was to estimate the run-off coefficient of Ferro-concrete catchment systems which used to collect rainwater in the Palestinians rural areas. This is to determine if, how and to what extent rainwater harvesting can be a feasible option technically in rural areas to alleviate the water shortage in these areas and to examine its appropriateness as a domestic water source. The objectives were reached through studying the following topics:

1 • Description of domestic rainwater harvesting (DRWH) techniques.

2

3 • Studying the rainwater harvesting quality in order to recommend and to convince the rainwater consumers and implementers: quality of RWH in relation to household water security. Health risk due to drinking domestic roof water harvested: Biological risks: TC, FC assessments (tests), risks due to type of catchments(by surveying), risks due to chemical and physical quality(e.g.: turbidity value has an positive or negative influences on chlorination treatment), risks from physical design of the system(e.g.: material used, distance from cesspits, etc…).

4 • Finding the run-off coefficient (R) for Ferro-concrete catchments which considered the most common type of catchments in Palestine to assess the feasibility for efficient rainwater harvesting.

1.4 Contents of the report

This study contains six chapters that can be summarized as follows:

Chapter two gives a description of the area of study including location, population, land use, topography, climate and general hydrology.

In chapter three, a literature review was discussed in terms of advantages, drawbacks, and structural components, identification of location, rainwater quality and quantity parameters and O & M of rainwater harvesting systems in the study area.

Chapter four gives the overall methods and the methodology which used to satisfy the objectives from this research.
Chapter five shows the results and discussion of the research include quality of rainwater, study site analysis, run-off coefficient; the potential of rainwater harvesting in the study area then analysis of results.

Chapter six gives a list of conclusions and recommendations.

Chapter Two

Study Area

2.1 General

The West Bank is an area of 5800 km², 130 km from north to south and between 40 and 65 km from east to west that is, from 31º 30´ N to 32º 30´ N and from 35º E to 35º 30´ E. It enjoys a Mediterranean climate, with hot, dry summers and mild, wet winters. The climate becomes more arid to the east and south. The central highlands, trending roughly north-south, with elevations up to 1000 m above sea level, are part of the South Syrian Arc fold system. These mountains act as a climatic barrier, responsible for the main- shadow desert to the east, down to the Dead Sea, at an elevation of 400 m below sea level. Rainfall on the central Highlands averages 700 mm/yr and becomes less than 100mm/yr at the Dead Sea. However, great variations in rainfall and distribution exist. It is not uncommon for only half the average to fall in any one year (Abed Rabbo, 1999).

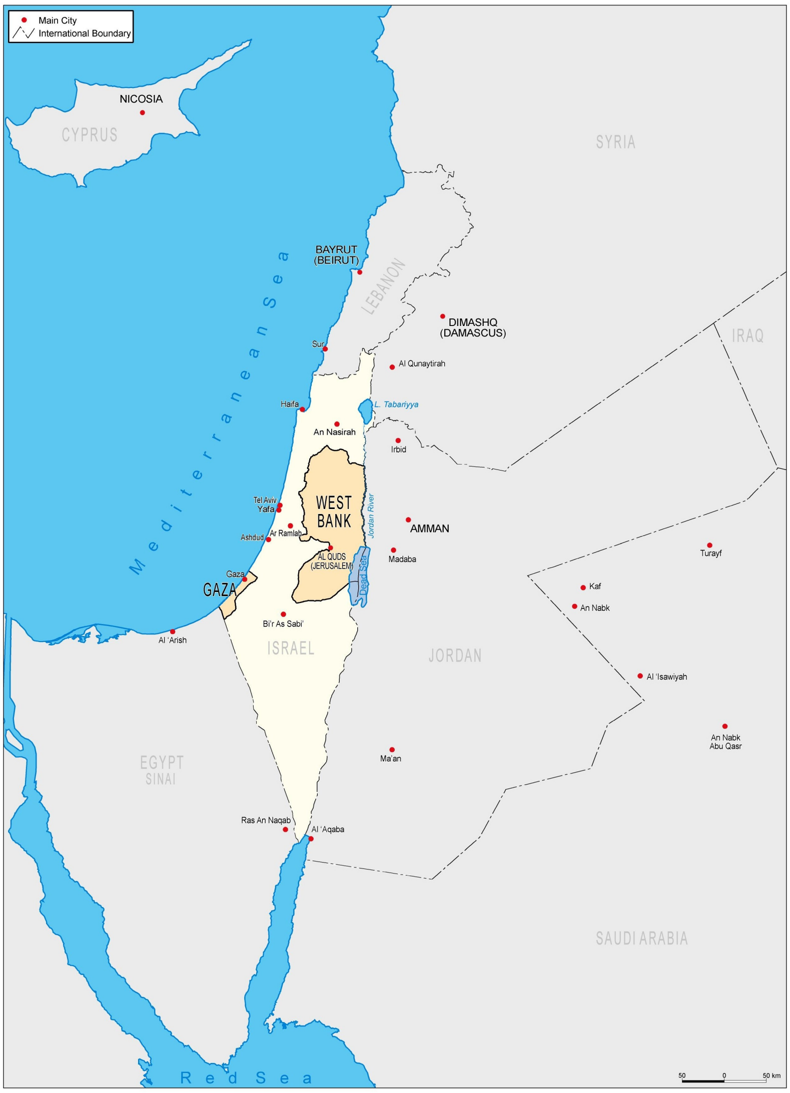


Figure 2.1.1: Palestine within the current regional context (PCBS, 1997).

2.2 Location, population and land use

Ramallah District is located in the middle part of the West Bank. The total number of people live in this District was estimated at approximately 278,018 inhabitants for the year 2007 (PCBS, 2007).

According to "Oslo II" interim agreement between Israel and the Palestinians, Ramallah District measures approximately 84,882.8 hectares which are distributed on three areas: A, B and C. Table 2.2.1 below shows the land use classification in the study area.

Table 2.2.1: Land use classification in the study area before segregation wall construction:

District name	Land use	Area (hectares)	% of land for Ramallah district
Ramallah	- Palestinian Built-up Areas - Israeli Settlements - Closed Areas - Military bases - Nature Reserves - Cultivated Areas - Others - Total Area	3,665.9 1,438.5 10,725.2 235.4 4,723.9 23,831 39742.2 84362.1	4.35 1.7 12.71 0.28 5.6 28.2 47.11 100

ARIJ, (1996)

After construction the segregation wall by Israelis; the land use/ land cover of area isolated behind it is 99069 dunums as a total (ARIJ, 2006).

Kubar and Abu shekheidim are located in Ramallah District over a mountainous area around 13 and 10 km North West of Ramallah and West of Bir Zeit town at altitude of about 640 and 740 meters above sea level respectively. The population of Kubar is around 2597, 3242, 3583 inhabitants in years 1997, 2002 and 2004. But the population of Abu shekheidim village is around 1316, 1643 and 1816 inhabitants in years 1997, 2002 and 2004. The total area of the Kubar is about 9678 dunums of which 360 dunums are urbanized and the rest is an agricultural area. But in case of Abu shekheidim the urbanized area of 243 dunums from 1430 of the total area. Two villages are served by a water networks from JWU and many of houses have rain water reservoirs and some of local springs which are used in periods of water supply interruption. The two villages are not served with sewerage networks, and still wastewater is disposed in cesspits which are potential non-point source of pollution threatening the quality of harvested rainwater.

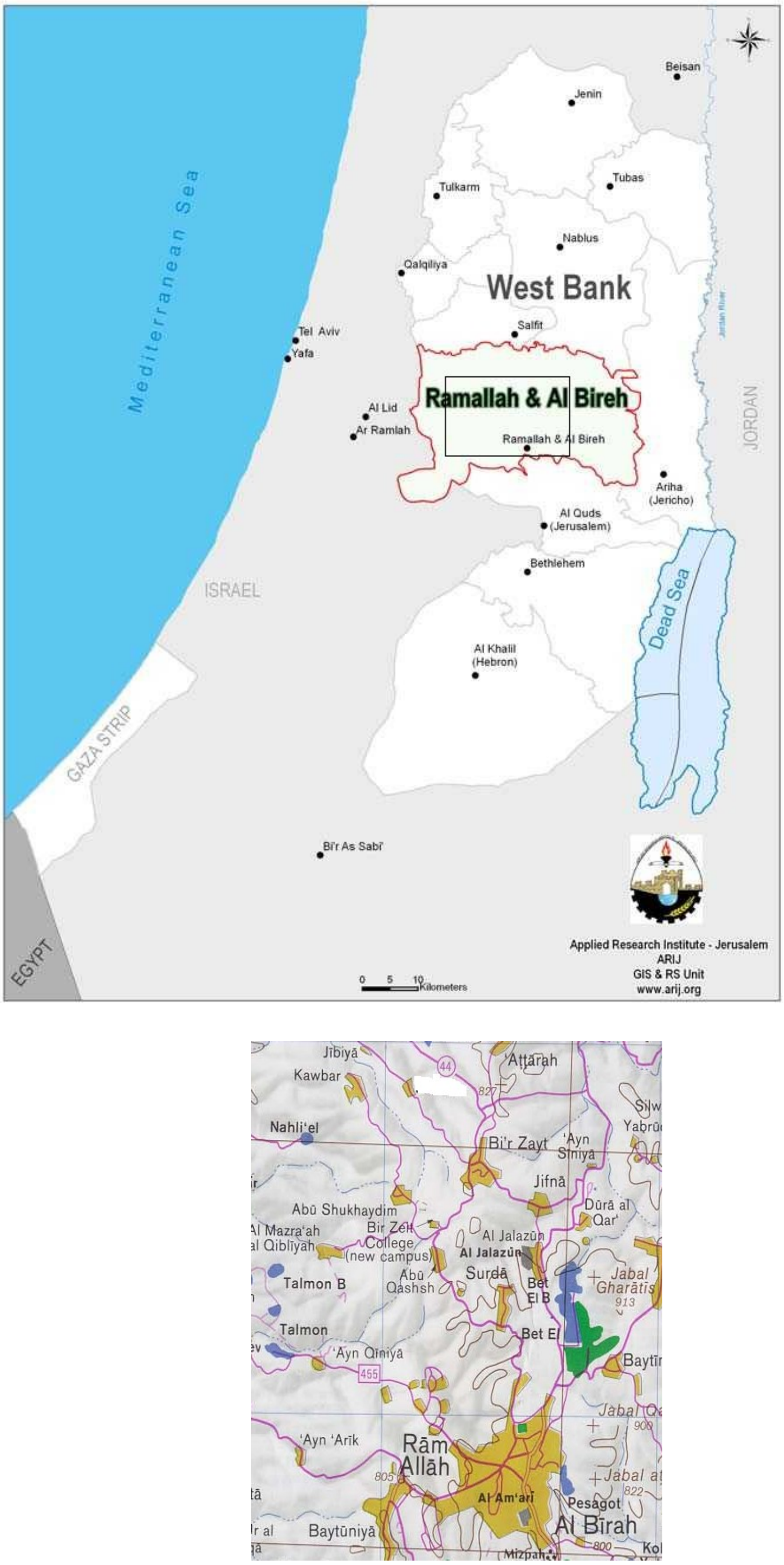


Figure 2.2.2: Study area location (ARIJ, 2006)

2.3 Topography and climate

The area of study enjoys a Mediterranean climate, with hot, dry summers and mild, wet winters. The annual average temperature is between 15-20 ºC while the average rainfall on the central highlands averages 700 mm/yr. Most rainfall falls between November and March. On average, 51 days out of 365 days are rainy days. The average humidity is 70.2% (Abed Rabbo, 1999).

The topography of Ramallah District can be divided into three parts: the eastern slopes, mountain crests and western slopes. The eastern slopes are located between the Jordan Valley in Jericho District and the Mountains. They are characterized by steep slope which contribute to forming young wadis such as wadi El-Maquk. Mountain crests in Ramallah District form the watershed line and separate the eastern and western slopes. While the mountain system in the Jerusalem District is composed of three main groups, the eastern slopes' hills, central mountain crests, and western slopes' hills. The eastern slopes' hills are located between the Jordan Valley and the central mountains. They are characterized by steep slopes which contribute to the formation of young wadis. The altitude of these eastern hills ranges between 100 and 250 meters above sea level. Ramallah District have an elevation ranges on average between 750 and 800 meters above sea level. Western slopes, characterized by gentle slopes, and have elevation ranges between 250 to 500 meters above sea level. The highest point in Ramallah District is 1022 m above sea level at Tal A'sur, and the lowest elevation is 24 m below sea level at the southeast corner of the district. While the highest point in the Jerusalem District is 880m above sea level located at an area called Radar Hill and the lowest elevation is 367m below sea level at the southeast corner of the district, adjacent to the Dead Sea. The study area locates at Western slopes which characterized by gentle slopes as mentioned above (ARIJ, 2006).

2.4 Hydrology

2.4.1 General

Until the 1950's, the area of study depended upon rainfall collection cisterns from roof tops and small local springs for its water supply. However, the growths in population, an improvement in the standard of living, the need to expand irrigated agriculture, and industrialization have multiplied the demand on drinking water. The existing infrastructure could not provide the needed water, so the municipalities in this area established the Ramallah and Al-Bireh Water Company. This company expanded the water supply by drawing water from the E'in Fara springs northeast of Jerusalem and from E'in Qinya springs. Even after these two projects, the water supply could not meet the domestic water needs. In 1963, the Jordanian government concluded an agreement with the International Development Agency (IDA) to construct new drinking water projects in Jordan. One of these projects was the E'in Samia Water Project designed to supplement the Ramallah District with drinking water supply. Also, the IDA agreed with the Jordanian Government to establish the Jerusalem Water Undertaking in 1966. Since that time, the Jerusalem Water Undertaking (JWU) is responsible for administrating water sources and providing domestic water for most of the population in the Ramallah District and some villages in Jerusalem District.

According to Palestinian Water Authority (PWA) in 2005, 10% of the total population in the West Bank has no access to piped water supply; while 90% are connected to piped system. The part that has no access to piped system depends mainly on local springs which almost has low flow rates or water extracted from cisterns (rainwater harvesting) which collected mainly from rooftops. Rainwater harvesting is collected by households in cisterns with an average volume of $70m^3$ each. Even the people who are connected to a water supply network are suffering continuously of shortage in quantity and pressure. Palestinian municipalities apply a scheduled supplying pattern for distributing water, in particular during summer. The distribution system is divided into several zones, each zone receive water one or two days a week. The middle part of West Bank suffers from water shortage, which is expected to increase continuously in the dry season. Due to the tremendous population explosion in the recent years, the population is increasing, because of the internal immigration due to economic situation for this region. People from all Palestine would like to live in this area as it is considered the commercial center in the West Bank. Consequently, the demand increases, while the supply is restricted. Therefore the shortage increases and it becomes more problematic (ARIJ, 2006).

2.4.2 Water Resources and consumption:

2.4.2.1 Water resources

Currently, ground water is considered the only source of water for the Palestinians living in Ramallah District, except for small- scale rainwater harvesting in rural areas as Kubar and Abu Shekheidim villages where the water networks are available but with inadequate water supply especially in dry season. This District overlies several aquifer systems, these are: Lower Cenomanian Aquifer, Upper Cenomanian Aquifer, Quaternary aquifer and Tertiary Aquifer Systems. Figure 2.4.1.1 below shows the groundwater basins in the West Bank. Depending on information adapted from Data file given from PHG institution and by using ARCVIEW3.1 software.

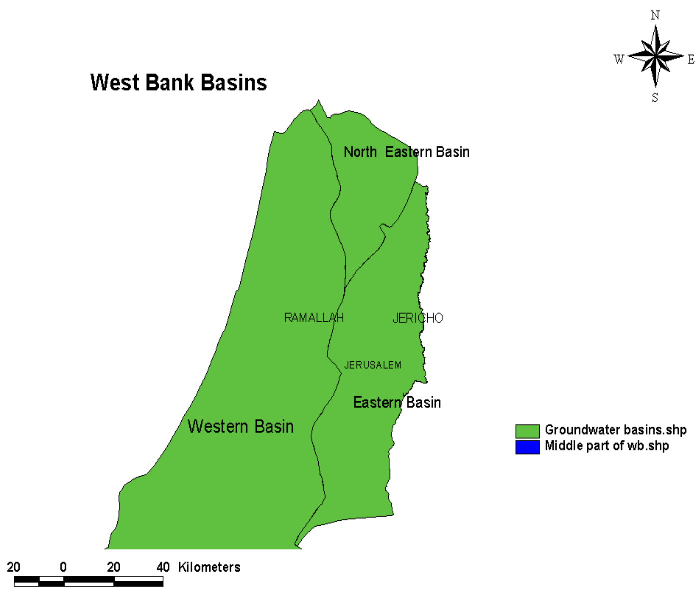


Figure 2.4.1.1: The groundwater basins in the West Bank

There are five wells located in Ein Samia and are owned by Jerusalem Water Undertaking (JWU), these wells are used for domestic purposes, while gap water is covered from wells are owned by Israeli water companies (ARIJ, 2006).

2.4.2.2 Water Consumption

There is a huge gap between Israeli and Palestinian consumption. The average Israeli consumes for domestic and urban use approximately 104 cubic meters a year, or 280 liters per person per day. In other words, per capita use in Israel is four and a half times higher than in the Occupied Territories. To make a more precise comparison, by also taking into account industrial water consumption in Israel, per capita use per year reaches 120 cubic meters - 330 liters per person a day - or five and a half times Palestinian per capita consumption. The World Health Organization and the United States Agency for International Development recommend 100 liters of water per person per day as the minimum quantity for basic consumption. This amount includes, in addition to domestic use, consumption in hospitals, schools, businesses, and other public institutions. Palestinian daily consumption is 40 percent less than the recommended quantity (B'TSELEM, 2006).

Chapter Three

Literature review

3.1 Introduction

The water situation in many developing countries is grim and water scarcity is recognized as one of the root causes of poverty. Currently, more than one billion people globally do not have access to adequate volumes of clean drinking water. Water professionals are becoming increasingly worried about water scarcity. The UN World Water Development Report of 2003 suggests that population growth; pollution and climate change are likely to produce a drastic decline in the amount of water available per person in many parts of the developing world. Domestic roof water harvesting (DRWH) provides an additional source from which to meet local water needs. In recent years, DRWH systems have become cheaper and more predictable in performance. There is a better understanding of the way to mix DRWH with other water supply options, in which DRWH is usually used to provide full coverage in the wet season and partial coverage during the dry season as well as providing short-term security against the failure of other sources. Interest in DRWH technology is reflected in the water policies of many developing countries, where it is now cited as a possible source of household water (Martinson and Thomas, 2006). Water is the key factor in changing the fundamental conditions for the existence and development of the poor areas. A supply of water, which is easily available, potable and affordable, is also a prerequisite to good hygiene and sanitation and hence central to the general welfare of a household and its members. Several different factors are related to insufficient water supply; for example divisions in wealth, class and socio-economic status, correlated with the degree of planning and provision of adequate infrastructure. Population growth impacts water demand in several ways. The demand of water for drinking and sanitation purposes increases proportionally with population growth. Furthermore, economic conditions and poverty rates are two important parameters that can significantly impact water use practices and patterns. Economic growth increases the demand for a wide variety of environmental services related to water.

Water is essential for all life and used in many different ways. It is also a part of the larger ecosystem in which the reproduction of the biodiversity depends. Fresh water scarcity is not limited to the arid climate regions only, but in areas with good supply the access of safe water is becoming critical problem (Sivanappan, 2006). Lack of fresh water is caused by natural and artificial reasons. Palestine faced today critical water scarcity not only due to lack of water but for uncontrolled on ground water basins by the Israelis.

Rainwater harvesting systems (RWHS) like many techniques in use today is not new but it has long history. In the Negev Desert, rainwater cisterns systems (RWCS) for storing runoff from hillsides for both domestic and agriculture purposes have allowed habitation and cultivation in area with as little as 100 mm of rain per year since 2000BC or earlier. The system involved clearing hill sides to smooth the soil and increase runoff and then building contour ditches to collect the water and carry it to low lying fields where the water was used to irrigate crops. By the time of the Roman Empire, these runoff farms had evolved into relatively sophisticated (Evenari *et al*., 1961).

Rainwater harvesting is the capture, diversion and storage of rainwater and conserving rainfall from a surface (catchments) to be used later in various purposes including landscape irrigation, drinking and domestic use, aquifer recharge and storm water abatement. Roof catchments system depends on three components: the collection area which is the individual rooftop on the house, the conveyance system which is a series of gutters or pipes that convey the water to the storage facility (cisterns) and the storage facility itself. The amount of the water that can be collected depends on the catchments' area, the amount of rainfall and the storage volume (PWA, 2003).

3.2 Historical development & previous studies

3.2.1 Historical development

Rainwater collection is one of the oldest means of collecting water for domestic purposes. The use of earth dams to control runoff was known in ancient Egypt. In India, simple stone-rubble structures for impounding rainwater date back to the third millennium BC (Agarwal and Narain, 1997). It was also a common technique throughout the Mediterranean and Middle East. In Palestine, water collected from roofs and other hard surfaces was stored in underground reservoirs (cisterns) with masonry domes since several thousands years ago (Evenari *et al*. 1961). In Western Europe, the Americas and Australia, rainwater was often the primary water source for drinking water. In all three continents it continues to be an important water source for isolated homesteads and farms. Collection and storage for agricultural use has equally been widely practiced for thousands of years.

3.2.2 Previous studies

Several international studies were performed to study the quality of fresh and harvested rainwater, only a few national studies have reported on water quality. Below are some examples;

3.2.2.1 Palestinian studies

- Abu Sharekh (1995) studied and investigated the feasibility of using roof rainwater catchment systems in South of West Bank (Palestine) as supplementary water source and water quality issues. Roof catchment systems in the West Bank are usually from flat roofs and have underground tanks. Gutters are an important component of the RWCS. Water quality was generally better in rain tanks than from municipal supplies and springs. Physical-chemical and bacteriological test results tabulated have been (pH, EC, TDS, Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, $CO_3^{\ -}$, HCO_3^{-}). It was found, rainwater stored in cisterns was used for drinking and domestic purposes. Level of total coliforms contamination were found 27%>0 coliform. Concentration of major constituents well within the prescribed limits.

- PHG (2003) analyzed water samples from thirty cisterns in Hebron district, of which 12 were collected from the Yatta area and 18 were collected from the Arab Ramadeen area. The samples were collected from household, public and school cisterns. It was found that the pH of some water samples is mostly alkaline. Also it was found that the water is aerobic with DO values of

4.8-6.62 mg/l. Water salinity values were low. Turbidity analysis showed that 6 samples have turbidity values greater than 5 NTU.

- Isam Al-Khatib and Moammar Orabi (2004), Institute of Community and Public Health, BZU have a study of the biological characteristic of drinking water in three villages in Ramallah District by testing the total coliforms in samples were collocated from rain-fed cisterns. The results show that 87% of tested samples were highly contaminated, 10.5% had low contamination and only 2.5% were not contaminated.

3.2.2.2 International studies

There are many international studies were performed to study the quality and design parameters of rainwater harvesting. Some of these studies were selected as follows (Vasudevan and Pathak, 1999):

- Gould (1984) has discussed bacteriological analysis (total coliform, faecal coliform and faecal streptococci) from roof tank water in Botswana, Africa. Accepted water quality standards of Botswana are also tabulated. Generally high quality of properly stored rainwater is seen.

- Per Jacobsen (1994) has tabulated concentrations of lead (0.1 mg/l) and Zinc (0.1-1.00 mg/l) exceeding the standards for drinking water in Denmark. Lead, Zinc, Cadmium and copper were estimated.

- Wilhelm Meemken (1994) has tabulated quality of rain water collected from roofs in Germany. Chemical parameters included (Fe, Mn, Cu, Pb, Zn, pH, Ca, Mg, Na, K, NH_4^+, SO_4^{2-}, Cl^-, NO_3^-, NO^{2-} and electrical conductivity. The results showed the rainwater collected from roofs could be used for flushing toilets, washing cloths and watering plants without special treatment.

- Gould and McPherson (1987) have described bacteriological analysis of water samples from 13 roof tanks and 8 ground catchments tanks in Botswana, Africa. The results show that rainwater collected from corrugated iron roofs and stored in covered tanks is of high quality compared with traditional water sources. Water from roof catchments systems in Botswana presents a serious health hazard.

- Mayo and Mashauri (1991) have given the bacteriological (total and faecal coliform and faecal streptococci), chemical (pH and total hardness) and physical (turbidity & colour) analyses of water samples from rainwater cistern system at the University of Dar es Salaam in Tanzania between October, 1988 and December, 1989. The results showed that 86% of samples were free from faecal coliform. However, faecal streptococci were obtained in 53% of the samples and 45% of the samples tested for total coliforms were positive. About 54% of the consumers raised objections over the taste of water. The pH range was found out to be 9.3-11.7 which is above standard limits.

- Most extensive study on quality aspects of water stored in domestic rainwater tanks in Australia has been given by Fuller *et al*. 1981 for South

Australia. Water samples from three different areas (Vineyard and Orchard areas: 7 cities), industrial areas: 4 cities, and residential areas: 2 cities) were collected which reflected conditions in water stored in domestic rain water tanks through South Australia. Galvanized iron tanks within the range of 10,000 to 25,000 liter with closed tops were selected. Tanks which had catchments of unpainted galvanized iron were chosen. Also householders were asked to answer a series of question regarding use and maintenance of their tanks. Microbiogiological parameters, heavy metals (Pb, Zinc, Cd), pesticides and other physical-chemical tests (temperature, pH, suspended solids, total dissolved solids and salinity). Results of the study are summarized: Coliform bacteria: coliform bacteria were present in 12 of 41 tanks, up to 500 coliforms/100 ml were recorded. E. coli: E. coli was detected in 6 tanks 15% of 41 tanks levels up to 220 E. coli/100 ml were recorded. Plate counts gave an indication of the general level of microbiological contamination of water. Plate counts in most rainwater tanks were in excess of 1000/ml. Heavy metals: Cadmium: One of the tanks reported relatively high cadmium concentration (0.018 mg/l). This could be a sampling error or contamination caused by an isolated event. Lead: Concentrations of lead in rainwater from tanks in Port Pirie were significantly higher (0.061 & 0.072 mg/l) than other sites. This could be a result of dust from surroundings country sides washed from roof tops with each rainfall. Zinc: Zinc concentrations were found to be excess of 15 mg/l. Pesticides were not detected in the majority of samples. Suspended solids: Concentrations were negligible in all samples. pH: range of pH values was 6.1 to 9.2 low. pH values can accelerate corrosion problems in domestic appliances while high pH is an indication of undesirable biological activity in the tank. TDS: Only samples taken from 2 rainwater tanks had T.D.S. concentrations in excess of 100 mg/ml (caused by sea spray).

- Sivanandan (1999) from India has reported chemical analysis of water sample from open wells in Adimalathura area, Kerala (Jan.-Feb., 99). 11 samples from all around villages were collected and chemical testing was done. Parameters studied were pH, EC, D.O., chloride, total hardness, Ca hardness, Mg, total alkalinity, bicarbonates and carbonates). Results indicated that chemical quality of water had potable status.

3.3 Advantages of rainwater harvesting systems

Advantages and benefits of rainwater harvesting are numerous (Krishna, 2003):

- ✓ The water is free; the only cost is for collection and use.
- ✓ The end use of harvested water is located close to the source, eliminating the need for complex and costly distribution systems.
- ✓ Rainwater provides a water source when groundwater is unacceptable or unavailable, or it can augment limited groundwater supplies.
- ✓ The zero hardness of rainwater helps prevent scale on appliances, extending their use; rainwater eliminates the need for a water softener and the salts added during the softening process.
- ✓ Rainwater is sodium-free, important for persons on low-sodium diets.
- ✓ Rainwater is superior for landscape irrigation.
- ✓ Rainwater harvesting reduces flow to storm water drains and also reduces non-point source pollution by reducing flooding, erosion and the

contamination of surface water with sediments, fertilizers and pesticides in rainfall run off.

- ✓ Rainwater harvesting helps utilities reduce the summer demand peak and delay expansion of existing water treatment plants.
- ✓ Rainwater harvesting saves money by reducing consumers' utility bills.

3.4 Drawbacks of rainwater harvesting systems

Disadvantages of RWHS are:

- ✓ The success of rainfall harvesting depends upon the frequency and amount of rainfall, also on the surface of the roof; therefore, it is not a dependable water source in times of dry weather or prolonged drought.
- ✓ Low storage capacities will limit RWH so that the system may not be able to provide water in a low rainfall period. Increased storage capacities add to construction and operating costs and may make the technology economically unfeasible, unless it is subsidized by government.
- ✓ Cisterns and storage tanks can be unsafe for small children if proper access protection is not provided.
- ✓ Where treatment of the water prior to potable use is infrequent, due to a lack of adequate resources or knowledge, health risks may result; further, cisterns can be a breeding ground for mosquitoes.
- ✓ Rainfall harvesting systems increase construction costs and may have an adverse effect on home ownership.
- ✓ Rainfall harvesting systems may reduce revenues to public utilities.
- ✓ The mineral-free water is tasteless and could cause nutritional deficiencies; people prefer to drink water rich in minerals.

3.5 Structural component of roof water harvesting (Palestinian Standards)

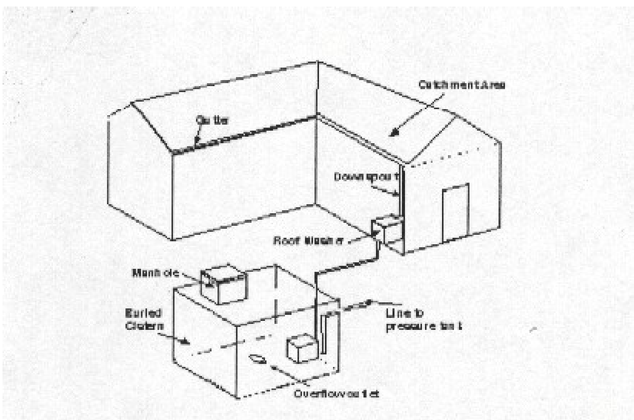


Figure 3.5.1: Components of the Rainwater Harvesting System (PWA, 2003)

Household roof rainwater collection systems comprise six basic components (see figure 3. 5.1):

1. Catchments surface: The collection surface from which rainfall runs off. Usually, it consists of rooftop areas. There are different types of roofs; Tiled, metal roofs or cement concrete roofs, they are easy to use and give clean water. Asbestos sheet roofs, especially when damaged, should not be used as asbestos fibers may be released into the harvested water. In the West Bank three types of roofs can be found: reinforced concrete, sheet metals and red tiles. Reinforced concrete roofs are the dominant; they are flat surfaces with a slope of 1-2%. This type of roofs is usually surrounded by concrete barrier of about 25-100cm height to prevent loss of rainwater to collect as much as possible. Water quality from different roof catchments is a function of the type of roof material, climatic conditions, and the surrounding environment (Vasudevan, 2002).

2. Conveyance: Gutters, downspouts and pipes convey roof runoff to the storage tanks (cisterns).
Gutters are installed to capture rainwater running off the eaves of a building. Some gutter installers can provide continuous or seamless gutters. For potable water systems, lead cannot be used as gutter solder, as is sometimes the case in older metal gutters. The most common materials for gutters and downspouts are half-round PVC, vinyl, pipe, seamless aluminum, and galvanized steel. Seamless aluminum gutters are usually installed by professionals, and, therefore, are more expensive than other options (see photo 3.5.1).

Photo 3.5.1: Galvanized steel gutters (Ramallah).

The downspout: A vertical down pipe is required to convey the harvested rainwater to the storage tank. An inlet screen to prevent entry of dry leaves and other debris into the down pipe should be fitted (see photo 3.5.2).

Photo 3.5.2: Galvanized steel downspout (Abu Shekheidim).

3. Leaf screens, first-flush diverters, and roof washers: Components which remove debris and dust which usually accumulate on roof surfaces between rainstorms from the captured rainwater before it goes to the tank to avoid polluting the stored rainwater. A roof washer and a sand filter unit at the inlet of the cistern should be incorporated into potable water systems. The roof washer diverts the first flush of runoff containing most of the contaminants away from the cistern. A common design is shown in Figure 3.5.2.

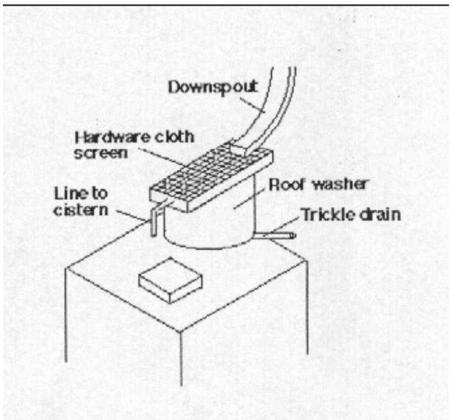


Figure 3.5.2: Example of a roof washer (PWA, 2003)

People whom have rainwater cisterns in Palestine foul flush only the first shower at the rainy season (Samhan, 1999) (see photo 3.5.3 below).

Photo 3.5.3: First-flush diverter (Ramallah).

4. Storage Tank: The storage tank accounts for a large fraction of the cost of any roof water harvesting system (PWA, 2005). Most poor households can not afford to buy as large a tank as their roof catchments area might justify. The cost of a tank depends upon its size, the type and quantity of materials used in its construction, the labor needed to build it and in some areas the hire of special equipment. The size of storage tank or cistern is dictated by several variables: the rainwater supply (local precipitation), the water used or demand, the projected length of dry spells without rain, the catchments surface area, aesthetics, personal preference, budget (available financial resources), available area for constructing the cistern and whether the cistern will be used as the sole source of water or as a supplementary supply. In Palestine, most of the storage tanks are divided into two types based on its shape:

i. Square/Rectangular shaped cisterns
ii. Pear shaped cisterns (conventional).

Usually, concrete cisterns are the most common types of cisterns. The recommended cistern volume is:

i. For single square/rectangular shaped cistern ranging from 50 to 70 cubic meters.
ii. For double square/rectangular shaped cistern ranging from 100 to 120 cubic meters.
iii. The recommended capacity for a pear shaped cistern is between 50-70m³.

For the determination of the approximate Cistern volume, simple calculations can be done depending on the relation between available catchments area and the average annual rainfall for the region where the cistern is going to be constructed (PWA, 2003) .The calculations are as follows:

Cistern Volume = R×CA×AVR/1000,

Where: R: Run-off coefficient is the percentage of total rainfall that can be harvested from a particular surface.

- The higher the run-off coefficient, the less absorbent the surface.
- Run-off coefficient is depending on: roof (surface) texture, conveyance systems status, evaporation from surface and tank (it is a function of temperature, wind, amount of sunlight and humidity), slope of catchments and rainfall received.

CA: Catchments Area (m^2)
AVR: Average Annual Rainfall (mm)

5. Delivery system: Gravity-fed or pumped to the end use. For underground tanks, the withdrawal can be done by installing a pump (see photo 3.5.5), while for ground and elevated by taps fitted at the bottom of the tank. In Palestinian areas, people either use a pump or a bucket.

Photo 3.5.4: Delivery system by using pumps (Kubar).

Photo 3.5.5: Delivery system by using bucket (Abu Shekheidim).

6. Overflow: Usually, 2-3 inches pipe diameter is equipped at about 15-20 cm from the roof of the cistern to prevent flooding during heavy intensity rainstorms.

3.6 Identification of location and sanitary requirements (PWA, 2003)

For hygienic criteria, the rainwater cistern should be located:

1. Downstream of a catchments area, where water drains naturally into the cistern.
2. Upstream of possible local sources of pollution, such as latrines, cesspits, septic tanks, etc.
3. At least 15 meters away from the nearest sources of pollution.
4. At least 15 meters away from the nearest public road.
5. Away from walking paths/playgrounds to consider health and safety issues during construction and operation.
6. At least 15 meters from trees so that the roots not cause damage to the cistern, and fallen leaves will not be washed into the cistern.
7. Where the geology formation is stable.
8. Where there is easy access for construction equipment and machinery, and for delivery of materials.
9. Where it is possible to divert easily the catchments runoff through natural or man made formations/structures such as bunds, land weirs, channels, etc.
10. Where it will be convenient for the family to gain access to the cistern.
11. Where sediments loading in runoff will be minimal.

The design and construction of the rainwater cistern system shall take into consideration the following sanitary requirements:

- ❖ Cisterns shall be watertight with a smooth, clean interior surface.
- ❖ Cisterns shall be accessed for cleaning and disinfections.
- ❖ Cistern outlet drains and overflow pipes shall be a minimum of 150mm in diameter and not be connected to any sewer, soil pipe, building drain, or other waste pipe.
- ❖ Outlet and overflow drain pipes end shall be equipped with non-corroding animal guards with a maximum opening of 1mm or flap valve. Such drains are to discharge at a point far away from flooding to prevent back-flow. The overflow pipe should be installed at a distance of 15-20cm under the internal surface of cistern roof slab.
- ❖ Cistern vents and other openings shall be constructed and protected with non-corroding fly screen or guards with a maximum opening of 1mm, to prevent the entrance of animals, insects or other contaminating materials.
- ❖ All vents shall be inverted.
- ❖ Where applicable, a minimum of one aboveground roof washer or filtering devices shall be provided on each cistern. The above-ground roof washer or filtering device shall be provided with an above-grade and easily removable debris trap with a minimum screen opening of 6mm.
- ❖ Water obtained from the cistern shall be continuously disinfected as prescribed by the Ministry of Health.

3.7 Rainwater quality and sources of contamination

'Contamination of rainwater systems has been linked with a number of human infections'. Many studies around the world including local studies are insure this statement (Ariyananda, 1999): Murrell and Stewart, 1983; Brodrinbb *et al*., 1995; and chemical intoxication (Body, 1986) and many of these studies looked at microbial (Waller *et al*., 1984; Fujioka and Chinn, 1987; Hable and Waller, 1987; Lye, 1987; Fujioka *et al*., 1991; Al-Khatib and Orabi, 2004 and chemical contamination of roof water collection: (Sharpe and Young, 1982; Gumbs and Dierberg, 1984; Young and Sharp, 1984; Olem and Berthouex, 1989; Ghanayem-ARIJ, 2000; Awadallah, 2004; Al-Khashman, 2005). However, local studies have found that for drinking and cooking people still prefer to use known groundwater to unknown rainwater. Reluctance to drink rainwater collected from the rooftop thought to be a perception of water quality. Quality of rainwater collected depends on when it is collected (after the first rain), how it is stored as well as method of use. Consumption of rainwater is related to the perception of quality (Ariyananda, 2001). Rainwater cisterns are generally not tested for water quality; therefore households have no knowledge of the quality of water, only a perception of water quality. In order to recommend and convince the people with confidence to use rainwater as a drinking water source, as an adaptation measure in time of drought, a comprehensive, systematic survey of rain water quality is needed. General quality of rain water is measured at household level by: Presence of leaves and other material, Presence of mosquito larvae and other insects, rodents and frogs, Color and Taste.

3.7.1 Factors Affecting Water Quality

If the rainwater is to be used for drinking purposes, its quality should comply with Palestinian Standards (PS 41).

The following may be considered as sources of contamination that may affect the quality of harvested rainwater:

1. **The environment:** As a raindrop falls and comes in contact with the atmosphere, it dissolves naturally occurring carbon dioxide to form a weak acid. pH is natural if it ranged from 6.5 to 8.5 according to Palestinian Standards. Total dissolved solids (TDS) in rainwater, originating from particulate matter suspended in the atmosphere. Particulate matter refers to smoke, dust, and soot suspended in the air. Fine particulates can be emitted by industrial and residential combustion, vehicle exhaust, agricultural controlled burns, and sandstorms. As rainwater falls through the atmosphere, it can incorporate these contaminants. In agricultural areas, rainwater could have a higher concentration of nitrates due to fertilizer residue in the atmosphere (Thomas and Grenne, 1993). Pesticide residues from crop dusting in agricultural areas may also be present. In industrial areas, rainwater samples can have slightly higher values of suspended solids concentration and turbidity due to the greater amount of particulate matter in the air (Thomas and Grenne, 1993).

2. **The catchments surface:** When rainwater comes in contact with a catchments surface, it can wash bacteria, molds, algae, fecal matter, other organic matter, and/or dust into storage tanks. The longer the span of continuous number of dry days (days without rainfall), the more catchments debris is washed off the roof by a rainfall event (Thomas and Grenne, 1993; Vasudevan, 2002). For health purposes it is good practice to divert out the first runoff of rainwater. A manually moved down pipe can be used for this purpose. Also complete removal of bacterial contamination from water can be obtained by using sand filters. The catchments itself can add pollutants to the water such as when it is painted with asphalt or any toxic materials. So roof isolation materials must be selected in such away that they do not have adverse health effects.

Photo 3.7.1.1: Contamination due to dirty catchments surface (Abu Shekheidim).

3. **The storage tanks:** The more filtering of rainwater prior to the storage tanks, the less sedimentation and introduction of organic matter will occur within the tanks. Gutter screens, first-flush diverters, roof washers, and other types of pre-tank filters are discussed before. Sedimentation reduces the capacity of tanks, and the breakdown of plant and animal matter may affect the color and taste of water, in addition to providing nutrients for microorganisms. A well designed tank with proper cover must be used to keep water of a good standard. To maintain water quality in cisterns, they should:

- ☒ have a means of being charged with water without unduly disturbing tank-bottom sediments and if possible maintaining stratified flow (the bacterial quality of outlet water is maximized if the flow through the tank resembles 'pipe flow', namely 'last in is last out',
- ☒ be able to handle excess input by overflowing in a convenient and safe manner preferably without leading water unnecessarily via the tank (such water may drop unwanted sediment in the tank),
- ☒ have a means by which the water can be extracted which is convenient for the user and which does not pollute the water left behind (as dipped buckets may),
- ☒ exclude vermin and as far as possible mosquitoes,
- ☒ exclude light (so that algae do not grow and larval growth is inhibited),
- ☒ have some form of ventilation, especially if there is not an efficient filter to prevent organic material from entering the tank and decaying there,

☒ be easy to access for cleaning (where cleaning is needed) and be unlikely to be damaged during cleaning,
☒ have a sufficient structural safety factor to withstand wear and tear, some impacts and occasional large natural forces caused by winds and (in places) earthquakes,
☒ not present hazards to passers-by or small children and (in some societies) offer some protection against deliberate poisoning, and
☒ not give the water a bad taste

4. **Contamination at home:** The way in which water is withdrawn from a tank needs careful consideration. If it is collected directly in containers lowered into water, contamination can easily occur. So, a pump must be used to extract water (see photo 3.7.1.2).

Photo 3.7.1.2: Contamination due to collecting water directly in bucket (Kubar).

5. **Contamination due to poor maintenance**: To keep water suitable for drinking, typical maintenance activities can be carried out including the following:

i. Using clean brush to sweep roofs and gutters near to the end of dry season.

ii. Catchments under trees should always be avoided because of high level of pollution from bird dropping and fallen dry leaves (see photo 3.7.1.3).

Photo 3.7.1.3: Contamination due to poor maintenance and because catchments very closed to cistern (Abu Shekheidim).

iii. Tanks and reservoirs need monitoring for leaks so that repairs can be carried out.

Photo 3.7.1.4: Contamination due to poor maintenance (Abu Shekheidim).

iv. Tanks and reservoirs need periodic desalting especially where ground surface are used without sediment traps.

6. **Contamination due to interference of water stored in cistern with cesspits**: This kind of contamination is more expected with underground cisterns. The factors affecting this kind of contamination are:

i. The distance between the cistern and the cesspits,
ii. Slope and elevation of the cistern and the cesspits, and
iii. Kind of soil in which the cistern was excavated, method of construction and its design life

3.7.2 Rainwater harvesting quality parameters

Water quality is a very important issue. According to WHO, 80% of diseases are caused due to contaminated water. The major contaminants may be classified into biological and non-biological. Water is tested to insure its quality. Tests done may be physical, chemical and/or biological**.** There is no single test by which the safety of drinking water can be determined. Water contains many elements and only one of them can be reason for rejection of the water for human consumption.

The collection cisterns were monitored over a period of 5 months for:

a. Physical quality

These tests include measurements of**:**

• Temperature, Turbidity, Salinity, pH, Total Dissolved Solids (TDS), Conductivity.

b. Chemical quality

• Dissolved Oxygen (DO), Total Hardness as $CaCO_3$ (TH), Calcium (Ca), Sodium (Na), Chloride (Cl), Nitrates (NO_3), Metals: Zinc (Zn), Chromium (Cr), Lead (Pb).

c. Bacteriological quality

These tests include measurements using the existence of biological organisms to measure the degree of contamination. Bacteriological quality was measured by total and fecal coliforms (TC, FC). This measurement in drinking water indicates for human and animal faeces. Therefore the presence of these contaminants in drinking water indicates potentially dangerous contamination by disease causing pathogens.

3.7.3 Significant rainwater quality parameters

- **Total Dissolved Solids (TDS):** TDS in rainwater, originating from particulate matter suspended in the atmosphere. TDS are the total weight of all solids (minerals, salts or metals) that are dissolved in a given volume of water expressed in mg/l, or in parts per million (ppm). The lower the TDS level in the water, the more efficiently your body's cells actually get hydrated by the water that you can drink. But the higher the TDS levels in the water, the greater the probability of harmful contaminants that can pose health risks or hinder the absorption of water molecules on the cellular level.

- **Particulate matter:** Particulate matter refers to smoke, dust, and soot suspended in the air. Fine particulates can be emitted by industrial and residential combustion, vehicle exhaust, agricultural controlled burns, and sandstorms. As rainwater falls through the atmosphere, it can incorporate these contaminants.

- **pH**: As a raindrop falls and comes in contact with the atmosphere, it dissolves naturally occurring carbon dioxide to form a weak acid. By time, when rainwater is harvested in cistern; the value of pH will rise and water become alkaline due to accumulation of alkaline sediments.

- **Chemical compounds**: In agricultural areas, rainwater could have a higher concentration of nitrates due to fertilizer residue in the atmosphere (Thomas and Grenne, 1993). Pesticide residues from crop dusting in agricultural areas may also be present. Also, dust derived from calcium-rich soil can add some of hardness to the water. Hard water has a high mineral content, usually consisting of calcium and magnesium in the form of carbonates. Usually rainwater described as a free of minerals; so it is considering as a soft. In industrial areas, rainwater samples can have slightly higher values of suspended solids concentration and turbidity due to the greater amount of particulate matter in the air (Thomas and Grenne, 1993).

- **Catchments:** When rainwater comes in contact with catchments it can wash bacteria, molds, algae, fecal matter, other organic matter, and/or dust into cisterns. The longer the span of continuous number of dry days (days without rainfall); the more catchments debris is washed off the roof by a rainfall event (Thomas and Grenne, 1993; Vasudevan, 2002).

- **Cisterns**: cisterns need for covers to prevent any pollutant from entering inside and need for sediments trap basin to allow particles from settling and removed; Sedimentation reduces the capacity of tanks, and the breakdown of plant and animal matter may affect the color and taste of water, in addition to providing nutrients for microorganisms.

To assess water quality, the above cited factors should be kept in mind.

3.8 Operation and maintenance of RWHS (PWA, 2003)

It is worth noting that owners of rainwater harvesting systems who supply all domestic needs essentially become owners of their "water supply systems," responsible for routine maintenance, including filter and lamp replacement, leak repair, monitoring of water quality, and system upgrades. The rainwater harvesting system owner is responsible for both water supply and water quality. Maintenance of a rainwater harvesting system is an ongoing periodic duty, to include:

- ✓ Cleaning the roof at the beginning of each rainy season to remove any type of trash and foreign matter, usually by using the water from the first rains; and
- ✓ Cleaning the storage tank, and monitoring tank levels,
- ✓ Cleaning gutters, cistern cover and first-flush devices,
- ✓ Repairing leaks. Cracks in the storage tanks can create major problems and should be repaired immediately. In the case of ground and rock catchments, additional care is required to avoid damage and contamination by people and animals, and proper fencing is required.
- ✓ Repairing and maintaining the system, and
- ✓ Adopting efficient water use practices,
- ✓ Keeping debris out of holding areas, gutters and downspouts

In addition, owners of potable systems must adopt a regimen of:

- ✓ Changing out filters regularly,
- ✓ Maintaining disinfections equipment, such as cleaning and replacing ultraviolet lamps, and
- ✓ Regularly testing water quality.

Chapter Four

Methodology

4.1 Overall methods

The overall research method is based on an interdisciplinary and integrated approach divided into two main interactive phases. A literature review and a case study including fieldwork in Kubar and Abu shekheidim villages. Secondary sources consist of literature studies of published material and data from scientific journals in the area of interest. Primary sources include data collected through oral interviews with householders who own cisterns. The interviews concentrated on the uses of rainwater harvesting systems (see Table 4.2.1). The sites were selected due to the high amount of households there, which use the Domestic Rain Water Harvesting-technique in an informal or formal way. Initially, 65 interviewed households were selected randomly but only if they were already using rainwater as part of the household water supply while 12 cisterns were analyzed to assess rainwater quality and quantity.

In addition, relevant local and national water agency professionals were visited and interviewed to collect information about statistics and uses of water sources and distribution in Palestine. Interviews were carried out at Palestinian Hydrology Group (PHG) which is a NGO working in Palestine with financial and technical support through local organizations to implement projects within the water and environment area. Furthermore, the Jerusalem Water Undertaking (JWU) who is responsible for the supply of water in the rural areas of Ramallah was visited. Palestine Standards Institution (PSI) was visited too, this Institution who regulates quality standards, as well as regulations relating to the drinking water standards. The final interviews were carried out at the Palestinian Water Authority (PWA) and Palestinien National Information Centre; these institutions gave me important information about technical aspects for rainwater harvesting systems (cisterns) and general information about the area of study.

4.2 Study Site Analysis

A survey was conducted in two villages in Ramallah district, Kubar and Abu Shekeidim in the North West of Ramallah. The locations selected within this district falls within the area have an annual rain fall of 688 mm at BZU weather station.

A survey was conducted to select 12 households with rain water harvesting cisterns in selected areas in Kubar and Abu Shekheidim villages. During the initial survey more than 65 households having rain water cisterns were visited in two villages and only the households which were operating, maintaining and using system and interested in the survey was selected for the monitoring. In both villages a drinking water wells was sampled as the other available source of drinking water for comparison of quality.

To assess water quality, Seven RWHS with two different shape storage tank and three rooftop types were selected in 2 villages: rectangular and pear shape are the most common types which used in the area of study while the rooftop types selected were

Ferro-cement, asphalted and tile roofs and underground pear shape cisterns which constructed in rocks and lined with cement materials. All cisterns selected at two villages were of 48 to 114 m^3 capacity. The quantity of harvested rainwater and run-off coefficient were determined for 5 cisterns with catchment areas of 60-230m^2, 57% of all cisterns have below 15 m from nearest household cesspits, all catchments were polluted with dust; small aggregates; broken glasses and bird dropping. 71% of total households were using these cisterns as a domestic water source while 29% for gardening and construction works. Table 4.2.1 present the details of households selected for survey in the study area.

Table 4.2.1: Details of households selected for survey in the study area.

Cistern .No	Cistern (Size(m^3	Cistern Shape	Cistern Status	Distance from (Cesspit(m	Catchments (Area(m^2	Catchments type & Status	Gutter Materials	Rain Water Harvesting Usage
1	72.24	Rectangular	Steel-Cover Lined-with Cement	down-17	111	Cement roof/Polluted by dust-small aggregates-broken glasses-bird dripping	PVC+Steel	Secondary Source as Domestic if Water Supplied from Network not Available – Dry Season
2	54.70	Rectangular	Steel-Cover Lined-with Cement mixed-with JWU Water	N/A	189	Cement/Polluted by dust-small aggregates-broken glasses-bird dripping	Steel + PE	Gardening
3	114	Pear	Old-Steel Cover Dirty-	down-22	150	Cement+tile roof/Polluted by dust-small aggregates-broken glasses-bird dripping-Plastic-Steel	PVC+Steel	Construction
4	93	Rectangular	Steel-Cover Lined-with Cement	down-18	189	Cement+Asphalt/ Polluted by dust-small aggregates-broken glasses-bird dripping-Plastic-Steel Asphalt Sheet-	PVC+Steel	Domestic including Drinking
5	48	Rectangular	Steel-Cover Lined-with Cement	N/A	200	Cement/ Polluted-by dust-small aggregates-broken glasses-bird dripping-Plastic-Steel	PVC+Steel	Domestic including Drinking
6	100	Rectangular	Steel-Cover Lined-with Cement	10	370	Cement / Polluted by dust-small aggregates-broken glasses-bird dripping-	PVC	Domestic including Drinking

						Plastic-Steel		
7	90	Rectangular	Steel-Cover Lined-with Cement	6	154	Cement / Polluted by dust-small aggregates-broken glasses-bird dripping-Plastic-Steel	PVC+Steel	Domestic including Drinking
8	56	Rectangular	Steel-Cover Lined-with Cement	10	120	Cement +tile/ Polluted by dust-small aggregates-broken glasses-bird dripping-Plastic-Steel	PVC	Domestic including Drinking
9	112.5	Rectangular	Tile Cover		220		PVC+Steel	Domestic including Drinking
10	100	Rectangular	Steel-Cover Lined-with Cement		320		PVC+PE	Domestic including Drinking
11	48	Rectangular	Steel-Cover Lined-with Cement		60		PVC	Domestic including Drinking
12	72	Rectangular	Steel-Cover Lined-with Cement	10	160			Domestic including Drinking

4. 3 Sampling of rainwater harvesting

- ✓ 7 cisterns were chosen in the study area to evaluate the water quality through the wet season of stored water and compare the results with local and international standards for drinking water.
- ✓ Selected physical, chemical and biological parameters were tested.
    - Physical parameters: pH, temperature, electrical conductivity, turbidity and salinity.
    - Chemical: Na^+, Cl^-, Nitrate, Total Hardness as $CaCO_3$, and some of heavy metals like Lead, Zinc and Chromium were analyzed using Atomic Absorption Spectroscopy.
    - Biological: Fecal coliforms (FC) and Total Coliforms (TC).
    - Heavy metals: lead (Pb), Chromium (Cr) and Zinc (Zn).
- ✓ Comparing and analyzing the results with previous studies (local and international).

4.3.1 Sample collection procedure

During sampling the following steps and activities were:

- Labeling sample containers: all water samples were filled with sample number, collection date and time and preservative if any.
- The sampling depth was in the middle of the existing water column.
- The samples were placed in polyethylene bottles for chemical analysis and glass sterilized bottles for microbiological analysis, put into ice-bag containers and transported to the laboratory the same day.
- pH, Temperature, Turbidity, Dissolved Oxygen; Electrical Conductivity and Salinity were tested immediately after sampling.
- All water samples were put in pre-washed bottles. Three bottles with 1000ml each were taken every 5 to 10 days or immediately after raining and then divided into three samples for each bottle.
- Water testing was done completely at the BZU Laboratories using procedures of the Standard Methods for the Examination of Water and Wastewater (APHA, 1998) and included the determination of main anions, cations and heavy metals:

    - pH
    - DO: dissolved oxygen (mg/l) and its percent of saturation
    - TDS: total dissolved solids (mg/l)
    - EC: electrical conductivity (µs/cm)
    - Sal: salinity (g/kg water)
    - Turbidity in NTU
    - TC: total coliform bacterial count (#/100 ml)
    - FC: Fecal Coliforms
    - T: temperature (°C)
    - NO_3: nitrate concentration (mg/l)
    - Zn: Zinc (ppm)
    - Pb: lead (ppm)
    - Cr: Chromium (ppm)
    - TH: Total Hardness ($CaCO_3$) (mg/l)
    - Ca: Calcium (mg/l)
    - Na: Sodium (mg/l)
    - Cl: Chloride (mg/l)
    - NO_3: nitrate concentration (mg/l) as nitrate
- The determination of heavy metals was carried out by atomic absorption spectrophotometer techniques.
- All samples were examined for the two widely used bacterial indicators, namely total coliforms and feacal coliforms by the membrane filter technique.
- 72 samples were collected and tested based on Standard Methods for examination while two samples were collected directly before it falls on the roofs and compared with the results obtained from another two samples were collected from the main drinking source (Tap water-groundwater source).
- Sampling form: all test results were filled in special form immediately after sample analysis complete.

4. 4 Runoff Coefficient Calculations

?How to calculate Runoff Coefficient 4.4.1

As a definition, the runoff coefficient is the ratio of the amount of water that is NOT absorbed by the surface to the total amount of water that falls during a rainstorm.

The total amount of water that is received in the form of rainfall over an area is called the rainwater endowment of that area. Out of this, the amount that can be effectively harvested is called the water harvesting potential (Bhattacharya & Rane, 2003).

:Factors affecting rainwater harvesting potential 4.4.2

Among the several factors that influence the rainwater harvesting potential of a site, eco-climatic conditions and the catchments characteristics are considered to be the most important.

a. **Rainfall**

i. **Quantity:** Rainfall is the most unpredictable variable in the calculation and hence, to determine the potential rainwater supply for a given catchments, reliable rainfall data are required, preferably for a period of at least 10 years. Also, it would be far better to use rainfall data from the nearest station with comparable conditions. In this study, rainfall at BZU Weather Station 1km far from study area is monitored in BZU (Rimawi and Shalash, 2007) and data given from this station as shown in table 4.4.2.1 and figure 4.4.2.1:

Table 4.4.2.1: Rainfall at BZU Weather Station 2003-2007 (Rimawi and Shalash, 2007)

Year /Month	Oct	Nov	Dec	Jan	Feb	March	April	May	Total (mm)
2003/2004	2	20	164	172	116	34	6	3	517
2004/2005	6	243	91	237	218	26	15	1	837
2005/2006	11	73	141	160	73	16	192	0	666
2006/2007	58	35	117	184	175.5	140.5	15	9.5	734
Annual average									**688**

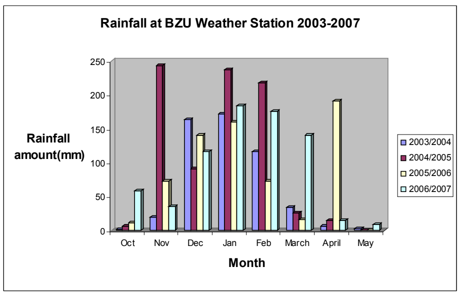


Figure 4.4.2.1: Rainfall at BZU Weather Station 2003-2007 (Rimawi and Shalash, (2007

ii. **Pattern (Climatic conditions: rainfall pattern & rate of evaporation):** The number of annual rainy days also influences the need and design for rainwater harvesting. The fewer the annual rainy days or longer the dry period, the more the need for rainwater collection in a region. However, if the dry period is too long, big storage tanks would be needed to store rainwater. Hence in such regions, it is more feasible to use rainwater to recharge groundwater aquifers rather than for storage.

b. Catchment size and characteristics

Runoff depends upon the area and type of the catchments over which it falls as well as surface features. All calculations relating to the performance of rainwater catchments systems involve the use of runoff coefficient to account for losses due to spillage, leakage, infiltration, catchments surface wetting and evaporation, which will all contribute to reducing the amount of runoff. Runoff coefficient for any catchments is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface. Before the cistern volume is assessed, the design parameters of cisterns must be reviewed. The volume of the storage tank is determined by five factors:

i. Number of persons in the household: The number of members in a family determines the size of the storage tank. Bigger the family, larger the storage capacity required to achieve the same efficiency of fewer people under the same roof area. The average household size in the study area is 5.3 (PCBS, 2007).

ii. Per capita water requirement: This varies from household to household based on habits and from season to season. Consumption rate has an impact on the storage systems design as well as the duration to which stored rainwater can last. On average the actual water consumption in the West Bank per capita amounts of 42 l/d generally using about one third of internationally daily amount of water for consumption, hygiene, and cleaning needs (Aliewi and Mimi, 2006).

iii. Average annual rainfall: The average annual rainfall for the area of study is 688mm/yr (Rainfall at Bir Zeit University Weather Station 2003-2007).

iv. Period of water scarcity: Apart from the total rainfall, the pattern of rainfall -whether evenly distributed through the year or concentrated in certain periods will determine the storage requirement. The more distributed the pattern, the lesser the size. On average, 51 days out of 365 days are rainy days (ARIJ, 2006).

v. Type and size of the catchments: Type of roofing material determines the selection of the runoff coefficient for designs. Size can be assessed by measuring the area covered by the catchments, i.e., the length and horizontal width. Larger the catchments, larger the size of the required cistern. All cisterns selected at two villages were of 48 to 114 m^3 capacity with catchment areas of 60-230m^2, 5 were rectangular while 2 pear shape cisterns, the common rooftop types selected were Ferro-cement, asphalted and underground pear shape cisterns which constructed in rocks and lined with cement materials.

Chapter Five

Results and discussion

5.1 Rainwater quality results and analysis

The average (AVG), standard deviation (STDEV), maximum (MAX) and minimum (MIN) values of parameters for rainwater collected in the study area are presented in Tables (5.1.1, 5.1.2, 5.1.3, and 5.1.4) while the detail rainwater harvesting results were shown in appendix I. The results present chemical, physical and microbiological water quality data as above parameters of the sampled cisterns compared with Palestinian Standards (PS41) and WHO guidelines. The parameters selected for analysis are those that are necessary for basic water quality monitoring programs.

Table 5.1.1: Characteristics of rain water samples collected direct from sky (fresh rain water)

Parameter item	Unit	PS41	Sample No.		
			1	2	AVG
1.Physical					
• pH		**6.5 - 8.5**	9.53	9.55	9.54
• DO	mg/l		8.79	9.15	8.97
• T	°C	**<20**	13.1	12.9	13.0
• EC	µs/cm		146	140.5	143.3
• Turbidity	NTU	**5.0**	28.2	27.4	27.8
• Salinity			0	0	0
2. Chemical					
I. Toxic					
• Pb	mg/l	**0.01**	0	0	0
• Cr	mg/l	**0.05**	0	0	0
• Zn	mg/l	**5.00**	<0.01	<0.01	<0.01
II. Others (Health)					
• TDS	mg/l	**1000**	69.0	66.0	67.5
• Total Hardness ($CaCO_3$)	mg/l	**500**	2.9	2.05	2.48
• Ca	mg/l	**100**	0.70	1.02	0.86
• Na	mg/l	**200**	0.01	0.01	0.01
• Cl	mg/l	**250**	9.5	8.7	9.1
• NO_3	mg/l	**50**	0.45	0.12	0.29
3. Biological					
• TC	#/100 ml	**3**	0	0	0
• FC	#/100 ml	**0**	0	0	0

Table 5.1.2: Characteristics of water samples collected from tap water (ground water source)

Parameter item	Unit	PS41	Sample No.		
			1	2	AVG
1.Physical					
•pH		**6.5 - 8.5**	7.47	7.41	7.44
•DO	mg/l		5.16	4.71	4.96
• T	°C	**<20**	16.5	16.6	16.55
• EC	µs/cm		849	702	760
• Turbidity	NTU	**5.00**	2.35	3.02	1.72
• Salinity			0.3	0.4	0.4
2. Chemical					

• TDS	mg/l	**1000**	338	407	366
• Total Hardness ($CaCO_3$)	mg/l	**500**	30.0	33.2	31.6
• Ca	mg/l	**100**	22	25	23.5
• Na	mg/l	**200**	12.0	15.1	13.55
3. Biological					
• TC	#/100 ml	**3**	0	0	0
• FC	#/100 ml	**0**	0	0	0

Results obtained from experiments of fresh rainwater samples showed that the samples were alkaline with pH values above 9 and have very low concentration of TDS of less than 68 mg/l for fresh water samples. Fresh rainwater had low–medium values for conductivity (average conductivity143.3 µs/cm). The salinity value is zero compared with relatively high value of samples which collected from tap water. The turbidity has very high values for fresh water samples; this is due to nature and atmospheric conditions. Tap water samples have turbidity within the standard limits. Also fresh water samples were found that the direct rainwater is aerobic with DO values range above 8.5 mg/l. Samples were not polluted with total and fecal coliforms. Samples showed that fresh rainwater has low level of ions as Ca^{++}, $Na^{+}$and Cl^{-} (avg. Ca^{++}: 0.86ppm, Na^{+}: 0.01ppm, Cl^{-}: 9.1ppm). The highest value of hardness measured in rainwater was 2.9 mg/l as $CaCO_3$ and the average value was 2.48mg/l as $CaCO_3$. The results show the level of NO_3 was closed to zero (average NO_3: 0.29 ppm All results for heavy metals shows the values fall within the PS41 and WHO guidelines. Generally, tests results show that the quality of direct rainwater is better than the quality of tap water (groundwater source).

Table 5.1.3: Characteristics of rainwater harvested (cisterns)

Cistern No. (1)

Parameter item	Unit	PS41	No. of samples	AVG	STDEV	MIN	MAX
1.Physical							
• pH		6.5 - 8.5	10	8.18	0.26	7.90	8.84
• DO	mg/l		10	6.14	0.19	5.80	6.37
• T	˚C	<20	10	15.17	1.51	13.50	17.70
• EC	µs/cm		10	284.2	8.24	261	300
• Turbidity	NTU	<5	10	10.1	5.87	1.84	15.80
• Salinity			10	0.1	0	0.1	0.1
2. Chemical							

I. Toxic							
•Pb	mg/l	0.01	2	0.00126			
•Cr	mg/l	0.05	2	0.0026			
•Zn	mg/l	5	2	0.0154			
II. Others							
•TDS	mg/l	1000	10	136.2	5.89	124	144
•Total hardness ($CaCO_3$)	mg/l	500	6	140	2.83	104	200
•Ca	mg/l	100	6	38.67	18.51	24	60
•Na	mg/l	200	4	17.63	1.89	15.5	20
•Cl	mg/l	250	3	38.2	20.66	14.6	53
•NO_3	mg/l	50	8	15.44	#REF!	9.52	23.93
3. Biological							
•TC	#/100 ml	3	5	31	36	8	85
•FC	#/100 ml	0	5	4	4	1	9

Cistern No. (2)

Parameter item	Unit	PS41	No. of samples	AVG	STDEV	MIN	MAX
1.Physical							
•pH		6.5 - 8.5	12	8.10	0.21	7.78	8.39
•DO	mg/l		12	5.23	0.95	3.32	6.01
• T	˚C	<20	12	16.1	1.34	13.6	17.7
•EC	µs/cm		12	252	91.65	156	407
•Turbidity	NTU	5	12	7.40	5.37	3.55	16.6
•Salinity			12	0.1	0.045	0.1	0.2
2. Chemical							
I. Toxic							
•Pb	mg/l	0.01	2	0.002			
•Cr	mg/l	0.05	2	0.0015			
•Zn	mg/l	5	2	0.0134			
II. Others							
•TDS	mg/l	1000	12	119.92	43.96	74	194
•Total hardness ($CaCO_3$)	mg/l	500	8	100.75	31.26	82	150
•Ca	mg/l	100	6	63.67	23.13	38	94
•Na	mg/l	200	2	17.25	6.72	12.5	22
•Cl	mg/l	250	3	31.33	30.29	10	66
•NO_3	mg/l	50	9	14.64		8.62	22.9

3. Biological							
•TC	#/100 ml	3	5	42	9	34	56
•FC	#/100 ml	0	5	4	1	2	5

Cistern No. (3)

Parameter item	Unit	PS41	No. of samples	AVG	STDEV	MIN	MAX
1.Physical							
•pH		6.5 - 8.5	10	8.36	0.15	8.15	8.5
•DO	mg/l		10	6.29	0.13	6.14	6.71
• T	˚C	<20	10	15.25	1.05	13.7	16.5
•EC	µs/cm		10	119.24	14.36	101.2	147
•Turbidity	NTU	5	10	18.19	11.83	8.02	31.6
•Salinity			10	0.1	1.32E-09	0.1	0.1
2. Chemical							
I. Toxic							
•Pb	mg/l	0.01	2	0.0017			
•Cr	mg/l	0.05	2	0.005			
•Zn	mg/l	5	2	0.023			
II. Others							
•TDS	mg/l	1000	10	56.3	6.87	48	69
•Total hardness ($CaCO_3$)	mg/l	500	6	56	21.58	30	80
•Ca	mg/l	100	4	35.75	14.98	22	55
•Na	mg/l	200	2	30	2.83	28	32
•Cl	mg/l	250	3	18.9	6.08	14	25.7
•NO_3	mg/l	50	9	15.19		11.6	22
3. Biological							
•TC	#/100 ml	3	4	95	37	75	150
•FC	#/100 ml	0	5	35	15	18	59

Cistern No. (4)

Parameter item	Unit	PS41	No. of samples	AVG	STDEV	MIN	MAX
1.Physical							
•pH		6.5 - 8.5	10	8.33	0.14	8.17	8.55
•DO	mg/l		10	5.98	1.15	3.91	7.85
• T	˚C	<20	10	15.21	0.98	13.7	16.7
•EC	µs/cm		10	173.81	33.54	153	234
•Turbidity	NTU	5	10	8.67	7.70	1.66	17.6

•Salinity			10	0.1	0	0.1	0.1
2. Chemical							
I. Toxic							
•Pb	mg/l	0.01	2	0.0017			
•Cr	mg/l	0.05	2	0.0094			
•Zn	mg/l	5	2	0.029			
II. Others							
•TDS	mg/l	1000	10	82.2	19.04	70	111
•Total hardness ($CaCO_3$)	mg/l	500	6	79.17	21.66	50	100
•Ca	mg/l	100	4	50.24	13.65	37	62
•Na	mg/l	200	2	26.5	9.19	20	33
•Cl	mg/l	250	2	16.5	13.21	0.6	26
•NO_3	mg/l	50	9	12.95		9.77	17.32
3. Biological							
•TC	#/100 ml	3	4	35	21	11	48
•FC	#/100 ml	0	4	2	1	0	3

Cistern No. (5)

Parameter item	Unit	PS41	No. of samples	AVG	STDEV	MIN	MAX
1.Physical							
•pH		6.5 - 8.5	12	8.01	0.14	7.77	8.2
•DO	mg/l		12	4.42	0.74	4.51	5.88
• T	˚C	<20	12	15.97	1.83	14.1	19.6
•EC	µs/cm		12	136.43	30.33	108.1	184.3
•Turbidity	NTU	5	10	12.779	7.09736 4	5.27	20.6
•Salinity			12	0.1	0	0.1	0.1
2. Chemical							
I. Toxic							
•Pb	mg/l	0.01	2	0.0007			
•Cr	mg/l	0.05	2	0.0021			
•Zn	mg/l	5	2	0.0152			
II. Others							
•TDS	mg/l	1000	12	64	14.74	51	88
•Total hardness ($CaCO_3$)	mg/l	500	5	53.2	4.60	50	60
•Ca	mg/l	100	3	35.33	13.61	20	46
•Na	mg/l	200	2	15.15	1.20	14.3	16

•Cl	mg/l	250	2	4.3	1.87	3.6	7.3
•NO_3	mg/l	50	6	13.15	1.67	8.8	16
3. Biological							
•TC	#/100 ml	3	2	28	11	20	35
•FC	#/100 ml	0	2	17	13	2	33

Cistern No. (6)

Parameter item	Unit	PS41	No. of samples	AVG	SDEV	MIN	MAX
1.Physical							
•pH		6.5 - 8.5	4	8.42	0.18	8.20	8.64
•DO	mg/l		4	7.51	1.44	6.07	8.75
• T	˚C	<20	4	14.53	0.13	14.4	14.7
•EC	µs/cm		4	88.3	6.7	81.2	96
•Turbidity	NTU	5	4	25.1	10.08	16.1	34.1
•Salinity			4	0	0	0	0
2. Chemical							
I. Toxic							
•Pb	mg/l	0.01	2	0.0008			
•Cr	mg/l	0.05	2	0.0055			
•Zn	mg/l	5	2	0.0152			
II. Others							
•TDS	mg/l	1000	4	42	3.56	39	46
•Tot. hardness ($CaCO_3$)	mg/l	500	1	40		40	40
•Cl	mg/l	250	1	23.6		23.6	23.6
•NO_3	mg/l	50	1	22		22	22
3. Biological							
•TC	#/100 ml	3	1	152		152	152
•FC	#/100 ml	0	4	2		0	3

Cistern No. (7)

Parameter item	Unit	PS41	No. of samples	AVG	STDEV	MIN	MAX
1.Physical							
•pH		6.5 - 8.5	4	7.87	0.14	769	7.99
•DO	mg/l		4	6.05	0.56	5.37	6.55
• T	˚C	<20	4	14.15	0.98	13.2	15.3
•EC	µs/cm		4	260	74.17	191	330
•Turbidity	NTU	5	4	16.88	7.94	9.9	23.8

.Salinity			4	0.1	0	0.1	0.1
2. Chemical							
I. Toxic							
•Pb	mg/l	0.01	2	0.00126			
•Cr	mg/l	0.05	2	0.0148			
•Zn	mg/l	5	2	0.01821			
II. Others							
•TDS	mg/l	1000	4	123.75	35.57	91	156
•Tot. hardness ($CaCO_3$)	mg/l	500	2	68	16.97	56	80
•Ca	mg/l	100	1	40		40	40
3. Biological							
•TC	#/100 ml	3	1	58		58	58
•FC	#/100 ml	0	2	2		0	3

Table 5.1.4: Characteristics of harvested rainwater in Abu Shekheidim–Kubar villages/Palestine

Cistern .No	Quality Parameter																
	Physical						Chemical									Biological	
	pH	Do	T	EC	.Tur	Sal.	Toxic			Health Aspect						TC	FC
							Pb	Cr	Zn	TDS	TH	Ca^{++}	Na^{+}	Cl^{-}	NO_3		
C01	8.18	6.14	15.17	284.2	10.1	0.1	0.0013	0.0026	0.0154	136.2	140	38.67	17.63	38.2	15.44	31	4
C02	8.10	5.23	16.10	252.0	7.4	0.1	0.002	0.0015	0.0134	119.92	100.75	63.67	17.25	31.33	14.64	42	4
C03	8.36	6.29	15.25	119.24	18.19	0.1	0.0017	0.005	0.023	56.3	56	35.75	30	18.9	15.19	95	35
C04	8.33	5.98	15.21	173.81	8.67	0.1	0.0017	0.0094	0.029	82.2	79.17	50.24	26.5	16.5	12.95	35	2
C05	8.01	4.42	15.97	136.43	12.78	0.1	0.0007	0.0021	0.015	64	53.2	35.33	15.15	4.3	13.15	28	17
C06	8.42	7.51	14.53	88.3	25.1	0.0	0.0008	0.0055	0.0152	42	40	-	-	23.6	22	152	2
C07	7.87	6.05	14.15	260	16.88	0.1	0.0013	0.0148	0.0182	123.75	68	40	-	-	-	58	2
N	62	62	62	62	62	62	14	14	14	62	62	28	12	14	42	21	21
AVG	8.18	5.95	15.2	187.7	14.16	0.1	0.0014	0.0058	0.0185	89.19	76.73	43.94	21.31	22.14	15.56	63	9.4
MIN	7.87	4.42	14.15	88.3	7.4	0.0	0.0007	0.0015	0.0134	42	40	35.33	15.15	4.3	12.95	28	2
MAX	8.42	7.51	16.10	284.2	25.1	0.1	0.002	0.0148	0.029	136.2	140	63.67	30	38.2	22	152	35
PS41	6.5-8.5				5		0.01	0.05	5	1000	500	100	200	250	50	3	0
WHO	6.5-				5		0.05	0.05	5	1000	500				45	3	0

guidelines	8.5																
Of avg. % samples that meet standards	100				0		100	100	100	100	100	100	100	100	100	0	0

All units in mg/l except in T in ˚C; EC in µs/cm; Turbidity in NTU, Salinity in mg/kg-% and TC, FC in #/100ml *

The results presented in Tables above (5.1.1 to 5.1.4) can be summarized as follows:

- The pH values of the collected rainwater harvesting ranged from 7.87 to 8.42 with an average value of 8.18.
- The harvested rainwater is aerobic with average DO values range of 5.95.
- Harvested rainwater had low–medium values for TDS (ranged from 42 to 136.2 mg/l and average value of 89.19 mg/l). These values are within PS41 and WHO guidelines-1000mg/l.
- Electrical conductivity of the water is also had low-medium levels and is about 2 folds of the TDS value.
- Water salinity values are closed to zero indicating the absence of any salinity hazard in harvested rainwater.
- Turbidity analysis shows that most rain water samples had turbidity values > 5 NTU (WHO guidelines and PS41). This is probably due to the resuspension of accumulated sediments during water extraction from the cistern and/or to particulate matter which refers to smoke, dust, and soot suspended in the air. As rainwater falls through the atmosphere, it can incorporate these contaminants. These values are the same in fresh rainwater for turbidity parameter, this is due to second reason shown above while for tap water is around 1NTU. High level of turbidity can protect microorganisms from the effect of disinfections, stimulate the growth of bacteria and give rise to significant chlorine demand (Ariyananda, 2003).
- All RWH samples had TC & FC counts more than 3 & 0/ 100 ml respectively. This indicates that water should be chlorinated at least once every rainy season and preferably after the cistern gets full of rainwater. The sources of microbiological contamination are the human and animal waste present in the cistern catchment area especially in cisterns which closed to cesspits within 15 m like in case cisterns 3, 6 and 7. Properly design and cleaning the catchments area before the rainy season starts is a must and people should be aware of that all the time. Survey also revealed that after the first rain, TC and FC count in the cisterns are high due to roof washout. This contradicts the popular concept that rain water collected during the rainy season is better quality than the stored water. However, later during the rainy season as the roof are been washed clean the bacterial quality become better.
- From the nitrate contamination point of view, all water samples shows values less PS41 and WHO guidelines (<50 mg/l). some of these samples show the levels of nitrate is relatively high than others in cases of distance from cesspits less than 15 m. Nitrate contamination is not usually present in cisterns filled with rainwater, as only small nitrate concentration is usually available in the waste present in the catchment area of the cisterns or in the rainwater itself.
- Results show that RWHS is not contaminated with heavy metals like Cr, Zn and Pb. All values are smaller than WHO guidelines and PS41 for both harvested and fresh rainwater.
- Samples showed that low-medium levels of ions as Ca^{++}, Na^{+} and Cl^{-}.

The relationship between physical properties can be introduced in Fig.5.1.1 while the chemical and biological can be introduced in Fig.5.1.2a, b and 5.1.3 respectively. It had been observed that in almost all cases (with few exceptions) with the same .ranges

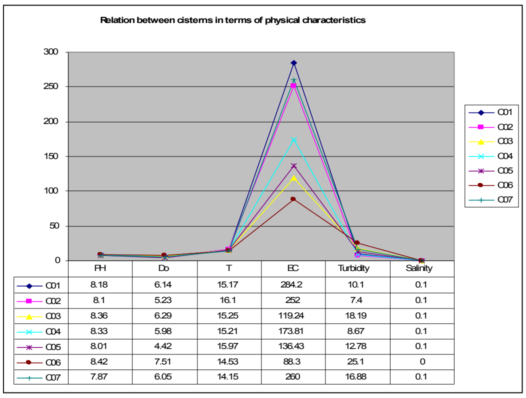


Figure 5.1.1 Relation between cisterns in terms of physical properties

- All physical parameters tested passed PS41 and WHO guidelines except for turbidity parameter for most samples. The failure in turbidity is attribute to dust in the atmosphere. The pH ranges of harvested rainwater samples were generally well within the acceptable limits. The harvested rainwater is aerobic with average DO values range of 6.01-8.75mg/l. The TDS values of the samples were very good (low) which less below136 mg/l. These values are within PS41 and WHO guidelines-1000mg/l. Electrical conductivity of the water is low and is about 2 folds of the TDS value. Water salinity values are closed to zero indicating the absence of any salinity hazard.

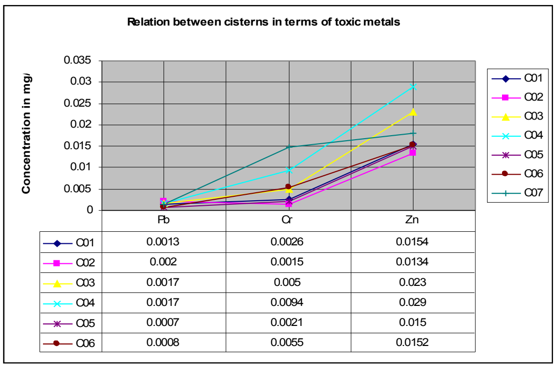
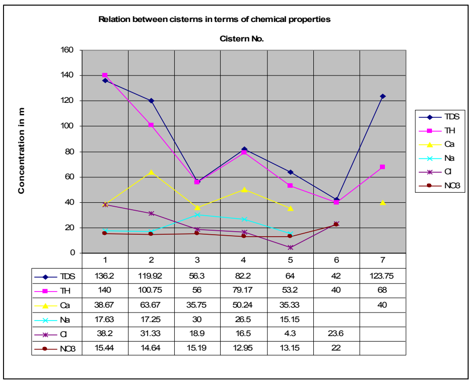


Figure 5.1.2a Relation between cisterns in terms of toxic metals characteristics

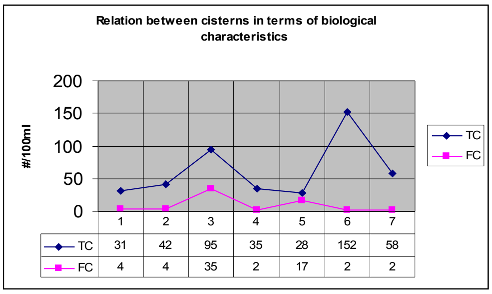
Heavy metals in all cisterns were complied with PS41 and WHO Standards so that the rainwater harvesting in the area of study are not contaminated with selected toxic metals like lead, chromium and zinc.



	1	2	3	4	5	6	7
TDS	136.2	119.92	56.3	82.2	64	42	123.75
TH	140	100.75	56	79.17	53.2	40	68
Ca	38.67	63.67	35.75	50.24	35.33		40
Na	17.63	17.25	30	26.5	15.15		
Cl	38.2	31.33	18.9	16.5	4.3	23.6	
NO3	15.44	14.64	15.19	12.95	13.15	22	

Figure 5.1.2b Relation between cisterns in terms of chemical properties

- From the nitrate contamination point of view, all water samples shows values comply with PS41 and WHO guidelines (<50 mg/l). Some of these samples show the concentration of nitrate is relatively high than others in cases of distance from cesspits less than 15 m and the pollution from catchments.
- Samples showed that low-medium levels of ions as Ca^{++}, Na^{+}, Cl^{-} and total hardness.



	1	2	3	4	5	6	7
TC	31	42	95	35	28	152	58
FC	4	4	35	2	17	2	2

Figure 5.1.3 Relation between cisterns in terms of biological characteristics

Table 5.1.4a: Characteristics of catchments and the distance between cisterns and cesspits

.Cistern No	NO_3 mg/l	TC CFU/100ml	FC CFU/100ml	Distance from (cesspit(m	Catchment status
C01	15.44	31	4	down-17 level	dust-small aggregates-broken glasses-bird dripping-Plastic-Steel
C02	14.64	42	4	N/A	dust-small aggregates-broken glasses-bird dripping
C03	15.19	95	35	down-22	dust-small aggregates-broken glasses-bird dripping
C04	12.95	35	2	down-18	dust-small aggregates-broken glasses-bird dripping
C05	13.15	28	17	N/A	dust-small aggregates-broken glasses-bird dripping
C06	22	152	2	relativly-10 at same level	dust-small aggregates-broken glasses-bird dripping
C07	-	58	2	down-6	dust-small aggregates-broken glasses-bird dripping

All RWH samples have TC & FC counts more than 3 & 0 CFU/ 100 ml (100% and 86% of tested samples respectively with detected counts between 10 to 152 CFU/100ml- see appendix I for all samples). This indicates that water should be treated by boiling or chlorinated at least once every rainy season and preferably after the cistern gets full of rainwater. The pollution might be from effluent from septic systems and/ or infiltration of domestic or animal fecal matter from catchments (see Table 5.1.4a). So the expected sources of microbiological contamination are the human and animal waste present in the cistern catchment area especially in cisterns which closed to cesspits within 15 m like in case cisterns 3, 6 and 7. Properly design and cleaning the catchments area before the rainy season starts is a must and people should be aware of that all the time. Survey also revealed that after the first rain, TC and FC count in the cisterns are high due to roof washout. This contradicts the popular concept that rain water collected during the rainy season is better quality than the stored water. However, later during the rainy .season as the roof are been washed clean the bacterial quality become better

This study is concordance with previous researches (Awadallah, 2004; Al-Khatib I. and Orabi M., 2004; Ariyananda, 2003; Coombes *et al*., 2000) in terms of biological characteristics. Similar studies have been performed in different countries; the quality of rainwater is varying depending on the atmospheric pollution of the individual area, the proximity to pollution sources and the level of cleaning and attendance (Zue *et al*, 2004). Some of related studies are shown in Table 3.1.5.

Table 5.1.5: Comparison of harvested rainwater with some local and international studies

Reference	Quality Parameter																
	Physical						**Chemical**									**Biological**	
	pH	Do	T	EC	.Tur	.Sal	Toxic			Health Aspect						TC	FC
							Pb	Cr	Zn	TDS	TH	$^{++}$Ca	$^{+}$Na	$^{-}$Cl	NO_3		
Present study/2008	8.18	5.95	15.2	187.7	14.16	0.1	0.0014	0.0058	0.0185	89.19	76.73	43.94	21.31	22.14	15.56	63	9.4
Ariyananda/2003	8.1<			10-)60 (160	7>						0-20						0-)28 (2000
Awadallah/2004 case1	9.11	5.44	20.58	375.48	4.26	0.18				181.53					12.69	127	
Awadallah/2004 case2	8.83	5.79	20	437	5.31	0.2				212					6.02	119	
Handia/2004	6.1-10.2				0.2-2.11		0.001->14		0.001->0.961	6.5-102	20			0-17		0-30	0-6
Coombes *et al*./2000	5.5-6						0.01-0.02					0.16-4.95	4.4-12.9	4.7-15.48	0.34-2.26	220<	39<
Fuller *et al.*/not known	6.1-9.2						0.072>		15<	Mostly<100						Up to 500	
IIT** Delhi, 2000	7.2-8.45									30-101	16-184	3.3-7.04		8.5-14.2	2-35.5		
Zhu *et al*., 2004					2-3.5		0.003-	004.-0		185-750	60.96	11.2-	3.02-	6.13-			3000<

							0.041				-149.2	31.15	11.2	79.2			
PS41	6.5-8.5				5		0.01	0.05	5	1000	500	100	200	250	50	3	0
WHO guidelines	6.5-8.5				5		0.05	0.05	5	1000	500				45	3	0

All units in mg/l except in T in ˚C; EC in µs/cm; Turbidity in NTU, Salinity in mg/kg-% and TC, FC in #/100ml *
IIT, Delhi: Indian Institute of Technology Delhi **

(A comparison of rainwater with other sources (Tap water-groundwater source

Table 5.1.6: Comparison of rainwater with Tap water

Source	Quality Parameter																
	Physical						**Chemical**									**Biological**	
	pH	Do	T	EC	.Tur	.Sal	Toxic			Health Aspect						TC	FC
							Pb	Cr	Zn	TDS	TH	^{++}Ca	^{+}Na	^{-}Cl	NO_3		
Harvested rainwater	8.18	5.95	15.2	187.7	14.16	0.1	0.0014	0.0058	0.0185	89.19	76.73	43.94	21.31	22.14	15.56	63	9.4
Direct rainwater from sky	9.54	8.97	13	143.3	27.8	0	0	0	0.01>	67.5	2.48	0.86	0.01	9.1	0.29	0	0
Tap water	7.44	4.96	16.55	760	1.72	0.4				366	31.6	23.5	13.55			0	0
PS41	6.5-8.5				5		0.01	0.05	5	1000	500	100	200	250	50	3	0
WHO guidelines	6.5-8.5				5		0.05	0.05	5	1000	500				45	3	0

All units in mg/l except in T in ˚C; EC in µs/cm; Turbidity in NTU, Salinity in mg/kg-% and TC, FC in #/100ml *

Direct rain water was of higher quality in terms of physical, chemical and biological than harvested water and of physical (except turbidity)-chemical from Tap water. Also direct rainwater was very soft (TH is 2.48mg/l) and had the lowest value of hardness compared with Tap and harvested water. From the results above, it was found the effect of some variables on the quality of the harvested rainwater. Proper maintenance .and operation of first flush had a high positive effect on the harvested rain water quality

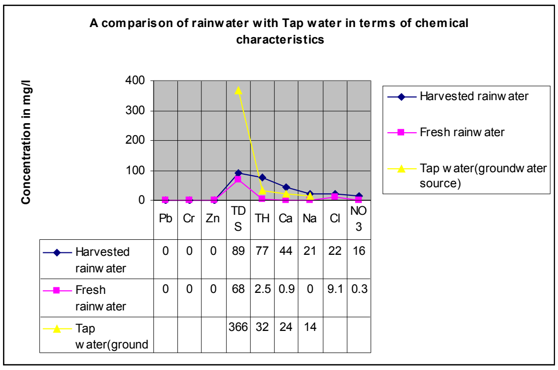


Figure 5.1.4 **A chemical characteristics comparison of rainwater with Tap-groundwater**

In the present study, the examined rainwater samples met the requirements for safe drinking water in terms of physical and chemical composition except for Turbidity. Turbidity analysis shows that most rain water samples (both direct and harvested) have turbidity values > 5 NTU (WHO guidelines and PS41). This is probably due to the resuspension of accumulated sediments during water extraction from the cistern and/or to particulate matter which refers to smoke, dust, and soot suspended in the air. As rainwater falls through the atmosphere, it can incorporate these contaminants. These values are the same in fresh rainwater for turbidity parameter, this is due to second reason shown above while for tap water is around 1NTU. High level of turbidity can protect microorganisms from the effect of disinfections, stimulate the growth of bacteria and give rise to significant chlorine demand (Ariyananda, 2003). As introduced above these sediments removal should take place regularly. Also the construction and frequent cleaning of sediment trap basin at the head of the water inlet of the cistern help in treating the collected water to acceptable turbidity levels. Kubar and Abu Sheskaidim are relatively pure from traffic emissions, industrial and agricultural wastes. This fact is validated by the absence of heavy metals. The high pH values indicate that in the studied area the rain is not acid. In future studies, it must be taken into account the seasonal variations which influence the quality of harvested rainwater.

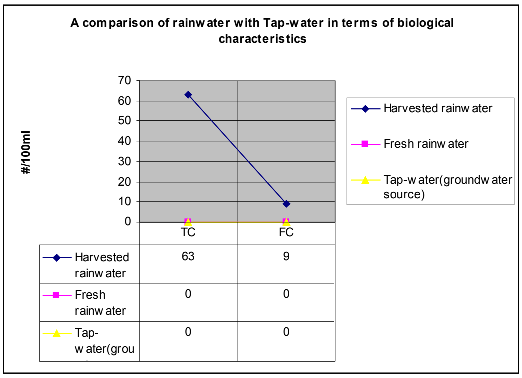


Figure 5.1.5 Biological comparison between rainwater and Tap-groundwater

Despite the acceptable chemical quality of the rainwater, the presence of microbial indicators makes it unsuitable for drinking, at least without any treatment. In this study about 25 water samples of TC and FC were tested. Regarding the test result of TC, out of total samples 4 were bacteria free in fresh and Tap water and 21 were contaminated for harvested ones. The contaminated samples could be attributed to some operation and maintenance problems, such as not cleaning the roof catchment and the inlet gutter before rain events, not opening the screw cap to divert the first flush water, and not washing the empty storage tank with bleaching powder besides the distances from cesspits. 66 water samples were tested for pH, Do, T, EC, Turbidity and Salinity. pH of 64 samples was found within the acceptable limit (6.5-8.5) while fresh rainwater was exceeded the upper limits. Salinity for Tap-water was higher than rainwater. All rainwater samples were found unacceptable (greater than 5 NTU). Testing 14 rain water samples collected, it was found that Pb, Cr and Zn were within acceptable limit.

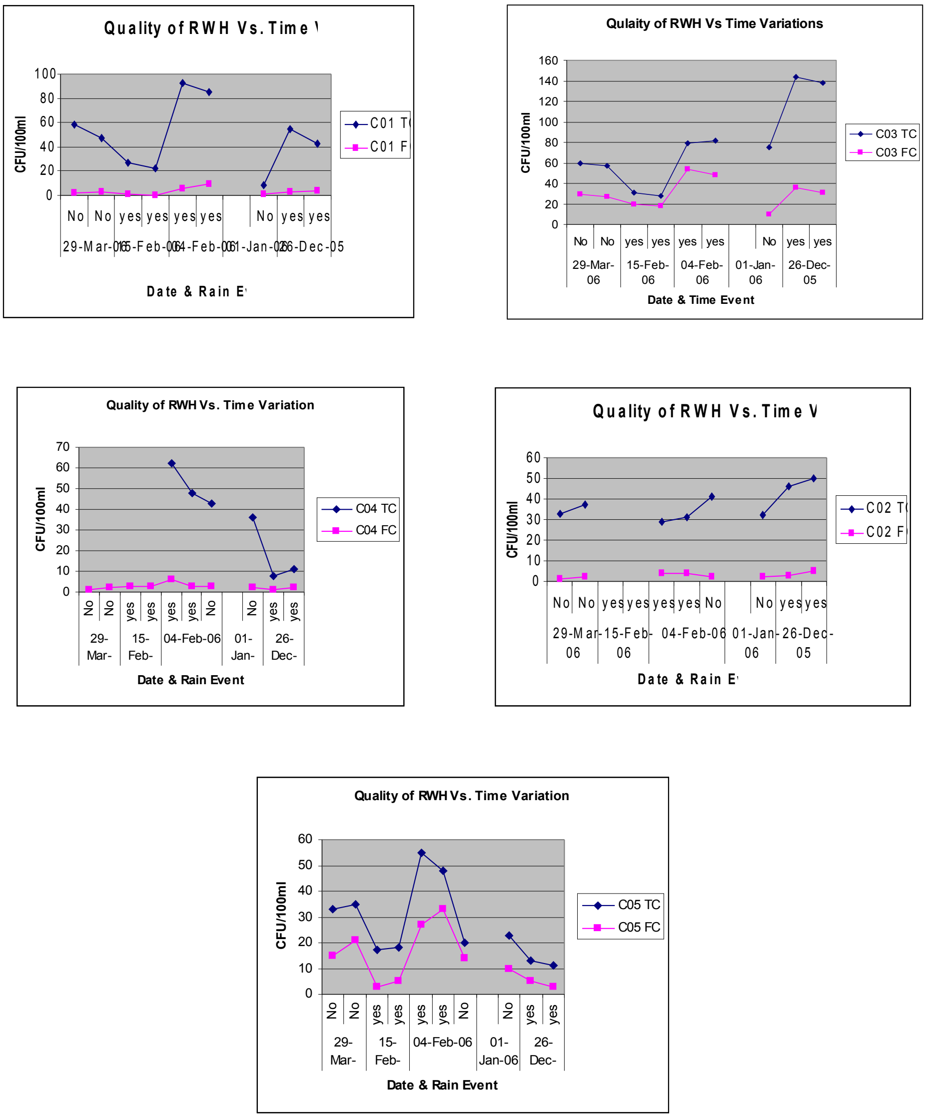


Figure 5.1.6 Climatic variation which affects the rainwater harvesting quality (yes means: rain event)

The microbial indicators were found in low-medium numbers – smaller than 100 CFU/100 ml (according to WHO guidelines). Apparently, in the examined area of Kubar and Abu Shekhaidim villages there are no prime sources of high microbial load. The main microbiological indicators, total coliforms and fecal coliforms also showed time and climatic variation. The highest ratio of positive samples was detected during rainy days except the first rainfall when the catchments were polluted with bird dropping and non-fecal pollution like trees waste while dry ones it was decreased at significant level and was gradually increased again when the duration between rainfall days extended. The medium numbers of microbial presence between fresh rainwater and harvested rainwater suggests that the microbial contamination be the result of contact with the catchment areas rather than the water itself. This fact is further validated by the absence of microbiological contamination in a number of samples taken during rainfall events directly from sky. It is suggested that the catchment surface and the interior of the cisterns should be cleaned regularly to remove dust and debris so as to maintain the quality of collected rainwater as high as possible.

Run-off coefficient (R) results and analysis 5.2

Results indicate that average potential for potable water savings range from 70% to 90% per year. Ideal rainwater tank capacities for dwellings with low potable water demand range from about 70 to 100 m³ depending on rainwater demand. For dwellings with high potable water demand, ideal rainwater tank capacities range from about 120 to 200 m³. The Run-Off Coefficient (R) as the major design parameters was assessed based on the analysis of rainfall data and technical aspects for these systems. Results appear the range of this coefficient is extending from 0.7 to 0.9 based on catchments types, intensity of rainfall, conveyance systems status and the materials which used for cisterns structure.

As a result, R was monitored at every rainy day and the depth of water in cistern was measured and based on the measurements; the results obtained the following:

Table 5.2.1: Detail survey on cisterns which used to calculate ROC

Cistern .No	Cistern Volume(m³ (	Cistern (Dimensions(m	Catchments (Area (m²	Constructed Materials
8	56	4*3.5*4	120	Reinforced concrete
9	112.5	5*5*4.5	220	Reinforced concrete
10	100	5*5*4	320	Reinforced concrete
11	48	4*4*3	60	Rocks+cement for lining

Table 5.2.2: R estimation

Cistern .No	Initial Depth of water in (Cistern(cm	Depth on end of (Dec.(cm	R	Depth on end of (Jan.(cm	R	**RAVG**
8	0	154	*0.856	291	0.862	**0.86**
9	131	319	0.916	474	0.89	**0.90**
10	0	241	0.72	423	0.67	**0.70**
11	0	93	0.88	158	0.80	**0.84**

.Note: Cistern no. 12 is excluded due to uncertainty of measurements

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*R Calculations: Initial depth 0 cm; Depth of water at end of Dec. 1.54 m; Cross sectional area of cistern 14 m²; Catchment area 120 m; Rainfall at end of Dec. based on table 4.4.2.1 is 210 mm; Collected water volume is 14*1.54= 21.56m³; R=COLLECTED VOLUME/(RAINFALL*CATCHMENT AREA) =21.56/(0.21*120)=0.856

?Is current cisterns volumes feasible 5.2.1

:Based on R values shown in table 5.2.2; the rainwater supply and demand as follows

Water supply and demand 5.2.1.1

In rain water-harvesting calculation of supply and demand of water is very important. Storage is the difference between actual supply of fresh water and the demand. Different methods can be used to calculate water demand and supply from rainwater. :One method is shown below

:For cistern no. 8

:Supply

(Average catchment area for rainwater harvesting=120m^2 (approximately

(Run-off coefficient = 0.86 (see table 5.2.2

(Average yearly rainfall = 688 mm (see table 4.4.2.1

Average yearly water supply from rainfall = 120 m^2 *0.86*0.688 m =71 m^3

:Demand

Consumption per capita per day, C = 50 liters (minimum requirements for domestic (purposes

(Number of people per household, n = 5.3 (PCBS, 2007

Monthly water demand = 50*5.3*30 = 7.95 m^3

(Yearly demand = 7.95* 12 =95.4 m^3 (Storage volume required

Gap is 95.4- 71= 24.4 m^3 can supplied from other sources (26% from total demand). From the above simple calculation, it concluded that the rain water harvesting systems in the study area is technically feasible by decrease the pressure on ground water .consumption to 74%

Rainwater Storage Reservoir 5.2.1.2

It was observed from the study that a total of 14 RWHS were constructed which were of different capacities ranging from 480 liters, 1140 litters (see table 4.2.1), and of .different materials such as Ferro-cement, tile and rocks with cement lining

A survey had been made among 14 families through interview. It had been observed that secondary source as domestic if water supplied from network not available in dry season is the main use, gardening and construction works are other uses, were being .(used by 12, 1, 1 families respectively (see Fig.5.2.1

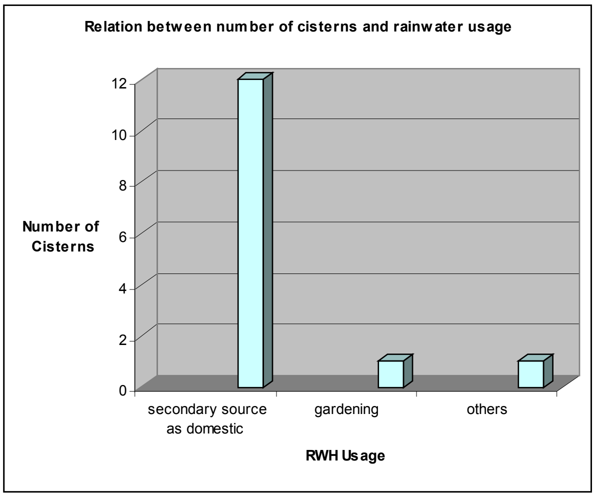

Figure 5.2.1 Relation between the number of cisterns and the type of usage

Amount of rainwater harvest annually 5.2.1.3

The annual rainwater harvesting potential is calculated in terms of area of .catchments, annual average rainfall, and runoff coefficient

Annual rainwater harvesting potential (cubic meter) = Area of catchment x)) ((annual average rainfall x runoff coefficient

.Area of catchment = roof area (m^2) = width x length of the roof

Annual rainfall in the study area – average: 688mm (see table 4.4.2.1)

Determinants for designing rainwater harvesting systems

:Calculations

a. *For cistern No. 8:*

Based on data obtained from table 5.2.2; the required cistern volume will be:

R=0.86

Avg. annual rain fall= 688mm

Catchments area= 120m^2

Supply (m^3) required = (0.86*688*120)/1000=68.9m^3> 56m^3(the (actual area

b. *For cistern No. 9:*

R=0.90

Avg. annual rain fall= 688mm

Catchments area=220m²

Supply (m³) required = (0.90*688*220)/1000 = 132.3 m³

Current volume = 112.5 m³ < 132.3 m³

:**c**. *For cistern No. 10*

R= 0.70

Avg. annual rain fall= 688mm

Catchments area= 320m²

Supply (m³) required = (0.70*688*320)/1000 = 150m³>>100m³ the current volume

:**d**. *For Cistern No. 11*

R=0.84

Avg. annual rain fall= 688mm

Catchments area= 60m²

Supply (m³) required = (0.84*688*60)/1000 = 33.7m³<48m³

From the calculations above it concluded the householders in the study area does not construct the cisterns correctly so that it must be needed to be sized correctly in order to give adequate storage capacity and at the same time minimize capital investment.

Table 5.2.3: Comparison between estimated values of R and international values. Runoff coefficients for various catchments surfaces:

Type of catchment	Coefficients*	Estimated R (AVG)
Roof catchments - Tiles - Corrugated metal sheets	0.8- 0.9 0.7- 0.9	0.9 -
Ground surface coverings - Concrete - Brick pavement	0.6- 0.8 0.5- 0.6	0.86 -
Untreated ground catchments - Soil on slopes less than 10 per cent - Rocky natural catchments	0.3 - 0.0 0.2 - 0.5	
Untreated ground catchments - Soil on slopes less than 10 per cent - Rocky natural catchments	1.0 - 0.3 0.2 - 0.5	

Source: Pacey, Arnold and Cullis, Adrian 1989, Rainwater Harvesting: The collection of* rainfall and runoff in rural areas, Intermediate Technology Publications, London

Chapter Six

Conclusions and recommendation

Conclusions 6.1

The main conclusions from this study are:

- ❖ Rainwater quality is good if the system well managed and can be used as drinking water. It comply with PS41 and WHO guidelines. However, contamination of water collected in the cisterns is possible. The results of the water quality tests can be summarized as follow:

  - ✓ The quality of rainwater harvesting systems is varies from system to system since these systems are classified as individual and there are no public health regulations for constructing, maintaining and testing the quality of the collected water.
  - ✓ The quality of harvested water from roof catchments meets mostly the drinking-water standards values in terms of Physical-chemical properties but not in biological while the quality of fresh rainwater is meeting the PS41 and WHO guidelines in all characteristics.
  - ✓ The study reveals that harvested water is heavily contaminated microbiologically by a variety of indicator and pathogenic organisms unless special care is taken during collection and storage of rainwater.
  - ✓ Most of the cisterns samples have pH value above 8; this indicates that water is alkaline but within acceptable limits.
  - ✓ Salinity values indicate the absence of any salinity hazard. Salinity in fresh RW was zero while in harvested RW in the range 0.1-0.2 % (mostly 0.1). Results show that the rainwater quality is better than the Palestinian main source – groundwater- according to this parameter.
  - ✓ The TDS values of the fresh and harvested RW samples were low if compared with ground water sources (Tap Water). Electrical conductivity of the rainwater is low and is about twice the TDS value for this source.
  - ✓ Mostly, Turbidity values were high above 5 NTU recommended by the WHO and Palestine Standards (PS41).
  - ✓ The rainwater (both direct and harvested) is aerobic with DO values above 7 mg/L.
  - ✓ Sampling at study area revealed that roof water collected following rain did not comply with PS41 & WHO Guidelines for Fecal and Total Coliforms. The FC & TC values were more than one colony in each sample.
  - ✓ RWHS is not contaminated with heavy metals like Cr, Zn and Pb. So that no problems or hazards on health when using rainwater as a domestic source.

❖ The Run-Off Coefficient (R) extends from 0.70 to 0.90 for Ferro-concrete catchment. The rain water harvesting systems in the study area is technically feasible by decrease the pressure on ground water consumption to 74%.

❖ The householders in the study area does not construct the cisterns correctly so that it must be needed to be sized correctly in order to give adequate storage capacity and at the same time minimize capital investment.

Recommendations 6.2

❖ Rainwater harvesting system should be implemented on large scale in rural areas to alleviate the pressure on water resources.

❖ Appropriate treatment like disinfection of collected rainwater would be necessary to make the harvested rainwater fit for drinking.

❖ Some precautions should be focused on when deciding to construct and locate an underground cistern, for example building it downstream of the catchments area and upstream of possible local sources of pollution, such as cesspits and septic systems. Cisterns should be located at least 15m away from the nearest sources of pollution and at least 15m away from the nearest public road. It should be away from public paths to consider health and safety issues during construction and operation. At the same time far away at least 15m from trees so that fallen leaves will not be washed into the cistern.

❖ Informs the public about the adverse health effects of contaminants and explains the steps people can take in their homes to reduce their exposure to pollutants in drinking water.

❖ To reduce the probability of coliform in rainwater harvesting systems and wells; always keep the rain catchment clean and free of debris; trim trees and brushes near the area to prevent animals from entering the storage tanks; keep water storage tanks shaded and use non-transparent tanks to prevent sunlight from fostering bacteria growth; all rain water cisterns should be fitted with filter and first flush system; rain water cistern should be securely covered for protection as well as to prevent dust and runoff as well as insects getting into the cistern (see photos 3.7.1.1-2-3-4).

❖ Studying in the future the influence of seasonal variation on quality of rainwater.

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APPENDECES

APPENDEX I:

A. Sampling form

Sample identification No.		Sample collection date:
Sample location:		Other information about sample:
Date of testing:		

Parameter item	Unit	PS41	Sample No.		
			1	2	AVG
1.Physical					
• pH		6.5 - 8.5			
• DO	mg/l				
• T	°C	<20			
• EC	µs/cm				
• Turbidity	NTU	5.0			
• Salinity					
2. Chemical					
I. Toxic					
• Pb	mg/l	0.01			
• Cr	mg/l	0.05			
• Zn	mg/l	5.00			
II. Others (Health)					
• TDS	mg/l	1000			
• Total Hardness ($CaCO_3$)	mg/l	500			
• Ca	mg/l	100			
• Na	mg/l	200			
• Cl	mg/l	250			
• NO_3	mg/l	50			
3. Biological					

• TC	#/100 ml	**3**			
• FC	#/100 ml	**0**			

B. Detailed Results obtained from Rain Water Harvesting Cisterns (RWHC)

Cistern No. 1:

Parameter Item	Unit	PS41								
			Sample No. :1			Sample No. :2		Sample No. :3		
			I	II	I	II	avg.	I	II	avg.
1.Physical										
•pH		**6.5 - 8.5**	8.072	8.1	7.901	7.943	7.922	8.336	8.839	8.588
•DO	mg/l		6.11	6.3	6.37	6.03	6.2	6.43	6.24	6.335
• T	˚C		16.2	15.7	17.1	17.7	17.4	14.7	14.6	14.65
•EC	µs/cm		281	283	283	282	282.5	261	286	273
•Turbidity	NTU	**5**	2.92	3.12	2.3	1.84	2.07	11.3	13.5	12.4
.Salinity			0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2. Chemical										
I.Toxic										
•Pb	mg/l	**0.01**								
•Ni	mg/l	**0.05**								
•Cd	mg/l	**0.05**								
•As	mg/l	**0.05**								
II. Others										
•TDS	mg/l	**1000**	129	132	141	144	142.5	124	136	130
•Tot. hardness ($CaCo_3$)	mg/l	**500**	140	132	132	132	132	200	193	196.5

•Ca	mg/l	**100**	38	31	24	22	24	50	44	47
•Na	mg/l	**200**	20	17	15.5	18	16.75	16	16	16
•Cl	mg/l	**250**	53	47	42	48	45	51.5	48	49.75
•No3	mg/l	**50**	230.3	230	201.2	201.4	201.3	213	207	210
			23.81	23.93	12.23	12.31	12.27	11.93	14.54	15.2
•Al	mg/l	**0.2**								
•Zn	mg/l	**5**								
3. Biological										
•TC	#/100 ml		43	55	8	11	10	85	93	89
•FC	#/100 ml		4	3	1	0	1	9	6	8
•Pseudomonas										

Sample No. :4			**Sample No. :5**		
I	**II**	**avg.**	**I**	**II**	**avg.**
8.213	8.235	8.224	8.019	8.086	8.0525
6.13	6.19	6.16	5.84	5.8	5.82
14.2	14.3	14.25	13.7	13.5	13.6
276	299	287.5	291	300	295.5
11.8	12.2	12	13.8	15.8	14.8

0.1	0.1	0.1	0.1	0.1	0.1
131	142	136.5	141	142	141.5
104	122	113	96	107	101.5
60	53	56.5	42	47	44.5
18	19	18.5	14	12	13
14.6	11	12.8	13.7	17.3	15.5
10.21	9.52	9.865	8.12	10.07	9.095
47	58	53	22	32	27
3	2	3	0	1	1
1	0	1	1	1	1

Cistern No. 2:

Parameter item	Unit	PS41			
			Sample No. :1		
			I	II	avg.
1.Physical					
•pH		**6.5 - 8.5**	8.323	8.337	8.33
•DO	mg/l		5.46	5.52	5.49
• T	Oc		17.7	17.5	17.6
•EC	µs/cm		179	177	178
•Turbidity	NTU	**5**	4.2	13.8	4
.Salinity			0.1	0.1	0.1
2. Chemical					
I.Toxic					
•Pb	mg/l	**0.01**			
•Ni	mg/l	**0.05**			
•Cd	mg/l	**0.05**			
•As	mg/l	**0.05**			
II. Others					
•TDS	mg/l	**1000**	84	84	84
•Tot. hardness ($CaCo_3$)	mg/l	**500**	88	88	88
•Ca	mg/l	**100**	56	52	54
•Na	mg/l	**200**	12.5	14.3	13.4

•Cl	mg/l	**250**	66	57.2	61.6
•No3	mg/l	**50**	22.9	22.74	22.82
•Zn	mg/l	**5**			
3. Biological					
•TC	#/100 ml		50	46	48
•FC	#/100 ml		5	3	4

Sample No. :2			**Sample No. :3**		
I	**II**	**avg.**	**I**	**II**	**avg.**
7.987	7.957	7.972	8.39	8.35	8.37
5.88	5.5	5.69	5.78	5.97	5.87
16.1	16.6	16.35	15.6	15.8	15.7
158.7	156	157.25	202	197	199.5
3.55	3.67	3.61	11.6	12.5	12.05
0.1	0.1	0.1	0.1	0.1	0.1

75	74	74.5	96	93	94
88	88	88	140	139	139.5
46	51.5	48.75	94	86	90
11.7	12.1	11.9	8.7	11.5	10.1
51	51	51	58.6	56	57.3
13.23	12.99	13.11	14.14	12.55	13.5
32	41	37			
2	2	2			

Sample No. :4			**Sample No. :5**			**Sample No. :6**		
I	**II**	**avg.**	**I**	**II**	**avg.**	**I**	**II**	**avg.**
8.088	8.108	8.098	7.89	7.78	7.835	7.86	8.1	7.98
5.99	6.01	6	4.94	4.99	4.965	3.32	3.57	3.445
13.8	13.6	13.7	15.9	16.6	16.25	16.7	17.2	16.95
394	407	400.5	295	282	288.5	281	298	289.5
15.9	16.6	16.25	4.16	3.87	4.015	5.27	4.31	4.79
0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1

187	194	190.5	141	135	138	134	142	138
150	141	145.5	82	80.3	81.18	82	79.9	80.95
90	90.5	90.25	38	41.2	39.6	58	49.3	53.65
22	20.5	21.25	17.1	17.6	17.35	19	18.2	18.6
18	14.7	16.35	15.5	15.9	15.7	10	13.1	11.55
9.57	8.62	9.095	7.12	8.03	7.575	14.8	14.1	14.45
26	31	29	37	33	35			
3	4	4	2	1	2			
2	1							

Cistern No.3:

Parameter item	Unit	PS41			

			Sample No. :1		
			I	II	avg.
1.Physical					
•pH		**6.5 - 8.5**	8.203	8.244	8.224
•DO	mg/l		6.14	6.26	6.2
• T	Oc		16.3	16.3	16.3
•EC	µs/cm		107	101.2	104.1
•Turbidity	NTU	**5**	9.63	9.83	9.73
.Salinity			0.1	0.1	0.1
2. Chemical					
I.Toxic					
•Pb	mg/l	**0.01**			
•Ni	mg/l	**0.05**			
•Cd	mg/l	**0.05**			
•As	mg/l	**0.05**			
II. Others					
•TDS	mg/l	**1000**	49	48	48.5
•Tot. hardness ($CaCo_3$)	mg/l	**500**	80	68	74
•Ca	mg/l	**100**	55	42	48.5
•Na	mg/l	**200**	32	26	29
•Cl	mg/l	**250**	17	14.9	15.95
•No3	mg/l	**50**	19.71	19.31	19.51

•Zn	mg/l	**5**			
3. Biological					
•TC	#/100 ml		150	138	144
•FC	#/100 ml		40	31	36

Sample No. :2			**Sample No. :3**		
I	**II**	**avg.**	**I**	**II**	**avg.**
8.151	8.18	8.166	8.5	8.49	8.495
6.29	6.71	6.5	6.41	6.22	6.315
16.5	15.6	16.05	15.3	15.1	15.2
112.8	112.3	112.55	112	111.7	111.85
8.02	8.02	8.02	11.4	10.6	11
0.1	0.1	0.1	0.1	0.1	0.1
54	53	53.5	53	53	53

72	72	72	56	58	57
50.2	48.7	49.45	40	43	41.5
33	27.7	30.35			
15.6	16.1	15.85			
12	12.51	12.25	12.15	11.6	11.8
78	75	77	75	82	79
17	10	14	59	48	54

Sample No. :4			**Sample No. :5**		
I	**II**	**avg.**	**I**	**II**	**avg.**
8.452	8.466	8.459	8.453	8.479	8.466
6.3	6.16	6.23	6.21	6.18	6.195
13.7	13.7	13.7	15.1	14.4	14.75
147	132.5	139.75	127.9	128	127.95
30.9	31.6	31.25	30.9	31	30.95
0.1	0.1	0.1	0.1	0.1	0.1

69	63	66	62	60	61
30	28	29	30	30	30
26	22	24	20	22	21
28	26.6	27.3	19.7	22	20.85
14	14.3	14.15	21	25.7	23.35
13	14.4	13.7	21.5	22	21.75
63	57	60	33	28	31
30	27	29	21	18	20
0	0			2	

Cistern No.4:

Parameter item	Unit	PS41								
			Sample No. :1			Sample No. :2		Sample No. :3		
			I	II	I	II	avg.	I	II	avg.
1.Physical										

•pH		**6.5 - 8.5**	8.373	8.273	8.169	8.193	8.181	8.515	8.551	8.533
•DO	mg/l		7.85	6.12	6.52	6.11	6.315	6.35	6.27	6.31
• T	Oc		15.3	15.4	15.4	15.3	15.35	15.5	14.7	15.1
•EC	µs/cm		156.6	156.4	157.5	163.2	160.35	153	157	155
•Turbidity	NTU	**5**	3.04	2.88	4.08	4.57	4.325	15.5	17.6	16.55
.Salinity			0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2. Chemical										
I.Toxic										
•Pb	mg/l	**0.01**								
•Ni	mg/l	**0.05**								
•Cd	mg/l	**0.05**								
•As	mg/l	**0.05**								
II. Others										
•TDS	mg/l	**1000**	74	66	83	85	84	122	130	126
•Tot. hardness ($CaCo_3$)	mg/l	**500**	88	79	71	71	71	91	87.6	89.3
•Ca	mg/l	**100**	62	58	55	54.2	54.6	66.4	59.1	62.75
•Na	mg/l	**200**	20	17	17.8	15.9	16.85	21	21	21
•Cl	mg/l	**250**	26							
•No3			17.32	17	11.76	14.62	13.19	9.97	10.56	10.1
•Zn	mg/l	**5**								
3. Biological										

•TC	#/100 ml		11	8	36	43	40	48	62	55
•FC	#/100 ml		2	1	2	3	3	3	6	5

Sample No. : 4			**Sample No. :5**		
I	**II**	**avg.**	**I**	**II**	**avg.**
8.374	8.358	8.366	8.2	8.24	8.22
6.16	6.4	6.28	3.91	4.08	3.995
13.8	13.7	13.75	16.7	16.3	16.5
163	164.4	163.7	234	233	233.5
17.6	17.5	17.55	1.66	2.27	1.965
0.1	0.1	0.1	0.1	0.1	0.1
77	78	77.5	111	111	111
51	46	48.5	50	52	51

37	37	37	40	41	40.5
33	34	33.5	35	32	33.5
7	4	5.5	0.6	1.3	0.95
10	9.91	9.955	15.3	13.3	14
2	1	2	3	3	3
0	1	1	1	0	1

Cistern No.5:

Parameter item	**Unit**	**PS41**								
			Sample No. :1			**Sample No. :2**		**Sample No. :3**		
			I	**II**	**I**	**II**	**avg.**	**I**	**II**	**avg.**
1.Physical										
•pH		**6.5 - 8.5**	8.135	8.153	7.992	8.049	8.0205	8.195	8.138	8.1665
•DO	mg/l		5.88	5.88	5.26	5.25	5.255	5.44	5.53	5.485
• T	Oc		15	14.6	15.7	15.3	15.5	15	15.2	15.1
•EC	µs/cm		108.8	108.1	117.8	119.1	118.45	117.3	118.6	117.95
•Turbidity	NTU	**5**	5.92	6.17	20.6	20.6	20.6	7.01	6.92	6.465
.Salinity			0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2. Chemical										

I.Toxic										
•Pb	mg/l	**0.01**								
•Ni	mg/l	**0.05**								
•Cd	mg/l	**0.05**								
•As	mg/l	**0.05**								
II. Others										
•TDS	mg/l	**1000**	51	51	61	58	59.5	55	56	55.5
•Tot. hardness ($CaCo_3$)	mg/l	**500**	60	62	65	64	64.5	50	54	52
•Ca	mg/l	**100**	40	38	37.7	42	39.85	35	35.5	35.25
•Na	mg/l	**200**	16	14.3	16.2	16.7	16.45	15.2	14.8	15
•Cl	mg/l	**250**	8.8	6.9	11	14.1	12.55	10.8	10.5	10.65
•No3			15.3	14.8	14.71	14.01	14.36	15.18	15.53	15.355
•Zn	mg/l	**5**								
3. Biological	mg/l									
•TC	#/100 ml		11	13	23	20	22	48	55	52
•FC	#/100 ml		3	5	10	14	12	33	27	30
•Pseudomonas			1	0	0	0		0	0	

Sample No. : 4			**Sample No. :5**			**Sample No. :6**		
I	**II**	**avg.**	**I**	**II**	**avg.**	**I**	**II**	**avg.**

7.77	7.82	7.795	7.91	7.93	7.92	7.98	7.99	7.985
5.32	5.31	5.315	4.51	4.62	4.565	3.75	3.89	3.82
14.1	14.3	14.2	17.1	17	17.05	19.6	18.7	19.15
126	123.1	124.55	169.7	165.2	167.45	184.3	179.1	181.7
19	19.4	19.2	12.6	12.6	12.6	5.63	5.27	5.45
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
60	58	59	80	78	79	88	85	86.5
50	50	50	50	49	49.5	56	61	58.5
20	18.2	19.1	22	22	22	46	43	44.5
14	14	14						
3.6	3.7	3.65	4.3	4.9	4.6	5	7.3	6.15
12.3	11.7	12	7.1	8	7.55	8.8	10	9.4

35	33	34	10	8	9	17	18	18
21	15	18	2	1	2	3	5	4

Cistern No. 6:

Parameter item	**Unit**	**PS41**					
			Sample No. :1			**Sample No. :2**	
			I	**II**		**I**	**II**
1.Physical							
•pH		**6.5 - 8.5**	8.258	8.203	8.242	8.593	8.4175
•DO	mg/l		8.73	8.75	6.07	6.44	6.255
• T	Oc		14.7	14.5	14.4	14.5	14.45
•EC	µs/cm		84.5	81.2	96	91.5	93.75
•Turbidity	NTU	**5**	16.6	16.1	33.5	34.1	33.8
.Salinity			0	0	0	0	0
2. Chemical							
I.Toxic							
•Pb	mg/l	**0.01**					
•Ni	mg/l	**0.05**					
•Cd	mg/l	**0.05**					
•As	mg/l	**0.05**					

II. Others							
•TDS	mg/l	**1000**	39	39	46	44	45
•Tot. hardness ($CaCo_3$)	mg/l	**500**	33	34	40	38	39
•Ca	mg/l	**100**	19	19	21	21.5	21.25
•Na	mg/l	**200**	12.8	13.2	17.3	16.9	17.2
•Cl	mg/l	**250**	19.3	20.2	23.6	22.8	23.2
•No3	mg/l	**50**	5.11	5.13	2.2	4.1	3.15
•Al	mg/l	**50**					
•Zn	mg/l	**0.2**					
3. Biological	mg/l	**5**					
•TC	#/100 ml		9	7	8	8	8
•FC	#/100 ml		3	2	1	0	1

Cistern No.7:

Parameter item	**Unit**	**PS41**						
			Sample No. :1					
			I	**II**	**Sample No. :2**			
1.Physical					**I**	**II**	**avg.**	
•pH		**6.5 - 8.5**	7.69	7.83	7.97	7.99	7.98	

•DO	mg/l		6.55	6.47	5.37	5.82	5.595	
• T	Oc		13.5	13.2	15.3	14.6	14.95	
•EC	µs/cm		191	201	318	330	324	
•Turbidity	NTU	**5**	23.8	23.7	9.9	10.1	10	
.Salinity			0.1	0.1	0.1	0.1	0.1	
2. Chemical								
I.Toxic								
•Pb	mg/l	**0.01**						
•Ni	mg/l	**0.05**						
•Cd	mg/l	**0.05**						
•As	mg/l	**0.05**						
II. Others								
•TDS	mg/l	**1000**	91	95	153	156	154.5	
•Tot. hardness ($CaCo_3$)	mg/l	**500**	56	55	80	78	79	
•Ca	mg/l	**100**	40	38	51	44	47.5	
•Na	mg/l	**200**	17.1	17.5	16.3	15	15.65	
•Cl	mg/l	**250**	22	17.5	18.5	16.7	17.6	
•No3	mg/l	**50**	29.1	31.2	22.5	29	25.75	
•Al	mg/l	**50**						
•Zn	mg/l	**0.2**						
3. Biological	mg/l	**5**						

•TC	#/100 ml		58	42	33	42	38	
•FC	#/100 ml		27	18	0	3	2	

ملخص

إن أنظمة تجميع مياه المطر أصبح حلا مناسبا للحد من مشكلة شح المياه في فلسطين خصوصا في المناطق الريفية التي لا يوجد بها شبكات لتوزيع المياه أو أن المياه المزودة لتلك المناطق غير كافية. جودة آبار جمع مياه المطر لاستخدامها كمصدر للاستهلاك المنزلي في منطقة الوسط في الضفة الغربية و العوامل البيئية المؤثرة فيها قيمت خلال فترة الدراسة (بين شهر تشرين ثاني من العام 2005 إلى شهر نيسان من العام 2006). أجريت الدراسة في قرى كوبر و أبو اشخيدم في محافظة رام الله. تم تقييم جودة المياه في 7 آبار بينما تم حساب معامل الجريان((R ل 5 آبار لتحديد كمية مياه المطر المتجمعة. 72 عينة أخذت من آبار تم إنشاؤها باستخدام الباطون المسلح أو آبار صخرية حيث يتراوح سعتها من 48 إلى 114 متر مكعب و زودت من خلال أسطح تجميع تتراوح مساحتها من 111 إلى 370 متر مربع حيث جمعت و فحصت هذه العينات على فترات مختلفة.

لتقييم جودة مياه المطر تم إجراء عدة فحوصات مخبرية: فيزيائية مثل درجة الحموضة و نسبة الأكسجين المذاب في الماء و درجة حرارة المياه المتجمعة و الموصلية الكهربائية و العكرة و درجة الملوحة. أما الفحوصات الكيماوية شملت: عسرة المياه و أيونات الكالسيوم و الصوديوم و الكلور و النيترات بالإضافة إلى تركيز بعض المعادن الثقيلة مثل الرصاص و الكروم و الزنك. كما شملت الدراسة فحوصات بيولوجية و هي فحوصات لكشف جراثيم من طائفة القولونيات (كوليفورم). و يتضح من نتائج الدراسة أن الخواص الفيزيائية تطابق في معظمها المواصفات الفلسطينية (PS41) و مواصفات منظمة الصحة العالمية (WHO). حيث لوحظ أن درجة الحموضة (pH) للمياه المتجمعة كانت قاعدية (أكبر من 8) و ذلك بسبب الغبار الناجم من طبيعة التربة القاعدية و نوعية الصخور في منطقة الدراسة و التي بشكل أساسي شكلت من الصخور الكلسية (lime & delomite). كما بينت النتائج أن تركيز المواد الصلبة المذابة (TDS) في المياه المتجمعة قليلة و لا تتعدى 68 ملغم/لتر. أما خاصية العكرة فانه لوحظ تغير واضح من خلال اختلاف نتائج الفحص لنفس البئر على عدة فترات و السبب في ذلك يعود إلى طبيعة المطرة نفسها في ذلك اليوم بسبب أحوال الطقس حيث سجلت في معظم الآبار بقيمة أكبر من 5 وحدات (5 (NTU. بالنسبة إلى تركيز الأكسجين المذاب (DO) فقد كانت جميع الآبار هوائية بقيم فاقت 6 ملغم/لتر. أشارت النتائج أيضا أن تركيز النيترات كان مختلف من بئر لآخر و ذلك يعود لعدة أسباب مثل حالة أسطح التجميع لتلك الآبار و كذلك بعد الحفر الامتصاصية و منسوبها عن الآبار خصوصا تلك التي لا تبعد أكثر من 10 م من الحفر الامتصاصية حيث لوحظ أن تركيز النيترات فيها أكثر نسبيا من غيرها و ذلك ربما لتسرب الأمونيوم لها. و بينت النتائج أن جميع آبار التجميع غير ملوثة بالمعادن الثقيلة مثل الرصاص و الكروم و الزنك. لكن أظهرت النتائج أن الخواص البيولوجية و بالتحديد فحص لكشف جراثيم من طائفة القولونيات (كوليفورم) أنها لا تطابق المواصفات المشار إليها في آبار التجميع حيث لوحظ أن 100% من العينات المفحوصة احتوت على (الكوليفورم الكلي) بينما 86% على (الكوليفورم الغائطي) و لكن تطابقت معها في العينات المفحوصة و التي أخذت من الجو مباشرة قبل وصولها إلى البئر حيث لم يشاهد أي من هذه الطائفة من الجراثيم. لذا من المهم قبل استخدام مياه المطر كمصدر منزلي يجب أن يتم تطهيره من خلال وزارة الصحة أو أي جهة معتمدة ذات صلة لتجنب أي تفاعلات كيماوية مسرطنة قد تنجم من عملية المعالجة بالتطهير بدون فحص كامل لبئر التجميع و المحافظة دائما على نظافة البئر.

كما بينت الدراسة أن معامل الجريان (R) كعامل مهم لاحتساب كمية مياه المطر الممكن تجميعها يتراوح ما بين 0.7 و 0.9 و ذلك بالنسبة إلى الأسطح الاسمنتية و التي تعتبر أسطح التجميع الشائعة في فلسطين.