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الجامعة الأردنيـــــة
كلية الدراسات العليا

التاريـــخ: ٢٠ / ١ / ٢٠١١

نموذج رقم (١٨)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

أنا الطالب: سما أحمد محمد صالح عثلان الرقم الجامعي: (٨٠٩٠٩١٥)
تخصص: الإدارة المتكاملة لمصادر المياه الكليـــــة: العلوم

عنوان الرسالة: دراسة امكانية حصاد مياه الأمطار بواسطة سطوح المنازل لمدينة صنعاء، اليمن

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

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تعتمد كلية الدراسات العليا
هذه النسخة من الرسالـــة
التوقيع ...... التاريخ ٣١ / ١ / ٢٠١١

THE POTENTIAL OF ROOFTOP RAINWATER HARVESTING FOR SANA'A, YEMEN

By

Musa'ed M. Aklan

Supervisor

Dr. Abbas AL-Omari, Prof.

Co-Supervisors

Dr. Lars Ribbe, Prof.
Dr. Taha Taher.

This Thesis was submitted in Partial Fulfillment of the Requirements for the Master's Degree of Science in Integrated Water Resources Management (IWRM)

Faculty of Graduate Studies
The University of Jordan

Institute for Technology and Resources Management in the Tropics and Subtropics (ITT)
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COMMITTEE DECISION

This Thesis/Dissertation (The Potential of Rooftop Rainwater Harvesting for Sana'a, Yemen) was Successfully Defended and Approved on 20/1/2019

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DEDICATION

To My Family

AKNOWLDGMENT

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LIST OF ABBREVIATIONS

A	Catchment Area
AOPP	An action Oriented Policy Paper
BC	Before Christ
CAMA	Civil Aviation and Meteorology Authority
CARE international	CARE International is a global confederation of 12 national member organizations working together to end poverty. www.care-international.org
CFU	Colony Forming Units
DEM	Digital Elevation Model
DRWH	Domestic Rainwater Harvesting
GARWP	General Authority for Rural Water Projects
GARWSP	General Authority for Rural Water Supply Projects
GIS	Geographic Information System
GTZ	German Agency for Technical Cooperation
GWP	Global Water Partnership
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
m.a.s.l	Meter above sea level
MCM	Million Cubic Meters
MENA	Middle East and North Africa
MUS$	Million united state dollar
MWE	Ministry of Water and Environment
NWRA-A	National Water Resources Authority Station
NWRA	National Water Resources Authority
NWRA-SB	National Water Resources Authority – Sana'a Basin
NWSA	National for Water and Sanitation Authority
NWSSIP	National Water Sector Strategy and Investment Plan
PFP	Potters for Peas
POU	Points of use
PVC	polyvinyl Chloride (Pipes)
RTRWH	Rooftop Rainwater Harvesting

RWH	Rainwater Harvesting
SAWAS	Sana'a Water and Sanitation Study
SBWMP	Sana'a Basin Management Project
SF	Silver Filter
SFD	Social Fund for Development
SICF	Silver impregnated Ceramic Filter
SODIS	solar disinfection
SWSLC	Sana'a Water and Sanitation Local Corporation
TNTC	Too Numerous To Count
TWSLC	Taiz Water and Sanitation Local Corporation
UN	United Nations
UNEP	United Nations Environment Program
UNESCO	United Nations Educational Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
USAID	United States Agency for International Development
WB	World Bank
WEC	Water & Environmental Center, Sana'a University
WH	Water Harvesting
WHO	World Health Organization
WUA	Water Users Association.
YR	Yamani Rial
$	United State Dollar

List of Appendices

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Abstract

Sana'a basin, where the city of Sana'a represents more than 80% of its population, suffers from groundwater abstraction counted up to four times of recharge. Rooftop rainwater Harvesting (RTRWH) is one of the most promising alternatives for supplying freshwater in the face of increasing water scarcity. Therefore it is wise to harvest it from rooftops and store it for different uses.

In this study the potential quantity of rainwater that can be harvested from the roofs of Sana'a city has been calculated based on digitizing 2009 satellite image. The city has been divided into three zones according to the rainfall density. The results show that annually 6.4 Million Cubic Meters (MCM) can be harvested from rooftops of buildings.

Rainwater quality has been assessed. With the exception of biological indicators, all other parameters are found to be below the maximum values of both Yemeni and World Health Organization (WHO) standards. However using filters such as silver filter (SF), make such harvested rooftop water potable.

From the economic point of view matrix for selection process of appropriate type of tanks has been developed. From the cheapest to the expensive ones, brick cement, ferrocement, block and concrete tanks are suggested.

Social survey has been cried out in order to define the locals' awareness, willingness to cooperate/pay and opinions on RTWH. There are more than 85% of interviewees are aware of water scarcity and encouraging the idea of RTRWH. However, 82% of them are willing to take apart of participation in RTRWH projects.

In the basin level, rehabilitation of 1615 dried-up wells to act as recharge wells has been done by developing different ground filters. Cesspits, ponds and check dams also are other possibilities that have been identified and discussed as groundwater recharge media.

Key words: *RTRWH, RWH, IWRM, Rain water quality, ground water recharge, storage tanks.*

CHAPTER ONE
INTRODUCTION

1.1 Background

Water scarcity and deterioration of its quality have become one of the biggest challenges all over the world. Yemen, which is one of the driest countries, suffers from severe water scarcity. Yemen is categorized as an arid to hyper-arid country with no surface water except what is coming from the rainfall. The renewable water resources in Yemen, sum up to an average of 2500 Million Cubic Meter per year (MCM/year) while the total water consumption in Yemen is about 3400 MCM/year, which means that the deficit is about 900 MCM (JICA, 2007).

In Yemen, the availability of water counted to be less than 120m^3 per capita per year, In contrast, 7500m^3 and 1250m^3 per capita are the world and Middle East and North Africa Region (MENA) averages respectively. Availability of water in Yemen is less than the minimum required for food self sufficiency (1,100m^3) (Hellegers, et al, 2008).

Sana’a basin, located in the western part of Yemen, is one of the most affected basins in the country in term of water scarcity. In Sana’a basin, where the capital of Yemen is located, groundwater abstraction counted up to six times of recharge. Rainfall in Sana'a basin is ranged between 110 – 350 mm/year. The tow rainy seasons are between March to May and July to September (JICA, 2007).

Sana'a city represents more than 80% of the basin population, Moreover Sana’a is considered as a center of the Yemenis culture since it has unique urban and architectural inheritance old town “old Sana’a”, dated back to 2000 years. Old Sana’a has been declared by United Nations Educational Scientific and Cultural Organization (UNESCO) as a World

Heritage Site in 1984 (World Bank, et al., 2009). Recently, Sana’a city is facing water shortage problem and looking for new sources.

1.2 Problem Statement

Sana’a, the political and administrative capital of Yemen, is the first capital all over the world is running out of water, in spite of the fact that the water consumption per capita is less than 120 CM/Y (Hellegers, et al., 2008). In Sana’a basin, groundwater is being depleted and the deficit reaches about 219 MCM every year (JICA, 2007).

There are many factors that led to water shortage in Sana’a basin: Population growth, expanding the agricultural area, using surface irrigation systems, limited water resources, lack of water conservation (awareness among societies), and absence of effective laws and regulations. Consequently, these reasons have led to the increasing in digging wells which results in an overexploitation of the groundwater.

Conflict among users, degradation of water quality, and increasing in the costs of pumping are some results of increasing the pressure on the only non-renewable groundwater resource. A problem tree is shown in Figure 1-1` describing the problem statement of Sana’a basin.

⇒ ***Population Growth:***

In Yemen, the population in Sana’a increases more than any other city in Yemen. In 1977, Sana’a population was only 162,000 people representing just 3% of the country’s population, due to the natural population growth and in-migrants from urban and rural parts of the country the population have grown to more than ten times to reach 1.7 million inhabitants in 2004, representing 9 percent of Yemen’s total population at that time (World Bank, et al., 2009).

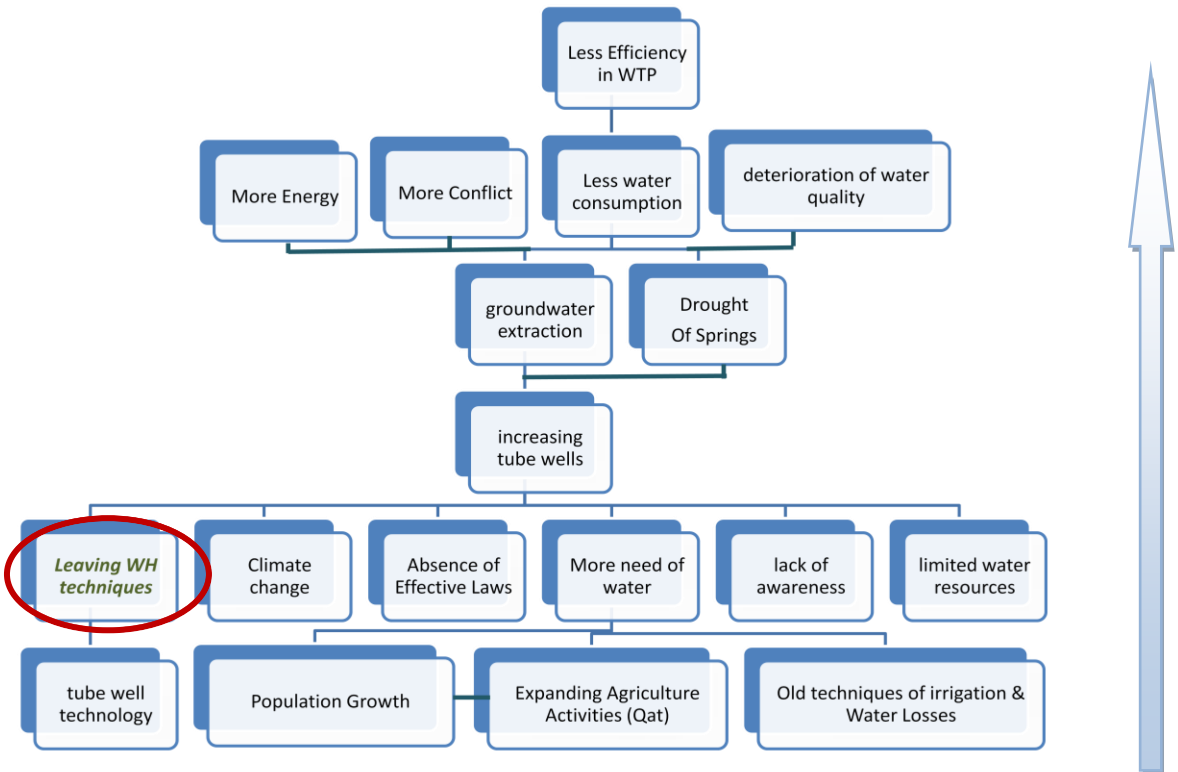

Figure 1-1. Problem statement tree for Sana'a basin

⇒ *Agricultural activities:*

Agricultural sector with its expansion is playing a big role in term of water consumption since 75% of the population of Sana'a basin depend totally on agricultural activities, mainly by cultivating qat, grapes and other fruits (World Bank, 2003). Good income and profitability of high value crops like qat and grapes, has driven rapid expansion of tube wells and pumps (Bruns and Taher, 2009). As a result, more than 90% of the extracted water goes for irrigation (hydrosult, 2010)

⇒ *Groundwater Governance*

With the arrival of tube well technology after 1970s (Hellegers, et al, 2008), illegal and authorized wells are being continually drilled in Sana'a basin. Study by Water and Environmental Center, Sana'a University (WEC), (2004) calculated the total wells within Sana'a basin to be 13256 wells.

1.3 The Importance and justifications of the study:

Sana'a, the study area with about 2 million people, is facing a real problem in terms of water scarcity. There is a great need of studies exploring new sources of water rather than groundwater. A study for Sana'a Basin Management Project (SBWMP) done by Japan International Cooperation Agency (JICA), 2007, estimated that the groundwater resource is going to be depleted before the year 2024; the study prepared a scenario for water saving through reduction of water consumption. However it is reported that such scenario can expand the period of water depletion only until the year of 2036.

Rainwater Harvesting considered as a significant renewable source that can contribute in groundwater saving. Within Sana'a basin, there are 44 surface dams and 24 dams/pools. Most of these dams are being used for groundwater recharge and irrigation (JICA, 2007). However, RTRWH is another potential source of Water Harvesting (WH) for Sana'a city. Urban areas like Sana'a represent a significant percentage of the large impermeable areas. Therefore, it offers a good possibility of RTRWH.

In Sana'a, RTRWH could contribute in closing the growing gap between water demand and water supply, reducing the high pressure on Sana'a Water and Sanitation Local Corporation (SWSLC), and mitigate the problem of increased number of tankers which are serving not only the households who aren't connected to the public network but also in so many cases those who are connected to the public network and receive intermittent water supply.

Last years, in Yemen, many RTRWH projects have been implemented successfully by Social Fund for Development (SFD). As a policy of SFD all of these projects have been implemented in rural areas. Accordingly a valid opinion about the potential of RTRWH in urban areas in Yemen needs an investigation.

Nevertheless and regarding to RTRWH in Sana'a, there are several questions remain open and required answers: How much of rainwater can be harvested from the rooftops of Sana'a? Is it feasible, Acceptable, usable, and applicable? What are the kinds, sizes and sites of storage systems? What about the costs? To what extent RTRWH could contribute to groundwater saving? Under Integrated Water Resources Management (IWRM) approach all of these questions and other related questions have been answered by this study.

1.4 Objectives of the study

⇒ ***Overall objectives***

- To contribute to propose a WH strategy for the Sana'a Basin in order to achieve sustainable development.
- To define the awareness and willingness to cooperate/pay of local people.
- Getting benefit and maximize utilization of surface water in Sana'a city by RTRWH to increase water availability, reduce people suffering and reduce the pressure on the non renewable groundwater resource.

⇒ ***Specific objectives***

- Estimate the amount of water that can be captured from the roofs.
- Identify for what purposes this water could be used.
- Identify potential sites, techniques, and sizes of the tanks.
- Identify other possibilities of Rainwater Harvesting (RWH) in Sana'a Basin rather than RTRW

CHAPTER TWO
LITERATURE REVIEW

2.1 Water Harvesting

The development, population growth and climate change are some factors that led to increasing water demand and put stress on the available water resources. WH provides an innovative solution to meet water needs. WH can contribute to environmental, social and economical benefits, as well as to poverty alleviation and sustainable development. For instance, RTRWH has a socio-gender impact. With RWH women and children can be saved from water fetching. So WH not only increases human well-being but also it improves the equity and creates a gender balance. Rainfed agriculture provides nearly 60% of global food (UNEP, 2009). WH under IWRM approach means recognizing its value and achieving its optimum benefit at the location where it falls.

2.1.1 Definition

Water harvesting is known as a general name for the whole techniques used to collect runoff or flood water that can be used for different purposes as follows (Texas Water Development Board, 2005; UNEP, 2009):

- For storage: either in man-made structures (dams, tanks or containers) or in the soil profile which can be used later on for human or livestock consumption,
- For irrigation or commercial and industrial purposes and,
- For groundwater recharge.

Harvested water is a renewable source of water for domestic, landscape and agricultural uses.

2.1.2 Components of rainwater harvesting systems

Catchment area, storage facilities and target area are the three main components of RWH systems according to (Oweis et al. 2001).

Catchment area:

It is defined as a part of land that receives rainwater and shares it for other target areas or uses outside its boundaries. Starting from a few square meters to several square kilometers the runoff area (catchment area) could be an agricultural or landscape area, rooftop or roads.

Storage facilities:

It is the place where rainwater is stored until it is used. Storage could be any type of containers, such as tanks above or under the ground, soil profile or groundwater aquifers.

Target area:

For different purposes it is the place where the harvested water is used. Human, plants, animals and landscape are end targets of harvested rainwater.

2.1.3 Rainwater harvesting systems

Rainwater Harvesting is an ancient technique that has been used for thousands of years; whether for irrigation purposes or for human and animal uses. Different techniques of WH have been used and developed. Selecting WH technique depends on many factors (AL-Zayed, 2010). These include:

- physical factors such as rainfall, hydrological, topographical, and soil characteristics,
- socioeconomic factors,
- environmental factors,
- ecological factors, and
- the purpose of rainwater use factor.

WH methods are classified in different ways. In spite of the type of use and storage, being the main classification criteria, catchment size is the commonly used method as it is shown in Figure 2-1 (Oweis et al. 2001; AL-Zayed 2010).

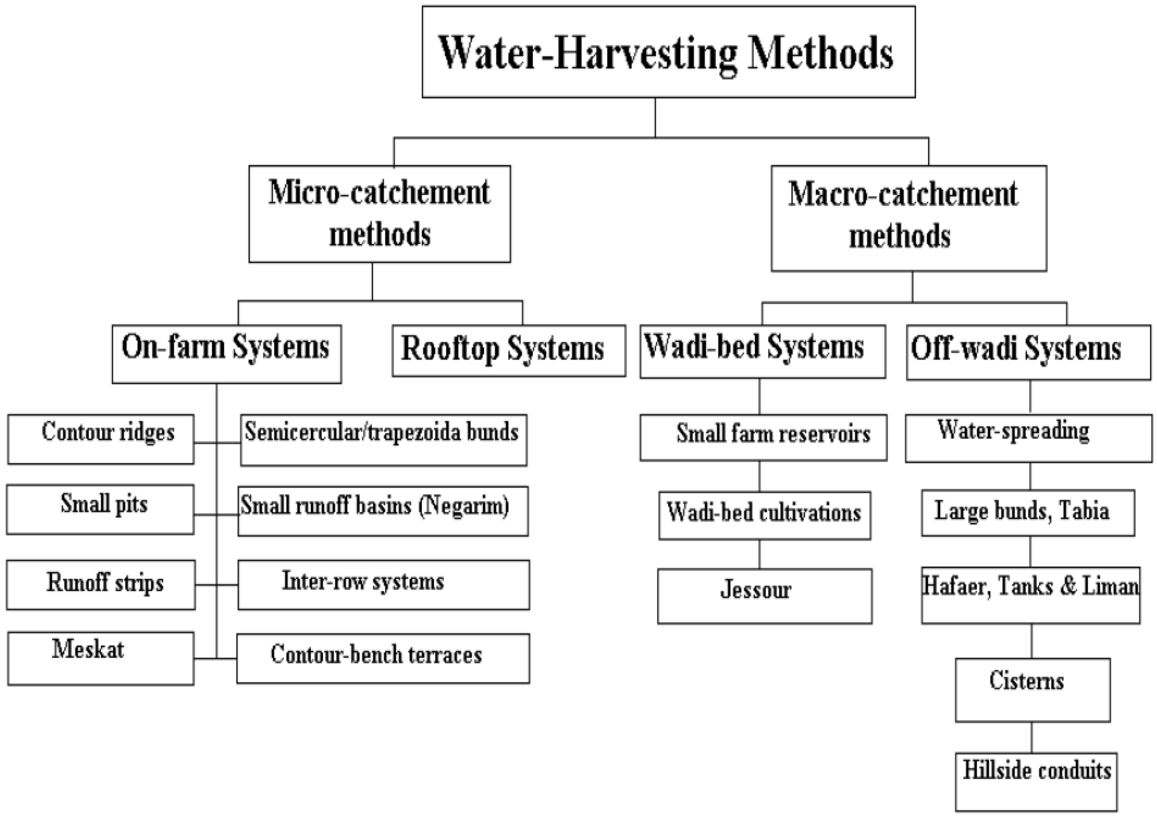

Figure 2-1. Rainwater harvesting methods

Source: (Oweis et al. 2001)

Micro-catchment systems:

Micro-catchment system is a small and simple catchment field based and ranges from a few square meters to about 1000 square meters. Micro-catchments are small countered areas with slopes to increase runoff and concentrate it in adjacent cultivated area. Accumulated runoff is stored in root zone where it is directly used or in small containers for later use (Critchley, et al. 1991; Oweis et al. 2001).

Macro-catchment systems:

Located outside target areas (farms) boundaries, Macro-catchments are relatively large catchments (30-200 meters in length) (Critchley, et al. 1991). Macro-catchment could be a natural rangeland, steppe or mountainous area. "WH from long or external catchment" and "flood WH system" are names used for macro-catchment system (Oweis et al. 2001).

Rooftop systems:

In rooftop systems, rainwater is collected from impermeable surfaces and stored or directly used for several purposes. Different surfaces such as roofs of the houses, courtyard and similar impermeable surfaces including roads and rock catchments can be used to collect better quality rainwater. In such surfaces almost all of the rainfall can be collected.

The use of rooftop rainwater depends on: the type of the system (surface, gutters, and storage container), frequently cleaning and maintenance of the system, as well as users' needs. Modern materials used for roofs and gutters, helped to collect clean rainwater that can be used for drinking. Livestock consumption, gardening, and landscape are other targets where rooftop rainwater can be used (UNEP, 2009; Abdulla & Al-Shareef 2009; Oweis et al. 2001).

2.2 Domestic Rainwater Harvesting (DRWH)

Using RTRWH for domestic uses improves the equity and creates a gender balance through saving women and children, especially in developing countries, from looking after and collecting the water (UNEP, 2009).

2.2.1 RTRWH components

There are three main components of RTRWH systems catchment area, delivery system and storage tanks (Figure 2-2). In this section, the three main components with other secondary components have been explained.

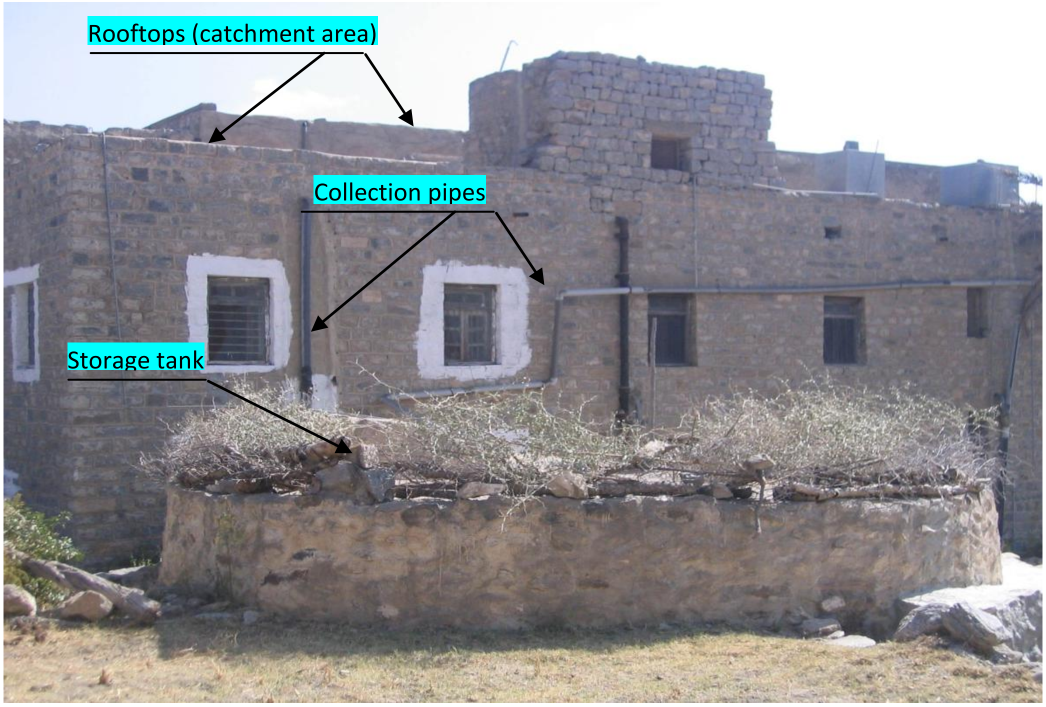

Figure 2-2.Roof catchments system-Taiz

Source: Taher and Saleh (2010).

Catchment area:

Catchment area is the roof of the house. The effective area of the roof (catchment size) and the material of construction affect the water quantity and quality (Texas Water Development Board, 2005). More details about the materials and its effect on water quality are explained in the rooftop rainwater quality part, chapter 2, section 2.3.3.

Delivery system (Gutters and downpipe)**:**

Gutters are fixed to the edges of the roof in order to collect and transport rainwater from the roof to the storage tank. Different materials have been used for gutters. Polyvinyl Chloride (PVC) is the most common material for gutters. Gutters from PVC, corrugated galvanized steel sheets or iron sheets can be prepared in semi-circular or rectangular shapes (Texas Water Development Board, 2005); however, for flat roofs with limited rainwater outlets, close gutters can be used as the case in Yemen.

Leaf screen (filtration screen):

Filtration screen is used to remove all debris and leaves that have gathered on the roofs. Such screen usually 0.25 inches mesh screen that should be fit along the length of open gutters or at the inlet of the gutters in case of close gutters(see Figure 2-7, a) (Texas Water Development Board, 2005).

First flush device:

Roofs as open surfaces are a natural collection surfaces for dust, leaves, blooms, animal faeces and other contaminants. The first flush device (diverter) helps to divert the first flow of rainwater from entering the tanks. First flush device gives the RWH system a chance to get rid of the accumulated contaminants or smaller collected contaminants that can't be removed by filtration screen.

There are deferent types of first flush device. Figure 2-3 shows PVC standpipe one. The device fills with rainwater first, and then allows water to flow through the outlet to the storage system. At the bottom of the device is a cleanout fitting, which through it the device must be emptied and cleaned out after each rainfall event (Texas Water Development Board, 2005).

Other simple and semi-automatic one (Figure 2-4), could be used just by installing a valve at one end of the downpipe while the other end goes to the storage tank. However, when the runoff from the roof starts, the first flush valve should be opened for a while to get rid of accumulated contaminants, then the valve should be closed allowing the clean rainwater to enter the storage tank. Furthermore, first flush can be done manually by moving the downpipe away from the tank until the runoff from the roof is clean.

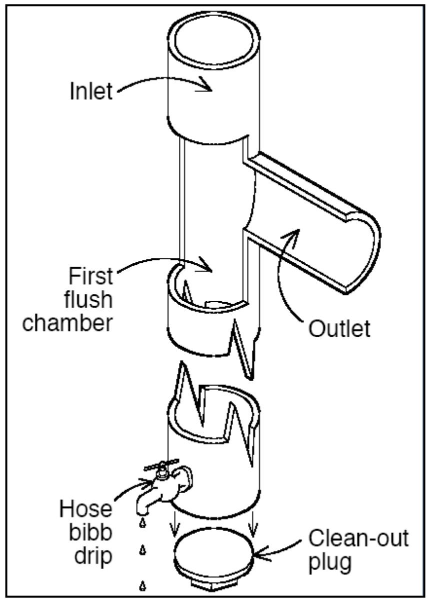

Figure 2-3. Standpipe first-flush device

Source: Texas Water Development Board (2005)

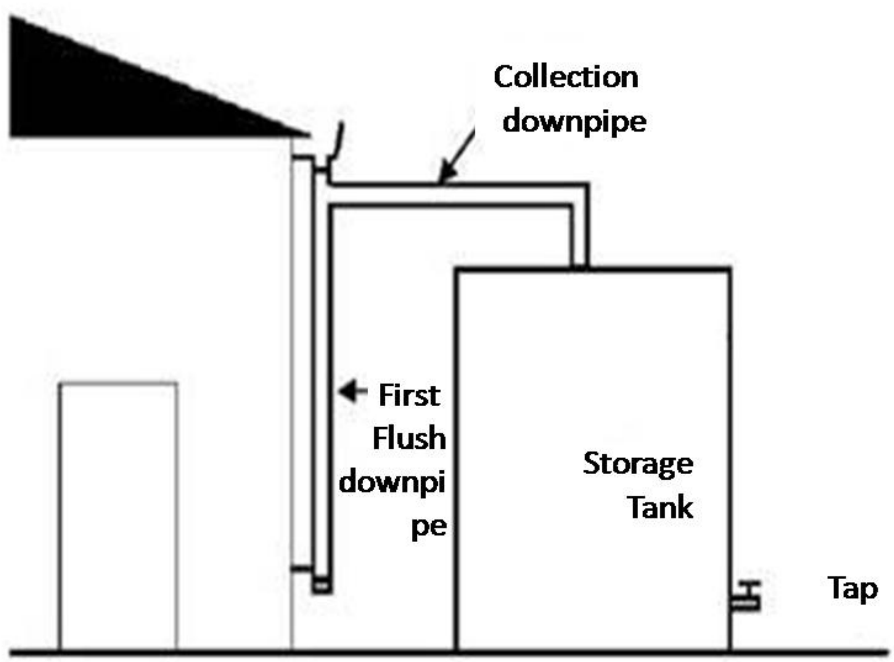

Figure 2-4. Semi-automatic Method: Simple down pipe first flush device

Source: Taher and Saleh (2010)

There are different opinions about the volume of rainwater that should be diverted out of the tanks. However, factors such as number of dry days, amount of debris and roof surface should be considered. Diverting a minimum of 10 gallons (38 liters) for every 1000 square feet (93 m^2) of surface is a one rule of thumb for first flush diversion. A study by a RWH components vendor in Australia recommends that between 13-49 gallons (49-186 liters) of diverted rainwater per 1000 square feet (93 m^2) (Texas Water Development Board, 2005). It is recommended by WHO (1997) that from 5 to 10 minutes or until it run clean as diverted rainwater in the first storm of the season.

Storage Tanks

Storage tank usually is the most expensive part of RWH system. Storage tanks should be adapted to local conditions. The type of the tanks depends on where they will be situated and what is the budget. The size of the tanks depends on: The required quantity of water, the patterns of both water supply and water demand, dry period, catchment area, personal preference and the budget. Practically, ferrocement tanks are the most suitable tanks. Brick, block, plastic and metal tanks also other common type of tanks (Sturm et al. 2009).

Rainwater tanks should be near both supply and demand points as well as near the other service points if it will be used for water sources, for example near the driveway if the tankers will be used. More over The tank should be located in an appropriate stable level pad for away from animals' stables, trees and other possible contaminations (Pace 2010; Texas Water Development Board, 2005).

- ***Fiberglass Tanks***

Fiberglass tanks are built in standard capacities from 50 - 1500 gallon (0.2 – 5.7m^3), it is light-weight and have reasonable price, and it is available in both vertical and low-horizontal cylinders. Less than 1000 gallons (3.8m^3) polyethylene or polypropylene might be preferred since fiberglass becomes more expensive. Fiberglass tanks have been tested and proved their durability. It can be easily repaired. Fiberglass fittings are integral, ignoring one common potential problem of fittings leaking (HarvesteH2o, 2010).

- ***Polypropylene Tanks***

Polypropylene Tanks should be stalled above the ground according to its standard, available in capacities from 50 -10,000 gallons (0.2-38m^3) they are inexpensive, durable, light weight and long lasting. The fittings are aftermarket modification, and easy to plumb (Texas Water Development Board, 2005).

- ***Wood Tanks***

For aesthetic appeal, wood tanks are used. Modern tanks are made from pine, cedar or cypress. They are lined with plastic and wrapped with steel tension cables. Food-grade liner must be used for drinking use (Kloss, 2008).

- ***Metal Tanks***

Like wood tanks, galvanized metal tanks are also an attractive option. They are available from 150 - 2500 gallons (0.57-9.5m^3). They are weight and easy to relocate. They should be lined with polyethylene or PVC as a food-grad liner, or coated with epoxy paint (Kloss, 2008). In case of Yemen, metal tanks are mostly used with neither lining nor painting.

- ***Concrete Tanks***

Concrete tanks can be prefabricated or poured in place, above or underground. Poured tanks are more attractive and easily integrated in to new construction; it can be placed under patio or basement. It can be adapted to the site diminutions. Concrete tanks considered as a permanent tanks.

Building concrete tanks required a structural engineer to determine construction details. For repairing leaks in concrete tanks, new proved products for potable use are available.

(HarvestH2o, 2010). In Yemen the High cost of building concrete tanks is one of its disadvantages.

- ***Stone and Mason Tanks***

Stone tanks are not as common as they were in developed countries. However they are still used in developing countries. In Yemen hand made stone tanks are custom-built and still widely used, especially in rural areas. One advantage of stone tanks is that they keep the beauty of nature. On the other hand high cost of construction is one of their disadvantages. The heavy-weight of stone tank has the advantage of keeping water cool during hot climate. Two ways of building its walls have being practiced in Yemen: Soil and water or concrete (cement, sand and water) is used for building the tank walls. Concrete is used for Lining, flooring and covering stone tanks. Metal or galvanized steel sheet some times are used as covers.

- ***In- ground polypropylene Tanks***

In-ground polypropylene tanks are costly because of excavation cost and the cost of more heavily reinforced required tank. Soil with high clay content is not commended to be buried on the tank; clay has expansion and contraction cycle which may affect the tank. Special care of below ground installation is required (HarvestH2o, 2010; Kloss, 2008; Texas Water Development Board, 2005).

Low-cost Options

- ***Ferrocement***

Ferrocement tanks are typically built with concrete, but have layers of wire mesh wrapped around a framework. Walls can be as thin as 1inch and still be strong. They have the advantage of low cost compared to concrete or stone tanks (Kloss, 2008).

Historically, Jean Louis Lambot is the first one used ferrocement in 1848, France. Nowadays it becomes a common structure in different countries. In Brazil, large cylindrical tanks were constructed, some of them with volume of 700m^3.

By Moita, et al., (2003), an investigation of the water treatment ferrocement tanks was carried out in Minas, Geris, Brazil. It was observed that the construction techniques used do not guarantee some geometric parameters, such as constant thickness and voids control. Mechanical properties are not homogeneous since it depends on the worker skills, Density of murder and condition of drying as well (Moita et al. 2003).

- ***Brick cement tank***

Brick cement tanks have been used in Nicaragua, Ghana and other countries. Local bricks, cement and steel wire are used in such thanks. It is cheaper and easier to be built than ferrocement. The volume can be from 0.5 to 30m^3. It is constructed in circle shape of bricks, three rings of steel wire tightened around the first row of bricks, for the up rows two rings for each, for more than 2 meter diameter more rings are needed. When constructing brick cement tanks, the bigger the volume the lower the cost, Brick cement tank of 1m^3 cost 20$ and 6m^3 cost 40$. Nonetheless, building small tank is advisable before attempting a large one (NWP, et al., 2007; Arrakis and Connect International, 2006).

Appendix (A) illustrates, with pictures, steps of building brick cement tanks, dimensions and required materials for different sizes of brick cement tanks have been included as well.

- ***Straw mat tanks***

Straw mat tanks are made from double layer of bamboo or strong grass in a cylinder shape. Three circles of steel wire are used to fix the straw. Cement, sand and small gravel (if available) are used for the bottom of the cylindrical. Mixture from 1 part of cement and 3 parts of sand are used for both inside and outside the cylindrical. However steps of constructions with pictures are shown in an Appendix (B)

- ***Rain barrel***

Rain barrel is one of the simplest RW installations, When small storage is needed barrel tank can be used. However, two or more barrels also could be used with overflow linking. Valves can be installed as well.(Helmreich and Horn, 2009; Pace, 2010).

2.3 Rooftop Rainwater Quality

2.3.1 Introduction

Water quality is playing a major role in public health improvement. Therefore, protecting water resources is essential to protect human health (Rain Foundation, 2008; Luke Mosley, 2005; Jacobson, et al,. 1996).

As it is far away from overland contaminations (domestic and industrial waste and pesticide runoff) rainwater is considered to be the safest water resource, unless there is atmospheric pollutions from industry. The main challenge regarding the rainwater quality for domestic use is keeping rooftops and storage tanks free from contaminations. Accordingly, appropriate maintenance and operation for RTRWH system are required (UNEP, 2009; Texas Water Development Board, 2005)

2.3.2 Harvested rainwater quality and risks of contamination

Factors determining quality of harvested rainwater:

For rainwater or any other water resource, there are three factors that determine water quality. The first and most important one is the biological factor followed by the more involved chemical factor and the last one is the physical factor. Figure 2-5 illustrates the three factors that affect water quality.

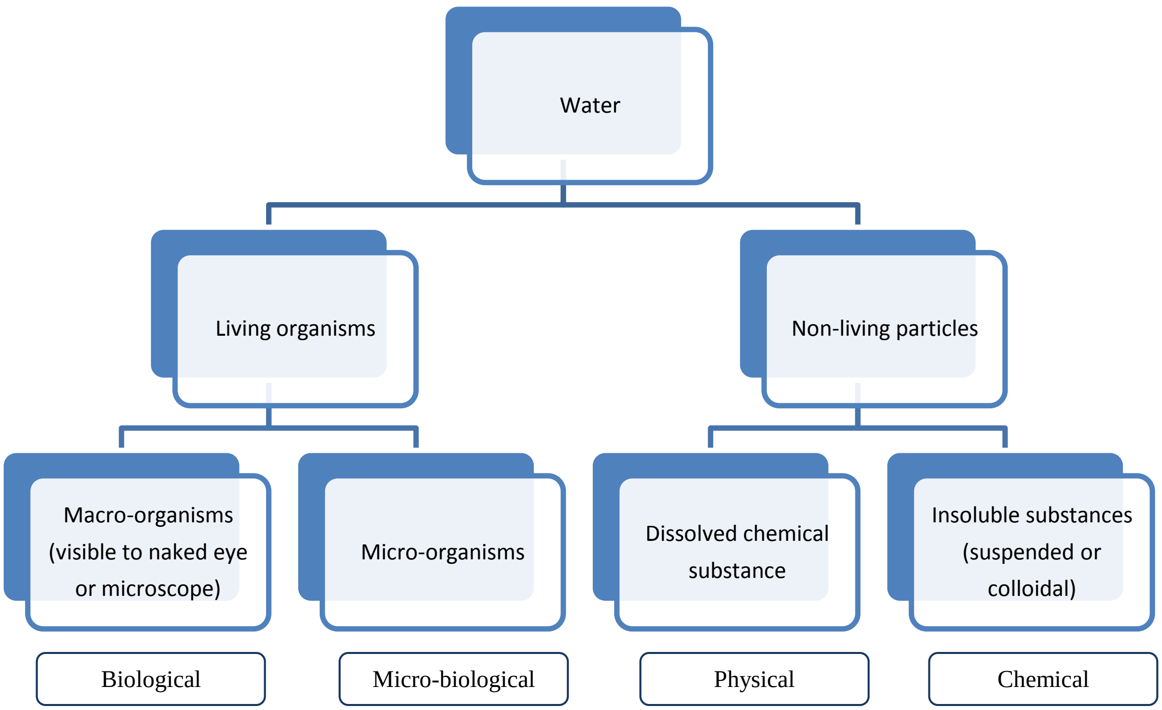

Figure 2-5. Factors that determine water quality

Source: Rain Foundation (2008)

System assessment: mapping the risks of contamination:

Assessment for the whole system of RTRWH is an essential step. Mapping the risks of contaminations is considered to be the main objective of the RTRWH system assessment. Such mapping help to take the appropriate measures to limit the contaminations which should be a preliminary step before thinking about end-of-pipe solutions such as filtration and treatment, otherwise re-contamination will occur. By rain foundation (2008) Top-down method of preventing contaminations is presented in Figure 2-6.

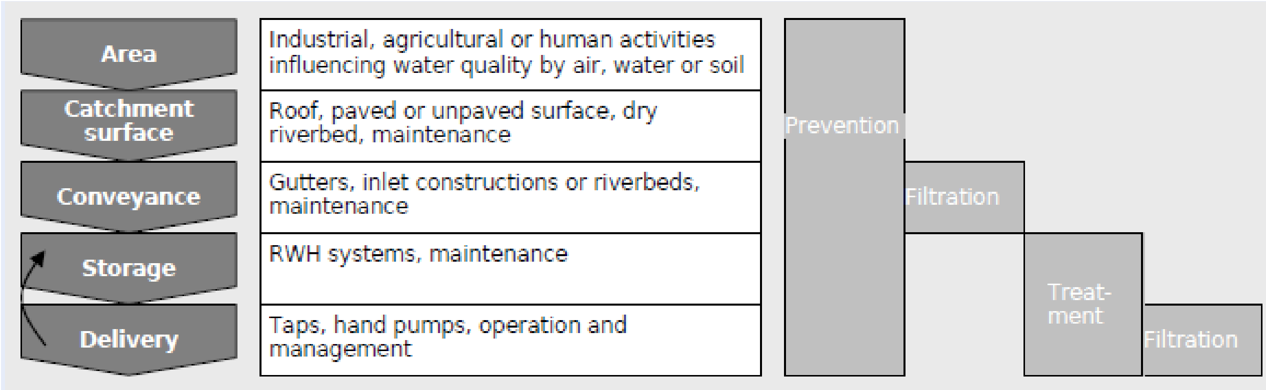

Figure 2-6. Mapping risks of contamination at RWH systems

Source: Rain Foundation, (2008)

Types of contaminants in rainwater system:

Common contaminations that could be found in rainwater systems were presented by Mosley, (2005). Table 2-1 shows the source risk and applicable mitigation tools of such contaminants.

Table 2- 1. Types of contaminants commonly found in rainwater collection systems

Contaminant	Source	Risk / mitigations
Dust and Ash	Surrounding dirt and vegetation Volcanic activity	Moderate: Can be minimized by regular roof and down drain pipe (gutter) maintenance and use of a first-flush device.
Pathogenic Bacteria	Bird and other animal droppings on roof, attached to dust	Moderate: Bacteria may be attached to dust or in animal droppings falling on the roof. Can be minimized by use of a first-flush device and good roof and tank maintenance.
Heavy metals	Dust, particularly in urban and industrialized areas, roof materials	Low: Unless downwind of industrial activity such as a metal smelter and/or rainfall is very acidic (this may occur in volcanic islands)
Mosquito Larvae	Mosquitoes laying eggs in guttering and/or tank	Moderate: If tank inlet is screened and there are no gaps, risks can be minimized.

Source: Mosley (2005)

Example of sanitary inspection form for rainwater collection and storage is shown in Appendix (C).

2.3.3 *Appropriate components of RTRWH systems:*

Roofs:

Different types of roof materials such as concrete, metal sheets, ceramic tiles and Ferro-cement have been used and considered as suitable materials for RWH roofs (Mosley, 2005). Probably the most common roofs in Yemen are concrete, cement mortar, ceramic, mad and corrugated galvanized steel sheets (Taher and Saleh, 2010). Galvanizing prevent steel corroding by coating with zinc compounds. Galvanized steel sheet has the advantage of smoothness and less likely to hold contamination (Mosley, 2005).

On the other hand, metal roofs under the atmospheric corrosion become source of heavy metals which effect water quality (Villarreal & Dixon 2005; Luke Mosley, 2005; Rain Foundation, 2008).

In summary contaminations from roofs can be prevented by two procedures (Rain Foundation, 2008):

- Avoiding metal roofs and using non-toxic materials such as Ferrocement.
- Frequently cleaning (from human, animal and organic matters), removing trees branches over roofs and leaves.

Gutters:

Gutters as transporters of water between the catchment area (rooftop) and storage tank, should be made from non-toxic materials and frequently cleaned. PVC gutter is recommended since it doesn't rust. Flat areas in gutters retain debris and water; consequently these provide a good environment for mosquitoes to breed. Consequently, correct installation for gutter is important. Gutter screen may be required at the end of gutter (entrance of water) to prevent leaf and other large materials from entering gutter and then storage tank. Moreover, first flush device at one end of the gutter should be installed to divert the first contaminated millimeters of rainfall out of the storage tank (Zhu et al. 2004; Luke Mosley, 2005; Villarreal & Dixon 2005; Rain Foundation, 2008).

Tanks:

Whatever the shape, size or position of the storage tank is, still construction materials, covers and types of the storage tanks are important regarding the water quality. Non-toxic construction materials should be used as appropriate tanks of Ferrocement, plastic and metal. DRWH tanks should be covered from animal, human, and organic matter, as well as from mosquito. Covered tank keeps the water away from sunlight to prevent algal growth and biological activities. Gaps in storage tank or its inlets should be closed. Such gaps allow mosquitoes to enter and exit to and from the stored rainwater which affect its quality. It is essential that two taps are used for the storage tanks. The first one is fixed at the base of the tank to be used for cleaning the tank and the second one for water use and should be installed above the first one. The water use tap should be protected from animals contact (Rain Foundation, 2008; Mosley, 2005).

Whenever the rainwater reaches the tanks, it starts to be improved by several processes such as biofilms and sedimentation (Villarreal & Dixon 2005).

2.3.4 Devices and techniques that further aid in better water quality:

Filtration screen:

Using coarse filter keeps out leaves and debris and helps for more improved water quality in the storage tank. Entering leaves and other materials to the storage tank will provide nutrients for micro-organisms; hence, such undesirable materials shouldn't enter the tank. Stainless steel and synthetic mesh as coarse filtration screens are simple, inexpensive and widely used technology; filtration screen can be installed in the inlets of gutters (Figure 2-7, a). Using a filtration on the top of the tank is an alternative for coarse filters (Figure 2-7, b) (Villarreal & Dixon 2005; Luke Mosley, 2005).

When using top tank filter, fine cloth filter is used. The cloth filter of 2 or 3 layers can be tied to the top of a bucket or vessel with bores at the bottom. The rest of the container is filled with gravel and sand, the filter should be cleaned after every rainfall event. New technologies of the top tank filters made from either aluminum or plastic container and have the advantage of ease in removing, cleaning and replacing.

(a) **(b)**

Figure 2-7. (a) Sample Filtration screen and (b) Sample Top tank filter

First flush devices:

Collected contaminations during dry period can be washed out of the storage tank by using first flush devices. Protecting roofs from contaminants and frequently cleaning them are not enough to ensure the removal of the all contaminants collected in roofs in dry periods. Therefore, first flush device should be installed in the gutter to dispose of the contaminated first flush out of the tank (Mosley, 2005). See Chapter (2), section (2.2.1) for more details about first flush devices.

2.3.5 Methods and measures for ensuring and improving water quality

Treatment and the local context

In developing countries, applying water treatment techniques seems to be impractical and expensive (Rain Foundation, 2008). Fact sheet "The place of DRWH in water supply strategies" developed by Development Technology Unit of the University of Warwick, UK [IRCSA website] suggested that:

…….

"In terms of organic and inorganic pollutants, untreated rainwater, withdrawn from well-maintained tanks fitted with inlet filters, is generally well within WHO standards and is superior to most groundwater. Microbiological contamination (indicated by levels of E.coli) is in the "low risk" category of WHO water quality standards, surpassing the quality of most traditional water sources and many improved sources. Such contamination falls further with storage. No additional treatment is usually needed. However if higher quality water is required, standard household treatments such as boiling, chlorination or solar disinfection (SODIS) are effective on stored rainwater."

Treatment and filtering methods

Some treatment and filtering techniques have been recommended by Rain Foundation, (2008), chlorination, silver coated ceramic balls as substances to be added to the water as a treatment process. Ceramic pot and bio sand as filters, boiling and SODIS are recommended as well. However, disinfection by adding chlorine for rainwater collection system is widely recommended, but misuse of such chemical material by users is considered to be dangerous. For this reason chlorination of tank is suggested if one or more of the following situations happened (Mosley, 2005):

- Faeces or an animal has entered the tank,

- Out of water testing, unknown bacteria has been identified,
- Getting someone sick after water drinking or,
- If it is not feasible to completely empty the tank for cleaning.

Otherwise filters seem safer and much easier to be used by citizens.

Lifestraw Filters:
Worked under the gravity, lifestraw is a cheap purification technology used where the lack of access to clean water existed. There are two types of lifestraw filters, the personal and family one.

- *Lifestraw "Personal":*

Lifestraw personal is a light filter that can be carried easily. Cost around $ 3.5, lifestraw personal has the total life of 700 liters which could be used for several months. It demonstrated (log6) efficiency in removal of waterborne bacteria and (log2) against viruses. When maintenance is needed either cleaning or replacement are required (Peter-Varbanets, et al., 2009; Schaefer, 2008; Yujuico,et al., 2010).

- *Lifestraw "family" :*

Bigger than the personal one with the total capacity of life 1800 liters (Figure 2-8), lifestraw filter cost is around $ 40. As maintenance daily back flushing is used, the first assessment was carried out by the University of Arizona. The result showed stable operation with high efficiency of bacteria and viruses removal (Peter-Varbanets, et al., 2009; Schaefer, 2008; Yujuico,et al., 2010).

Figure 2-8. Lifestraw "family"

Source: Lifestraw (2010)

(Peter-Varbanets et al. 2009) showed that among several filters lifstraw is located in the range of affordability. Lifestraw has the ability to remove 99.9999% (>log6) of bacteria, 99.99% (>log4) of viruses and 99.9% of waterborne protozoan parasites (Lifestraw, 2010).

Silver Filters:

Colloidal silver impregnated Ceramic Filter (SICF) known as SF or Potters for Peas (PFP) as a nonprofit organization promote such filters. SF was developed in Central American industrial research institute, Guatemala in 1981 and promoted by Potters for peace a member of WHO networks (Lantagne 2001a; AL-Nasiri 2010).

Low cost filter is widely spread in different countries around the world. It provides potable water for poor communities who have limited access to clean water. SF efficiently removes nearly all bacterial indicators (Lantagne 2001a; AL-Nasiri 2010) .

A study conducted by (Bielefeldt et al. 2009) installed six SFs in six points of use (POU) for four years. The study proved that the Initial disinfection efficiencies ranged between 3-

4.5log. Water spiked with 10^6 CFU/Ml of Escherichia coli was dosed to the filters. More subsequent batches of water affected the results.

Contracted by United States Agency for International Development (USAID), Jubile House Community studied SF in September 2001. The study proves that because of the small pore sizes in SF, it can remove E-Coli and total coliform even without colloidal silver. But total removal up to 100% required colloidal silver. SICF efficiently removes 100% of total and fecal coli form even after seven years of its working. The study also proved the efficient removal of bacteria but not viruses (Lantagne 2001b).

2.3.6 Yemeni Silver Filter Factory:

In 2007 SF Factory was established with only one sale point in Sana'a. Silver Filter (Figure 2-8) has being sold widely to villages supported by several organizations such as German Technical Cooperation (GTZ), SFD, United Nations International Children's Emergency Fund (UNICEF), World Bank (WB) and CARE international. SF is produced from local materials with flow rate of 1.5-3 liters per hour. SF Can remove 100% of total coliform, fecal coliform and E-Coli but not viruses (Silver Filter, 2010; Lantagne 2001a; AL-Nasiri 2010).

Figure 2-9. Silver Filter

Source: SF (2010)

2.3.7 Hygienic practices and its importance:

Supplying high water quality means nothing in the absence of hygienic practices. Hygiene education and monitoring operation and maintenance of the rainwater system with sanitary practices is considered to be an integrated important package for supplying clean water. Awareness plays an important role in educating users of treatment methods and giving guidelines in operating, managing and maintaining RWH systems (Rain Foundation, 2008).

2.4 History of Water Harvesting

Thousands of years ago, people in arid and semi-arid areas have used harvested water for the development of cities. First WH system in history was constructed in MENA region. In Jordan it is believed that WH structures have been constructed over 9000 years ago. In southern of Mesopotamia in Iraq simple WH techniques were used as early as 4500 Before Christ (BC) (Prinz, 1996; Oweis et al. 2001).

2.4.1 History of water harvesting in Yemen

Throughout history Yemen depended on collecting rainwater in cisterns, and dams to cover the demand during the draught season (AL-Mujahed, 2010).

In south Yemen, Tawila Tanks (Figure 2-10), located in the hills at the western edge of Crater District, are a collection of pre-historic rain water tanks. Tawila system has channels that capture rainwater runoff from the nearby mountains. Tawila system is dated back to around 1,500 BC and represents probably the oldest element in Aden’s cultural heritage and Yemen. As well as in the other part of Yemen (North of Yemen), a system dating back to at least 1,000 B.C. diverted enough floodwater to produce agricultural products (Prinz, 1996; Taher and Saleh, 2010).

Figure 2-10. Tawila RWH tanks, Aden

Source: Taher and Saleh (2010)

In Yemen, ruins of dams and reservoirs as well as the unique, spectacular mountain terraces, confirm the long history of WH. Marib dam in north Yemen was a floodwater diversion technique (Prinz, 1996). The great historical Marib dam and its collapse are mentioned in the Holy Quran. Recent archaeological excavations discovered ruins of irrigation structures around Marib city dating from the middle of the third millennium BC (some 4000 years ago). Farmers in this same area are still irrigating with floodwater, making the region perhaps one of the few places on earth where runoff agriculture has been continuously used since the earliest settlement (Bamatraf, 1994; Centre for Science and Environment, 2005).

Recent studies in Yemen indicate that the villagers in the mountainous areas know RWH systems since hundreds of years. They use harvested water for different purposes starting from drinking purpose to supplementary irrigation. Old local manufactured materials such as Kadhadh[1] are used to build the cisterns. Such material proved its resistance to all environmental changes (Taher, 2003; AL-Mujahed, 2010).

Up to seventeen several traditional methods of RWH have been used by Yemenis such as terraces, dams, AL-Berak AL-Asadiah[2], AL-Kohoof[3], Karifs[4], rock bound and AL-Seegayat (cisterns) are some of the traditional methods of RWH used by Yemenis. Some pictures for such techniques are shown in Appendix (D).

In the recent years, SFD is the only institution that has good experience in WH, started to rehabilitate RWH structures and develop new structures. In 2006, RTRWH projects have been piloted in two villages in Taiz and Hajah governorates. Consequently, the policy was developed and the RTRWH projects have been expanded throughout the country.

In level of households SFD has implemented 99 projects of RTRWH in the period of 2007-2009. A total of 8381 tanks with total capacity of 476852 cubic meters is the result of these projects. The total cost of the projects is 24.5 Million united state dollar (MUS$). Most of these projects are located in rural areas while some are located in the pre-urban area of Taiz governorate (AL-Mujahed, 2010).

There are many reasons why the RTRWH projects are concentrated in rural areas rather than urban, among them are:

- 3/4 of the population is rural,
- The water needs is much higher in rural than in urban,

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[1]Kadhadh: is a traditional sealing material composed of a mixture of burnt lime stone, sand or volcanic ash, and water.

[2] AL-Berak AL-Asadiah: Water pounds built from stone masonry and clay for RWH.

[3] AL-Kohoof: Natural underground holes used as underground rainwater tanks.

[4] Karifs: are natural or manmade depression in impervious soil used for storing water

- The rural population is scattered which makes it difficult to serve with conventional systems of General Authority for Rural Water Projects (GARWP). The population scattered make the RWH and RTRWH in particular a perfect solution.
- The policy of the RTRWH requests the homogeneity of the community which will insure the inclusion of poor families, as the policy states that the community shall identify the poor families and agree to support them in building their cisterns. However this condition isn't available in urban areas.

For 2011, SFD is going to pilot RTRWH in Taiz city with the cooperation of Taiz Water and Sanitation Local Corporation (TWSLC). The pilot project is going to be implemented in areas served by the public water network (AL-Mujahed, 2010).

2.5 IWRM, RTRWH and Sana'a Basin

2.5.1 IWRM and water management

According to Global Water Partnership (GWP) (2000), IWRM is *"a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".*

IWRM is an appropriate approach to water management. It has been accepted globally as the way of efficient, equitable and sustainable development and management of the limited water resources. However, achieving sustainable development management of the whole water sources including the renewable WH source required three factors (Figure 2-11) to be taken into consideration (UNDP, 2009; GWP, 2000). Below are the factors:

- Ecological sustainability,
- Economic efficiency and

- Social equity.

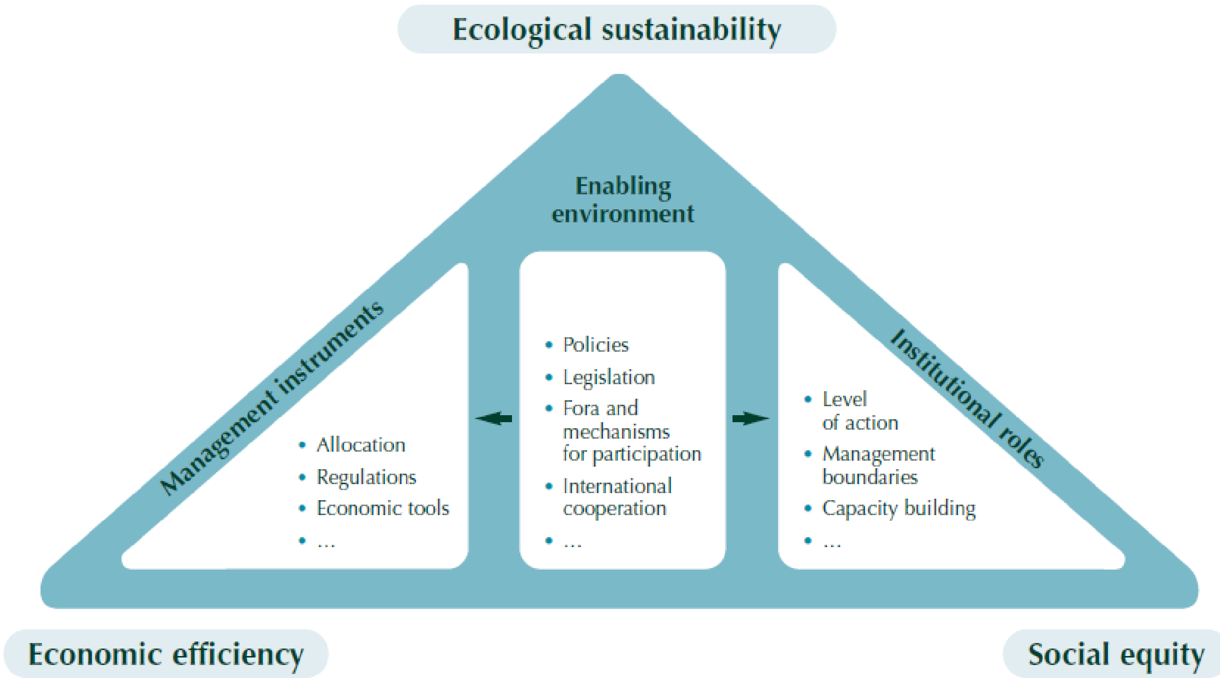


Figure 2-11. General framwork of IWRM

Source: GWP, (2000)

2.5.2 Three Phases of IWRM in Sana'a Basin

In 2003, Yemen started a long term process of IWRM in Sana'a basin where the water is scarce. Through three phases, 15 years were selected as a timeframe of IWRM process. However, on May 30-31, 2010 an Action Oriented Policy Paper (AOPP) evaluated the achievements and the challenges of the first implemented phase. AOPP also recommended the preparation of the second phase of IWRM covering 5 years period (2011- 2015) (Ward, et al., 2010).

Proposed IWRM goals and Phase II outcomes:

An action Oriented Policy Paper conference discussed the following water resources management objectives for IWRM in Sana'a basin (Ward, et al., 2010):

1. Affordable safe water for domestic and industrial use, with the deep Tawilah sandstone aquifer which should be reserved for this purpose,

2. Sustainable farm incomes in “greenbelt” areas reserved for farming
3. Any transfer of water between uses should be done on a win-win basis without any uncompensated harm
4. Sustainable governance institutions and agencies for integrated water resource management (IWRM)

2.5.3 RWH, activities of IWRM phase II

Rainwater Harvesting activities at the west and southwest sub basins have been stated as activities of IWRM phase II. National Water Sector Strategy and Investment Plan (NWSSIP) and SWSLC have been pointed out as responsible bodies of the implementation. A number of rainfall harvesting projects completed within the Sana’a basin that can store up to 500,000 m^3 per year in 2015, stated as an output of the WH activities. Rainfall harvesting projects start to be a popular solution to face water scarcity in Sana’a basin is the final indicators that ensure the successful implementation of the WH activities.

2.5.4 RTRWH emphases IWRM in Sana’a Basin

Besides using it as safe water, RWH, as a significant tool under the umbrella of IWRM, yields numerous environmental social and economical benefits. RWH can contribute significantly to poverty alleviation and sustainable development (Bancy, et al., 2005).

The public awareness program, authorized by National Water Resources Authority, Sana’a Branch (NWRA-SB) during the first phase of IWRM, will continue in the second phase. Annual budget of USD 150,000 has been allocated for the program. However, RTRWH from houses and public buildings has been sated as a one key emphasis area in this program that linked to decentralized IWRM and technical conservation measures (Ward, et al., 2010).

2.6 RTRWH in Urban Areas

Accelerated development and increasing water demand in urban areas are putting stress on existing water resources (Villarreal and Dixon, 2005). Sustainability of urban future requires an efficient and appropriate water use. RWH has an essential role in this task. Roofs in urban cities represent a significant percentage of the large impermeable areas. Hence, offering a good possibility of rainwater collection (Villarreal and Dixon, 2005; Abdulla and Al-Shareef, 2009).

for the sustainability of the RTRWH in urban areas, developing the ownership and skills through cooperation between the government, the private sector (NGOs and Scientists) and the urban households is required (Figure 2-12) , all stakeholders should be involved in all phases of planning, designing and implementing of RTRWH projects. Stakeholders' consultation and public participation consider as a key to negotiate positive and negative points (UNEP, 2009; Mwenge Kahinda, et al., 2007).

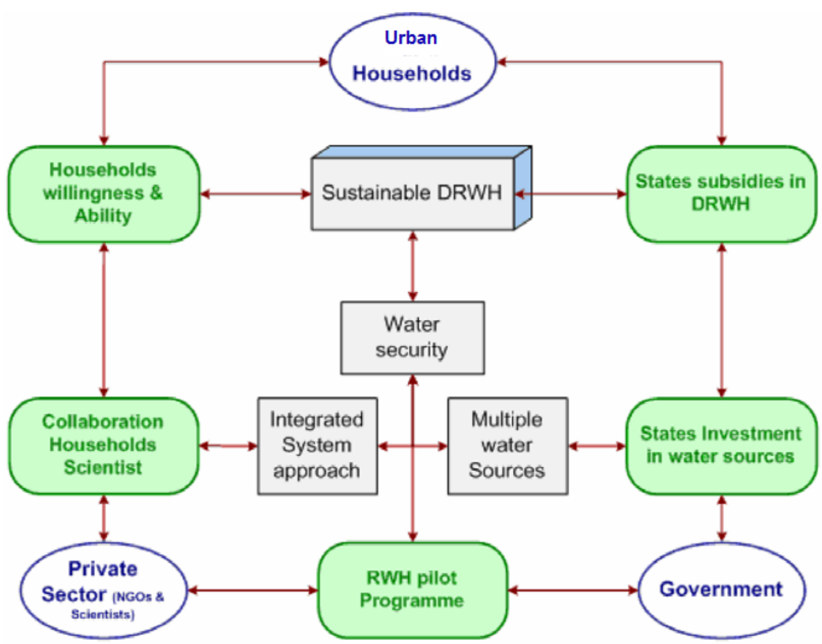


Figure 2-12. Cooperation between all the stakeholders

Source: Adapted from (Mwenge Kahinda, et al., 2007)

2.7 Previous Studies

In different countries, it has been reported that RWH can promote significant water saving, reduce the water shortage and used for drinking purposes.

(Villarreal & Dixon 2005) carried out a study in Ringdansen, Norrkoping, Sweden. Rainwater reservoir storage model has been used, moreover, four main scenarios for different domestic rainwater uses have been considered. The study showed that RWH will give an important water saving efficiencies. However rainwater tanks should be included as a part of dual water supply solution.

(Handia et al. 2003) carried out a study to assess the potential of RWH in urban Zambia. It showed that rainwater is suitable for drinking purposes. Most of the residents express their interest in RWH but they were concerned with its taste and debris.

A RTRWH study analyzing 27 houses in Newcastle Australia, gave the result of 60% as a potable water saving (Coombes, et al., 1999 as cited in (Abdulla & Al-Shareef 2009).

Another study performed by Ghisi, et al. (2006) as cited in (Abdulla & Al-Shareef 2009), showed that by using RWH for 62 Brazilian cities the potential of water saving ranged from 34%-92% with an average of 69% of water saving potential.

A study in Germany by Herrmann and Schmida (1999) as cited in (Abdulla & Al-Shareef 2009), showed that the potential of potable water saving in houses vary from 30% to 60%, water demand and roof areas are the main factors that affected this percentage.

A study in Jordan showed the result ranged from 0.27% to 19.7% as the potential of potable water saving in 12 governorates. Rainwater sampling indicated that the measured inorganic parameters met the WHO standers for drinking water while fecal coliform as an important indicator, exceeded the maximum allowable value of drinking water (Abdulla & Al-Shareef 2009).

(Sturm et al. 2009) study of RWH as an alternative water resource in rural areas in central northern Namibia presented the fact of reasonable, sustainable and effective way of applying decentralized techniques of RWH in areas like Epyeshona. Ferrocement and block tanks have proven to be the most efficient options among other alternative of tanks. Both types are affordable by users and economically feasible.

CHAPTER THREE
STUDY AREA

3.1 Location

Sana'a basin, with 22 sub-basins, is a highland located in the western part of Yemen and in the central part of Sana'a governorate (Figure 3-1) with an area about 3200 square Km (24% of Sana'a governorate) (World Bank, 2003; WEC, 2001).

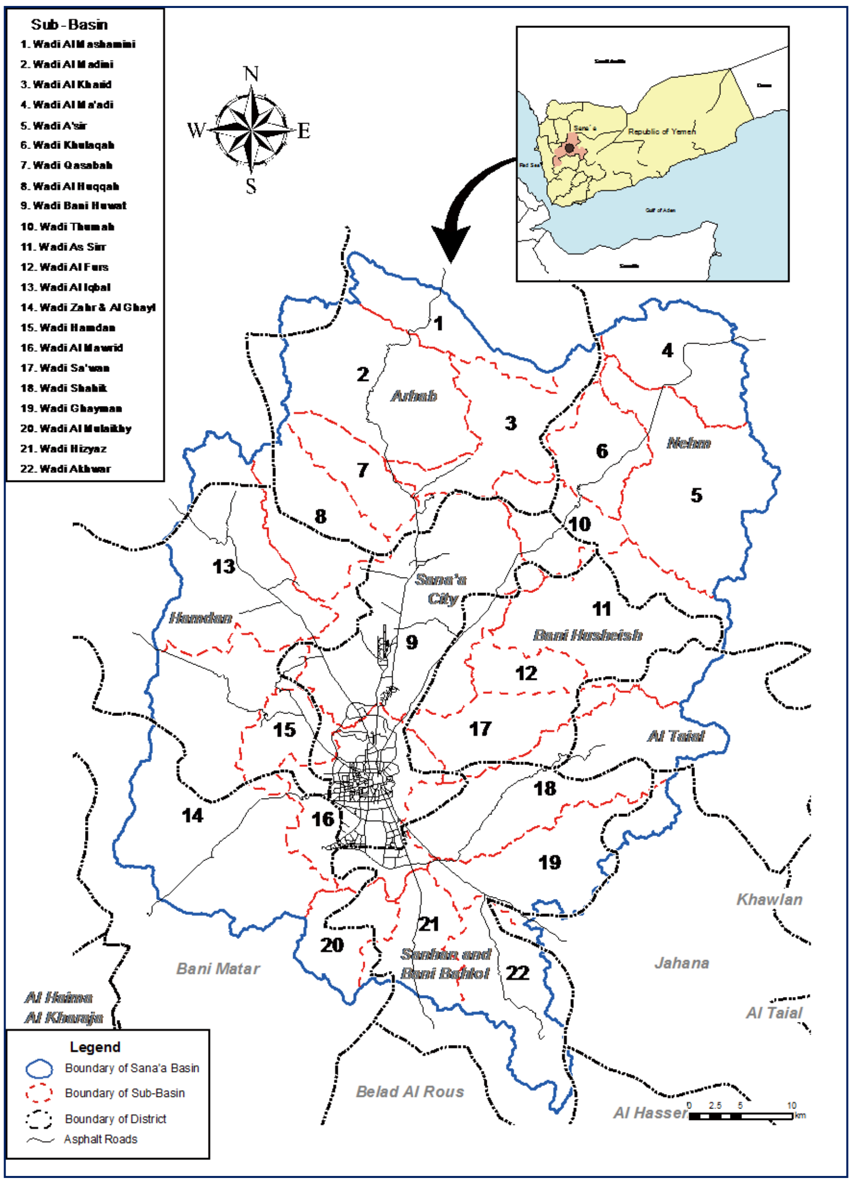


Figure 3-1. Sana'a Basin

Source: JICA (2007)

3.2 Population

Sana'a basin is one of the most heavily populated areas in Yemen. The location of the national capital in the basin, strongly contribute to the high population growth (5.55% according to 2004 census). Using the forecast from 2004 census Sana'a city population in the year 2014 will be 3 million, for the rest of the basin (rural areas) it is estimated to be 0.5 million, in total the Sana'a basin population in 2014 will be 3.5 million. Population density over the basin especially Sana'a city, is shown in Figure 3-2.

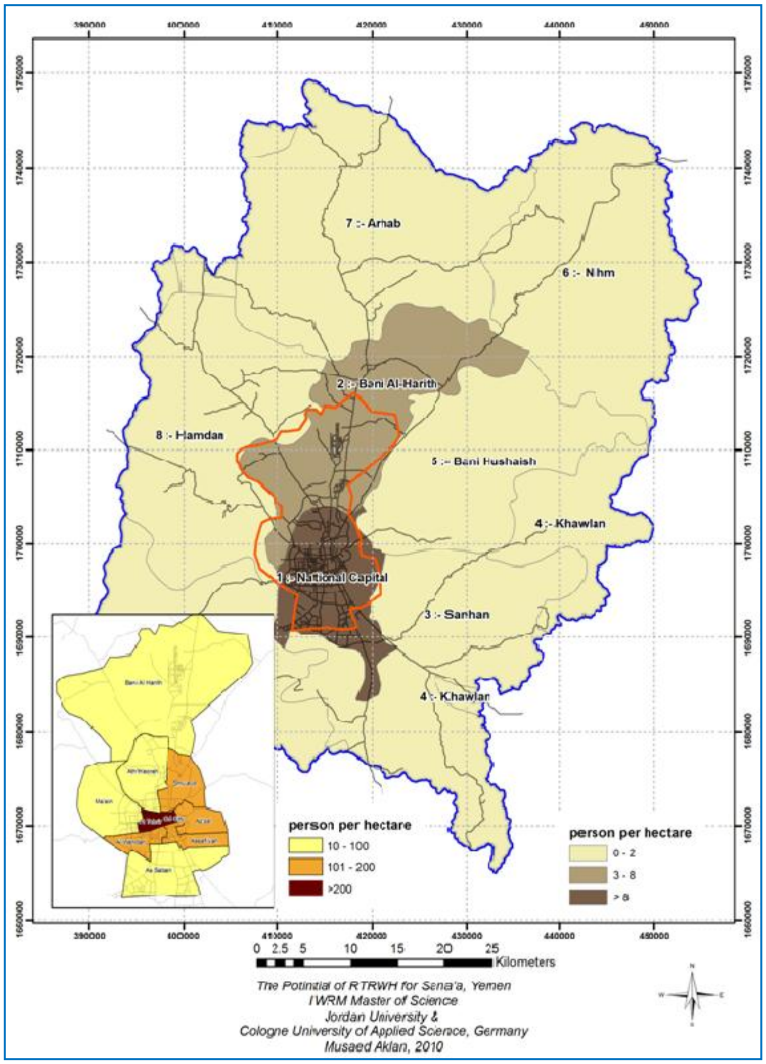


Figure 3-2. Population density, 2004

3.3 Geomorphology

Sana'a basin has a significant variation in its altitude; the highest point of the basin is located in (Jabal An Nabi Shuayb) with an elevation of 3700 m.a.s.l, whereas the lowest point with an elevation of 1900 m.a.s.l is located in Wadi Al-Karid. However, the mean altitude of the basin is about 2300 m.a.s.l (AL-Suba'I and Barat, 2006). Digital elevation model (DEM) of the basin is with 30m resolution is shown in Figure 3-3

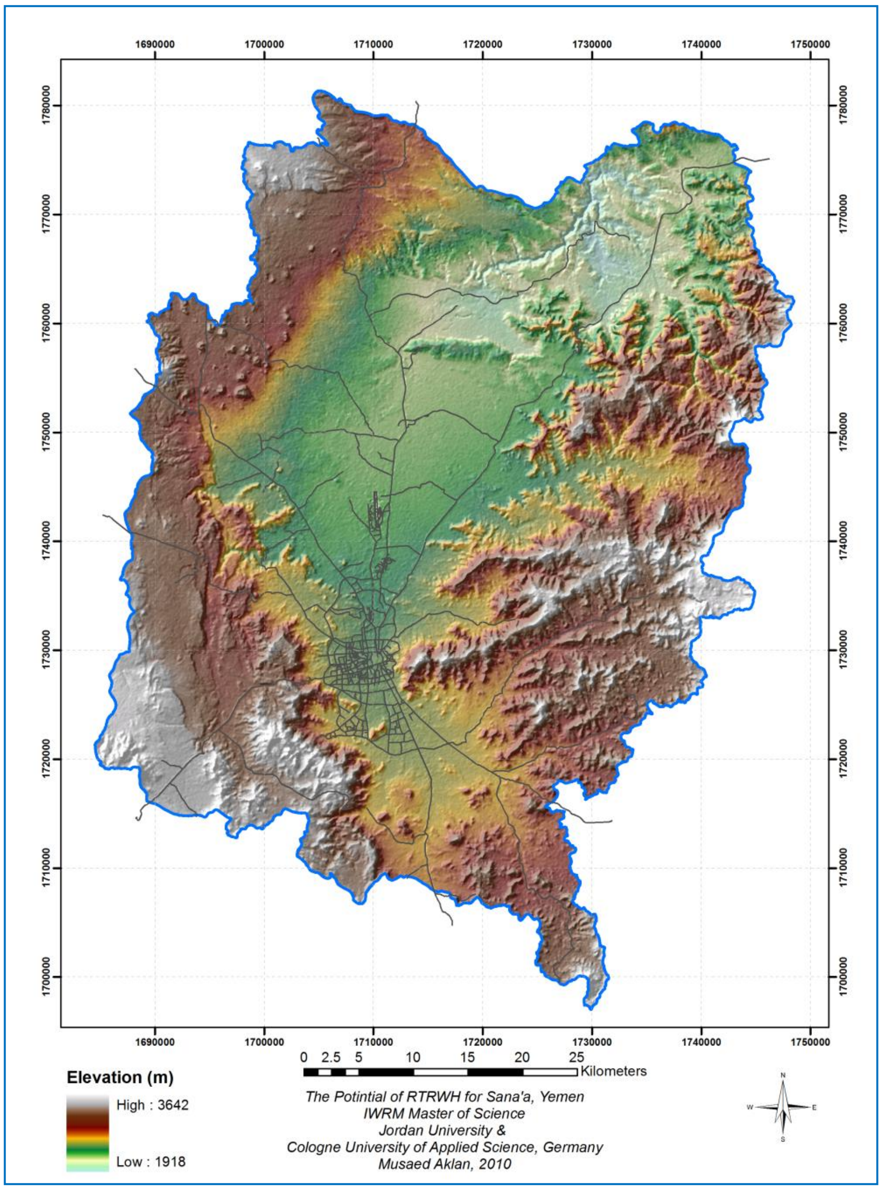


Figure 3-3. Digital elevation model (DEM)

3.4 Geological of the Basin

Sana’a basin geology has not yet been studied structurally in details; nevertheless, there are limited studies that depend on seismic and drilling information. Sana’a basin is close to an active and complicated structural trends, which they control the formation of the Sana’a basin. Sana’a basin is incurred to different tectonic trends of both extensional and compressional regimes. However, extensional regime considered to be the most dominant structures has covered all old structures (Hydrosult, 2010). Geological map (Figure 3-4) by GAF, (2007) shows the compiled structural features according to their hydrogeologcal relevance. The following are some description points for the main features in the map:

- The Tawila Sandstone is the most important aquifer, it has a good recharge potential
- Lower Teriary Basilt is a fractured aquifer with a hydraulic connection to the underlying Tawila sandstone, this also make it a potential aquifer for recharge.
- Upper Tertiary and Quaternary Basalts have good aquifer properties. However the composition of the rock is heterogeneous and groundwater flow and storage seem to be complex.
- Alluvium is a poor aquifer with a limited recharge capacity. But the recharge can take place along foot of the slops and wadi courses.

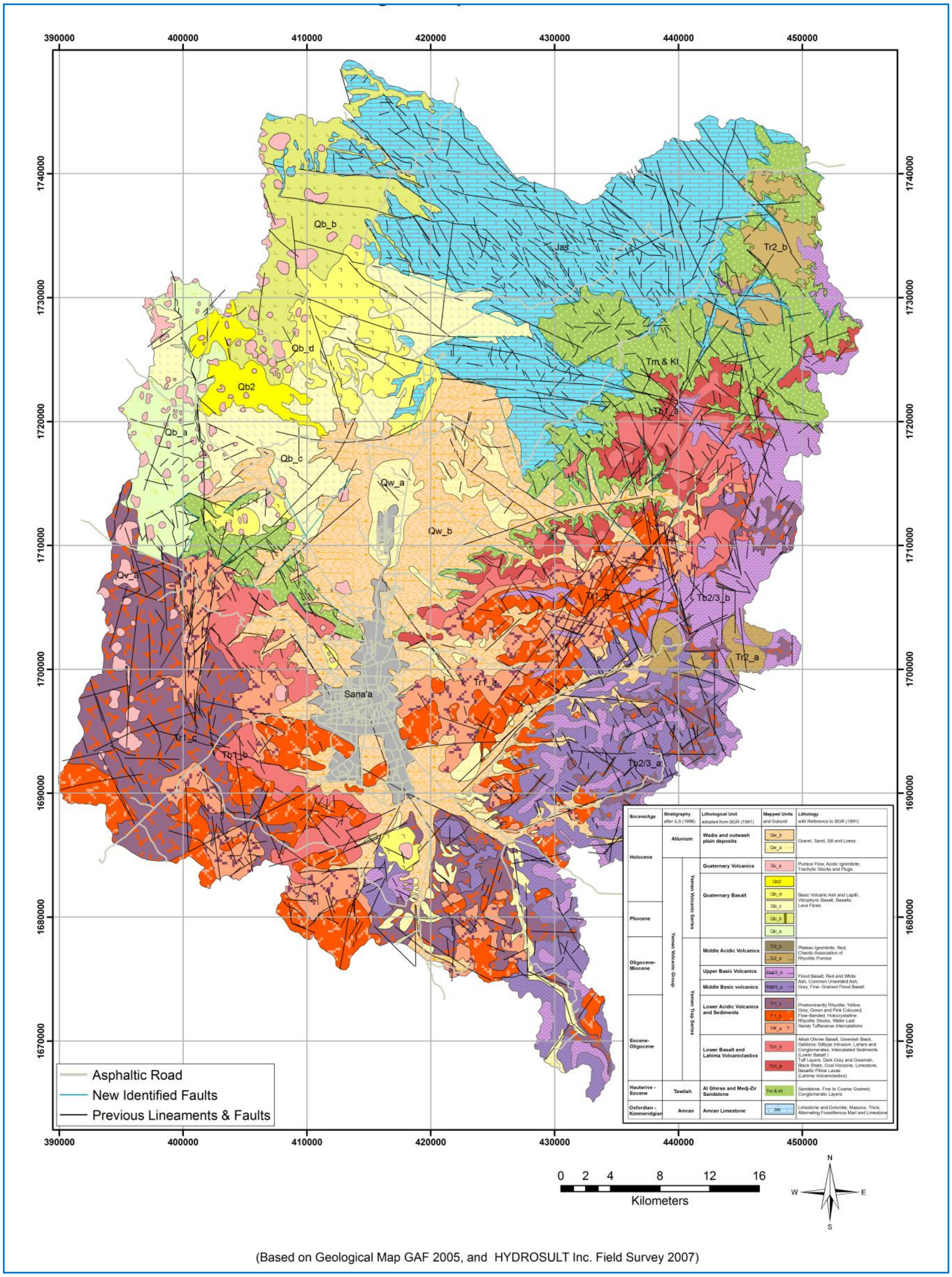


Figure 3-4. Geological Map, Sana'a Basin

Source: GAF (2007)

3.5 Land use:

Qat and grapes crops are more dominant among other crops. GAF, 2007 concluded that 91% of the irrigation acreage is covered by these two crops. Furthermore, Qat and grapes are dominant cash crops. Table 1-3 illustrates the cropping pattern characteristics in the basin.

Table 3- 1. Cropping pattern

Crop	Acreage (ha)	Percentage %
Qat	11471.5	3.5
Grapes	5814.3	1.8
Irrigated mixed crops	1554.3	0.5
Rainfed crops natural/ vegetation	18498.7	5.7
Orchard	113.1	0.03
Other land	286518.2	88.4
Total	3239768376	100

Source: GAF 2007

3.6 Temperature, Humidity and Wind

The average temperature in Sana'a recorded by National Water Resources Authority Station (NWRA-A) is showed in Figure 3-5. The hottest season is between June and August, while the coldest season stars from November and end in February.

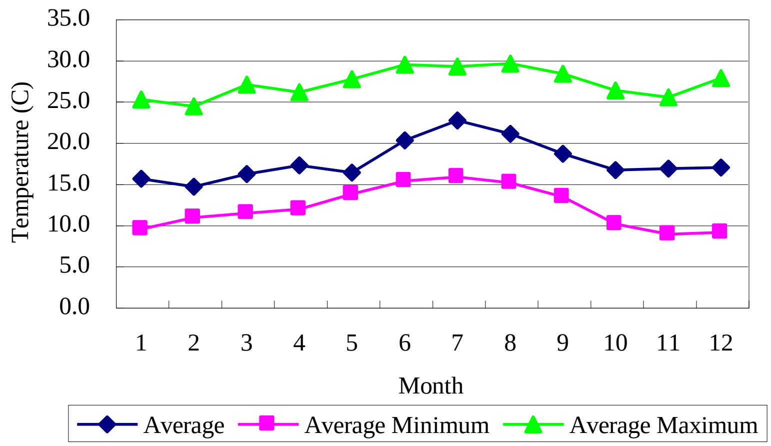


Figure 3-5. Monthly Temperature (NWRA-A, 1989-1997)

Source: JICA (2007)

For Sana'a basin, Table 3-2 shows records of the meteorological data of the temperature, relative humidity and wind speed for the period 1983-1990.

Table 3- 2. Meteorological data (means of 1983-1990) Sana'a, CAMA (Civil Aviation and Meteorology Authority)

months	Mean Temperature (^{o}c)	Relative Humidity (%)	Wind Speed (m/s)
Jan	12.9	46.3	2.8
Feb	16.8	49.9	2.7
Mar	19.1	49.9	3.2
Apr	19.6	57.8	4.4
May	21.9	43.8	3.8
Jun	23.5	41.0	4.8
Jul	24.0	35.8	4.6
Aug	23.5	47.7	4.3
Sep	21.4	39.4	3.2
Oct	18.5	38.7	2.9
Nov	15.7	39.5	2.4
Dec	13.0	39.4	2.8

Source: Hydrosult (2010)

3.7 Precipitation

Rainfall in Sana'a is recorded at NWRA-A station for separated years. Table 3-3 shows the rainfall for the years 1990 – 2003 with some gaps. Rainfall in Sana'a is ranged between 110 – 350 mm/year. The tow rainy seasons are between March to May and July to September.

The rainfall distribution over the Sana'a basin is shown in Isohyets map Figure 3-6. The north eastern basin has less than 200 mm/year of rainfall while the southern part has more than 300 mm of annual rainfall. However the central of the basin, where Sana'a city is located, has between 200 – 250 mm/year.

Table 3- 3. Monthly rainfall NWRA-A

Type of year	Year	Months												Annual
		1	2	3	4	5	6	7	8	9	10	11	12	
	1990	0	2.5	40.5	19	3.5	0	31.5	2	25	0	0	0	124
Mini Year	1991	0	5.5	45	11	11.5	0	2.5	35	0.5	0	0	0.5	111.5
Max Year	1992	2.5	0.5	20	20	64.5	3	10	140	24.5	26	0	39.5	350
	1993	2.5	9	13.5	83	79.5	6	3	25	30.5	1	45	19	316.5
	1997	5.5	1.5	14.5	29.5	7.5	2	12.5	33.5	0	60.5	34	1	201.5
	1998	0	0.5	8	19	68.5	0	63	176	0	0	6.5		341
	2000		0.5	8	30	57.5		9	58.5	2.5	16	2.5	146	330
Median Year	2001	29	108	31	13	1	0	49	21.5	21	22.5	7	1	303
	2002	0	0.5	8	1	1	0	49	21.5	21	22.5	0	0	124.5
	2003	0	0	10.5	52.5	12.5	0.5	0	0	0	3	2	146	227
Ave year		4.33	12.80	19.90	27.80	30.70	1.28	22.95	51.20	12.50	15.15	9.60	39.17	243

Source: Hartong and Kariuki (2008); Taher and Saleh (2010)

3.8 Evapotranspiration

Robertson (1990) cited in JICA (2007), had estimated the potential evaporation by penman method with an average of 2000 mm annually. SAWAS, (1995) cited in JICA (2007) estimated the potential of evapotranspiration to be 2475 mm based on meteorological statistics.

The maximum evapotranpiration was estimated in June (average 9.4 mm/day) and the minimum in February (4.8 mm/day)

Based on satellite imagery analysis GAF (2007) estimated evapotranspiration with the total of 113.1 MCM of water transpired in Sana'a basin during the period 1 July 2004 to 30 June 2005. An amount of 83.8 MCM was assigned to irrigated fields surfaces whereas 29.3 MCM of water were evapotranspired from crops or natural vegetation surfaces (GAF, 2007)

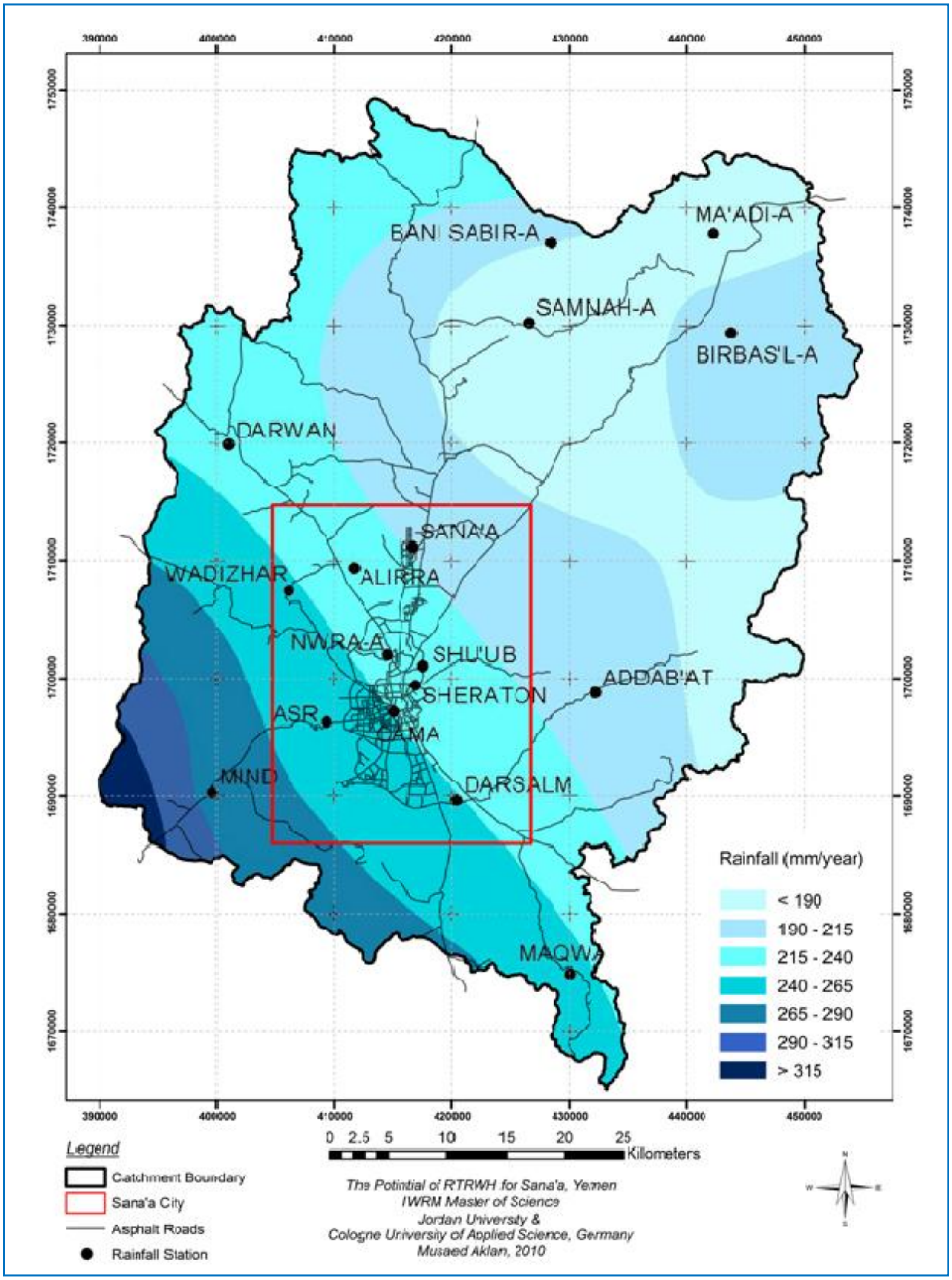


Figure 3-6. Annual rainfall Isohyets map for Sana'a basin, after BGR (2004) and JAF (2005)

Source: GAF (2005) cited from BGR, 2004

3.9 Water resources

3.9.1 Surface water

44 surface dam, 24 dams/pools and 145 springs are surface water used for recharging groundwater, irrigation and domestic purposes. Most of the dams (Figure 3-7) are constructed for ground water recharge. A number of 15 dams are used for irrigation and another 3 dams are used for domestic uses. 15 small-scale dams built by rural people are mainly used for irrigation. However the total annual flow of the dams is 24 MCM. Springs (Figure 3-8) also are used for different purposes, 34% of them (49 springs) are used for domestic uses in rural areas, and the rest are used for irrigation and livestock. About 6-9 MCM was estimated as an annual yield of the springs (Hydrosult, 2010, JICA, 2007).

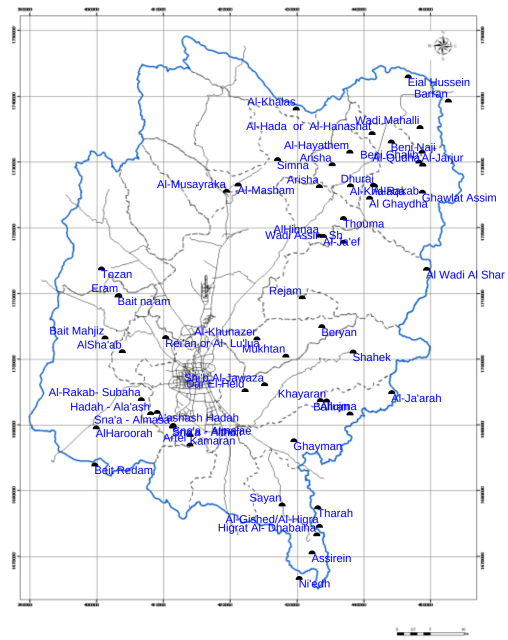


Figure 3-7. Locations of Dams

Source: JICA (2007)

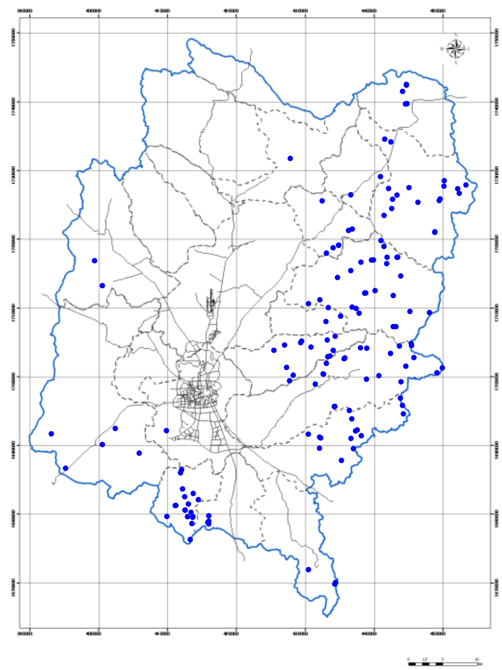


Figure 3-8. Locations of springs

Source: JICA (2007)

3.9.2 Groundwater

3.9.2.1 Ground water recharge

Since 1970s, different studies have estimated the amount of groundwater recharge which is ranged from 28-63 MCM annually, the latest estimation by Norman and Mulat (2007), cited in JICA (2007) was 50.7 MCM.

3.9.2.2 Ground water uses

I. Domestic water use

1) Urban water supply

Whether public or private water supply, groundwater is the main source of water for different urban uses (domestic, non-domestic, industrial and touristic uses).

- *Public water supply*

Sana'a city is the urban area in the basin. It has three main well fields that have being used for water supply. SWSLC drilled about 130 wells in these fields, 80 well have been operated while the rest have been stopped due to the groundwater level dropped. Water supply is increased by 27% from 1998-2006, number of wells has been increased as well by 39%. In 2005 it is reported that 24.4 MCM is the production amount of water, 12.5 MCM is billed for domestic consumption for 672,141 inhabitants with average consumption of 50.8 l/d per person (JICA, 2007).

- *Private water supply*

For the population not connected to the public network, private water sources are used, namely private piped network, water tankers (as sole/main source or as supplementary sources) and treated water in containers. From private water sources Sana'a city received an amount of 29.89 MCM as estimated in 2005. It covers 1,169.421 inhabitants with an average consumption of 70 l/d per person (JICA, 2007).

2) Rural water supply

WEC, (2001) carried out the estimation of water consumption; in rural areas the consumption of 21 l/d per person was estimated. General Authority for Rural Water Supply Projects (GARWSP), the responsible body for rural water supply, adopted an average of 40 l/d as daily consumption in rural areas. JICA, (2007) used The last estimation in order to calculate the total rural water supply which was estimated to be about 4.40 MCM in the year of 2005. In rural areas surface water from springs and some dams are being used. However, according to the NWSSIP, the percentage of rural population with access to safe water accounts only to 25% for entire Yemen. When applying this rate for Sana'a Basin in the year of 2005, only 1.1 MCM of water is abstracted to serve the rural population through the public water supply systems.

II. Irrigation water use

With an irrigation water efficiency of 40% the annual water abstraction for irrigated area was estimated to be 209.2 MCM in 2005 (JICA, 2007).

III. Industrial and touristic water uses

Water use for both industrial and tourism sectors was estimated to be 4.76 and 0.36 respectively (JICA, 2007). However, industrial and touristic activities are in urban areas (Sana'a city) where ground water is used for such activities.

3.10 Water balance in Sana'a basin

Water balance in Sana'a basin was calculated by JICA, (2007) based on the previous data of water resources and water uses. Table 3-4 illustrates the calculation of the water balance for Sana'a basin for the year 2005. Water balance calculations are based on the ground water abstraction for different uses and groundwater recharge.

Table 3- 4. Water Balance in Sana'a Basin (2005)

Urban water use*		Rural water supply	Irrigation	Industry	Tourism	**Total**	Recharge	**Balance**
Public	Private							
24.4	29.9	1.1	209.2	4.76	0.36	**269.7**	50.7	**-219**

*: It is composed of both domestic and non-domestic
Unit: million cubic meter

Source: JICA (2007)

From the table above, the abstraction is six times of recharge with a deficit of 219 MCM per year."*If these annual amount is accumulated, non-renewable water resources will continue to be depleted*" (JICA, 2007).

CHAPTER FOUR
METHODOLOGY

4.1 Introduction:

To fulfill the study objectives, especial methodology should be followed. The study type, objectives, type and reliability of required data, study area characteristics and required tools are some factors that determine the methodology of the study. In this study whether for desk or field works different steps have been followed. Starting with summary, this chapter discussed the study methodology in details.

Methodology Summary:

To achieve study objectives the following methodology is applied.

- Relevant data about the study area have been collected; previous studies and literature review related to Sana'a basin and Sana'a City have been studied as well.
- Social Fund for Development is visited many times in order to get an overview about their experience in the field of WH. As well as Ministry of Water and Environment (MWE), NWRA, NWRA-SB, SWSLC, and other institutions have been visited whether for Key informant interviews or collecting related data.
- Conduct two types of interviews; Key informant interviews and household interviews. Presenting the study proposal followed by unprepared open ended questions were the main two steps of the Key informant interviews while three forms of prepared questions have been conducted to cover three deferent types of the public interviewees. The samples size was estimated to be 114 questionnaires; however the study has conducted of 119 interviews, covering different sites in the city.

- Conduct water quality surveys through collecting and analyzing six samples of rainfall, four samples of them were from existing RTRWH systems.

- ArcGIS and AutoCAD programs have been used to digitize 2009 satellite image of Sana'a and combine it with annual rainfall isohyets map. The city is divided into three zones according to rainfall density. Rational method then used to calculate the potential quantity of rainwater that can be harvested from the rooftops of Sana'a city.

- Matrix for the selection process of tanks types has been developed based on the factors of cost, required capacity and space area availability

- Dried-up wells, ponds, check dams, and unused cesspits have been evaluated and identified as other possibilities of RWH. Different suggested techniques of rehabilitation were stated in order to get use of dried-up unused wells through adapt them to recharge wells. According to the type of dried-up wells, different options of ground filters have been illustrated by sketches. AutoCAD program has been used to draw cross sections of filters.

4.2 Rooftops Runoff calculations

There are different methods used for runoff calculation. The rational method is the most popular method for calculating rooftops runoff that generated from the rainfall. Moreover it is mostly preferable for designing the systems in urban areas. This method is unanimously used with all RTRWH studies reviewed in calculating the roof top surface runoffs

Rooftop runoff can be calculated by rational method as follows:

$$Q = 0.278\ CIA \quad \text{………………………………………………………….Eq 1}$$

Where:

Q: runoff rate (m^3/sec)

C: runoff coefficient.

I: rainfall intensity (mm/hr)

A: catchment area (km^2)

4.2.1 Rainfall data, collection and analysis

Rainfall data for 16 Rainfall stations were collected from two sources, NWRA and NWRA–SB. The rainfall records are not complete since big gabs of missing data were existed.

Rainfall in Sana'a basin has time and space variable of distribution. Sana'a airport station is the only station that had more than 30 years complete data with some gaps in some months. Some stations had major gabs and some of them only had a few years of data (World Bank, 2009). Figure 4-1 shows how the lacks of measurements are included in NWRA-A station.

Lack of financial and the technical support were reported the major reasons for such of gaps in the rainfall data. The fine temporal resolution of rainfall is very limited. 5 minute rainfall data were found for only eight stations, where the zero values were recorded in the most of the time series.

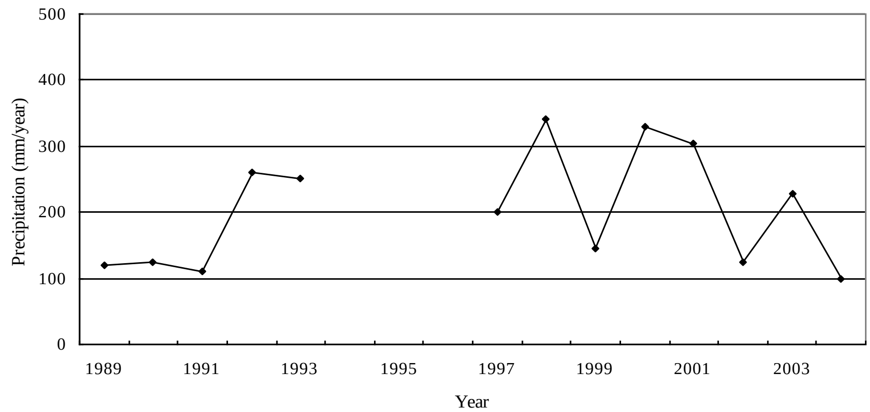


Figure 4 - 1. Annual Precipitation (NWRA-A)

Source: JICA 2005

Rainfall data from NWRA database have several data problems such as accumulation of data over several days recorded as a daily rainfall, repeated data and confusion between no data days and zero rainfall. No spatial correlation of rainfall data was found (World Bank, 2009).

Because of the uncompleted and missing rainfall data, it was too difficult for the city to be divided into zones according to the rainfall stations. As a result isohyets map of the annual rainfall for Sana'a basin (Figure 3-6, Chapter 3) have been used. Located between the equal rainfall lines of 195 mm/year and 265 mm/year Sana'a city is divided to three zones namely north, middle, and south zone. Table 4-1 shows the annual rainfall for the three identified zones.

Table 4 - 1. Three rainfall zones of Sana’a city

zone	South	Middle	North
Rainfall (mm/year)	190-215	215-240	240-265

4.2.2 Rooftops area calculation:

Based on 2009 satellite image, Sana'a city rooftops areas have been calculated. Deferent programs were used in such calculation. Starting with ENVI software, supervised classification method is applied. Several training data have been created, at the same times different methods of enhancements under supervised classification have been used. As a result Sana'a city is classified. However the outputs of the program were not enough to make a good separation for different objects including the rooftops.

In all attempts, none of the output thematic maps correctly detects and separates rooftops from other objects. Equal color for different objects (e.g. mad roofs and mad roads) considered as the main reason.

AutoCAD 2007 program then has been used to produce the digitizing map with thousands of boundaries. Figure 4-2 shows part of the final output of digitizing map. These boundaries have been drawn one by one in order to cover the whole city and classify the rooftops from other objects in the city. Figure 4-3 illustrates the final output digitizing map.

Figure 4 - 2. Part of the final output of digitizing map, Sana'a city

ArcGIS desktop software then used. Digitizing map as an output of AutoCAD program is inserted to ArcGIS program in order to make a combination of digitizing map with isohyets map. Such combination helps to divide the city to three zones according to the equal rainfall lines. ArcGIS has the tool to divide the city into zones and calculated the total rooftops areas in each zone.

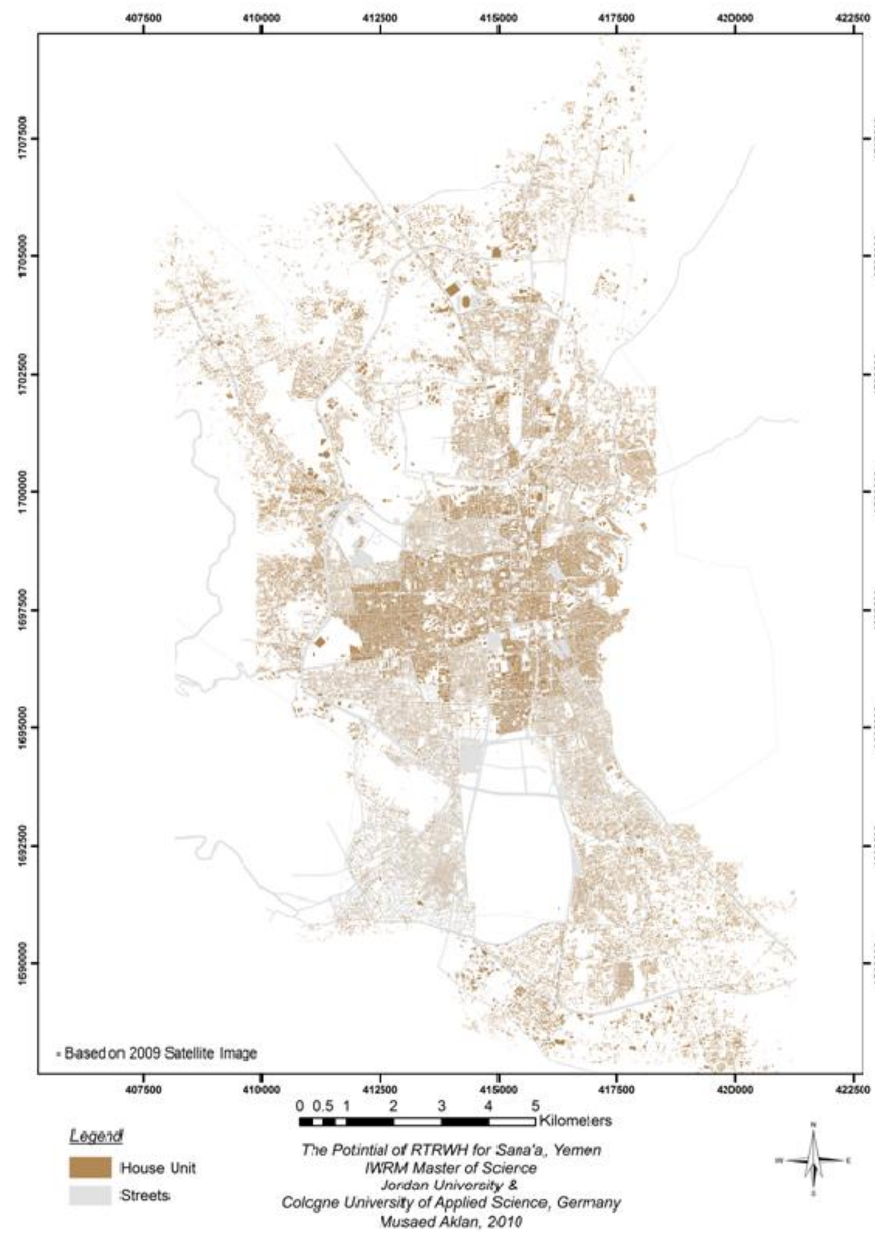


Figure 4 - 3. Sana'a digitizing map

4.3 Rooftop Rainwater Samples:

4.3.1 Introduction

“*Rainwater collected from clean house roofs can be of better microbiological quality than water collected from untreated household wells*” (WHO, 1997). Nevertheless, using rainwater for the purpose of drinking required sampling and testing with special care of the necessary requirements. Containers type, sample volume, time constraints for return of samples are essential factors to be taken into consideration. Accuracy of testing results primarily depends on the accuracy of the sampling and storing ways. Since concentration of parameters can change over time, the requirements of collection and storing of the sample depend on the parameters that are needed to be tested.

4.3.2 Rainwater Sampling:

Six samples have been collected and tested at the end of rainy season with difficulties such as, time constraints , in appropriate roofs and tanks, along with the absence of RTRWH idea among citizens,. Figure (4-4), shows sampling locations.

Samples were tested in two different laboratories. In NWRA-SB laboratory the first four samples are tested without turbidity results. The fifth and sixth samples are the only samples tested at SWSLC laboratory and they are the only samples which have turbidity results. For other reason the first two samples have no biological results.

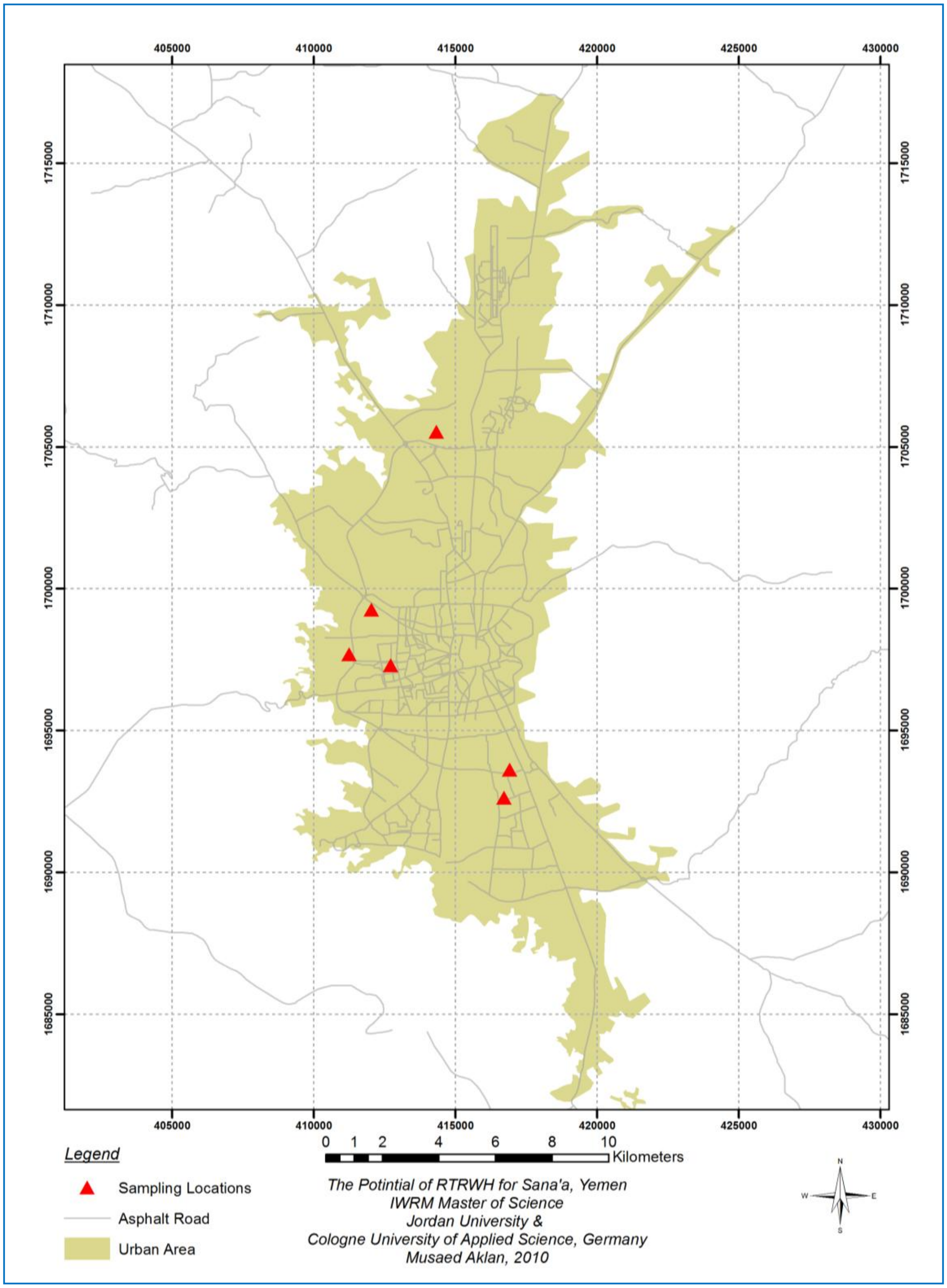


Figure 4 - 4. Rainwater sampling locations

The first and second samples were collected from the Al-Sabain district and WEC, Sana'a University in two consecutive days. The samples were collected from the gutters during the rainfall events. For those two samples, physical and chemical parameters have been analyzed.

From the down pipe of the cleaning gutter the third sample was taken from RWH system in AL-Qader Massjed. Located in AL-Sonaina. AL-Qader Massjed has a ceramic roof connected to the underground concrete tank by PVC gutter. The first flush has not been used since the system has no first flush device. The tank is used for both harvested rainwater and water provided by tankers. As a result of this mixed water and the difficulties of reaching the main gutter inside the tank, the sample has been taken from the other gutter. However the second gutter (where the sample is taken) is located in the lowest point of the roof and used for cleaning (Figure 4-5). In this sample physical, chemical and biological parameters have been tested.

Figure 4 - 5. The place of sampling (cleaning gutter), Massjed AL-Qader

The fourth sample has been collected from a private owned multi-roof building located in Hail Street. The building has a different unit with different levels of corrugated galvanized steel sheets and concrete roofs. RWH techniques are used. Different levels of roofs made from different materials are connected to each other ending with one outlet (gutter). The first rain in the beginning of the rainy season or after a long period of dry days goes to a small garden as a first flush; from the next rain the gutter located over the garden is connected by tube pipe to the underground concrete tank. Like the previous sampling the sample has been collected from the gutter since the tank is used for rainwater and water from other source (public network or tankers). Physical, chemical and biological parameters were tested.

After more than 10 days of rainfall, the fifth and sixth samples were collected from RWH systems implemented by SFD in two different schools. Akwan Thabt and Aminah Bent Wahb schools are located in different places in Sana'a; namely AL-Asbahi and West of Rodah. The schools use the technique of Ferrocement as harvested rainwater tanks connected to ceramic roofs by PVC pipes. The roofs are not clear (see Chapter 5, Figure 5-12)

Moreover first flush is not being used. In fact, In Akwan Thabet School the sample has been taken from the tap after it is pumped from a ferrocement tank to the top surface steel tank. In Aminah Bent Wahb School the sample was collected after it was pumped from the direct outside pipe.

4.3.3 Constraints of Sampling:

Before judging the sampling results, different parameters should be applied. During rainy season, the right way of sample collection along with the temporal and spatial distribution of the samples to cover the study area is an important step to judge the harvested rainwater quality and its uses. Furthermore, samples as a representative should cover different systems depending on the type and size of tanks, roofs and gutters. Below are some of the constraints and obstacles of sampling:

- During the study there were only two days of rainfall events separated by a long period of dry days,
- Difficulties of preparing appropriate roofs and empty tank. All existing ground and underground tanks are used for storing water whether from the public network or from tankers. As a result waiting for an unknown date of rainfall days during the research period didn't help in the preparation of appropriate roofs and empty tanks,
- Spatial distribution of the rainfall doesn't help to collect the sample from where it was planned and,
- Lack of awareness of about RWH technology.

4.4 Social Survey:

4.4.1 Introduction

Under IWRM approach, socioeconomic data is essential. It should be taken into account in the overall water resources management (GWP, 2000). Socioeconomic data collection is a bottom up approach that reflects and identifies the real situation and people desires. However, it usually may not be clear for the decision makers. Therefore, it is important to analyze this kind of data in order to help decision makers to achieve sustainable development planning goals.

Household sample surveys, as one of the fixable methods, provide a cheaper alternative way of data collection. They have become a good indicator source of data on social phenomena in the last 60-70 years (Department of Economic and Social Affairs, UN, 2005). Household sample surveys should cover all data related to people condition of living, activities, traditions, habits, opinions, demographic characteristics, cultural factors, as well as social and economic changes (Department of Economic and Social Affairs, UN, 2005; AL-Zayed, 2010).

In this survey, several key informant interviews with decision makers and specialists in water and WH sciences have been conducted. Then, three forms of questionnaire have been designed for three different target groups, households (form 1); public buildings (form 2); and existed RTRWH systems (form 3).

4.4.2 Planning of survey

Having a successful survey and desired results out of it requires careful preparations which precede the field work (Department of Economic and Social Affairs, UN, 2005).

4.4.2.1 Objectives of the survey

Objectives as a first step of the survey planning have to be clearly stated. Clear objectives help to know what kind of information is needed. Consequently, having clear objectives is considered to be a basis of the questionnaire design which plays the central role in the survey process. On the other hand, in this stage it is essential to identify how the results are going to be used (Department of Economic and Social Affairs, UN, 2005).

With respect to the main objectives of th study, below are the main objectives of the social survey:

- To get peoples’ opinion about RTRWH;
- To assess quality, quantity, uses and resources of current water supplied;
- To assess people awareness towards water scarcity and;
- To discover and describe briefly the existing RTRWH systems and its applications.

4.4.2.2 Sampling Size

In sample survey, part of the population should be selected as a representative of the whole population. Accordingly, the results obtained from collected data represent the whole population (Department of Economic and Social Affairs, UN, 2005). The question of how big the sample is should be an important question. Such question needs to be asked in the early stage of the planning phase. A large sample more than needed is wasteful, while a small one leads to unpractical represented results. Consequently, an appropriate sample helps to obtain desirable accuracy and confidence level with minimum cost. Dissimilar features in different countries lead to the complexity of sample designing (Department of Economic and Social Affairs, UN, 2005).

With 95% population percentage, ±4% precision, and 95% confidence level, According to Sample Size Lookup Table by National Audit Office (2000); the sample size is calculated to be 114 samples. Accordingly by this study a number of 119 questionnaires have been conducted.

4.4.2.3 Survey Scope

When planning, it is important for the target population and geographical areas to be identified. Using sample of convenience will not represent the actual population, in other words, the result of survey will apply only to the particular population from which the sample has been chosen (Arsham, 2002; Department of Economic and Social Affairs,UN, 2005). Hence, multistage random sampling has been used to select interviewees from different areas.

Water situation was the main factor of determining the target samples. Taking into consideration six parameters, samples were drawn to cover the whole Sana'a city as follows:

1. Crowded built areas;
2. Developed and under-development areas;
3. Areas with public network and high pressure;
4. Areas with public network and low pressure;
5. Areas without network and;
6. New suburbs built areas;

Moreover, ministries, organizations, institutions and universities, located in different areas within the Sana'a city, were visited in order to conduct key informant interviews. Besides, some of the users, who have existing RWH systems, are visited incidentally, while the rest, who are well known, had organized visits. Figure 4-6 Shows interview locations.

4.4.3 Questionnaire Designing:

Questionnaire is considered to be the core and main tool of the survey. Whenever the survey objectives have been determined, the related questionnaire can be designed. It is an instrument that transfers the information from those who have it to those who need it. Simplicity and attraction of the questionnaire increase the response rate and enhance accuracy in the survey data (Department of Economic and Social Affairs, UN, 2005).

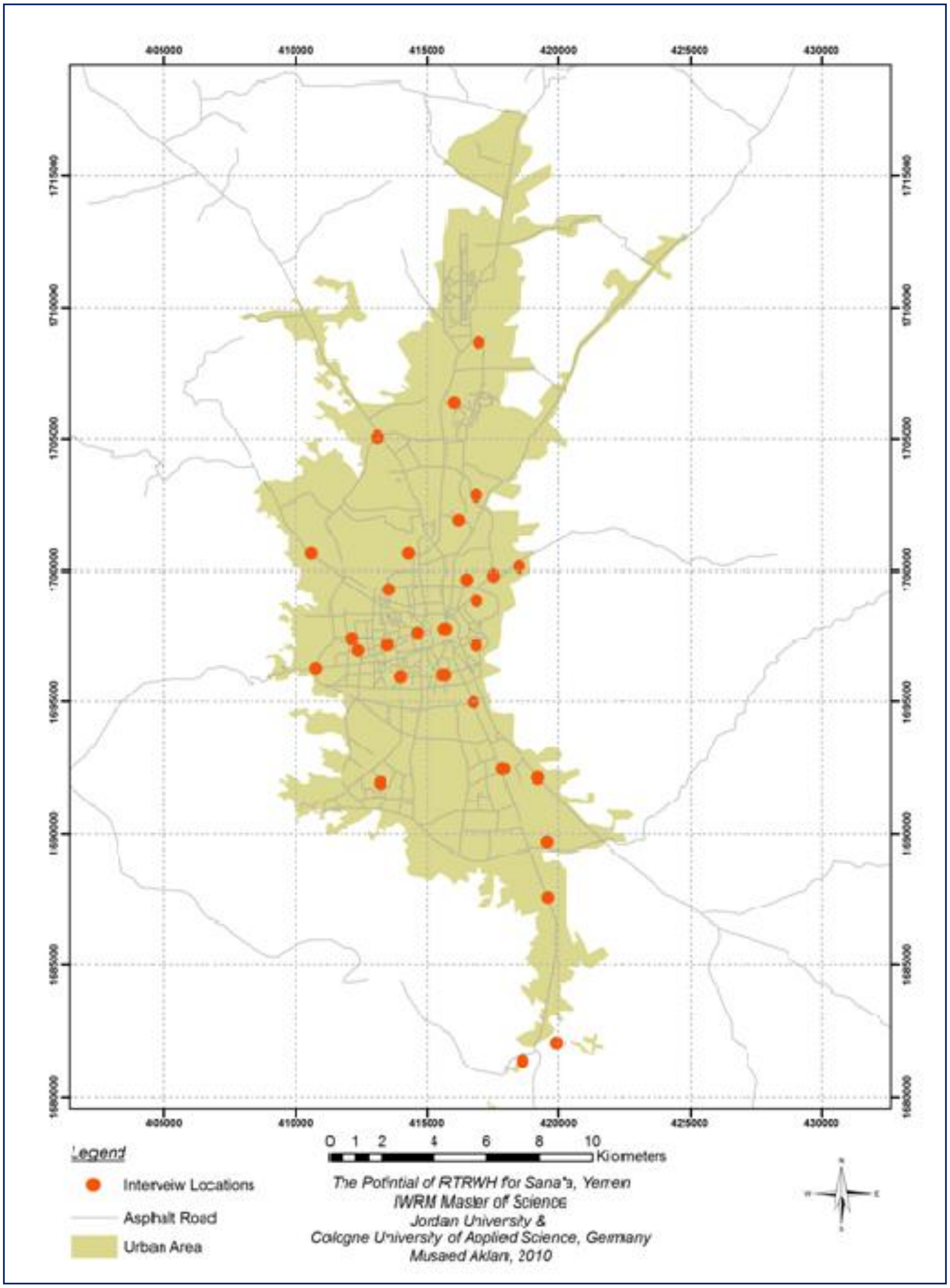


Figure 4 - 6. Interview locations

Three necessary questions should be answered in the initial phase of the questionnaire design (Arsham, 2002). These questions are as follows: What is the main purpose of the questionnaire? What kind of questions is needed in order to cover this purpose? and what sorts of actions that should be taken based on the results of the survey?. Indeed, in the survey some supplementary information such as, age, sex and education may ensure the results and enrich the analysis (Department of Economic and Social Affairs, UN, 2005).

For the key informant interviews there are no prepared or designed questions since unprepared open ended questions are used. As for the interviews there are three forms of designed questionnaire:

1. Household form, which is the majority;
2. Organizations, institutions and public buildings and;
3. Existing RTRWH systems' form.

In the beginning of the three forms there are the same general information about, date, time, zone and number of the questionnaire. The rest of the forms are differently designed. Explanation and more details about the contents of the three forms are as follows.

4.4.3.1 Household form

The questions in this form have been categorized in four parts:

a. Socio-economic,
b. General water situation,
c. People's awareness and
d. Technical questions related to RTRWH projects.

Socio-economic:

Education level, qualification, family size and the monthly income are stated in this part. Such information enables the researcher, later on, to decide the economic ability for the household. Hence, decide if there is a need for financial support.

General water situation:

General water situation as a second part of the questionnaire, conducted information about households water sources and the importance of each source for the drinking purposes.

People's awareness:

Third part is about the people awareness towards water scarcity in Sana'a basin. It was looked at from the interviewees' perspective regarding reasons of the scarcity and the future solutions for water shortage in the basin are obtained.

RTRWH part (Technical part):

Last category of the questionnaire is designed to cover questions related to RTRWH, type and size of the buildings, roofs and tanks found. In the same part the people have been asked about their willingness to pay and participate in case of implementing RTRWH projects in the city. They have as well been asked how and for what purposes harvested rainwater is going to be used.

Yards Level:

Five questions in the households form have been added. The aim of these questions is to get the targeted people opinion about using unused cesspits to recharge groundwater. Getting complaints from some interviewees about the sewage flooding during rainy seasons led to add two questions. The reason is because of using the sewage system as a rainwater drainage system.

Cesspits situation:

Cesspits for wastewater are still being used widely in Sana'a and they are considered as a source of contamination to groundwater. Costing millions, 'cesspits' can be used for harvested rainwater to recharge groundwater. Whenever the sewage network has been implemented, cesspits should be refilled by excess construction materials and replaced by the sewage network. However, cesspits situation, usage and people's opinion about using unused cesspits to recharge groundwater have been obtained from interviewees.

4.4.3.2 Public building form

Public buildings form has been designed differently from the first one. Nonetheless, the household and public building forms almost have the same categorization. Users number, type of uses and size of roofs have been the main differences and reasons for the design of two different forms.

4.4.3.3 Existing RTRWH systems' form

With only one part, the questionnaire for the Existing RTRWH systems' form has been designed. In this part with seventeen questions related to RTRWH systems, their applications and feasibility from the owners' perspective eleven existing RTRWH systems in Sana'a city have been visited and identified (Figure 4-7)

Question wording

Questions must be simple and easy to understand (Department of Economic and Social Affairs, UN, 2005). In spite of the fact that, the researcher have tried to write the questions in a simple and easy way, the interviewers have been advised to ask the questions in an intelligent way (slang language) to help the interviewee to understand the questions and answer them correctly.

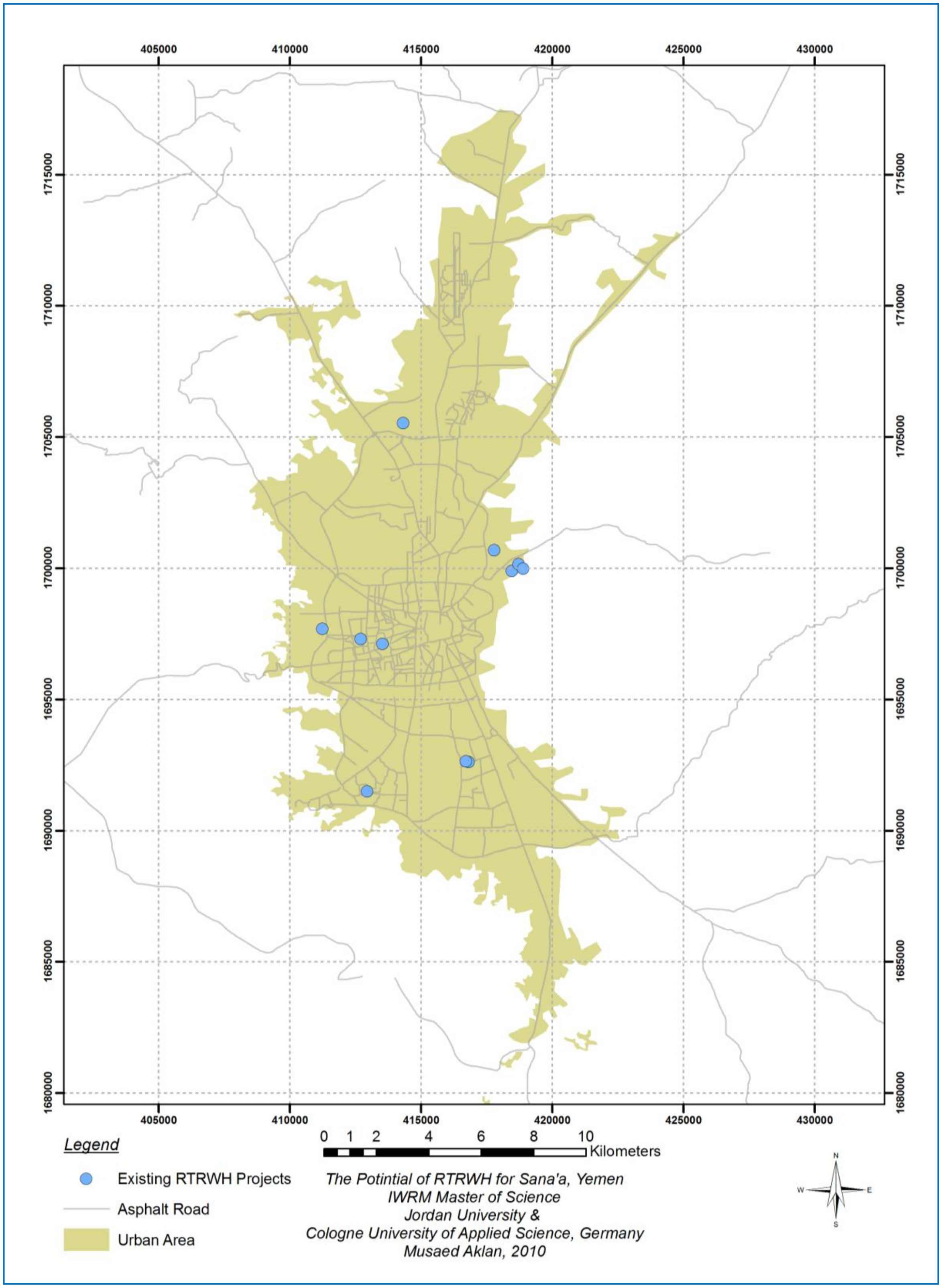


Figure 4 - 7. Existing RTRWH Systems

Test the questionnaire

Pre-testing questionnaire is an important activity to undertake, unless, it is validated from previous survey. Whether in wording or in order, pre-test help to identify the strengths and weakness of the questionnaire (Department of Economic and Social Affairs, UN, 2005; AL-Zayed 2010), Getting the supervisors' feedback about the first draft of the questionnaire, leads to prepare the last draft for pre-testing. However, during questionnaire pre-testing, difficulties and obstacles have been identified. As a result, the last version of the questionnaire has been modified.

Questionnaire sequence

Asking easy and interesting questions in the beginning of the questionnaire help to build up the confidence of the respondents. In other words sensitive and detailed questions should be at the end of the questionnaire (Department of Economic and Social Affairs, UN, 2005).

From the experience of the questionnaire pre-testing, socio-economic questions are very sensitive. Almost no one needs to answer such questions. For instance, the most sensitive question is about monthly income that everyone has been trying not to answer. Hence, the options have been changed from numbers to words as in the table 4-2.

However, in the last version of the questionnaire several questions have been modified and the whole part of socio-economic questions being asked at the end of the questionnaire.

Table 4 - 2. Monthly income question, from numbers to words

Income question in pre-testing version:		
What is your monthly household income? Range	a) 0-50000 YR b) 50000-100000 c) More than 100000	*1 $ = 215 YR
Income question in last questionnaire version:		
Does your monthly household income cover all what you need?	a) Yes b) insufficient at times c) covers only basic needs d) totally insufficient e) Others	*1 $ = 215 YR

4.4.4 Implement the questionnaire:

4.4.4.1 Select the interviewers

A careful selection of the interviewers is required. They should have an appropriate level of education and commendation skills (Department of Economic and Social Affairs, UN, 2005).

Beside the researcher, two well known interviewers from National for Water and Sanitation Authority (NWSA) and NWRA-SB were chosen. Both selected interviewers are working in the field of water and its applications. Therefore it should be easy for them to pick what is required from the interviewees.

4.4.4.2 Training the interviewers

After pre-testing the questionnaire and designing the last version of it, one day of desk training has been planned for the interviewers. General introduction about the research and its objectives are explained. From the experience of the pre-testing questionnaire beside general information gathered from respondents, a good introduction has been prepared as a key tool in the hands of the interviewers. In fact, such introduction has helped in attracting the interviewees' attention and response. One day before the desk training day, the questionnaire forms were distributed to the interviewers. Accordingly, queries about the questionnaire forms are being answered and explained. In practice and in the day after, the field work training is conducted. However, questionnaire forms are asked by the researcher while the other interviewers are listening and vice versa. During the same day of field work training, at least one questionnaire from the three forms of the questionnaires is asked and filled.

4.4.4.3 Field supervision

Beside the frequent visits by the researcher, the interviewers are furnished with the researcher's phone number in case of facing any obstacles.

4.4.4.4 Interviews method

Whether for key informant interviews or interviews, face to face interview method is conducted. Key informant interviews as a first phase, is conducted by the researcher. Presenting the study's proposal and unprepared open questions are the main components of the key informant interviews.

In the field where the task is harder, the interviews are initiated with general talking and an introduction about the study and its objectives. However, within groups or individuals, both genders men and women[5] are approached. Due to illiteracy faced with some respondents, slang language was used. Some meeting pictures are shown in Appendix (E). After all, the two interviewers with the researcher have conducted a number of 119 questionnaires, numbers of 101, 11 and 7 forms for households, existing RRWH systems and for public buildings respectively. In both Arabic and English Appendix (F) includes unfilled samples of the three forms of the questionnaire.

[5] As social impediments, only interviewers' relatives and work colleagues women have been conducted.

CHAPTER FIVE
RESULTS AND DISCUSSIONS

5.1 Survey Result and Analysis:

5.1.1 Key informant interviews

Key informant interviews have been conducted by the researcher himself during meetings with specialists, decision makers, representatives and active people in water and WH fields. Therefore ministries, organizations, institutions and universities have been visited in order to meet these people and get the required information. Presenting the study proposal followed by unprepared open ended questions have been the main two steps of the pre interview meetings. All of the interviewees were aware of the water scarcity in Sana'a and strongly encouraged and welcomed the idea of RTRWH projects. Groundwater saving, mitigate floods and reduce the cost of water bills have been some of the benefits of RTRWH projects mentioned by respondents. The following points, which are required to apply WH projects, are some of the key informant interviews findings:

- Setting of laws and regulations in the field of WH are required in order to implement such projects
- As a motivational step, implementation of RTRWH projects should be initiated in government and public buildings as the best appropriate sites for such projects
- Shard tanks where there are no enough places (In the crowded built areas) could be a good option.
- Dried wells should be used as a recharge wells getting benefits of the rainwater
- Integrated water resources management is required

- The SWSLC, as the responsible body for water and wastewater systems, should adopt the idea of RTRWH projects Instead of constructing new network projects.

More details about key informant interviews are shown in Appendix (G).

5.1.2 Interviews

Households Form (form 1)

Socio-economic:

Question (Q4) is about monthly income where 41% of the respondents suggest they do not have sufficient income. Only 16% of the interviewees admit that they have sufficient monthly income. Another 15% of the respondents said that their income is insufficient but at specific times while 14% of them their income covers the basic needs (Figure 5-1). In brief, the high percentage of low income people could be an indicator of the need for support in case of implementing new projects.

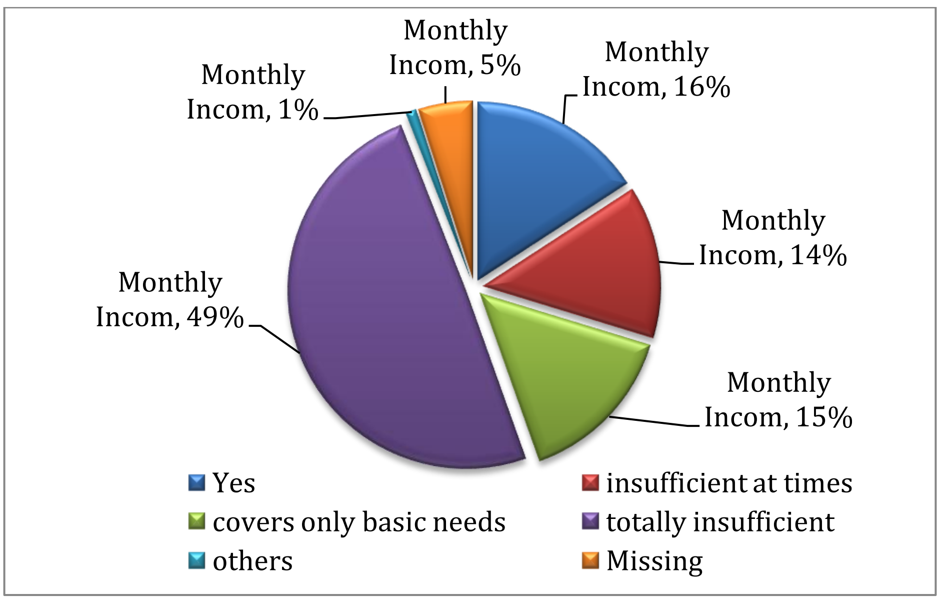


Figure 5 - 1. Monthly income of Sana'a people

The finding of question (Q4) where most of the people have insufficient income, corresponds to the answers of question (Q20, 1), Figure (5-8) which shows the big percentage of the people ability and willingness of practical participation in RTRWH projects.

Water Resources Situation (Q7-Q13):

Questions (Q7, Q13) are about the water sources of the target group. Out of the answers, a public pipeline network has been selected as a major water source. However, there are 54% of the households using both public network and tankers. 32%, 13%, and 2% are using tankers, public network and private networks as main sources of water respectively (Figure 5-2). Around 65% of the interviewees believe that the water sources are not suitable for drinking. Meanwhile most of them referred to the non-reliability of the sources as a reason of their belief (water isn't suitable for drinking). Others referred the reasons to unclean network, pollutions, water taste and color (Q8, Q13).

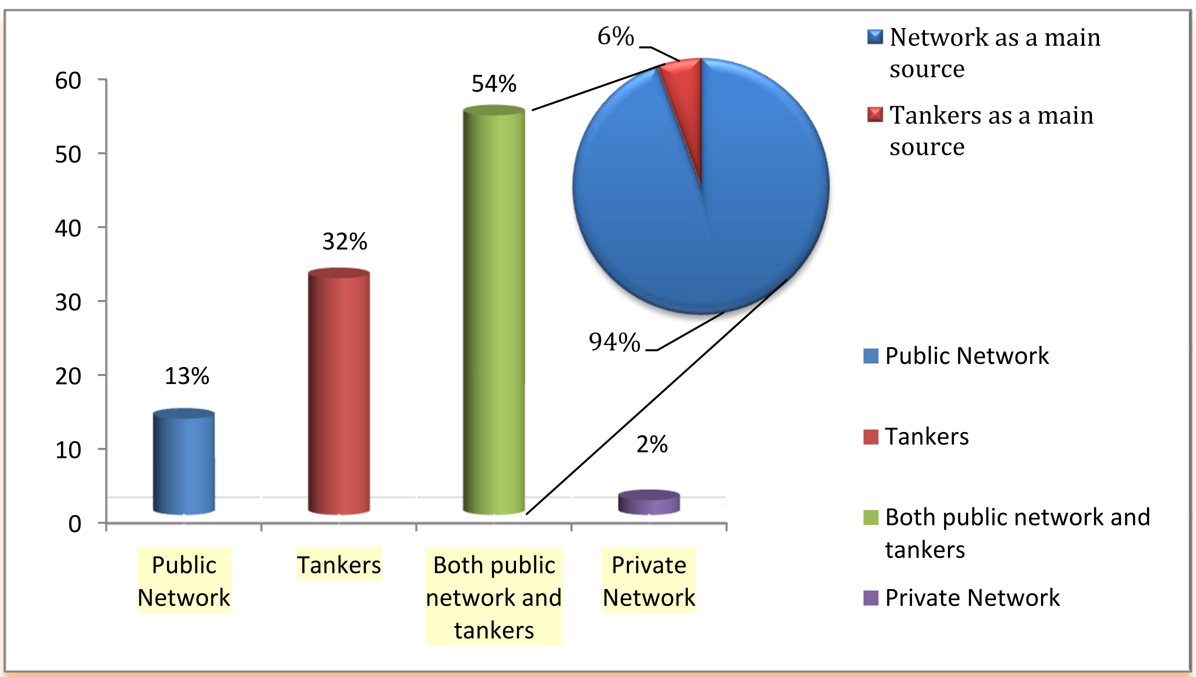


Figure 5 - 2. The main water resources

Question (Q10) was about the main water source for the purpose of drinking. The answers are shown in (Figure 5-3) that the majority of households (63%) are using bottled or mineral water. Only 4% are using filters with the water supply network and tankers, while 13% and 16% of the respondents are drinking directly from public network and tankers respectively. Such high percentage of people who are using bottled or mineral water indicate to the poor water quality from different source, hence rainwater may have better quality.

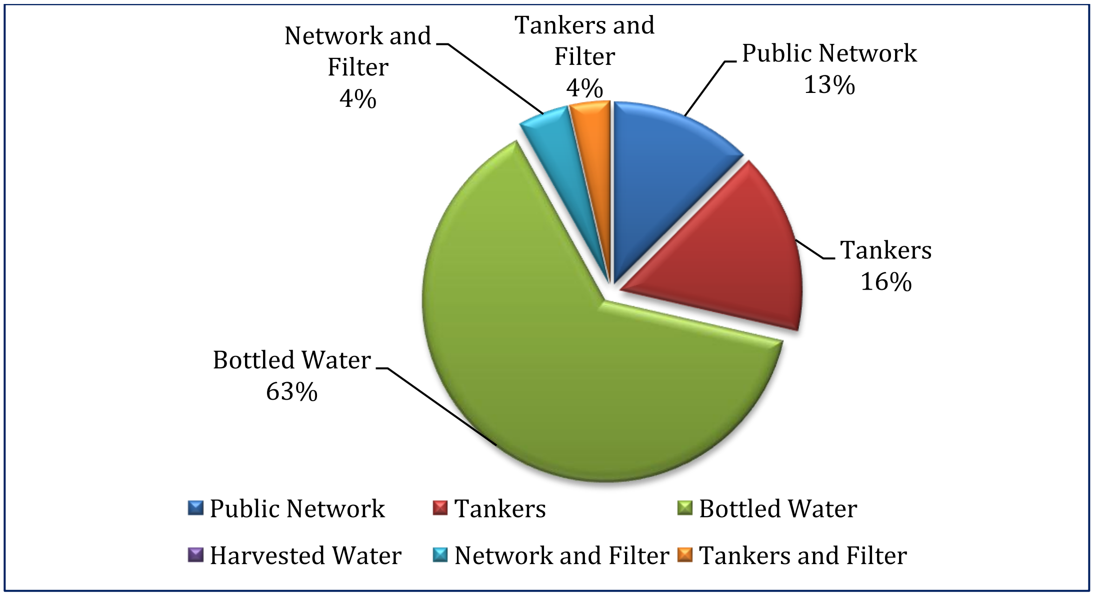


Figure 5 - 3. Main source of drinking water

Awareness of the Water Problem:

Beside the questions on water sources quality and its uses, questions (Q14, Q15) have been designed to measure the people awareness. Table 5-1 illustrates the results of awareness questions with 91% of interviewees are aware of the water scarcity in Sana'a basin, see also Figure 5-4.

However, those, who are aware of the water scarcity, have been asked the other two parts of the next questions (Q15-1, Q15-2). From their point of view, WH, subsidizing the improved irrigation technology and punishing illegal drilling of wells are the winner future solutions to face water scarcity problem.

Table 5 - 1. Awareness results

No	Questions	Options	Yes %	No %	No Answers & Missing Data %	Other Suggestions
15	Are you aware that there is a water scarcity in Sana'a?		91	9		
Q 16 applied only for those who said yes in Q15						
16,1	What is the reason or reasons do you think?	a) Rainfall is rare	41	51	8	11% Paving 3% Loss & Illegal 5% Failure of Government
		b) Irrational use of water	75	18*	6.6	
		c) Agriculture use	61	18	21	
		d) Wells	61	11	28	
		e) Immigration to Sana'a	72	11	16	
16,2	In your opinion what is the future solution?	a) Stop new well digging	23	51	26	16% Rationalization of consumption; 16% Laws; 7% Awareness.
		b) Stop deepening of wells	28	43	30	
		c) Reduce irrigated area	48	26**	26	
		d) WH tanks/ dams/……..	97	0	3	
		e) Subsidize improved irrigation technology	93	0	7	
		f) Punish illegal drilling	92	0	8	

* 66% of yes answered people referred to Qat
** 34% of yes answerd people referred to Qat

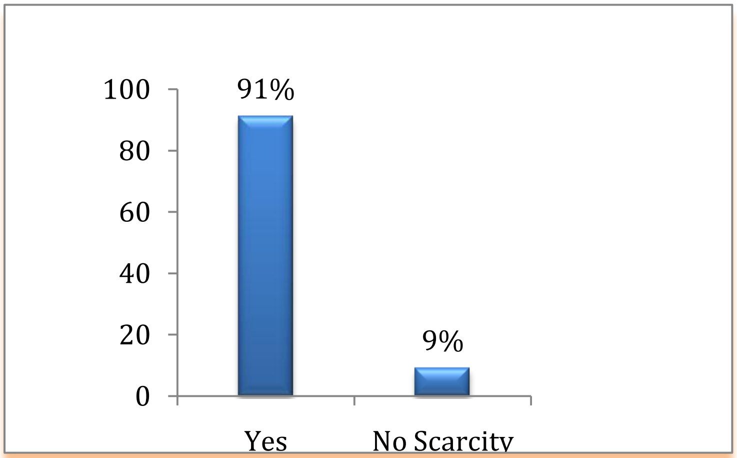


Figure 5 - 4. People awareness of the water scarcity in Sana'a Basin

People Opinion about RTRWH:

People's opinions and encouragement to use RTRWH are measured by Q18. Only 14% (Figure 5-5) didn't like the idea. However, their reasons for this objection are illustrated in Figure 5-6.

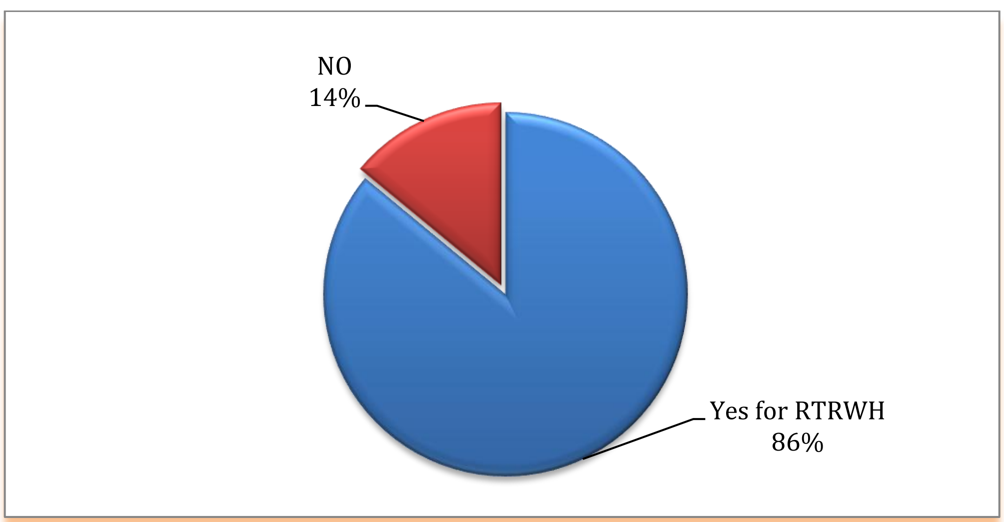


Figure 5 - 5. The agreement and encouraging RTRWH

The other majority (86 %) are encouraging the idea of using RTRWH systems. Question (Q20, 1) asked the 86% respondents about their ability and willingness to participate in such projects (see Figure5-7). Anyhow, most of the people, who encouraged the idea of

RTRWH, are not willing to participate financially, while, 38% of the samples are willing to participate financially and practically. However there are some people willing to provide financial support even though they either retired or sick. Some of the arguments in not participate that people have low income, they are sick and retired. Moreover they think it is the responsibility of government. “We are only house tenants and not owners” are comments or pretexts for rejection.

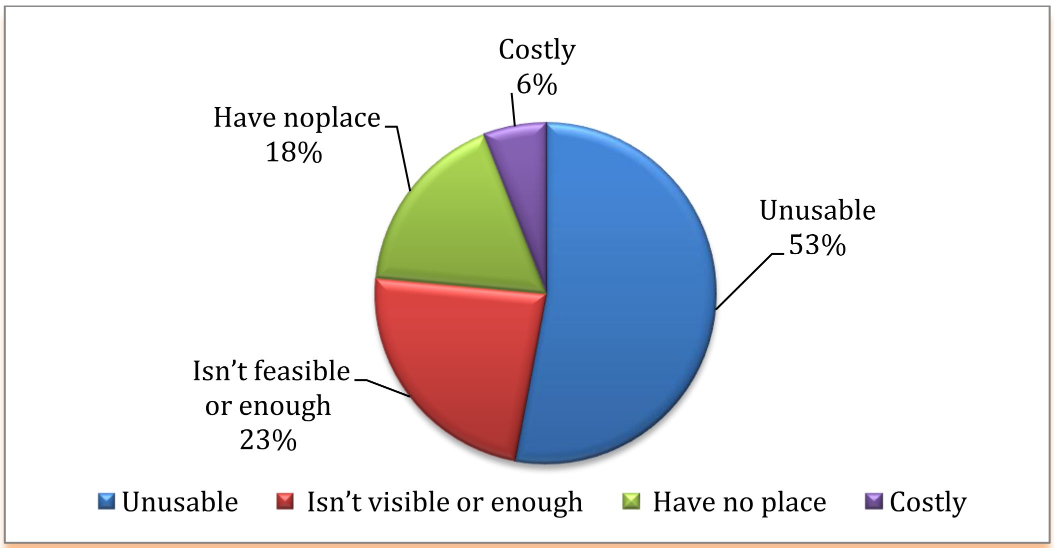


Figure 5 - 6. People reasons of not encouraging RTRWH

Question (Q20-2) is about quality of harvested rainwater and its usage (in case of using such systems) from the interviewed households’ point of view. The answers of this question (Figure 5-8) shows that the majority of them (40%) would use harvested rainwater for all domestic uses. However 29% of the respondents are happy to use rooftop rainwater for all domestic uses except drinking while the rest (31%) would use harvested water only for cleaning and gardening purposes.

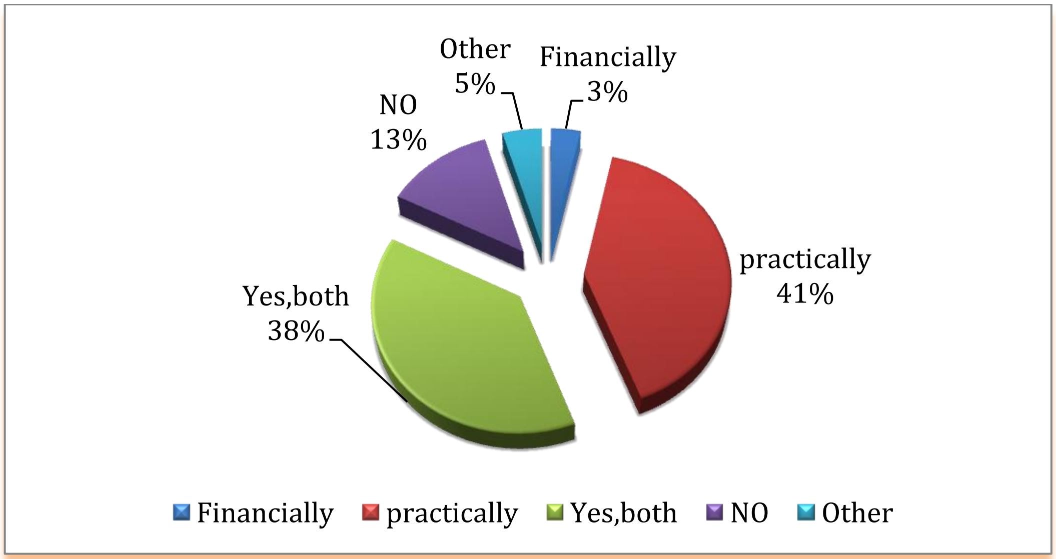


Figure 5 - 7. Interviewees' willingness and ability to participate in RTRWH projects

Questions Q20, 3-Q20, 4 are about the ability of using existed tanks for both rainwater and water from other sources. 11% of the RTRWH agreed people accept the idea whereas 89% of them didn't agree since the existed tanks are not enough. 42% of respondents, who encourage RTRWH and didn't agree to use inadequate existed tanks for the rainfall, have places for new harvested rainwater tanks while the rest don't have.

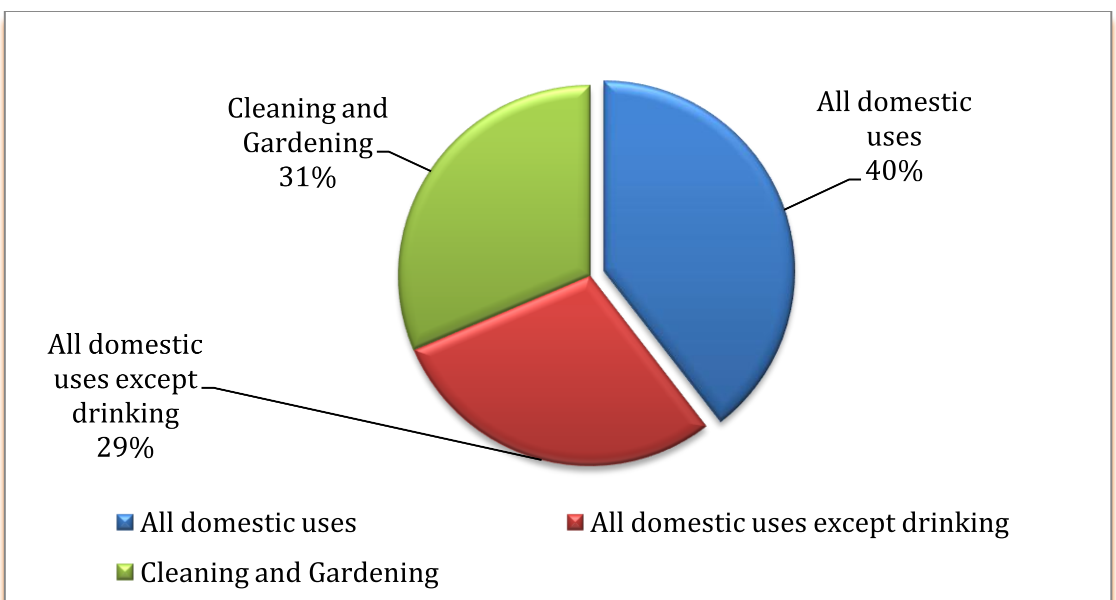


Figure 5 - 8. Different uses of rainwater when applying RTRWH projects

Although the ferrocement tanks are cheaper than reinforcement concrete tanks, households prefer the last one because of the inability of building on the ferrocement tanks where the land is too expensive.

Cesspits Situation and Yards Level:

During the rainy season, how the rainwater is discharged from house yards situated below the street levels? Two questions (Q22-Q23) were about the level of the house yards compared to the streets level and the way of discharging rainwater from low-level yards. (21%)[6] of the yards were below the street level. However, rainwater during the rainy season for all of those yards is discharged whether to the sewage network or to the cesspits, where there is no sewage network.

The cesspits situations have been illustrated by question (Q25-1). It has been found that 58% of the inspected cesspits are still used while 31% have been buried while using the sewage network. Only 11% of inspected unused cesspits still exist and unfilled. Whenever the sewage network is implemented, why not using cesspits to harvest rainwater (whether from roofs as an alternative for domestic uses or from street and clean areas) to recharge groundwater. People opinion about this idea was illustrated by question Q25-2. Most of the households (56%) believe that it will be a good idea, whereas 26% of them rejected the idea for the fear that cesspits might collapse. They proved their rejection by citing some incidents of cesspits collapse that took place causing material damage and human loss.

[6] Most of those below street level yards were found in old city of Sana'a and AL-Qa'a which are crowded and old built areas.

Social survey of Public buildings (form 2):

AL-Thorah Hospital, MWE, NWRA, few massjeds and other three schools have been visited as public and governmental buildings. 100% of the respondents stated that the water from public network is not suitable for drinking. Instead, bottled and mineral water are used for the purpose of drinking. Sizes and fabricated materials of the roofs and tanks in such buildings are appropriate for RTRWH. Using RTRWH will reduce the high cost of the water bills.

Social survey of Existing RTRWH Systems (form 3):

Eleven RTRWH systems existed in Sana'a city have been visited and identified. A number of 3768 inhabitants are getting benefit from the existing systems. Five of these systems are known while to the six of them, 5% of the whole sample, are found during field survey. It is worth mentioning that one of these existing systems is owned by the Minister of the transportation. All existed systems have Ceramic and concrete roofs. Reinforcement concrete, steel, plastic, Ferro-cements tanks beside only one recharge well are used.

In spite of 75% (Q9) of the owners are cleaning the roofs and tanks with varying periods, 75% of them are not using first flush devices. Questions Q10, Q11 and Q12-1 investigate the different uses of harvested rainwater. Figure (5-9) shows that only two owners of existing RTRWH systems out of eleven are using rainwater for all uses. However, the majority of them mentioned the unclean RTRWH systems as a reason preventing them from using harvested rainwater for drinking purposes.

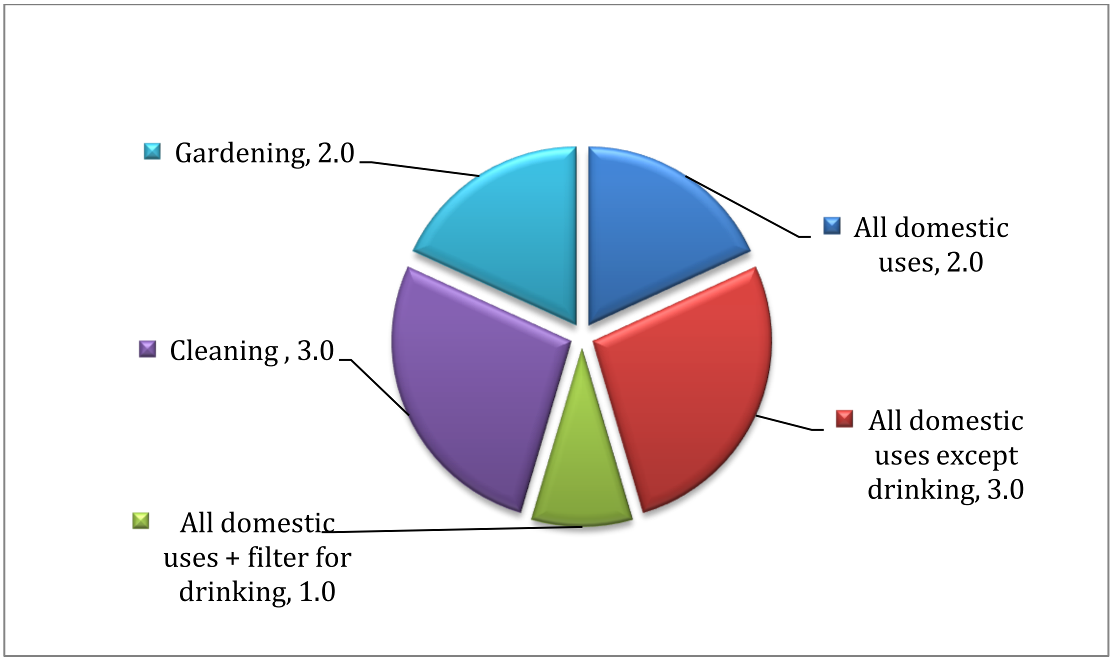


Figure 5 - 9. Different type of uses for harvested rainwater in the existing RTRWH systems

Likewise the households, who have no RTRWH systems, bottled and mineral waters, are the main drinking water source for households who have existing RTRWH systems. The answers of question Q12-2 are illustrated in Figure 5-10

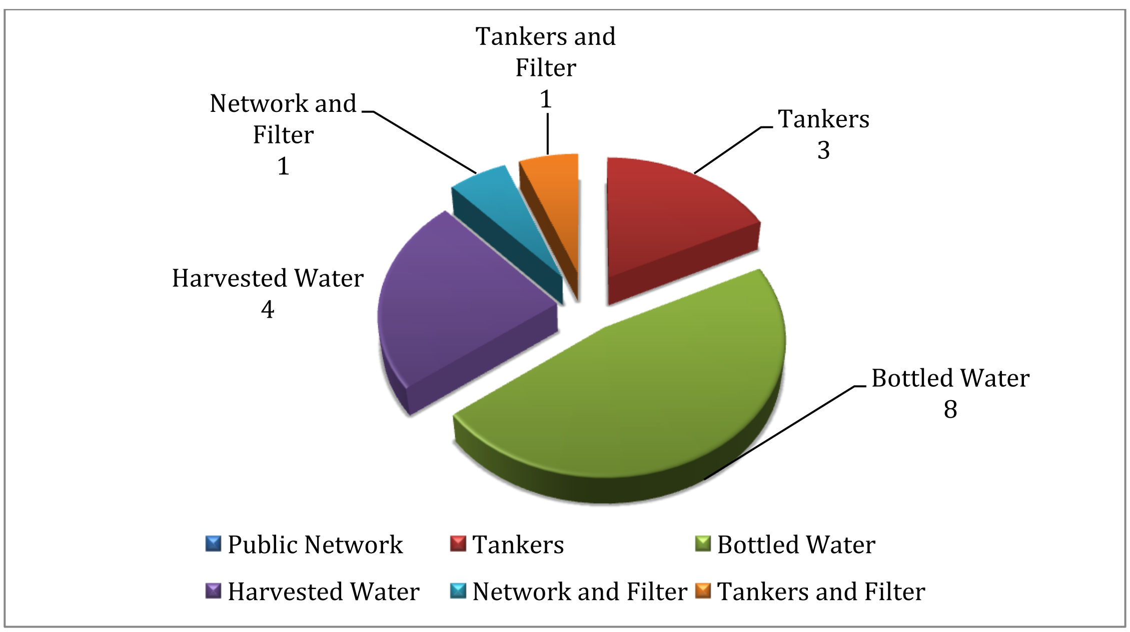


Figure 5 - 10. Main source of drinking water for those who have RTRWH existing system

Half of the existing RTRWH systems' tanks are used for both rainwater and water from other sources. The rest use separate tanks, and the harvested rainwater is used for cleaning and gardening (Q13).

While the owners and users of the existing RTRWH systems believe that they are feasible at least during the rainfall season with different concepts of uses, the owners strongly encouraged the idea of spreading the RTRWH projects for the whole city (Q15, Q16 and Q17).

In an Appendix (H), more questionnaires results are shown.

5.2 Water Sampling, Results and Discussions:

Water safety is determined by two main factors namely; absolute measurements at laboratories, people awareness and understanding of water quality at the house level as a second factor (Abdulla, et al., 2009). The results stated in this research are the first to deal with harvested rainwater quality in Sana'a. Here in this section chemical, physical and biological results of water samples are stated and discussed.

In Table 5-2 Physical, chemical and biological parameters analysis results are presented compared to (drinking water Yemeni standard prepared by the sector of water policy and programming, NWRA) (1999) and WHO (1993) drinking water guidelines.

Table 5 - 2. Physical, chemical and biological parameters analysis results for rainwater that have been collected from different locations (tanks and gutters)

Parameter	*Unit*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Mean Value*	*Samples above*	*NWRA*	*WHO*
pH		6.83	7	7.92	7.43	7.83	7.94	7.49	0	6.5 - 9	6.5 - 8.5
Turbidity		NA	NA	NA	NA	2.34	6.4	4.37	1	5	5
Electrical Conductivity 【EC】	µS/cm	106	105.4	135.8	374	115.3	205	173.58	0	2500	
Total Dissolves Solids 【TDS】	mg/L	69	69	88	243	75	133	112.83	0	1500	1000
Total Hardness 【TH as $CaCO_3$】	mg/L	43	45	30	148	44	75	64.17	0	500	500
Total Alkalinity 【TA as CaCO3】	mg/L	34	36	35	53	39	58	42.50	0		
Bicarbonate 【HCO_3】	mg/L	41	44	43	65	47	71	51.83	0	500	
Carbonate 【CO_3^-】	mg/L	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0		
Chloride 【Cl】	mg/L	1	1	6	46	7	11	12.00	0	600	250
Sulphate 【SO_4】	mg/L	19	13	16	33	15	40	22.67	0	400	400
Fluoride 【F】	mg/L	<0.01	<0.01	<0.01	0.14	<0.01	0.43	0.29	0	1.5	1.5
Calcium 【Ca】	mg/L	9	11	8	49	16	20	18.83	0	200	
Magnesium 【Mg】	mg/L	5	4	2	6	1	6	4.00	0	150	
Sodium 【Na】	mg/L	4	4	12	9.9	6.4	17	8.88	0	400	200
Potassium 【K】	mg/L	5.3	5	9.3	8.5	4.9	6.1	6.52	0	12	
Nitrate as NO_3^-	mg/L	<1	<1	1.32	11.88	15	16	11.05	0	50	50
Iron 【Fe】	mg/L	0.07	0.09	0.06	0.3	0.084	0.068	0.11	0	1	0.3
Total Colliforms	col./100mL	NA	NA	NIL	NIL	21	3	12.00	2	0	10 *
Fecal Coliforms	col./100mL	NA	NA	NIL	NIL	17	1	9.00	2	0	0

* Here the guideline value of Fecal Coliform is only for an individual water supply source. For the municipal water supply system, the value should be zero.

With the exception of the turbidity and biological indicators (total coliforms and fecal coliforms), all other physical, chemical, and biological measured parameters are laid below the maximum values of both NWRA and WHO standards.

Turbidity results of fifth and sixth samples, as the only samples representing turbidity, were (2.34 and 6.4 NTU) respectively. The first results are below the allowable maximum values (5 NTU) of NWRA and WHO guidelines while the second result exceeds both standards.

The water samples showed clear turbidity, even though no turbidity analyses were made for all samples. Most likely, long period of dry days before collecting samples, unclean roofs and unavailability of first flush system have effect in such results. Accumulated dust in the roof of Aminah bent Wahb School, where the sixth sample has been taken is shown in Figure 5-11.

Figure 5 - 11. Accumulated dust in the roof of Aminah bent Wahb School, Existing system.

The biological quality of rainwater was tested for four samples by the common indicators of total coliform and fecal coliform. Except what were collected from the tanks, both indicators were totally absent from the other two tested samples collected from gutters. The samples collected from the tanks (Akwan Thabt and Aminah Bint Wahb Schools) have the results of total coliform and fecal coliforms which exceed both Yemeni and WHO standards of drinking water.

According to WHO (1993), Table 5-3 shows the distribution of collected samples according to the level of TC concentration and treatments required. While the Table 5-4 shows the degree of risk according to FC (WHO, 1997)

As it is obvious in Table 5-3 all samples are located in the first two fields, three samples (75% of the tested samples) are located in the first field where no treatment is required while the fourth one requires only chlorination. Under the typical classification scheme according to FC, half of the samples met WHO guidelines while the other half of the tested samples were with low and intermediate risk. In other words, none of the samples were with a high or very high risk.

Table 5 - 3. Distribution of collected samples according to the level of TC concentration and treatments required

Range of TC	Degree of Contamination	Number of tested samples	Treatment Procedure
0-3	0	3	No treatment required
3- 50	1	1	Chlorination only
51- 5000	2	0	Flocculation, Sedimentation then Chlorination
>50000	3	0	Very high contamination, need special treatment

Source: (Al-Khatib,et al., 2004)

Table 5 - 4. Typical Classification scheme based on increasing orders of magnitude of faecal contamination

Range of FC	Number of tested samples	Degree of Risk
0	2	In conformity with WHO guidelines
1-10	1	Low Risk
11-100	1	Intermediate risk
101-1000	0	High risk
> 1000	0	Very high risk

Source: WHO, (1997)

In spite of the fact that, biological contaminated samples were collected from inappropriate RWH systems, still the results seem good. In both systems, where the samples are taken from, harvested rainwater was supposed not to be used for drinking purposes. Neither cleaning of roofs nor first flush devices existed or used. Moreover, samples were collected at the end of the rainy season, after several days of the last rain event. Nevertheless, in comparison with other similar studies (Villarreal, et al., 2005; Simmons, et al., 2001; Al-Salaymeh, et al., 2010), the quality of the tested samples seemed much better.

SFD with GTZ (IWRM) conducted a joint pilot Project of utilizing 180 SF (Figure 5-12) for 4 villages in Amran governorate. Studying the socio-economic impacts of those filters was the main aim of this study. The results of socio-economic survey showed that diarrhea among adults has been decreased from 63.9% before using the filters to 14.4% after one month of using SF, and from 25% to 0.0% among children.

Figure 5 - 12. Silver Filter

Source: SF, (2010)

During the study, 21 samples of water were taken from the main water sources and were biologically tested. As a result, only one sample was not contaminated biologically while 20 samples were contaminated. Number of 9 samples gave a “Too Numerous To Count” (TNTC) results while the rest (11 samples) were contaminated and gave results of total coliform between (20 coli/100mg) as the minimum value and (183 coli/100mg) as the maximum value. The mean value lies at 57 coli/100mg. On the other hand, fecal coliform results for the 11 samples had a mean value of 27, and the minimum and maximum values were 10, 104 coli/100mg respectively. Six months later, 20 POU filtered tested samples were totally clean from biological indicators and gave the value of zero (AL-Nasiri 2010).

Other similar study in different area done by CARE international showed almost the same results. The baseline study showed that 80% of users stated that their children have at least once a month diarrhea. However 77% of them never have diarrhea after 6 months and during the evaluation phase. On the side of sampling, the results of biological contaminations were absent. In the physical side, PH ranged between 8-8.3 while the turbidity results also were under the standards value (> 5) (SF, 2010).

Here and out of the two previous studies, SF proved its efficiency in the removal of biological contaminants and turbidity, with time it proved its acceptance among users as well. In this study, the two parameters exceeded the standard values are the biological indicators and turbidity, which can be easily removed by using SF[7]. Hence, either SF or lifstraw[8] filter is highly recommended by this study. Using such filter for the sampled sources will make it under the maximum allowable values of NWRA and WHO drinking water standards. Nevertheless, the samples are still not enough and making a final decision on the rainwater quality requires further quality studies.

5.3 Possible amount of rainwater that can be harvested from the roofs

Digitizing Sana'a city image 2009 by AutoCAD followed by inserting it to ArcGIS program. In ArcGIS program digitizing map has been accompanied with average annual

[7] SF: is preferable since it is cheap and locally made.

[8] Lifestraw filter: was explained in water quality in chapter 2 , it has not only the efficiency of bacterial removal like SF but further it can remove viruses which SF can’t.

rainfall isohyets map, isohyets map was developed for the Sana'a basin by BGR, (2004) cited in GAF,(2005) (Figure 3-6, Chapter 3, Section 3-7).

The final combined map is shown in Figure 5-13. The city was divided into three zones, south, middle and north zone according to the rainfall density. The rational method is used to calculate the potential of runoff from the roofs. More details about this method are presented in the methodology part (Chapter 4 section 4-2)

The value of 0.8 has been used as runoff coefficient for roofs (Abdulla & Al-Shareef 2009). Zone name, average annual rainfall, rooftops area and the volume of rainwater that can be harvested from the roofs all are shown in Table 5-5

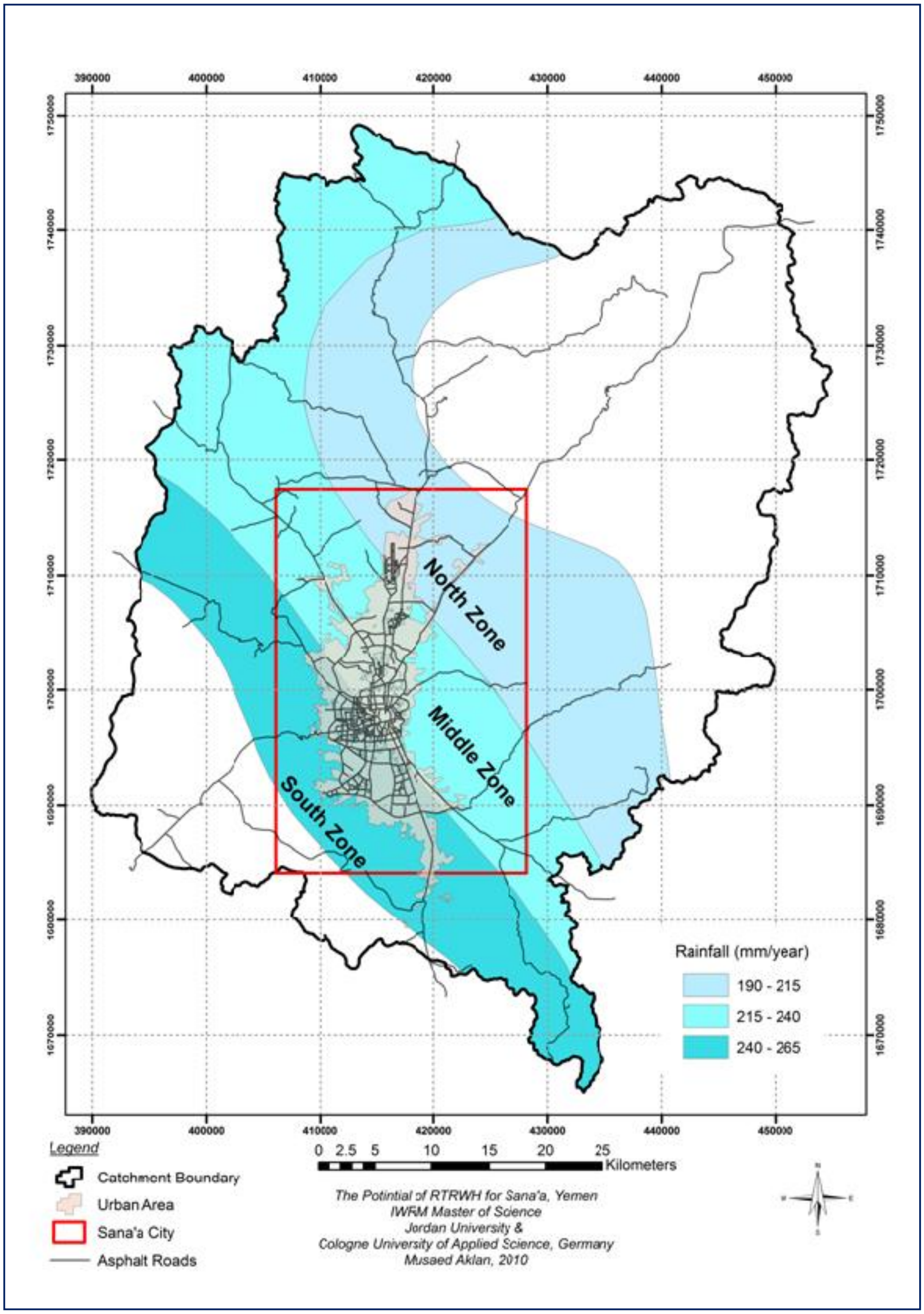


Figure 5 - 13. Digitizing and average annual rainfall isohyets companied map

Table 5 - 5. Summary calculation for the potential quantity of rainwater that can be harvested from the rooftops of Sana'a city.

Zone name	Annual rainfall mm/year	Average rainfall mm/year	Rooftops area (km2)	Annual volume of harvested water (MCM)
South zone	190 - 215	202.5	0.4225	**0.0685**
Middle zone	215 – 240	227.5	15.6415	**2.840**
North zone	240 – 265	252.5	17.2471	**3.4867**
Total			**33.311**	**6.395**

The total volume of water that can be harvested from the roofs was calculated to be 6.4 MCM in the year of 2009. However, 6.4 MCM will be saved groundwater resources every year.

According to censes 2004, population of Sana'a city is 1.74 million inhabitants with growth rate of 5.55 between the years 1994 and 2004. Based on that, the projected population for the year 2009 is calculated to be 2.28 million inhabitants.

The estimated water consumption per capita per day is ranged between 30-50 liters (World Bank, et al., 2009). Accordingly, the required water supply for the year 2009 is calculated to be 33.3 MCM per year. When comparing to the potential quantity of rain water that can be harvested from the roofs, RTRWH gives 20% potential water saving.

According to the annual report of SWSLC, (2009), network water losses are 34%. When supplying the potential quantity of RWH by networks, more 2.2 MCM per year is needed as water losses to deliver an amount of 6.4 MCM of water to the consumers. In other words

8.6 MCM per year can be saved when using RTRWH. Not only saving water losses but also pumping, distribution, maintenance and operating costs all are added values for using RTRWH. So, even the amount of 6.4 MCM/year is relatively small compared to the deficit, it makes a good portion of the domestic water needs for Sana' city. Moreover and due to severe water shortage, any additional water is helpful.

Installing RTRWH projects in Sana'a city will increase the public awareness about the current critical situation of Sana'a basin and promote RWH in different levels. Moreover in Sana'a the rainfall events have high intensity causing floods hazards. RTRWH can significantly contribute in floods mitigation.

RTRWH can be an efficient source and a complementary alternative to large-scale water withdrawals; it can reduce the negative impacts in the Sana'a water stressed basin.

In Sana'a RTRWH considered as a complementary source. Therefore, more water for domestic uses from other sources is required. However this study suggested one system for different sources, which means reducing the sharing-cost of using RTRWH. In detailed, this point is discussed in the coming part.

5.4 One System for Different Water Sources:

Recently the houses in Sana'a are receiving intermittent water supply i.e. once or twice a week with very low water pressure that does not allow water to be pumped directly to the buildings pipes. The people in the house solved this problem by installing ground or underground storage tanks connected to either small or medium size of steel or plastic tanks on the rooftops. In some of the commercial and big buildings concrete tanks with various sizes are installed in the roofs. However small pumps are usually used in such cases to lift the water from the underground storage tanks to the roof tanks in order to keep the building supplied with water. When the storage tanks are empty and the SWSLC water supply is not on time, people ask the tankers to fill out the ground or underground storage tanks.

Since storage tanks at level of houses are required to utilize water supply network, this study suggested that the same tanks could be used for RWH. Following are some supporting points for this suggestion:

1. When installing Two tanks for RWH and network water, this means more area is required where the area is too expensive,
2. Two tanks mean more efforts for cleaning and maintenance.
3. More budget is required.
4. Out of the Social survey, most of the people (63%) are using bottled and mineral waters for drinking purpose because of unreliability of water supply network and tanker water. On the other hand, rainwater quality results showed that rainwater could be used for drinking (cleaning the system and using SF before drinking is needed). This means mixing rainwater with network or tankers water will not affect the current practices.
5. In spite of the questionable quality of tanker waters, people use one tank for both tanker and network waters.
6. With intermittent of network water supply, it is too difficult to insure drinking quality of water. With intermittent supply the possibility of water pollution is high. During water flow stoppage the pressure in the pipes is zero, therefore contaminants around the pipes can find their way into the pipes through weak joints, and putting

the pipes under pressure again will transport the water with the contaminants to the consumers.

To summarize, harvested rainwater from kept clean systems could be more reliable and will not be worse than water from other unknown and infrequently tested sources. Therefore, harvested rainwater can be stored in the existed and new appropriate tanks together with water from other sources.

5.5 Tank Size and Control:

There are several computer-based programs for calculating tank size that connected to more than one source. For instance a computer based modeling tool called RainCycle was developed to perform more detailed analysis. It allow for more than one source of water. Furthermore, the whole life cost performance can be modeled in detail by such tool (Roebuck and Ashley, 2006). However, At least the tank should have the minimum size that can utilize and meet harvested rainwater requirements and the available space.

Using one tank for more than one source required special control. Beside float valve, control valve is required for other source connection rather than rainwater connection. During rainy season, daily Rainfall data never fixed. So, to have 100% optimum use of rainwater it'll be good to install this control valve of other source connection before the float valve and Depending on the need and the availability of harvested rainwater, this valve can be closed or opened. In other words If there is some empty space in the tank it is wise to be kept for the next event of harvested rainwater, so control valve should be closed during rainy season unless there is an especial need for network water. Overflow pipe is also other good tool that control received water from different sources.

5.6 Potential Sites, Techniques and Sizes of the Tanks:

In Sana'a, steel, concrete and plastic tanks are the most common used types. Selecting the type of tank in Sana'a mostly depends on two factors, the budget and space area. In poor and crowded zones, steel and plastic tanks are used, while the concrete tanks are more used in rich zones.

In this study the potential and appropriate type of tanks for Sana'a city have been suggested. However, since the most expensive part of the water systems in Yemen is the storage tanks, the cost of the tank has been taken as a main factor of the selection process in this research. Accordingly, from cheaper tank to the expensive one the type, size, location of the tanks have been selected considering the availability of space area and capacities of tanks that fulfill the required demand.

However, brick cement, ferrocement, blocks and concrete tanks are indicated and discussed as appropriate tanks that can be installed in different areas among the city. Types of tanks, costs and capacities in level of the houses are shown in Table 5-6.

Table 5 - 6. Appropriate suggested tanks for Sana'a city, capacities and costs,

Tanks	Capacity (m^3)	Cost $/ m^3	Source
Brick cement	0.5 – 30	10 - 40	Calculation
Ferrocement	50 – 100	47 - 65	SFD
Block tank	< 20	75-100	SFD
Concrete	< 100	110 - 180	SFD

Ferrocement tanks are still new technique for the whole country, only few tanks of this type have been installed in the last three years by SFD. The cost of these tanks ranged between 47- 60 $/$m^3$ with capacities up to 100m3 (see table above).

The advantage of these tanks is the low cost of construction. According to the social part of the study, many interviewees refused the usage ferrocement tanks due to the unavailability of enough space area, and it is not suitable to install them underground of the buildings.. However, the installation of ferrocement tanks seems to be suitable for the buildings or houses where there are enough space areas, for instance villas, schools, ministries universities and other public buildings.

Another cheap type of tanks, even cheaper than ferrocement, are the brick cement tanks. They are not practiced yet in Yemen. As a maximum the brick cement tanks cost about 20 $\$/m^3$ in Nicaragua, Ghana (NWP, et al., 2007). In Yemen it is calculated to cost about 10-40 $\$/m^3$. Such tanks can be built in small areas, starting from of 0.85m in diameter with capacities starts from less than 0.5 up to $30m^3$. Like ferrocement tanks, brick cement tanks it is not allowed to be built underground other buildings.

Block tanks are more expensive than both ferrocement and brick cement tanks, but they are cheaper than concrete tanks. However, block and concrete tanks can be installed underground the buildings which make them very appropriate and acceptable to the people.

Selection process of tanks

In this part three situations are identified for the selection process of the tanks and summarized in Table 5-7:

i. For crowded areas where there are no enough places for installing big tanks, brick cement tank is suggested. For more capacities, or unsuitable location two brick tanks could be installed.

Although, shared tanks are other option that can be used in crowded built areas, or where there is no place for constructing brick cement tank. When using shared tank two or more roofs are connected together to the nearest adequate selected place of this tank.

Table 5 - 7. Suitable tanks from the economic point of view, sites, according to the area availability and required capacity.

No	Area properties	Examples	Tank type				
			Brick cement	Ferrocement	Block	Concrete	Shared
1	Crowded built area	Old Sana'a	√√			√	√√
2	- Non-crowded area - Required capacity $<30m^3$		√√				
	- Non-crowded area - Required capacity >30m3	Public buildings		√√		√	
3	- Required building above the tank - Required capacity $<20m^3$				√√	√	
	- Required building above the tank - Required capacity $>20m^3$					√√	

√√ Strongly recommended option

√ Second option

ii. For non-crowded areas which have enough space areas, also brick cement tank is suggested for the required volume up to $30m^3$. If more capacity is needed (more than $30m^3$) ferrocement is installed, for example, for public and big buildings such as ministries, which require more capacities of storage..

iii. Third case, when more storage capacity is needed and there is enough area for installing big tank but building over this tank is a must, then, above or underground, block or concrete tanks are used. For storage capacity up to $20m^3$ block tanks are used and for more concrete tank, the most expensive choice among suggested tanks is used.

For the areas where there are already existing tanks, redesigning the system should be carried out. If not replacement, rehabilitation or/and additional tank may be needed.

However, the owner's preference and his income also play an essential role in selecting the type of tank.

5.7 Other possibilities of rainwater harvesting:

5.7.1 Dried-up well s

Out of 13280 Wells and dams/pool within Sana'a basin, there have been more than 1600 dried-up wells and water points, 1423 dug wells, 32 dug/bore wells, 161 bore wells And 3 dams/pool. However they are subject for increasing due to the continuous drop in groundwater level. All of these dried-up water points are abandoned (WEC, 2001).

Harvested rainwater through dried-up wells in the basin is considered to be a fast way to recharge ground water level. Using dried-up wells to recharge groundwater need to be rehabilitated in a way that helps to catch as much as possible of rainwater.

For dug wells, bore wells and dug/bore wells, this study suggests different initial techniques of rehabilitation that can be developed and used for using the three type of wells, as a recharge wells.

5.7.1.1 Bore wells:

Bore wells can be utilized as recharge structures. Developing a round filter will be a good way to get benefit of such unused dried-up wells. Ground filter has three suggested layers, sand, gravel, and boulders from top to bottom. Storms in Sana'a basin happens in short time with relatively high intensity, this kind of storms affect surface runoff and the peak flow rate. As a result, circular surface filter with gradual depth towards the well case is suggested. The cross section of the filter could be in trapezoidal shapes or in semi-circle (Figure 5-14 and 5-15).

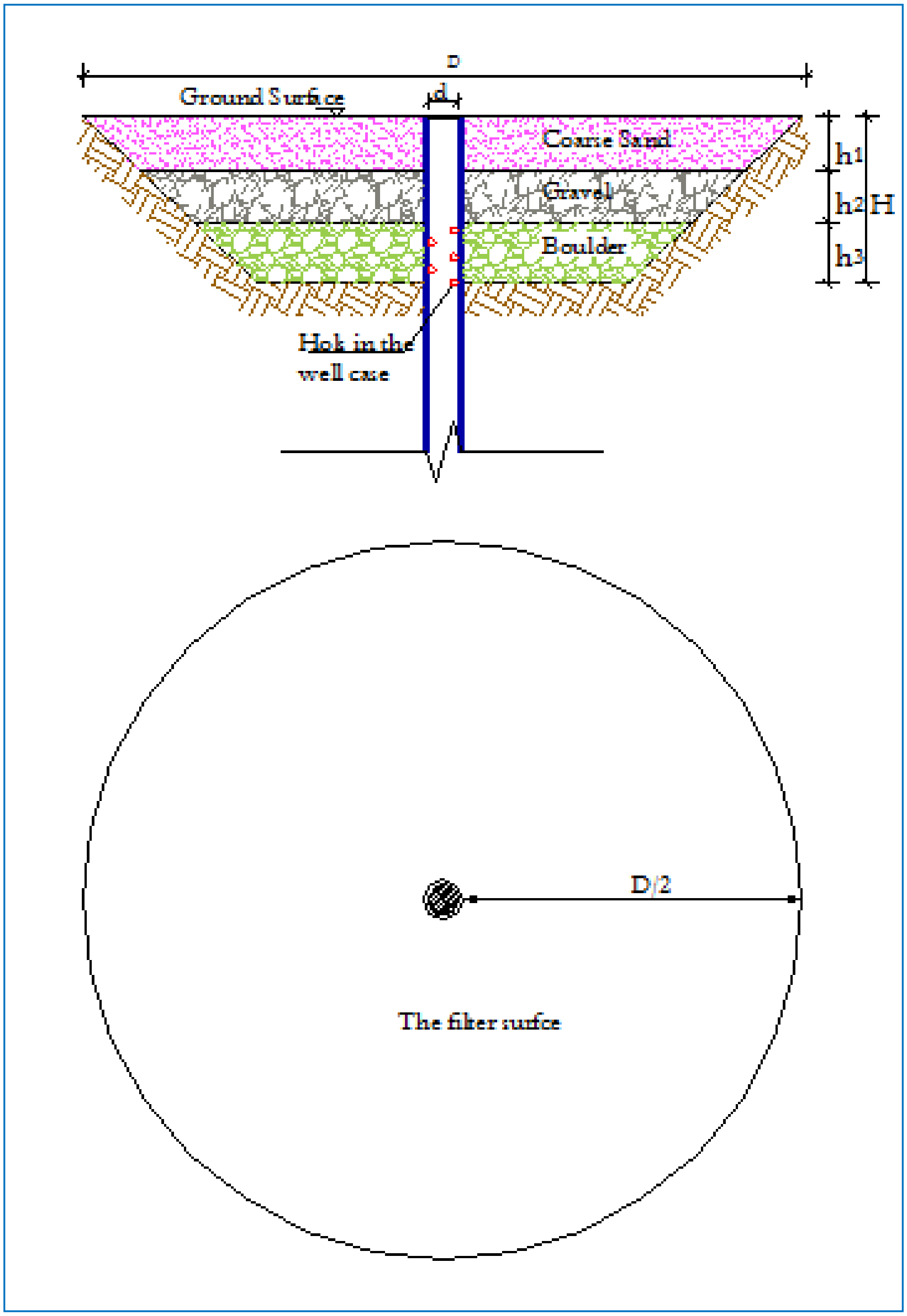


Figure 5 - 14. Suggested RWH ground filter for dry bore wells to be used for groundwater recharge (trapezoidal shape)

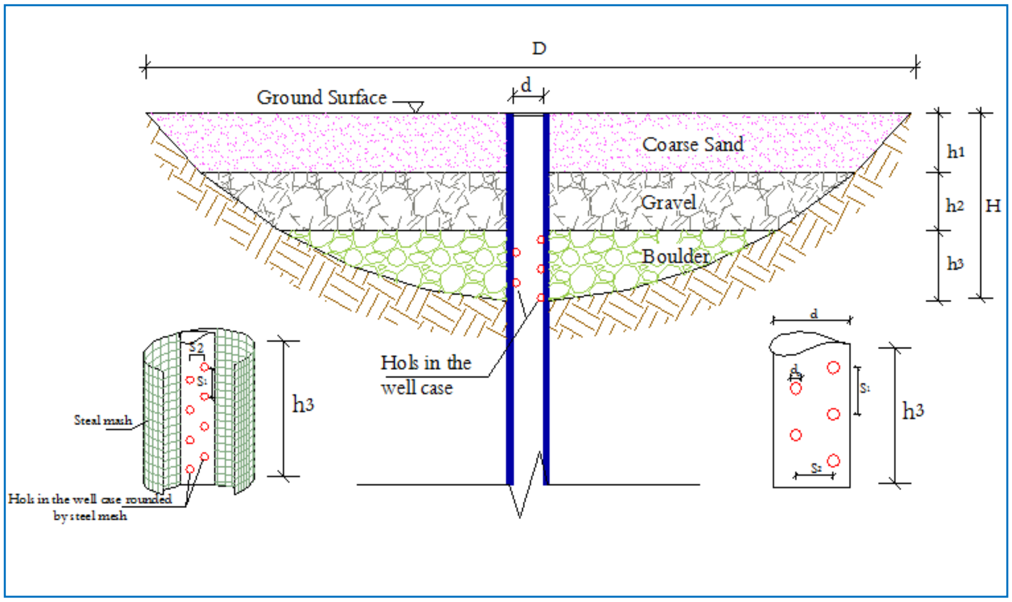


Figure 5 - 15. Suggested RWH ground filter for dry bore wells to be used for groundwater recharge (semi-circle shape)

Such filters will help to have a large circular filter area (the plan of the upper surface of the filter) compared to a surface area of the cylindrical filters.

Hence increasing surface area of the filter will give more area for the rainfall that will be filtered to the well, as well as it will give more time for the runoff passing on the upper surface of the filter to be filtered through the filter layers. More over it is easier to construct this filter than the cylindrical one.

Dimensions of these filters and the holes on the case of the well will depend on:

- Rainfall duration,
- Rate and duration of the surface run off,
- Materials of the filter, and
- Geometry of filter.

In case the well is located in a flooded area, protection zone and pre-basin for suspended solids reduction around the filter is needed.

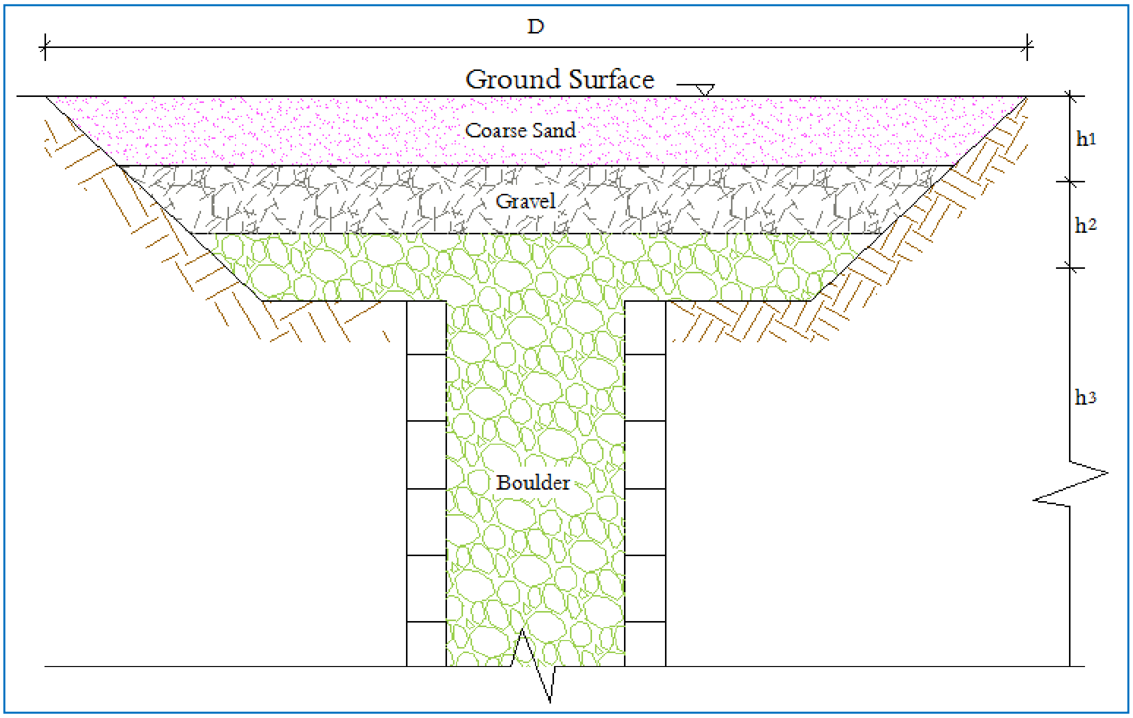
In case there is no runoff passing the filter, converting some of the runoff by pipes or canals from other places is advisable. When using bore well and rehabilitate it as a filter, tight sealing head for the well is needed.

For bore wells (tube wells) that have been installed in hard rock soil. Outside or Upland-filters can be used.

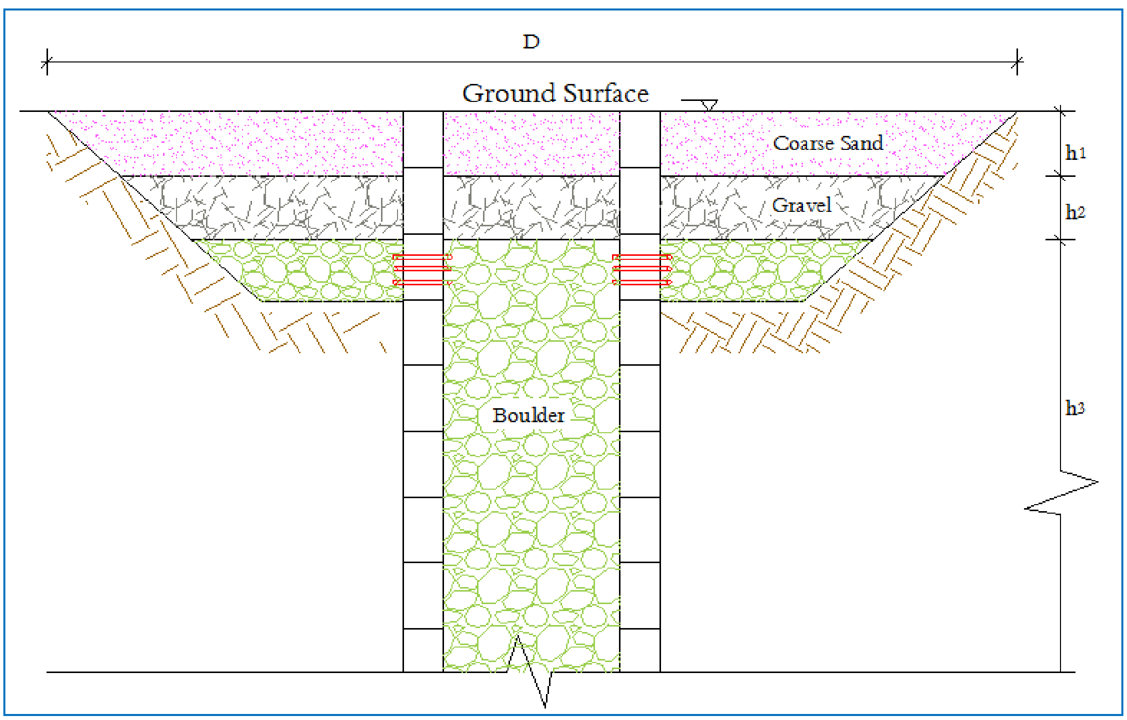
5.7.1.2 dug wells:-

A number of 1423 dug wells also can be reutilized to be recharge wells. Two cases are identified:

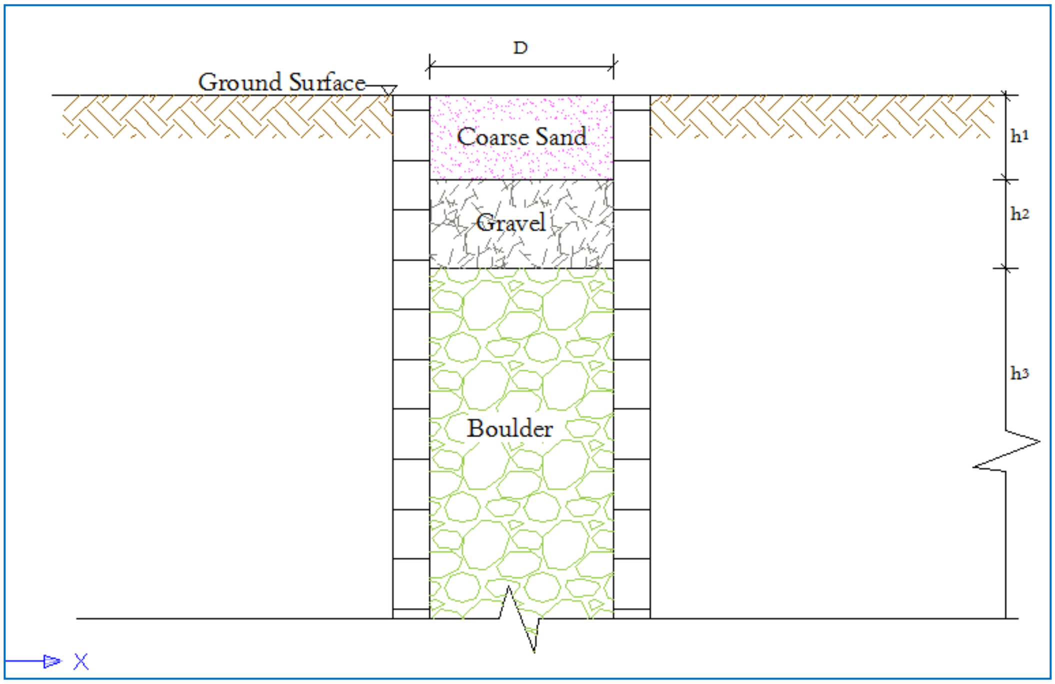
i. In case the well is subjected to threats that threaten its permanency, as risk of floods or there is no more need for the dug well, it can be refilled with filter materials. Figures 5-16 a, b, c, and d, show different techniques of dug wells rehabilitation. For all suggested filters, $h_{0,}$ h_1 and h_2, are very important to be determined, the rest (h_3) will be filled with boulders. However, Figures 5-16 a, and b are strongly recommended since they will create more space and time for runoff over the well and more space for the rain fall, this will increase the opportunity for rainwater to be filtered (see section 5.7.1.1 for more discussions), however cost of filling the well with filter materials should be taken in consideration.


D
Ground Surface
Coarse Sand
Gravel
Boulder
h1
h2
h3

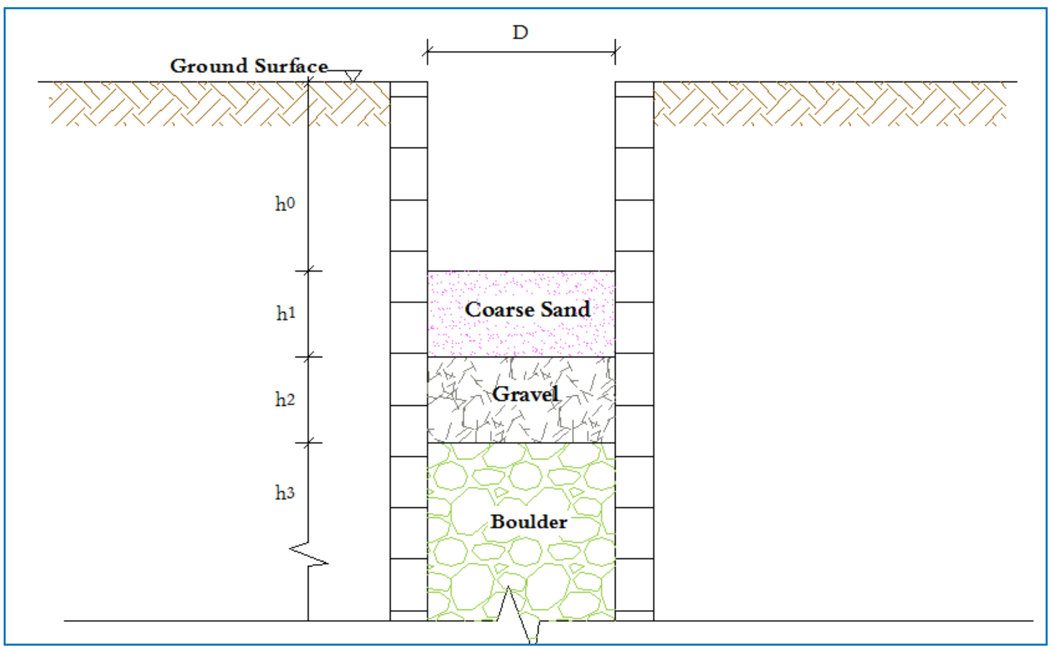
(a)


D
Ground Surface
Coarse Sand
Gravel
Boulder
h1
h2
h3

(b)



(c)



(d)

Figure 5 - 16. (a),(b),(c) and (d), different suggested techniques of RWH inside ground filters for dry dug wells to be used for groundwater recharge.

ii. If the dried-up dug well is protected from any threats, pollution and flooding, place the filter materials around the outside the well with drainage pipes. Figure 5-17 explains how this filter can be constructed. h_1, h_2, h_3, are very important dimension to be selected carefully for the well.

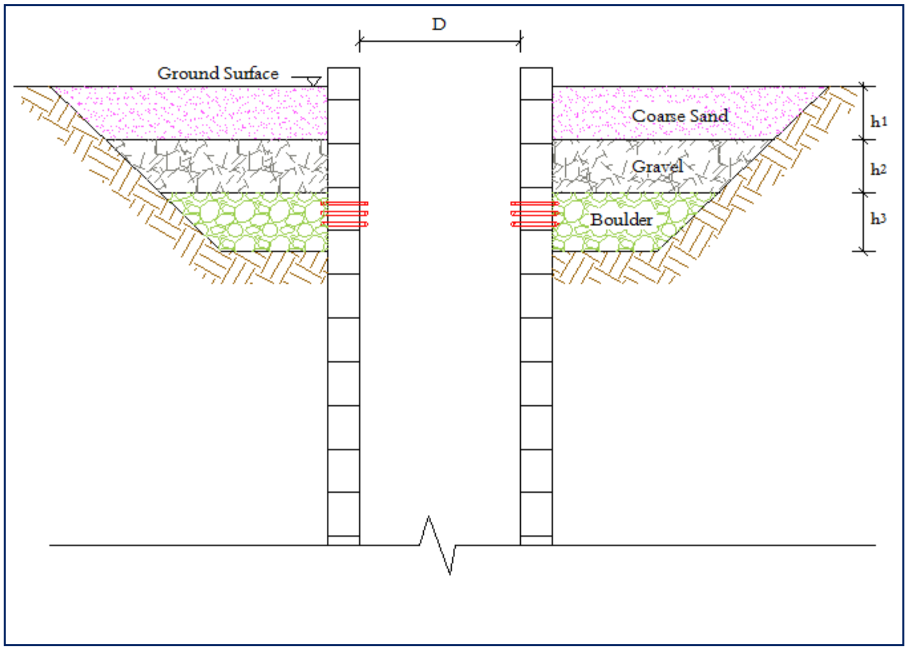


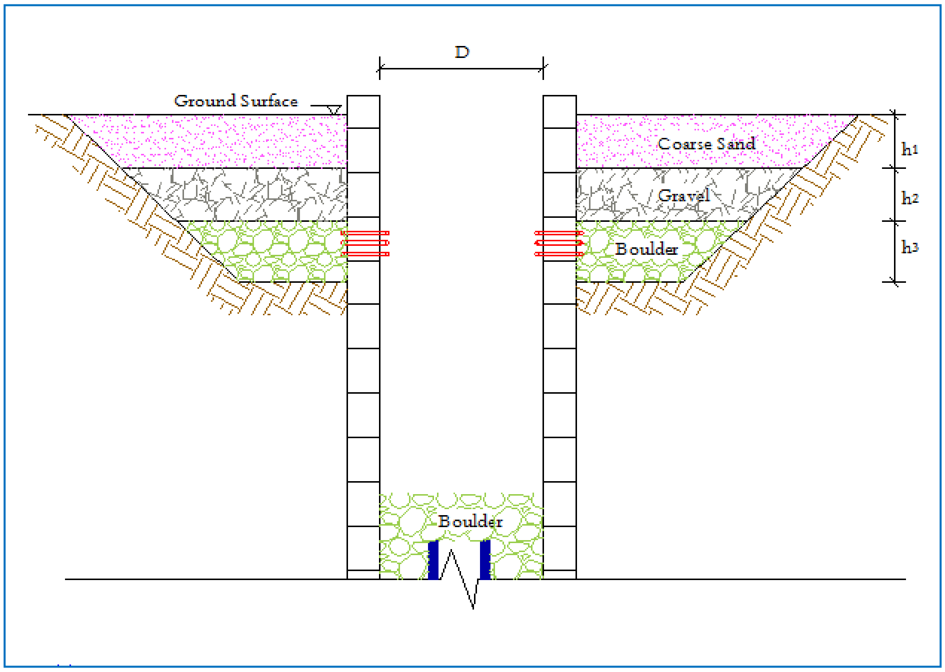
Figure 5 - 17. Suggested technique of RWH outside ground filter for dry dug wells to be used for groundwater recharge.

5.7.1.3 Dug/bore wells

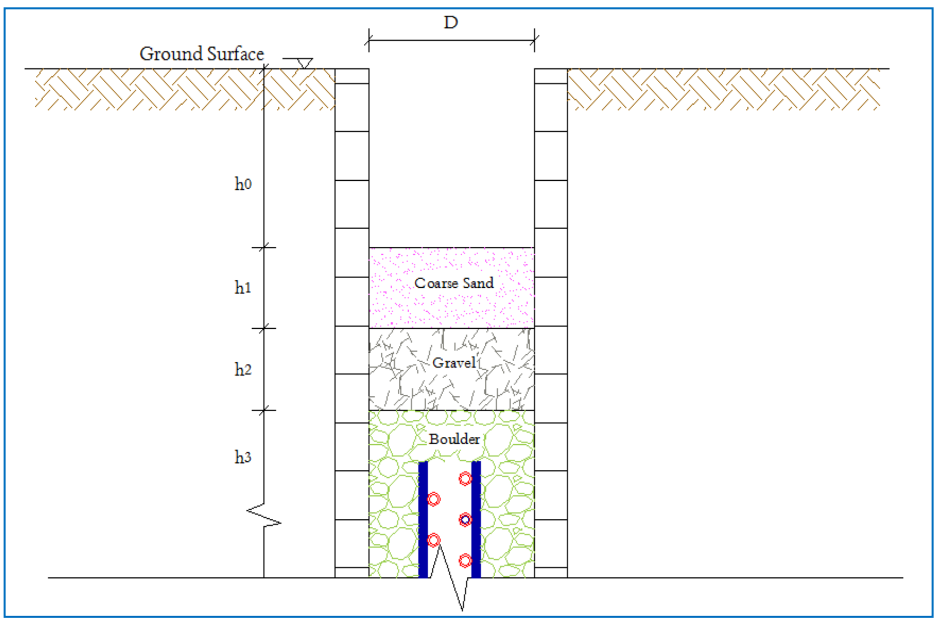
Using dug /bore dried-up wells also have two cases:

i. Placing the filter inside the dug well will identify two situations:

   a. The bore well head with the bottom of the dug well: Figures (5-16 a, b, c and d) can be used with special care when installing the first layer of the filter (boulders) over the bore wellhead, the first boulders located on the top of the bore wellhead should leave some space in between that allow the filtered rainwater to go through the wellhead (Figure 5- 18, a). More holes around the bore wellhead may be needed (Figure 5- 18, b)



(a)



(b)

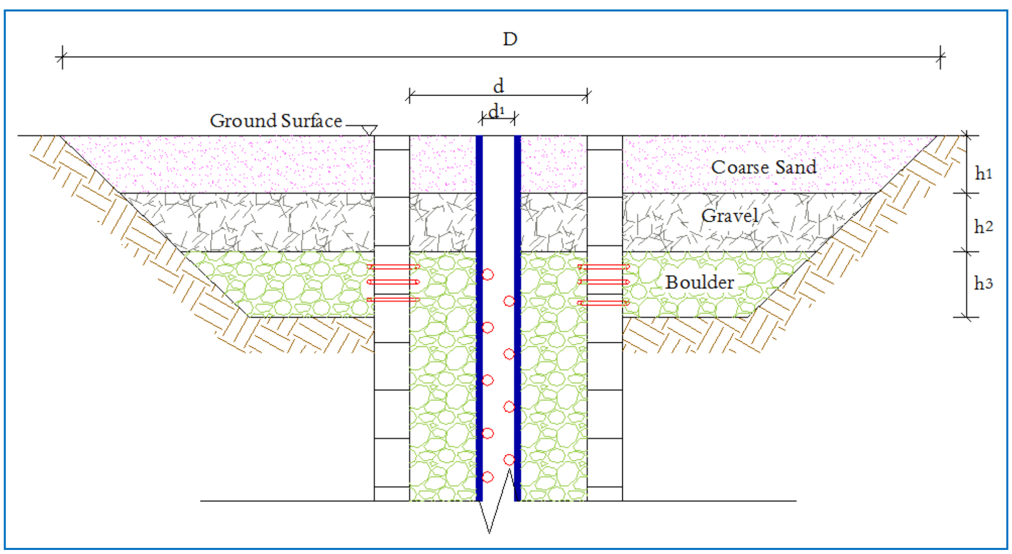
Figure 5 - 18. Suggested techniques of RWH outside (a) and inside (b) ground filters for dry dug/bore wells to be used for groundwater recharge

b. The bore wellhead with the ground surface: whether it is cut to be with the bottom level of the dug well and the same suggested fitters (5-16 a, b, c and d) can be used with special care for the two points mentioned in previous section and illustrated by Figure (5- 18, a and b) or Installing the filter material inside the dug well all around the bore well and/or outside the dug well, three suggestion have been illustrated in Figures (5-19, a and b)

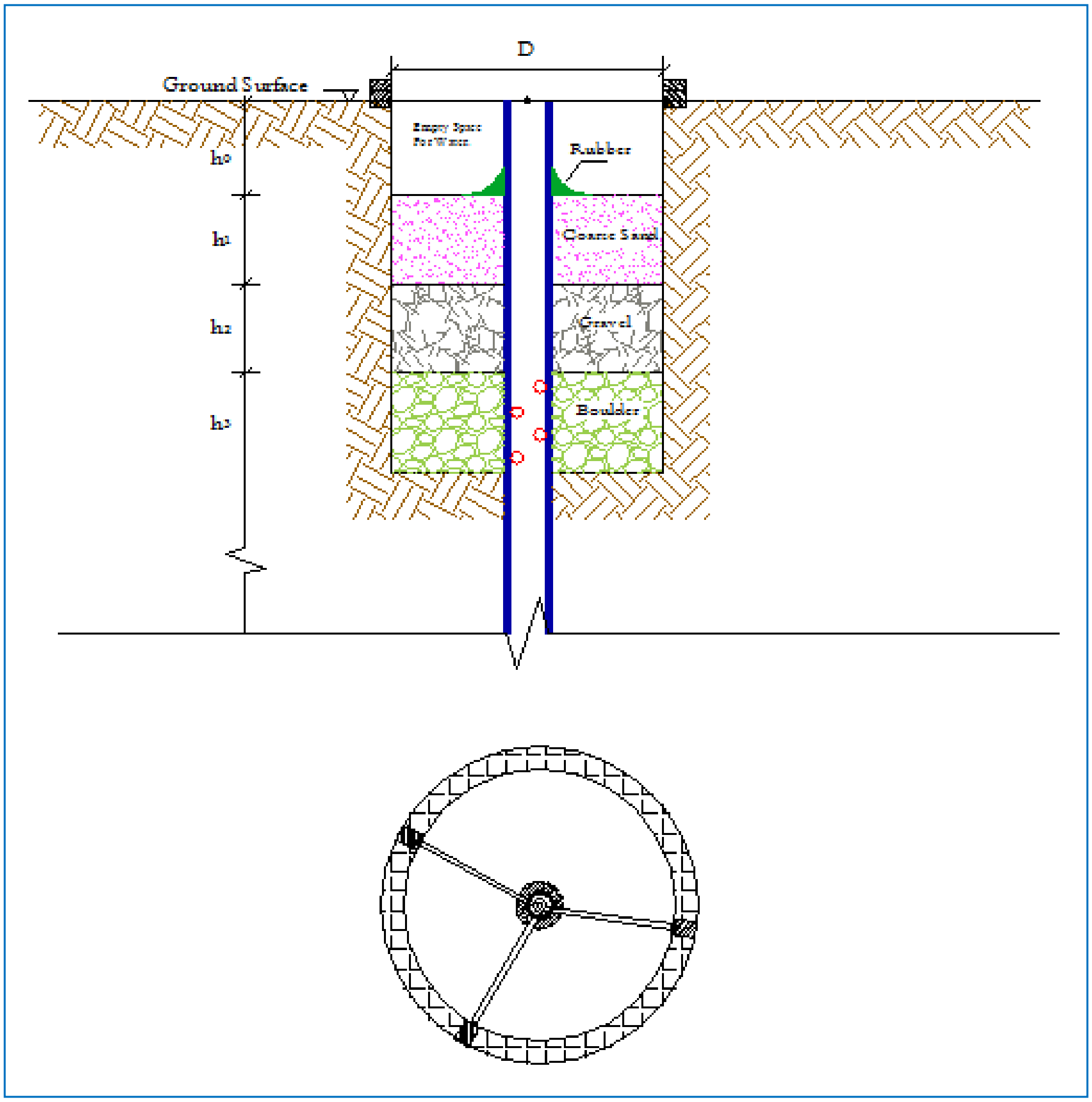
ii. placing the filter outside the dug well (keeping the well empty):

Figure (5-20) explains how to use the dug/bore well as a recharge well without filling the inside of the well. In this case the top part of both wells should be closed and protected.

For all filters mentioned rainwater can be diverted from clean catchments, roofs or wadis by pipes or canals. Moreover filters far away from the dried-up wells can be constructed and pipes can be used to transport runoff filtered water to the well.



(a)



(b)

Figure 5 - 19. Suggested techniques of RWH inside/outside (a) and inside (b) ground filters for dry dug/bore wells to be used for groundwater recharge, the bore wellhead with the ground surface.

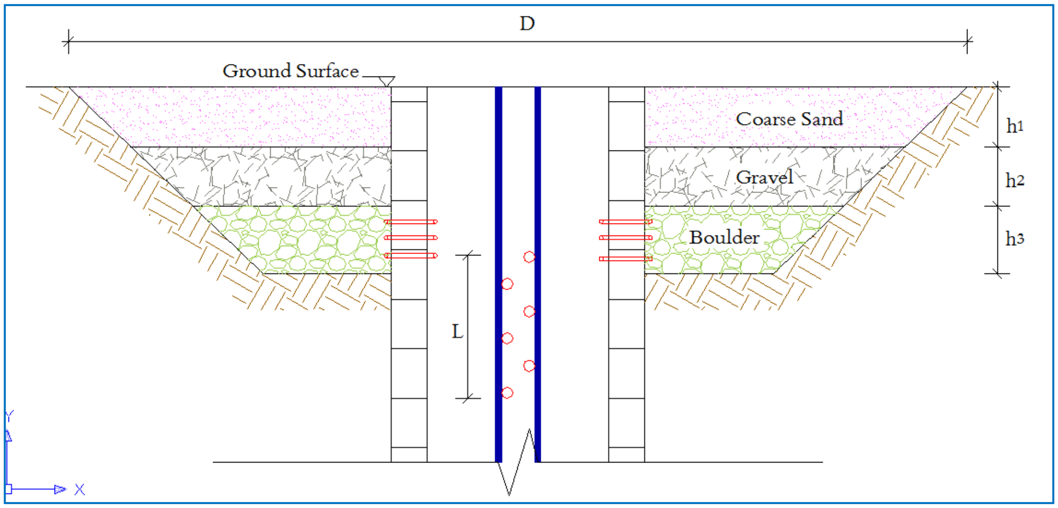


Figure 5 - 20. Suggested technique of RWH outside ground filter for dry dug/bore wells to be used for groundwater recharge, (bore wellhead with the ground surface).

Benefits of using dried-up wells to recharge groundwater:

(1) Easy to be utilized and rehabilitated to recharge wells.

(2) Fast way of reaching and recharging groundwater

(3) Good and strong tool that easily connect between surface and ground water.

(4) Big amount of water can be harvested and injected to underlying groundwater aquifers.

(5) Economically feasible.

5.7.2 Cesspits:

Sana'a city is not covered yet by both water supply and wastewater networks. Only 40% of the city is covered by swage system and 55% by water supply system (World Bank, et al., 2009). Out of the sewerage network areas, cesspits are constructed regardless of the geographical and soil type. These cesspits cost a lot of money. Whenever, the sewage system is installed, cesspits were to be buried and replaced by this system. During the social survey, 42% of the inspected cesspits are not used any more due to the installation of sewerage network system. 31% of them are filled out and buried with building material while (11%) are unused while they are not buried or filled with building materials. protecting such cesspits in a way that ensure its resistance against collapse will help to make use of these untapped cesspit.

Harvesting rain water from clean catchments or/and roofs through these cesspits will be much better than the first situation where they were used for recharge groundwater with sewage water.

However; using unfilled protected cesspits for harvested rainwater will help to harvest as much as possible of the rainfall. But if there is no way to protect them against collapse, which the people complain about, burying them is the practical option.

Using suggested filters (Figures 5-16 a, b, c and d) will expand the benefit of money that have been paid to dug these cesspits.

If the cesspits will be used without inside filter, screen for the rainwater inlet should be installed, and actually this is the best way of using streets cesspits.

5.7.3 Dug wells in the level of households:

During the survey it was found that there are many dug wells still exist, some of these dug wells were found in AL-Qa’a zone. Existing dug wells have been constructed inside the underground level of the houses. Reutilize dug wells inside the city to be recharge wells considered to be another opportunity to recharge groundwater. The some suggested techniques of the dug wells that have been discussed in section 5.7.1.2 can be used.

5.7.4 Ponds:

The idea of constructing ponds in the city is now readily expanded. Such ponds contribute in recharging groundwater as well as for gardening and street trees irrigation (figure 5-21)

Figure 5 - 21. Tankers using pond water for street trees watering

Chain of ponds and wetlands construction along Al-Sailah[9] and its branches, where there are enough space, in Sana'a city will form an ecological system and beautiful places and parks with a recreational value (Niemczynowict, 1999). The filtration rate decrease, with time, is one of the ponds problems, however, sedimentation basins are a good solution for such problem. When using lined ponds

[9] Al-Sailah is the main paved wadi (stream) that cross the Sana'a city, it is used as a road as well.

with injection wells, including sedimentation basins, sediments removal and wells cleaning from the main ponds can be applied. According to the amount of sediments the ponds can be cleaned whether during dry season or if not possible the bond should not receive any more water, and the inlet of the pond should be diverted out of the pond, till the pond get dry for cleaning.

Dimensions of the ponds embankments and wells stability are very important factors that should be taken into consideration when designing ponds.

Al-Rea’sa pond (Figure 5-22) was visited. It was found that after more than two months of the last rainfall event, the water stored in this pond still used. Tankers still take the water for street plants instead of watering them by groundwater. Hence, such ponds can contribute in groundwater saving term.

Figure 5 - 22. AL-Rea’sa pond

Paving Al-Sailah canal along the city of Sana'a prevents any more infiltration to underlying layers. Several main and secondary branches of Al-Sailah are still under planning and constructing. So finding ways to allow rainwater filtration to the underlying layers will play a significant role in recharge groundwater, as well as recharge wells located around, that have been affected after constructing and paving Al-Sailah (especially in old city of Sana'a). Boxes of buried boulders or filters, connected to the side walls of Al-Sailah by pipes or canals and installing recharge wells along the bed of Al-Sailah are some examples of techniques that can be used.

5.7.5 Check dams

Check dams are good practiced technology in the basin, stone masonry structures are constructed in the streams across the water way. Check dams are useful structures to recharged groundwater and near wells. Moreover it can be used to convert runoff into canals or farms.

Benefits of check dams (located in Bahman village, Beni Hushaish District, Sana'a Basin) are already felt by communities. The annually Ground water declining cost farmers to deepen their wells and buy new pumps. However the implementation of this kind of dams helps to save formers money. Open dried-up dug wells have been restored as a result of the water levels that rise in the aquifer. Moreover the farmers' income has increased.

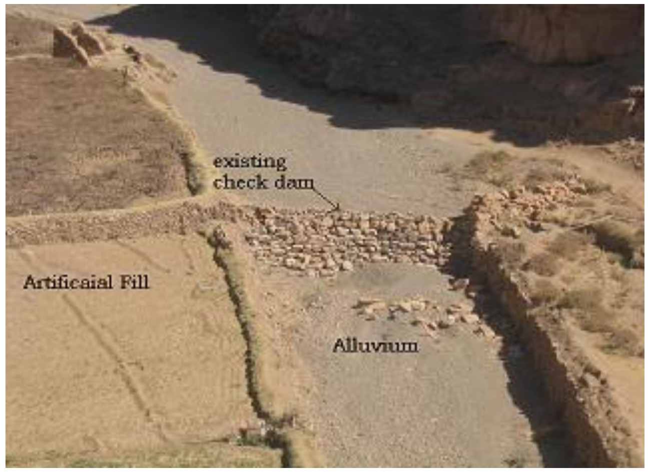


Figure 5 - 23. Downstream of Check Dam Area

Source: Alderwish (2010) cited from Stanley (2006)

Check dams seems to be more economical and effective in groundwater recharge comparing to gravity dams. Average annual incremental recharge of Bahman check dams is 75000m^3. The total cost of check dams construction is US $ 182,082. However the payback period of such dams was calculated to be two years. With only one fifth of cost of Beryan dam, one of the gravity dams in the basin, check dams shows triple amount of incremental recharged water than Beryan dam. Check dams recharge more than 57% of the stored water (Alderwish, 2010).

According to Alderwish study at Dynamic recharge assessment (2010), check dams show the highest efficiency of recharge, percentage of 94% of efficiency has been achieved. Maintenance and silt removal should be overcome by establishment Water Users Association (WUA).

To increase groundwater recharges such check dams are advisable to be in the southern part of the basin in both volcanic and an alluvial aquifers where sub-basins 14, 18, 19, 20, 21, and 22 (see are situated). Moreover floods will be reduced since these sub-basins are located in the Upper part of the basin (Ward, et al., 2010).

CHAPTER SIX
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

- The potential amount of rainwater that can be harvested from the rooftops of Sana'a city has been calculated:
  - Both ArcGIS and AutoCAD programs are used to digitize 2009 satellite image of the city. Digitizing map was combined with annual rainfall isohyets map. The output combined map has been used where the city was divided to south, middle and north zones depending on the average rainfall.
  - For each zone, the total rooftops area was calculated, and then rational method was applied to calculate runoff from rooftops. About 6.4 (MCM/year) was the total potential volume of rainwater that can be harvested from the roofs
- Rainwater quality was assessed, the measured inorganic parameters met both WHO and Yemeni standards. In contrast, organic parameters exceeded the maximum allowable values. For insuring and improving water quality different measures and treatments were carried out. Filtering method using sliver filter has been chosen as a suitable method that proved its efficiency for the removal of biological contaminants and its acceptance among local people.
- Using one system for harvested rainwater and network water was suggested and discussed.

- Different type of storage tanks have been identified through assessing the potential techniques, sizes and sites:
    - Evaluate and identify different techniques and types of tanks that can be implemented within Sana'a considering the factors of cost. However, brick cement tanks were included as cheapest techniques but not practiced in Yemen.
    - Economically brick cement tanks were suggested for all water systems unless there are other factors make brick cement tanks impossible to be installed. Limited volume of brick cement tanks (from 0.5 up to $30m^3$) and its inability to withstand roof construction were the main factors that stand in the face of installing such brick cement tanks. Ferrocement, block and concrete tanks were the other options.
    - Matrix for the selection process of tanks has been developed based on many factors: cost, required capacity and space area availability. People preference also another factor that can play a major role in the tanks selection.
- Other possibilities of RWH in the scale of Sana'a basin have been identified:
    - More than 1615 dried-up wells become abandoned. So, different suggested techniques of rehabilitation were stated in order to benefit from dried-up unused wells through adapting them to recharge wells.
    - According to the type of dried-up well types, different options of ground filters, which can be suited with the well, have been illustrated by sketches. AutoCAD program has been used to draw cross sections of filters.

- With respect to the main objectives of the study, social survey as an important factor was carried out in order to get the information that aimed:
    - To get people opinion in RTRWH;
    - To assess quality, quantity, uses and resources of current supplied water;
    - To assess people awareness towards water scarcity in Sana'a basin and;
    - To discover the existing RTRWH systems and their applications.

More than 90% of interviewees are aware of water scarcity in Sana'a basin while 86% of them are encouraging the idea of RTRWH. In term of willingness to cooperate/ pay, (41%) of the respondents, who encouraged the idea of RTRWH, are willing to participate practically, while, 38% of them are willing to participate in both financially and practically, however only 3% are willing to take a part of financial participation. 40% of the respondents would use harvested rainwater for all domestic uses while 60% would use it for other uses rather than drinking purpose.

While the owners and users of the 6 found existing RTRWH systems believe that the projects are feasible at least during the rainfall season, with different concepts of uses, they strongly encouraged the idea of spreading the RTRWH projects for the whole city.

6.2 Recommendations

- Rainwater should be considered in the water management policies, strategies and plans in Sana'a basin and other places in Yemen.

- Rainwater quality requires further quality studies and test. Representative samples should cover different systems depending on the types and sizes of both tanks and roofs. Moreover, temporal and spatial distribution of the samples to cover the study area is an important required factor.
- Beside brick cement and ferrocement tanks that have been suggested as cheap techniques by this study, Ghala basket, cement jars and concrete ring tanks are also other cheap techniques practiced in Kenya and required further investigation in order to be used locally.
- Raising public awareness through awareness campaigns and workshops are required as a first step to promote the use of RTRWH harvesting.

- Setting of laws, regulations, and building codes to use WH in old and new buildings is recommended.
- In term of implementation, RTRWH systems should be initiated in government and public buildings as a motivational step.
- At the same time, One system for different sources of water is recommended by this study, so rehabilitation the old systems to meet RTRWH requirements should be started with the appropriate once that required only cleaning and delivery systems. SFD as an experienced institutional and SWSLC as a responsible body of water supply are considered to develop a shared plan for existing systems rehabilitations.

- Introducing incentives is needed to play an important rule to encourage the use of WH as well as to help poor households.
- Physical protection and frequently cleaning of RTRWH systems are recommended for better rainwater quality. Moreover, Mesh filter (course filter) should be fixed by the entrance of the gutters on the roofs to prevent debris, leaves and reduce the turbidity. Simple first flush device and filtering before drinking is recommended.
- For the sustainability of the RTRWH, close cooperation between the government, the private sector, and the urban households is required; all stakeholders should be involved in all phases of planning, designing and implementing of RTRWH systems. Such cooperation will help in developing the ownership and skills of all participants, moreover, stakeholders' consultation and public participation is considered as key issues for WH systems success.

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Appendix (A): Fabricating Brick Cement Tanks

How to build a brick cement tank (General steps) as in Pace (2010)[10]:

- *Number of bricks to be laid in one layer (X)* = Circumference of tank / length of single brick
- *Number of bricks required for tank height (Y)* = Height of tank / height of single brick
- *Total number of bricks = X * Y*

Step 1: Foundation

- Clear the site free of bushes, tree stumps etc. to facilitate the ease of construction
- Excavate foundation down to a firm ground depending on soil type
- Fill it with hard core and compact well to level
- Cut the reinforcements (weld mesh) to fit the floor slab area, tie with binding and place in position
- Place the outlet and washout pipes tying them on to the reinforcement with binding wire. The pipes should project by 25cm into the proposed water tap area
- Place a 2.5m long GI (galvanized iron) pipe exactly at the centre vertical to help the builder keep circumference when placing the bricks. Also fix the project reinforcement for the king post in position at the centre
- Prepare a 1:2:4 concrete and compact it well to fill all voids to form a slab of 100-150 mm thick, covering all the reinforcement and piping as necessary
- Cover the newly cast slab with sacks or polythene sheet to keep it wet to cure at least for 1 day

[10] *Pace (2010),* ***Brick Tanks for Rainwater Storage****, action sheet 22, Retrieved on December 02, 2010 from* *http://www.paceproject.net/UserFiles/File/Water/Brick%20tanks%20for%20storage.pdf*

Step 2: Wall Construction

- Bricks can be laid in different ways i.e. lengthwise, across or both mixed depending on the desired wall thickness and size of bricks available to make a strong water tank
- Remove the sacks/polythene and using a binding wire attached to the centre pipe, mark out 2 circles corresponding to the outer and inner diameter of the proposed brick wall
- Soak bricks to be used in water overnight
- Prepare a 1:3 mortar (cement: sand) and make a weak mix of water and cement and pour along the marked strip where the bricks are to be laid
- Lay the bricks in the strip making sure that all joints are about 1 cm thick. Fill with mortar and compact well, while checking verticality of bricks
- Build the brick wall making sure not to construct more than 1m high or 7 courses per day. A maximum tank height of 2m is preferable
- Place a 2" overflow pipe at the top of the tank and build one extra course above it

Step 3: Plaster and Roofing

- Apply rough plaster on the inside of the tank with 1:3 (cement: sand) mortar to obtain an even surface. Then place a chicken wire mesh over the rough plaster and then apply the final coat of about 1 cm thick with cement slurry ('nil') to make it watertight. Special cement (waterproof or other sealant) could be used where necessary
- Provide a roof structure (concrete or iron sheets) to exclude dust, and sunlight, but with a suitable access manhole near the inlet down pipe
- Fix the gutters ready to harvest rainwater from all sides of the roof

How to build a brick cement tank, (Example of 400 liter brick cement Tank) As in Arrakis and Connect International (2006)[11]:

Materials for a 400 liter tank. 3 layers of bricks. Diameter 0.85 m. Height 0.70 m (Figure A-1):

• 90 bricks (23 cm x 11cm),

• 30 m black steel wire (1.5 mm),

•1/2 bag of cement,

• 2 bags of sand,

• 0.5 m of 1” PVC pipe or other pipe.

1. Take the materials to the place where you will build the tank.
2. Clean surface of a round of diameter plus 0.5 m, make it horizontal and flat.
3. Draw a circle of 85 cm, for instance with a piece of wire and 2 sticks
4. Put a first round of bricks around this circle, with long sides vertical. Make sure that bricks are more or less straight and without obstacles
5. Put a wire around the bricks, 3 cm from the top. Tighten the wire by making a loop on 1 end and pulling through the other end
6. Put 2 other wires, 1 in the middle and one 3 cm from the bottom
7. Put a second and a third round of bricks on top and also place wires, step 5 and 6.
8. Make cement starting with 1/3 bag of cement. Mix 1 part of cement with 4 parts of sand, small gravel (if available), and water
9. Apply a thin layer on outside and inside of the tank just to cover bricks
10. Make a water outlet. a steel pipe or thick walled PVC pipe of 1 “ , 25 cm long

[11] *Arrakis and Connect International (2006), **Draft Short Manual On Fabricating Brick Cement Tanks**, Retrieved on December 01, 2010 from http://www.arrakis.nl/reports/Manual_Fabricating_Brick_Cement_Tanks_short_03_lr.pdf , Available on www.connectinternational.nl*

11. If steel is used weld pieces of round bar to it to fix it in the cement. If PVC is used put PVC glue and sand to increase grip of the Pipe in the cement, or make the PVC pipe end a bit square by heat from a fire
12. Place it 3 cm from the bottom and make wall thickness at the part of the outlet 15 cm thick
13. Put cement on the floor of the tank 3 cm thick
14. Mix only cement and water to form a thin solution and "paint" on the inside of the tank with a tool or large brush. Let it dry for about half a day.
15. Let the cement cure, Cover the tank with plastic sheet or paper and KEEP IT WET during 10 days, Put water 2 times or more every day!!
16. Place a filter (Sock or other piece) on the water outlet to filter impurities. This is important if the water is used for drip irrigation. It will keep the little holes from getting blocked.)

If bigger tanks are needed make bigger circle and increase number of bricks and cement accordingly.

Table (A-1) Materials needed for different sizes of brick cement tanks

Tank Data		TANK of 400 ltr	Tank of 2 m3	Tank of 10 m3
Description	**Unit**	**Measure**	**Measure**	**Measure**
D=Diameter tank	m	0.85	1.95	3.60
H=Height of tank	m	0.70	0.70	1.00
Layers of stones	nr	3.00	3.00	4.00
V= Volume of tank	M3	0.40	2.09	10.17
Size of stones	m x m	0.23 x 0.11	0.23 x 0.11	0.23 x 0.11
Number of stones (+spares)	**nr**	**90**	**200**	**540**
NET Length of 1.5 mm black steel wire	m	30	60	140
Bags of cement	bags	0.5	1	2
Sand	bags	2	4	8
1 " PVC pipe	m	0.5	0.5	0.5

Source: Arrakis and Connect International (2006)

Figure (A-1) Brick cement tank (400 Liter) Construction Used in Arrakis and CI projects

Source: Arrakis and Connect International (2006)

Appendix (B): Fabricating Straw Mat Tanks

How to build a Straw Mat Tank (General steps) as Christian Fenger (2006)[12]:

1. Take the materials to the place where you will build the tank. It should be a place where it is easy to collect water.
2. A mat made of bamboo or strong grass is made into the shape of a cylinder or. There should be a double layer. Which means the mat can be cut into two long strips to make a small cylinder. Or use two mats to make a larger tank.
3. Reinforce the cylinder with three circles of steel wire (Figure B-1).

Figure B-1. Making the bamboo mat in a cylinder shape and reinforcing it with three circles of steel wire

Source: Christian Fenger (2006)

4. Mix 1 part of cement with 5 parts of sand, small gravel (if available), and water to make the bottom of the cylinder.

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[12] *Christian Fenger (2006), 40 Green World Actions: 40 manuals to improve the environment in rural communities,* ***The GAIA-Movement Trust Living Earth*** *Green World Action 2006, 24-26.*

5. Place a PVC pipe 20 cm long (8") in the lower part of the cylinder. This tube will remain closed and only be used to drain the tank after cleaning. Place another PVC pipe 20 cm (8 inch) over the bottom of the tank. This tube will be the water outlet.
6. Mix cement and water to form a thin solution and "paint" both the inside and the outside of the cylinder with a large brush (Figure B-2). Let it dry for about half a day.
7. Mix 1 part of cement with 3 parts of sand and water. Place the mixture on both sides of the cylinder as thinly as possible - maximum 3 to 4 cm.

Figure B-2. Painting both the inside and the outside of the cylinder straw mat tank using water and cement solution and large brush

8. The area where the tubes are, need to be reinforced with a thicker layer - about 7 to 8 cm. The area where the wall ends meet the bottom should also be reinforced.
9. Let the tank dry for 10 days in a humid environment - covered with grass or leaves and watered every day.
10. Place a sponge or a piece of cotton in the water outlet to filter impurities. This step is also important if the water is being used for drip irrigation. It will keep the little holes from getting blocked.

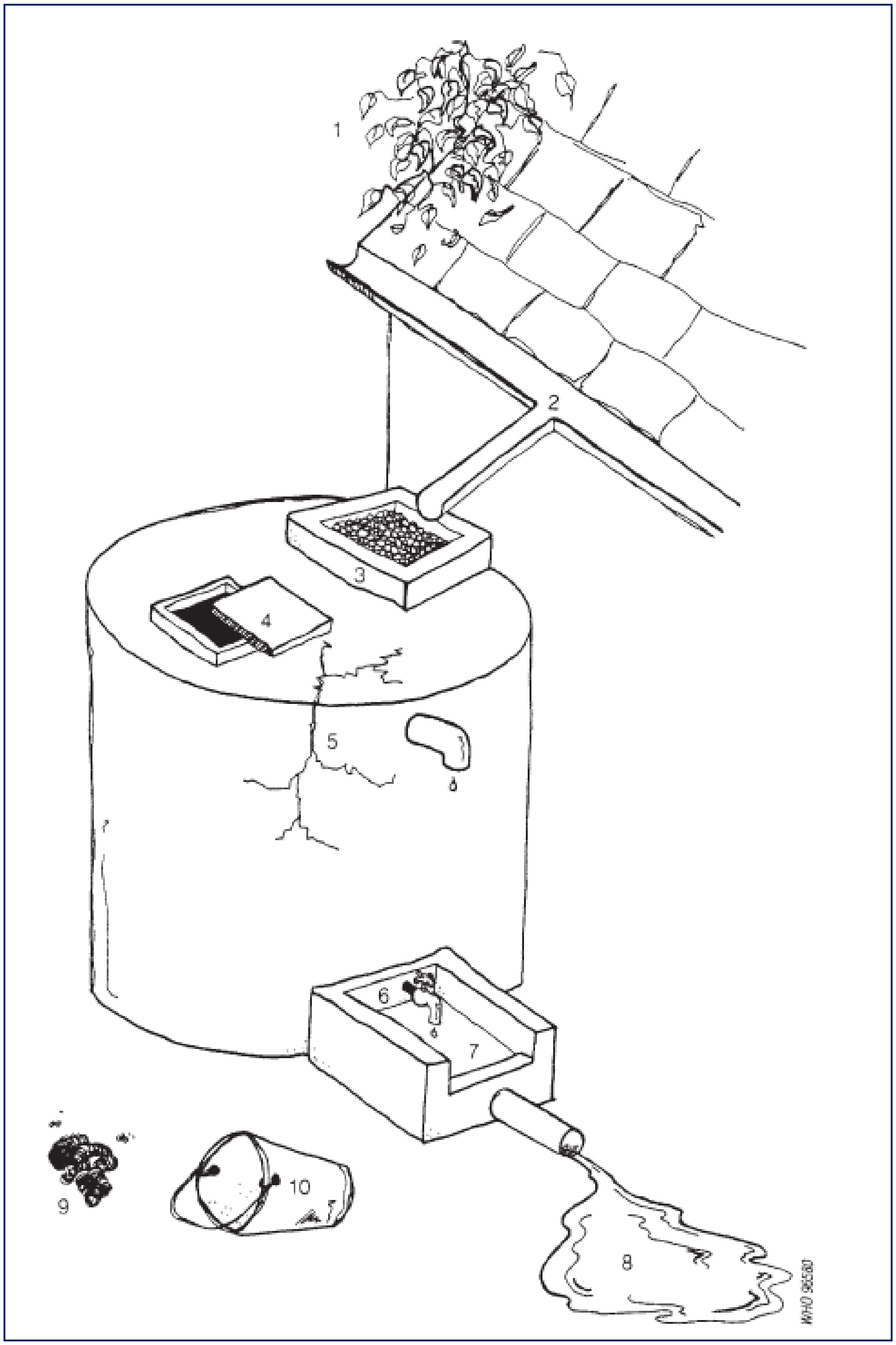
Helmreich and Horn (2009)[13] shows that Bamboo together with a polythene sheet can be used in building a basket structure tank.

Figure B-3. Bamboo tank developed by ARTI in Pune, India, uses a polythene sheet in a basket structure

Source: Helmreich and Horn (2009)

[13] *Helmreich, B. and Horn, H. (2009), Opportunities in rainwater harvesting.* ***Desalination****, 248(1-3), 118-124.*

Appendix (C), Example of sanitary inspection form for rainwater collection and storage. (WHO, 1997)



I Type of facility RAINWATER COLLECTION AND STORAGE

1. General information: Health centre ....
   Village ....
2. Code no.—Address ....
3. Water authority/community representative signature ....
4. Date of visit ....
5. Water sample taken? .... Sample no. .... Thermotolerant coliform grade ....

II Specific diagnostic information for assessment

	Specific diagnostic information for assessment	Risk
1.	Is there any visible contamination of the roof catchment area (plants, dirt, or excreta)?	Y/N
2.	Are the guttering channels that collect water dirty?	Y/N
3.	Is there any deficiency in the filter box at the tank inlet (e.g. lacks fine gravel)?	Y/N
4.	Is there any other point of entry to the tank that is not properly covered?	Y/N
5.	Is there any defect in the walls or top of the tank (e.g. cracks) that could let water in?	Y/N
6.	Is the tap leaking or otherwise defective?	Y/N
7.	Is the concrete floor under the tap defective or dirty?	Y/N
8.	Is the water collection area inadequately drained?	Y/N
9.	Is there any source of pollution around the tank or water collection area (e.g. excreta)?	Y/N
10.	Is a bucket in use and left in a place where it may become contaminated?	Y/N
	Total score of risks	/10

Contamination risk score: 9–10 = very high; 6–8 = high; 3–5 = intermediate; 0–2 = low

III Results and recommendations

The following important points of risk were noted: .... (list nos 1–10) and the authority advised on remedial action.

Signature of sanitarian ....

Appendix (D): WH Yemeni Techniques

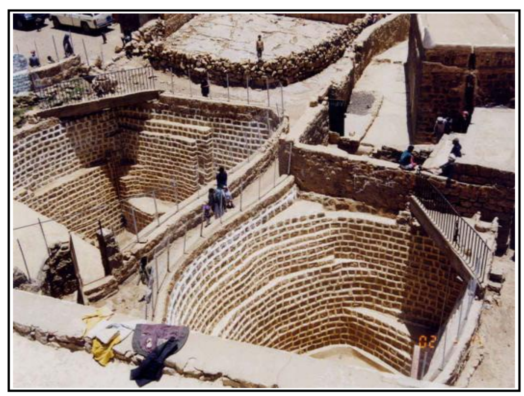
AL-Berak AL-Asadiah | 1

AL-Kohoof 1 | 2

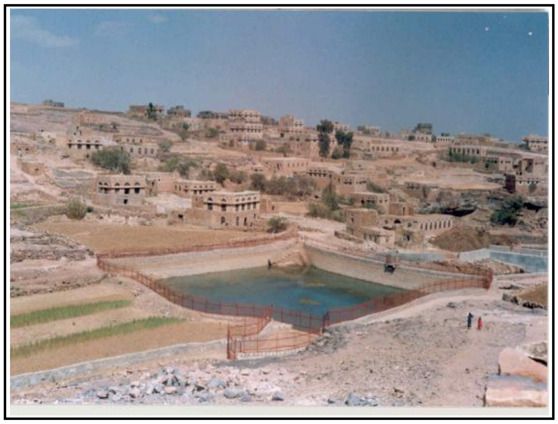
Karifs | 3

Terraces on mountain slopes in the Yemen | 4

The ancient cistern of Beit Bawss. | 5



Traditional water harvesting cistern | 6



a village community water harvesting

7

Tawila Tanks, Adens

8

Appendix (E): Some Meetings Pictures

Appendix (F): Questionnaires forms

1. Questionnaires forms:

1.1 Arabic Forms:

استبيان عن امكانية حصاد الامطار من اسطح المنازل بمدينة صنعاء, لاصحاب المنازل (نموذج1)

معلومات عامة

التاريخ	
الوقت	
منطقة الاستبيان	
رقم الاستبيان	
اسم الباحث	
اسم االمبحوث (اختياري)	
الجنس	

الوضع الاجتماعي الاقتصادي

1	(المستوى التعليمي) المؤه		
2	كم عدد افراد الاسرة؟		
3	ما هو عملك (مهنتك)؟		
	هل الدخل الشهري للعائلة يغطي جميع احتياجاتكم طوال الشهر؟	أ. نعم ب. غير كافي في بعض الاوقات ت. يغطي الإحتياجات الأساسية ث. غير كافي كلياً ج. أخرى	
5	هل انت اصلا من صنعاء ؟	أ. نعم ب. لا	
6	**اذا لا,** ما سبب انتقالكم للعيش في صنعاء؟		

معلومات عن المياه

7	ما هو مصدر المياه الرئيسي للاستخدام المنزلي لديك ؟	أ. الشبكه..كل كم ياتي الماء.... ب. وايتات ت. الامطار ث. بئر خاص ج. اخرى	

8	هل تشعر أن هذه المياه صالحة للشرب ؟	أ. نعم ب. لا ت. لا أعلم	
9	**إذا كانت الإجابه لا:** لماذا تشعر بأن هذه المياه غير صالحه للشرب؟	أ. الشبكه ليست نظيفه ب. المصدر الرئيسي غير موثوق ت. مختلط مع مياه الصرف الصحي ث. الزراعه (الأسمدة) ج. الطعم سيئ ح. المياه لها لون خ. غير ذلك .....حدد	
1	مصدر مياه الشرب لديك؟ ما هو	أ. شبكة المياه ب. الوايتات ت. كوثر او قوارير المياه ث. حصاد الامطار ج. من الشبكه + فلتر ح. واي ات + فلتر	
11	في حالة ان مصدر الرئيسي غير كافي للاستخدام المنزلي , فما هو مصدر المياه الثانوي لديك؟	أ. الشبكة.. كل كم ياتي الماء... ب. الوايتات ت. كوثر او قوارير المياه ث. حصاد الامطار ج. اخرى	
12	تعتقد ان هذا المصدر الثانوي نظيف للشرب؟ ه	أ. نعم ب. لا	
13	**إذا كانت الإجابه لا:** لماذا تشعر بأن مياه المصدر الثانوي غير صالحه للشرب؟	أ. الشبكه ليست نظيفه ب. المصدر الرئيسي غير موثوق ت. مختلط مع مياه الصرف الصحي ث. الزراعه (الأسمدة) ج. الطعم سيئ ح. المياه لها لون خ. غير ذلك .....حدد	

الوعي الاجتماعي

14	ازمه مائيه في صنعاء؟ هل تعتقد بوجو	أ. نعم ب. لا	
15 15,1	**اذا الاجابه بنعم,** باعتقادك ما هو السبب او الاسباب المؤديه الى هذه الازمه؟	أ. قلة الامطار ب. الاسراف بالمياه ت. استخدام المياه للزراعه ث. الابار ج. الهجره من بقية المناطق الى صنعاء ح. اخرى..حدد (القات,الرصف..	نعم ( ) لا( ) نعم ( ) لا( ) نعم ( ) لا( ) نعم ( ) لا( ) نعم ( ) لا( )

15.2	برايك ما هي الحلول المستقبليه لحل هذه الازمه؟	أ. ايقاف اي حفر جديد للابار ب. ايقاف تعميق الابار الموجوده ت. تخفيض الاراضي الزراعيه ث. استخدام حصاد الامطار , سدود/ خزانات .... ج. دعم حكومي لاستخدام تكنولوجيا الري الحديث ح. معاقبة الحفر غير المرخص خ. اقتراحات اخرى	نعم ( ) لا( ) نعم ( ) لا( ) نعم ( ) لا( ) نعم ( ) لا( ) نعم ( ) لا( ) نعم ( ) لا( )

اسئله متعلقه بحصاد الامطار من اسطح المنازل

16	ما هي نوعية سطح المبنى؟	أ. صبه (اسمنت) ب. بلاط ت. ترابي ث. اخرى	
17	ما هي نوعية خزان المياه في المبنى؟	أ. ارضي ب. حديد ت. بلاستيك ث. اخر . ..	
8	هل تشجع فكرة حصاد الامطار من اسطح المنازل	أ. نعم ب. لا	
19	**إذا كانت الإجابه لا**: ما هي الاسباب؟	أ. كمية الحصاد غير مجديه او غير كفايه ب. لا يمكن استخدامها ت. لا يوجد لدي مكان كافي لعمل خزان ث. مكلف ماديا ج. غير ذلك .....حدد	
20 20,1	**إذا كانت الإجابه نعم :** تسال بقية الاسئله اذا كانت الاجابه نعم في حالة اقامة مشاريع حصاد الامطار من اسطح المنازل هل لديك ا رغبه للمساهمة في مثل هذه المشاريع؟	أ. المساهمة بالمال ب. المساهمة بالعمل ت. لا ارغب ث. اخرى	
20,2	لاي اغراض ستستخدم مياه الحصاد؟	أ. لجميع الاستخدامات المنزليه ب. لجميع الاستخدامات المنزليه ما عدا الشرب ت. للتنظيف والغسيل ث. للري والتشجير(ري الاشجار) ج. للاستخدامات المنزليه والشرب في حالة الفلتره ح. اخرى	
20,3	في حال اثبت نقاوة مياه الامطار هل تعتقد ان الخزان الحالي كافي لمياه الامطار والمياه من المصادر الاخرى ؟	أ. نعم ب. لا	

20,4	اذا الاجابه لا في السؤال السابق, هل يوجد لديك مكان لعمل خزان اضافي لحصاد الامطار(ارضي او سطحي)؟	أ. نعم ب. لا	
20,5	اي نوع من انواع الخزانات تفضل لحصاد الامطار من اسطح المنازل؟	أ. خزان ارضي ب. خزان بلاستيك ت. خزان حديدي ث. فروسمنت مع ملاحظة انه لا يمكن البناء عليه او استخدام سطحه أ. اخر............	

اسئله اضافيه حول البيارات:

21	هل انت موصل الى شبكة الصرف الصحي؟	أ. نعم ب. لا	
22	ايهما ارفع الشارع ام الحوش ؟	أ. الحوش ب. الشارع	
23	**في حالة ان الشارع ارفع من الحوش**, كيف يتم تصريف مياه المطر من الحوش	أ. الى شبكة المجاري ب. للري ت. اخرى...حدد..	
24	هل قمت بحفر بياره للبيت ؟	أ. نعم ب. لا	
25,1	**اذا الاجابه نعم** , ما حالت هذه البياره الان؟	أ. ما زالت مستخدمه للمجاري ب. تم دفنها بعد التوصيل للشبكه ت. موجوده وغير مستخدمه ث. لا اعلم	
25,2	ما رايك في تعقيم البيارات الستغنى عنها و استخدامها لحصاد الامطار لتغذية المياه الجوفيه؟	أ. فكره ممتازه ب. لا انصح بها بسبب.......	

استبيان عن امكانية حصاد الامطار من اسطح المباني بمدينة صنعاء,للمؤسسات والهيئات الحكوميه (نموذج2)

معلومات عامة

التاريخ	
الوقت	
منطقة الاستبيان, المؤسسه واسم	
رقم الاستبيان	
حث ب اسم ا	
اسم االمبحوث (اختياري)	
الجنس	

الوضع الاجتماعي الاقتصادي

1	المؤهل (المستوى التعليمي)		
2	كم عدد العاملين في المبنى ؟		
3	ما هو عملك (مهنتك)؟		
4	هل الدخل الشهري يغطي جميع احتياجاتك طوال الشهر؟	أ. نعم ب. غير كافي في بعض الاوقات ت. يغطي الإحتياجات الأساسية ث. غير كافي كلياً ج. أخر	
5	هل انت اصلا من صنعاء ؟	أ. نعم ب. لا	

معلومات عن المياه

6	ما هو مصدر المياه الرئيسي للاستخدام في المنشاه؟	أ. الشبكه..كل كم ياتي الماء.... ب. وايتات ت. الامطار ث. بئر خاص ج. اخرى	
7	كم تدفع ثمنا لهذه المياه شهريا؟		
8	هل تشعر أن هذه المياه صالحة للشرب ؟	أ. نعم ب. لا ت. لا أعلم	

9	و مصدر مياه الشرب لديكم؟ ما	أ. شبكة المياه ب. الوايتات ت. كوثر او قوارير المياه ث. حصاد الامطار ج. من الشبكه + فلتر ح. وايتات + فلتر	
10	في حالة ان مصدر الرئيسي غير كافي للاستخدامات العامه, فما هو مصدر المياه الثانوي لديك؟	أ. الشبكة.. كل كم ياتي الماء... ب. الوايتات ت. كوثر او قوارير المياه ث. حصاد الامطار ج. اخرى	
11	هل تعتقد ان هذا المصدر الثانوي نظيف وامن للشرب؟	أ. نعم ب. لا اذا لا لماذا؟........	
12	كم تدفع ثمنا لمصدر المياه الثانوي شهريا؟ تقريبا		

اسئله متعلقه بحصاد الامطار من اسطح المنازل

13	كم ابعاد سطح المبنى ؟ تقريبا	أ. باللبن العشاري **او بالمتر كم الطول والعرض** ب. الطول ت. العرض	
14	ما هي نوعية سطح المبنى؟	أ. صبه (اسمنت) ب. بلاط ت. ترابي ث. اخرى	
15	ما هي نوعية خزا المياه في لمبنى؟	أ. ارضي ب. حديد ت. بلاستيك ث. اخر	
16	كم سعة الخزان او ابعاد الخزان التقريبيه ؟	أ. السعه بالمتر المكعب **او** ب. السعة بالبرميل **او ابعاد الخزان التقريبيه بالمتر** ت. الطول ث. العرض ج. العمق	اذا كانت السعه بالوايت يتم التحديد وايت صغير ام كبير

استبيان عن امكانية حصاد الامطار من اسطح المنازل بمدينة صنعاء (للمشاريع القائمة)

(نموذج3)

معلومات عامة

ريخ الت	
الوقت	
منطقة الاستبيان	
رقم الاستبيان	
اسم الباحث	
اسم المبحوث (اختياري)	
الجنس	

اسئله متعلقه بحصاد الامطار من اسطح المباني

1	موقع المشروع ؟	أ. فيلا ب. عمارة ت. مدرسة ث. جامع ج. اخرى	
2	كم ابعاد سطح المبنى (المس حه ل اكبه) ؟ ت ريبا	أ. باللبن العشاري **<u>او بالمتر كم الطول والعرض</u>** ب. الطول ت. العرض	
3	ما هي نوعية سطح المبنى؟	أ. صبه (اسمنت) ب. بلاط ت. ترابي ث. اخرى	
4	ما هي نوعية خزان حصاد المياه في المبنى؟	أ. ارضي ب. حديد ت. بلاستيك ث. اخر	
5	كم سعة الخزان او ابعاد الخزان التقريبيه ؟	أ. السعه بالمتر المكعب ب. السعة بالبرميل **<u>او ابعاد الخزان التقريبيه بالمتر</u>** ت. الطول ث. العرض ج. العمق	
6	هل المشروع مبادره ذاتيه ام مشروع ممول؟	أ. مبادره ذاتيه ب. ممول من قبل	
7	كم فرد يستفيد من مياه الامطار في نفس المبنى؟		

8	هل يتم توجيه جزء من مياه المطر الى خارج الخزان لغرض تنظيف السطح؟	أ. نعم في بداية كل مطره ب. نعم في بداية موسم الامطار ت. لا ث. اخرى		
9	هل يتم تنظيف السطح والخزان دوريا ؟	أ. نعم .كل كم السطح.... الخزان.... ب. لا		
10	لاي اغراض تستخدم مياه الحصاد؟	أ. لجميع الاستخدامات ب. لجميع الاستخدامات ما عدا الشرب ت. للتنظيف والغسيل ث. للري والتشجير(ري الاشجار) ج. اخرى		
11	هل تشعر أن هذه المياه صالحة للشرب ؟	أ. نعم ب. لا ت. لا أعلم		
12,1	**إذا كانت الإجابه لا**: لماذا تشعر بأن هذه المياه غير صالحه للشرب؟	أ. النظام ليس نظيف ب. الطعم سيئ ت. المياه لها لون ث. غير ذلك .....حدد		
12,2	ما هو مصدر مياه الشرب لديك؟	أ. شبكة المياه ب. الوايتات ت. كوثر او قوارير المياه ث. حصاد الامطار ج. من الشبكه + فلتر ح. وايتات + فلتر		
13	هل يتم استخدام الخزان لتخزين المياه من مصادر اخرى غير الامطار؟	أ. نعم ما هي ...... ب. لا		
14	اي نوع ن انواع الخ انات تفضل لحصاد الامطار من الاسطح ؟	أ. خزان ارضي ب. خزان بلاستيك ت. خزان حديدي ث. فروسمنت مع ملاحظة انه لا يمكن البناء عل ه او استخدام سطحه		
15	هل تعتقد ان المشروع مجدي ويقوم بتوفير كميه لا باس بها من الماء والمال مقارنة بتكلفة التنفيذ في حالة استخدامه للامطار فقط؟ .... في حالة استخدامه للامطار والمصادر الاخرى؟...	اشرح		
16	خلال موسم الامطار هل تحتاج الى مياه من مصادر اخرى	أ. نعم حدد الكميه في موسم الامطار........... في غير موسم الامطار..... ب. لا	بالمتر المكعب اوعدد الوايتات مع معرفة حجم الوايت	
7	هل تنصح بتنفيذ مشاريع الحصاد في العاصمه؟	أ. نعم ب. لا		

1, 2. English Forms:

Questionnaire about the Potential of RTRWH in Sana'a, for Household

(Form 1)

General Information

Date	
Time	
Place of Interview (Zone)	
Questionnaire NO	
Name of Interviewer	
Name of Interviewee, optional	
Gender	

Socio-economic Questions

1	Education?		
2	How many people live in your household?		
3	What do people do for living in your family? What is your job?		
4	Does your monthly household income cover all what you need?	a) Yes b) insufficient at times c) covers only basic needs d) totally insufficient e) others	
5	Are you originally from Sana'a?	a) Yes b) No	
6	If not, why you or your fathers came to Sana'a?		

Questions on the general Water Situation

7	What is your main water source for domestic use?	a) Network b) Tankers c) Rainwater d) Own well e) Others	
8	Do you feel that this source is safe for drinking?	a) Yes b) No c) Don't know	
9	If not Why?	a) Network isn't clean b) The source isn't reliable c) Mixed with sewage d) agriculture (fertilizers) e) tastes bad f) is colored g) others…. specify	
10	What is your drinking water source?	a) Network b) Tankers c) Bottles or (Kother) d) rainwater harvesting e) Network + Filter f) Tankers + Filter	
11	If the main source isn't enough for domestic uses, what is your second source?	a) Network b) Tankers c) Bottles d) rainwater harvesting e) Other	
12	Do you think this second source is clean and safe for drinking	a) Yes b) No	
13	If not Why?	a) Network isn't clean b) The source isn't reliable c) Mixed with sewage d) agriculture (fertilizers) e) tastes bad f) is colored g) others…. specify	

Awareness Questions

14	Are you aware that there is a	a) Yes b) No	

	water scarcity in Sana'a?		
15,1	If Yes What is the reason or reasons do you think?	a) Rainfall is rare b) Irrational use of water c) Agriculture use d) Wells e) Immigration to Sana'a f) Others….. specify	yes ( ) no ( ) yes ( ) no ( ) yes ( ) no ( ) yes ( ) no ( ) yes ( ) no ( )
15,2	In your opinion what is the future solution?	a) Stop new well digging b) Stop deepening of wells c) Reduce irrigated area d) Water harvesting tanks/ dams/…….. e) Subsidize improved irrigation technology f) Punish illegal drilling g) Other suggestions	yes ( ) no ( ) yes ( ) no ( ) yes ( ) no ( ) yes ( ) no ( ) yes ( ) no ( ) yes ( ) no ( ) yes ( ) no ( )

Roof Rainwater Harvesting Related Questions

16	What kind of cover the floor has?	a) Concrete b) Ceramic c) Soil d) Other…	
17	What kind of tank do you have	a) Underground tank b) Steel tank c) Plastic tank d) Other…	
18	Do you encourage the idea of roof rainwater harvesting?	a) Yes b) NO	
19	If not, Why?	a) It isn't feasible or enough b) unusable c) I have no place d) I can't do it e) Other…	
20 20,1	If yes, Would you be willing to participate in roof rainwater harvesting Projects?	a) a) financially b) b) practically c) c) No	
	For what purposes you will use this harvested water?	a) All domestic uses b) All domestic uses except drinking	

20,2		c) Only for cleaning d) Gardening and irrigation e) Other….	
20,3	In case the rainwater is pure, do you think the current tank is enough for harvested water and the other sours of water?	a) Yes b) No	
	If not, do you have another place for additional tank?	a) Yes b) No	
20,4 20,5	What kind of tank do you prefer for water harvesting?	a) Underground tank b) Plastic tank c) Steel tank d) Ferro -cement e) Other…	

Additional questions

21	Is there a sewage system?	a) Yes b) No	
22	Which is higher your yard or the street level?	a) Yard is higher b) Street is higher	
23	In Case the street is higher than the yard level, how is rainwater discharged from the yard during the rainy seasons?	a) To the sewage system b) For gardening c) Other Specify………	
24	Did you had or have a cesspit?	a) Yes b) No	
25,1	If yes, What its condition?	a) Still used b) Filled by sewage system c) Existed and unused d) Don't know	
25,2	What do you think if the unused cesspits are used as rainwater storage to recharge groundwater?	a) Good idea b) Don't know c) Not advice Because……………	

Questionnaire about the Potential of RTRWH in Sana'a, for Public Buildings

(Form 2)

General Information

Date	
Time	
Place of Interview (Organization Name)	
Questionnaire NO	
Name of Interviewer	
Name of Interviewee, optional	
Gender	

Socio-economic Questions

1	Education?		
2	How many people are working here (in the organization)?		
3	What is your job (responsibility)?		
4	Does your monthly household income cover all what you need?	f) Yes g) insufficient at times h) covers only basic needs i) totally insufficient j) others	
5	Are you originally from Sana'a?	a) Yes b) No	

Questions on the general Water Situation

6	What is your main water source for domestic use?	a) Network b) Tankers c) Rainwater d) Own well e) Other	

7	How much you pay for this source? Monthly		*1 $ = 215 YR
8	Do you feel that this source is safe for drinking?	a) Yes b) No c) Don't know	
9	What is your drinking water source?	a) Network b) Tankers c) Bottles or (Kother) d) rainwater harvesting e) Network + Filter f) Tankers + Filter	
10	If the main source isn't enough for domestic uses, what is your second source?	a) Network b) Tankers c) Bottles d) rainwater harvesting e) Other	
11	Do you think this second source is clean and safe for drinking	a) Yes b) No	
12	How much do you pay for this second source? Monthly		*1 $ = 215 RY

Roof Rainwater Harvesting Related Questions

13	What is the building floor (catchment area) size? Approx	a) Length… b) Width…	
14	What kind of cover the floor has?	e) Concrete f) Ceramic g) Soil h) Other…	
15	What kind of tank do you have	a) Underground tank b) Steel tank c) Plastic tank d) Other…	
16	What is the size of the tank? Approximately	a) Length… b) Width… c) Depth…	

Questionnaire about the Potential of RTRWH in Sana'a, for Existed Systems

(Form 3)

General Information

Date	
Time	
Place of Interview (Zone)	
Questionnaire NO	
Name of Interviewer	
Name of Interviewee, optional	
Gender	

Rooftop Rainwater Harvesting Related Questions

1	Project location?	a) Villa b) Building c) School d) Massjed e) others	
2	What is the building floor (catchment area) size? Approx	a) Length… b) Width…	
3	What kind of cover the floor has?	a) Concrete b) Ceramic c) Soil d) Other…	
4	What kind of tank do you have	a) Underground tank b) Steel tank c) Plastic tank d) Other…	
5	What is the size of the tank? Approximately	a) Length… b) Width… c) Depth…	

6	Is the project self-initiative or funded project?	a) Self-initiative b) Funded by ……………..	
7	How many people getting benefits from the project?		
8	How do you use first flush for the purpose of roof cleaning?	a) In the beginning of every rainfall event. b) In the beginning of rainfall season c) Don't use it d) Others…..	
9	Do you clean both rooftop and storage tank frequently?	a) Yes, Rooftop every…. Tank………… b) No	
10	For what purposes harvested water is used?	a) All domestic uses b) All domestic uses except drinking c) Only for cleaning d) Gardening and irrigation c) Other	
11	Do you feel that harvested rainwater is safe for drinking?	a) Yes b) No c) Don't know	
12,1	If not Why?	a) Unclean System b) tastes bad c) is colored d) others…. specify	
12,2	What is your drinking water source?	a) Network b) Tankers c) Bottles or (Kother) d) rainwater e) Network + Filter f) Tankers + Filter	
13	Do you use the current tank for harvested water beside water from other sources?	a) Yes, Which……… b) No	
14	What kind of tank do you prefer for water harvesting?	a) Underground tank b) Plastic tank c) Steel tank d) Ferro -cement e) Other…	

15	For only harvested water, is this project feasible when compared to the cost of construction? What if it is used also for other sources?	Explain Please…..	
16	During rainy season, do you need additional water?	a) Yes, How much……… b) No	
17	Do you advice such project for the whole city?	a) Yes b) No	

Appendix (G): Key informant interviews

Eng, Abdulwahab M. Almujahed "the Head of Water and Environment Unit, Social Fund for Development" strongly welcomed the idea of RWH in Sana'a. He stated that, in Sana'a we don't have a continuous bumping in the public network, not only that, but also some of the connected areas doesn't receive water because of the pressure problems. Accordingly, the possibility of water quality deterioration is high. From this sense, rainwater quality may be much better than the quality of the public network water, ALmujahed added.

From his point of view ALmujahed suggested that, the RTRWH projects should start in the areas where there is no network. In those areas, the SWSLC, as a responsible authority for water and wastewater systems, should adopt the idea of RTRWH projects Instead of constructing new network projects. He quoted Taize project, in which more than 1000 (Sekaih) small tanks around Taiz have been sucssesfuly implemented, as a good example of such projects. There the people are happy and satisfied since their suffering has been reduced. From his economic point of view, ALmujahed recommended ferrrcement tanks as appropriate cheap tanks.

ALmujahed as one effected by the rush of sewage during rainy season, ensured that the rainwater harvesting will limit and solve this kind of sewage flooding. The reason as he mentioned, network was designed only for a sewage water, nevertheless, some people discharge rainwater to this system especially whose yards are below the streets level he added.

Answering the question about other possibilities of rainwater harvesting, ALmujahed criticized refilling the recharge ponds which were found almost everywhere in Sana'a city. Such ponds were made to recharge groundwater. For the problem of sediments in the bonds, he mentioned sedimentation basins as an appropriate solution.

Eng, Abdulkarim AL-Fusail "NWRA senior staff" believe that the idea of RRWH will be feasible only for public buildings and More feasible in case of using RWH for agriculture sector. Alfusail signified reasons for the infeasibility of RWH in normal houses; the first reason is the inappropriate small roof areas of the houses, and the rare rainfall. Institutions, public and government buildings are appropriate for RTRWH projects because such buildings have appropriate roofs with suitable big areas.

As he strongly supports the three following recommendations, Alfusail refers these recommendations to JICA report (2007)

- A good management and searching for other alternative of water resources rather than ground water, will extend the underground water life not save it from drying up.
- Irrigated agriculture depends upon groundwater should be stopped. Instead, agriculture should depend only on rainfall and treated wastewater.
- Sana'a as a political, economical and agriculture capital, attract the people from different areas in Yemen. Consequently, Sana'a should be only a political capital.

Eng, Abdulkhaleq alwan "IWRM Specialist at Department of Public awareness, NWRA - Sana'a Branch" ruled out the idea of RTRWH in sana'a city. No one will implement such costly project as long as he has other sources such as network and tankers, Alwan added. On the contrary, Alwan mentioned the absence of any water sources in many villages in Yemen as a reason that led to the implementation of such projects.

According to *Dr, Taha Tahir "Faculty of Engineering, Sana'a University*" not only legislations and lows are required in order to implement RTRWH, but also the government should start with its buildings as an encouraging step.

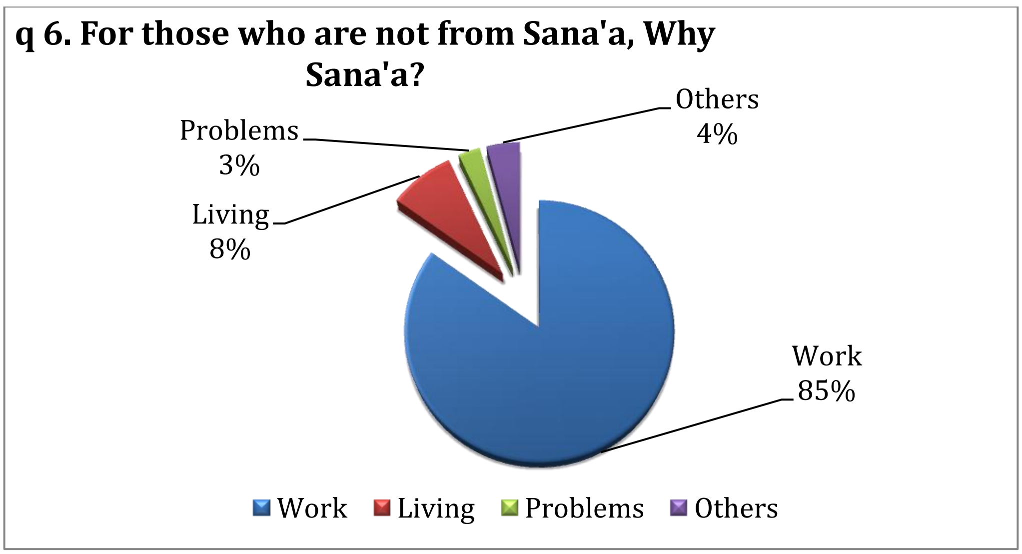
In the crowded areas where there are no enough places for RWH tanks, Dr, Tahir suggested a shard tanks in the appropriate empty areas.

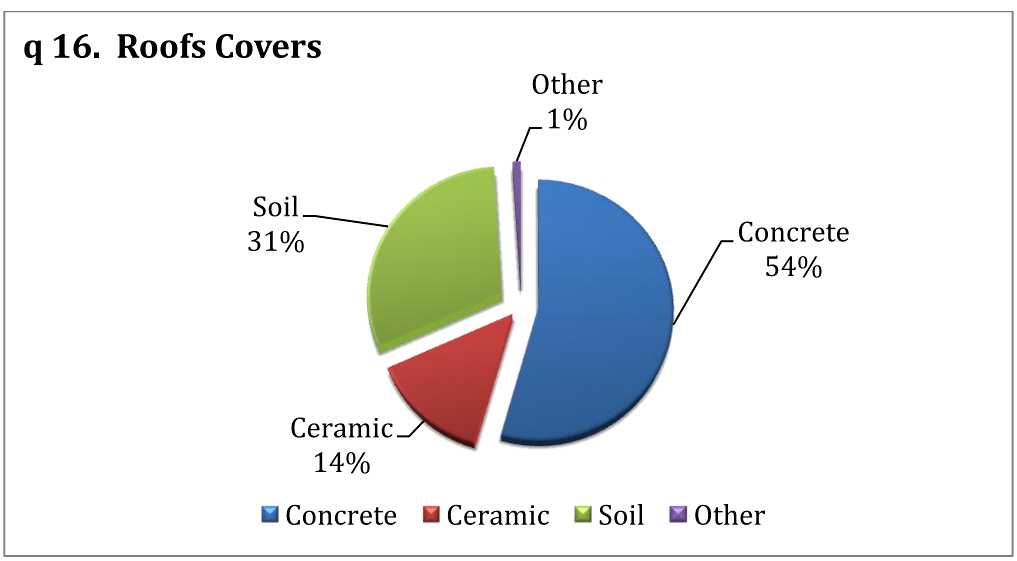
According to *Dr, Abdula Noaman* “*Faculty of Engineering, Sana’a University*” Two advantages of RTRWH, RTRWH is a mitigation tool against high pressure of demand in the network, as well as against the high load on the SWSLC. About the quality of RW Dr, Noamman said, at least we know from where the rain is coming not like tankers that come to the users from unknown sources.

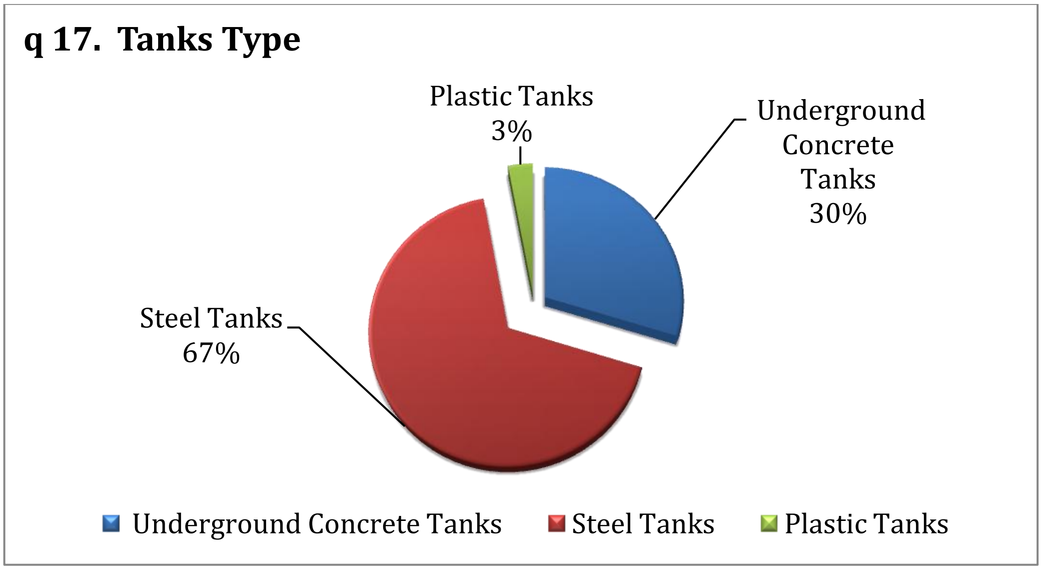
Eng. Abdulrahim AL-Hadidi, the general manager of licensing and water rights department. Put the idea of getting benift from the dried wells and use them to recharge ground water. Dried wells could be rehabilitated and used to recharge ground water.

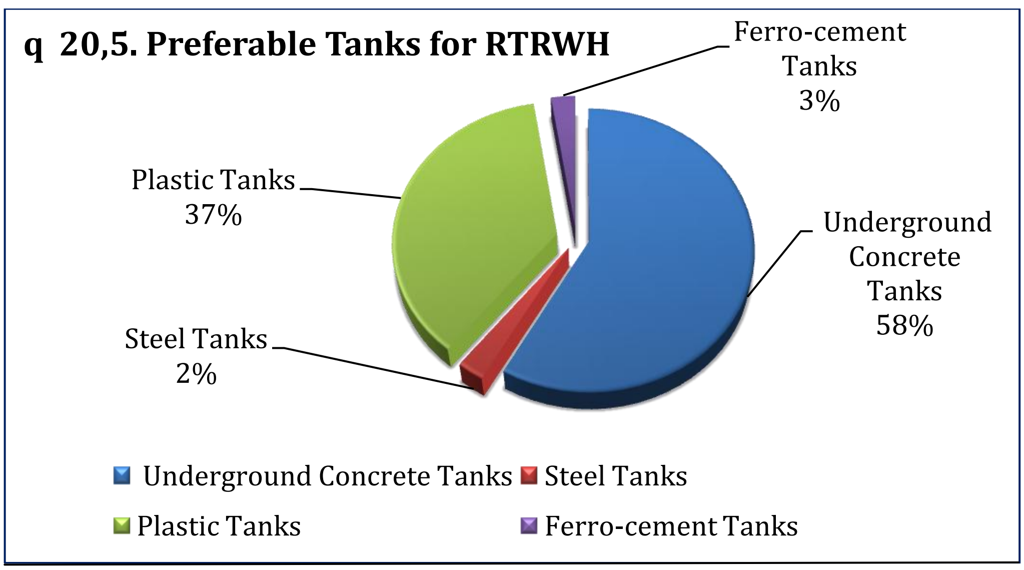
Appendix (H) Some of the Questionnaires Results:

- **Households Form 1,**
  Not only population growth but also immigration to Sana'a is being another factor that plays a role in the population growth in Sana'a city (World Bank, et al., 2009; JICA, 2007). Questions (Q5 and Q6) have shown the in-originality of the interviewees and the reasons of their migration to Sana'a. The big percentage of them (75%) is not originally from Sana'a. Figure below shows that work was the main reason of the migration to Sana'a.

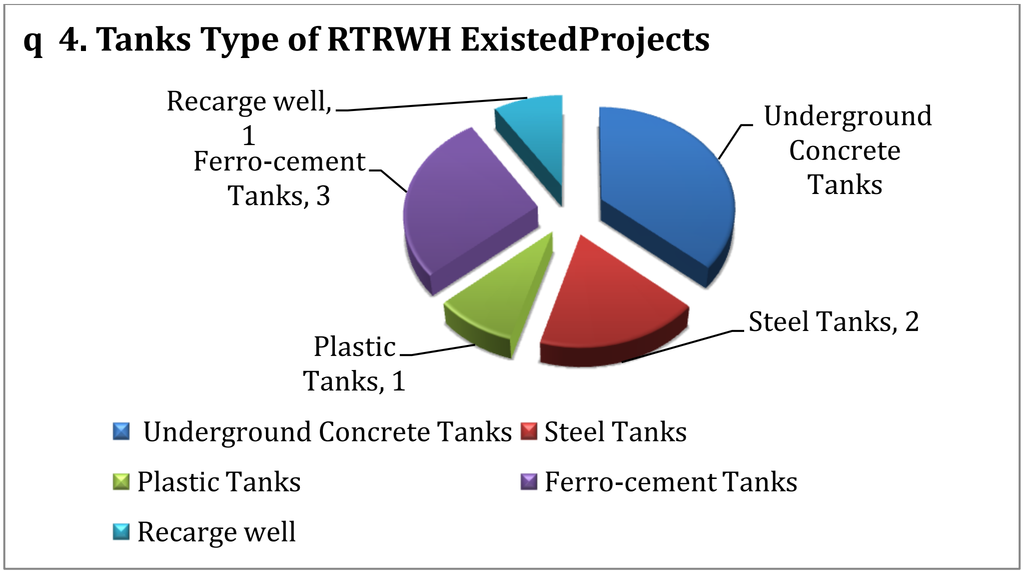


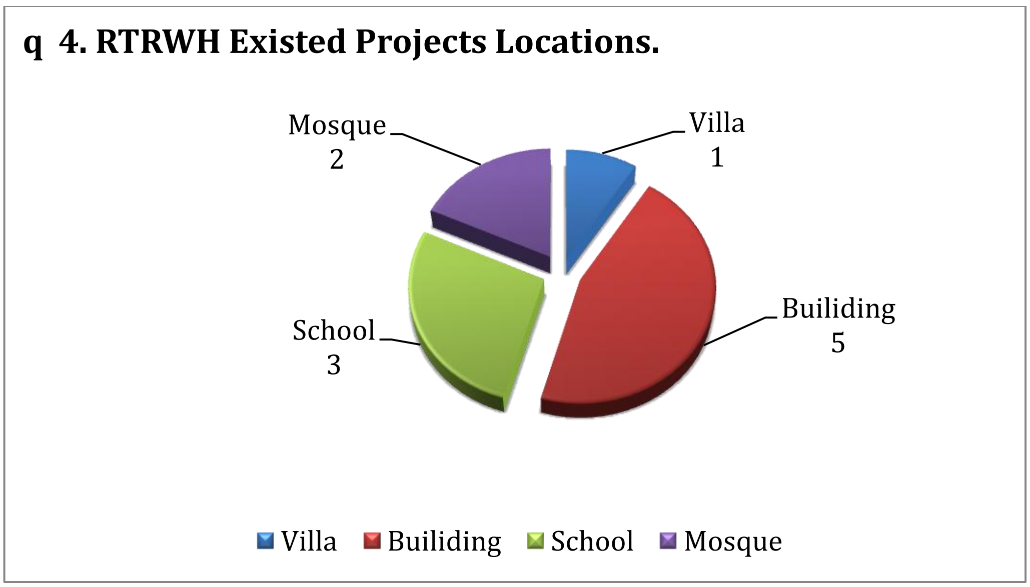



q 17. Tanks Type
Plastic Tanks
3%
Underground
Concrete
Tanks
30%
Steel Tanks
67%
Underground Concrete Tanks
Steel Tanks
Plastic Tanks


q 20,5. Preferable Tanks for RTRWH
Ferro-cement
Tanks
3%
Plastic Tanks
37%
Underground
Concrete
Tanks
58%
Steel Tanks
2%
Underground Concrete Tanks
Steel Tanks
Plastic Tanks
Ferro-cement Tanks

Existed Systems Form 3,





دراسة امكانية حصاد مياه الامطار من اسطح المنازل لمدينة صنعاء، اليمن

اعداد
مساعد محمد عقلان

المشرف
الاستاذ الدكتور عباس العمري

المشرف المشارك الاول
الاستاذ الدكتور لارس ريبي

المشرف المشارك الثاني
الدكتور طه طاهر

ملخص

حوض صنعاء, الذي تشكل مدينة صنعاء 80% من سكانه, يعاني من استنزاف حاد للمياه الجوفيه والتي وصلت الى اربعة اضعاف التغذيه السنويه. حصاد الامطار من اسطح المنازل يعتبر واحد من اهم الخيارات الواعده بامداد مياه عذبه في مواجهة شحة المياه المتزايده. لذا فمن الحكمة ان يتم حصادها للاستخدامات المختلفه.

في هذه الدراسه تم احتساب كمية مياه الامطار التي يمكن حصادها من اسطح منازل مدينة صنعاء اعتمادا على صوره جويه رقميه للعام 2009 . تم تقسيم المدينه الى ثلاث مناطق بناء على الغزاره المطريه. اظهرت النتائج ان 6.4 مليون متر مكعب من مياه الامطار يمكن حصادها سنويا من اسطح المنازل.

بناء على تقييم مياه الامطار وباستثناء الموشرات البيلوجيه , جميع الموشرات الاخرى كانت تحت الحدود المسموح بها لمعايير مياه الشرب لكل من المعايير اليمنيه ومنظمة الصحة العالمية WHO. الجدير ذكره ان استخدام المرشحات مثل المرشحات المطليه بالفضه كفيله لجعل مثل هذه المياه صالحه للشرب.

من وجهة نظر اقتصادية تم وضع مصفوفه لاختيار وتحديد النوع المناسب من الخزانات . من الاقل الى الاعلى تكلفة خزانات الطوب الاسمنتي والفروسمنت والبلك والخرسانه المسلحه تم اقتراحها في هذه الدراسه بناء على عدة معايير اهمها التكلفه والمساحه المتوفره وكذا حجم التخزين المطلوب.

من خلال الدراسه الاجتماعيه تم قياس وعي السكان المحليين واستعدادهم للتعاون والمساهمه وكذالك وجهات النظر المختلفة حول حصاد مياه الامطار من اسطح المنازل. اكثر من 85% من الذين تم مقابلتهم يدركون شحة المياه ويشجعون فكرة حصاد الامطار. 82% منهم على استعداد للمشاركه في مثل هذه المشاريع.

على مستوى الحوض، اقترحت الدراسة اعادة تاهيل عدد 1615 بئر جاف لتعمل كابار تغذية عن طريق تطوير عدة انواع من المرشحات. الحفر الامتصاصية و حفر التغذية (البرك) والسدود الصغيره تم تحديدها ومناقشتها كوسائل اخرى لتغذية المياه الجوفيه.