MEDRC Series of R & D Reports
MEDRC Project: 16-JS-038

GUIDELINES FOR DESIGN OF DOMESTIC RAINWATER HARVESTING SYSTEMS IN JORDAN

MSc. Thesis By

Farah Mohammad Ababneh

Supervisor

Prof. Majed Abu-Zreig
Civil Engineering Department
Jordan University of science and Technology

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master in Civil Engineering/ Water Resources and Environment

The Middle East Desalination Research Center
Muscat
Sultanate of Oman

17/04/2017

GUIDELINES FOR DESIGN OF DOMESTIC RAINWATER HARVESTING SYSTEMS IN JORDAN

GUIDELINES FOR DESIGN OF DOMESTIC RAINWATER HARVESTING SYSTEMS IN JORDAN

BY

Farah Mohammad Khlaif Ababneh

Advisor

Prof. Majed Abu Zreig

Thesis submitted in partial fulfilment of the requirements for the degree of

M.Sc. in Civil Engineering

At

The Faculty of Graduate Studies

Jordan University of Science and Technology

January, 2017

GUIDELINES FOR DESIGN OF DOMESTIC RAINWATER HARVESTING SYSTEMS IN JORDAN

By

Farah Ababneh

Signature of Author ....

Committee Member	Signature and Date
Dr. Majed Abu- Zareig (Chairman)	....
Dr. Jamal Abu-Ashour (Member)	....
Dr. Bashar Al-Smadi (External Examiner)	....

January, 2017

تفويض

نحن الموقعين أدناه, نتعهد بمنح جامعة العلوم و التكنولوجيا الأردنية حرية التصرف في نشر محتوى الرسالة الجامعية, بحيث تعود حقوق الملكية الفكرية لرسالة الماجستير إلى الجامعة وفق القوانين والأنظمة والتعليمات المتعلقة بالملكية الفكرية وبراءة الاختراع.

المشرف الرئيس	الطالب
....	....
التوقيع والتاريخ	**الرقم الجامعي و التوقيع**
....	....

DEDICATION

إلى أمي و أبي ...

إلى رفيق دربي ... زايد

إلى ابني ... جود

ACKNOWLEDGMENT

I would deeply like to thank Allah for helping me to achieve this degree.

I would like to express my deep gratitude and appreciation to my advisor Professor Majed Abu-Zreig for his time, efforts, patient guidance and continuous support throughout the course of this research.

I would like to extend my sincere thanks and appreciation to the committee members Dr. Jamal Abu-Ashour and Dr. Bashar Al-Smadi for their time, effort, valuable comments and cooperation.

I would deeply like to thanks the Middle East Desalination Research Center for giving me a full scholarship which reduces the financial burden.

Many thanks to Professor Abdullah Al-Smadi from Yarmouk University/ Department of Statistics, Jordan Valley Authority specially Mohammad Karajeghli, Al-Balqa Applied University specially Eng. Ahmad Bni-Hani, Princess Haya Biotechnology Center at King Abdullah University Hospital, for their interaction during this research.

Many thanks to my brother Qutaibah for his interaction during the distribution of the questionnaires.

I would like to thank my best friend Rana for her friendship and encouragement throughout this research.

TABLE OF CONTENTS

Title	Page

LIST OF FIGURES

Figure	Description	Page

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

Abbreviations	Description
RWH	Rainwater Harvesting
DRWH	Domestic Rainwater Harvesting
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
TDS	Total Dissolved Solids
TS	Total Solids
JS	Jordanian Standards

ABSTRACT

GUIDELINES FOR DESIGN OF DOMESTIC RAINWATER HARVESTING SYSTEMS IN JORDAN

By

Farah Ababneh

Jordan is an arid country with scarce water resources. The needs to secure additional water supply from non-conventional sources, such as rooftop rainwater harvesting, is high priority to the government of Jordan. The objective of this research is to investigate the potential use of roof top rainwater harvesting at northern Jordan. A survey questionnaire was used to identify the awareness and the difficulties people face in their attempts to collect water from the rooftop. A mathematical analysis was also performed to investigate the historic trend of rainwater depth at northern Jordan in order to understand the reliability of collecting rainwater in the future. The quality of collected rainwater along the season was tested to see how water quality changes along the rainy season due to some weather factors and human activities, and to determine how safe rainwater can be used for domestic purposes. Finally, a methodology was developed to determine the smallest tank needed for a given house in a given area because the cost of the tank is the main reason that force people not to collect rainwater from the rooftop.

The two hundred fifty questionnaires that were collected back shows that 87% of people are aware of water resources problems in Jordan, and only 54% of people are collecting rainwater, 22% of people do not believe that the quality of rainwater is good enough. The main question among those who practice rooftop rainwater harvesting was related to the size of tank; 78% of them chose the volume of collection tank in random bases and based on the recommendation of contractor, while 22% had said that they have chosen the tank volume according to the rain depth of the area, but none of those showed a proof for demonstrating this in a scientific way. Laboratory test for rainwater samples showed that rainwater quality parameters such as TDS and Hardness had a general trend of decreasing along the rainy season, and almost that the first storm having the highest values due to the dust in the atmosphere before the rain storm, for example TDS at the first storm was 225.3 mg/L while the average after the first storm was 61.1 mg/L. The trend of annual historical rainfall depth for 22 weather stations has been investigated using linear regression and the Mann-Kendall trend test. The results showed that 13 stations have no rainfall trend, and the other 9 stations showed a significant decreasing trend by at least on of tests used. Among those 5 stations had a significant decreasing trends as shown by linear regression and Mann-Kendall trend analysis.

Optimization program was developed to determine the optimum/smallest storage tank based on the historic average of monthly rainfall and therefore the collected rainwater

volume, the area of roof top for a house and the monthly water demand for a family. The minimum tank volume was determined for each roof area, each station and for several hypothesize monthly demand. The minimum storage tank was calculated for each case and the results were plotted and interpolated as contour maps for northern Jordan. For example, the minimum tank volume required in Al-Taibah station for a family with monthly consumption of 12 m^3 and a house of 300 m^3, with 75% reliability is 16.9 m^3, knowing that the maximum water that can be collected in that location is 113.4 m^3. The contour maps of tank volume can be used as a guideline of sizing a storage tank based on the location of the house, its rooftop area, and the monthly water consumption.

Chapter One: Introduction

1.1 General Introduction

Water is the basic of life, the urbanization and population growth have increased the need for potable water and demands development of non-traditional water resources for domestic uses (Abu-Zreig et al., 2013).

Jordan ranks as one of the world's 10 most water stressed countries, it has suffered water sources shortages since 1960's. In 2009, per capita share of water was about 170 m^3/capita/year, and in 2014, per capita share of water in Jordan was less than 123 m^3/year which is 12% less than the international water poverty line (MWI report, 2014).

It is a reality that the water shortages exist in Jordan, depletion of non-renewable water sources because of the over pumping from exploited aquifers, that led to the degradation of water quality due to increasing salinity. Jaber and Mohsen (2001) said that the population growth rate in Jordan is 3.6% and it is considered one of the highest at the global level, and it was estimated to be around 6.5 million in the year 2010, but in 2015 the population growth was 5.3% due to the development in multi sectors and the political instability, and a relatively fast development this made an expectation of increase in water demand and wastewater production (Jaber and Mohsen, 2001; DOS report, 2015). The climate change, limited water resources, population growth, rapid development in multi sectors like industry and agricultural, socioeconomic and political instability, all affect water resource adversely.

Rainfall harvesting from rooftop and open yards has gained interest in arid countries like Jordan and Tunisia for essential potable water uses, also in humid countries like

Germany, Japan, Sweden and Brazil. In order to reduce urban runoff, to improve self-dependence on water supply facilities and to reduce the water bill. Rainwater harvesting is an old technique used by Jordanian, especially in the north of Jordan, Irbid and Ajloun governorates had accounted the highest number of cisterns, approximately 27,000 and Ajloun comes second with 2,650 (Abu-Zreig et al., 2013).

1.2 Rainfall and Climate of Jordan

Jordan have a high spatial and temporal variability due to it is location in the eastern part of the Mediterranean region, so the annual rainfall has a large spatial variation from station to another (Ghanem, 2011). Rainfall ranges between 50 mm in the eastern and south desert regions to 600 mm in the northern highlands, (AbdelKhaleq and Alhaj, 2007; Al-Mashabah and Al-Farajat, 2013). Most of regions in Jordan received less than 200 mm of annual rainfall (Al-Mashabah and Al-Farajat, 2013; Ghanem, 2011). The average annual quantity of rainfall which falls on Jordan is approximately $7200*10^6$ m^3/y (Abdulla and Al-Shareef, 2009).

Extreme weather conditions are becoming more frequent in the region, like flash floods during winter season and heat waves during summer season. There are multi reasons that influence the climate on the earth, these reasons are natural like volcanic activity, which cause cooling of surface temperature and variation in solar activity, and reasons from human activity like the unusual increase in the concentration of greenhouse gases, mainly carbon dioxide from burning fossil fuel (Hamdi et al., 2009).

Moshrik et al. (2009) found that the minimum temperature of air has increased since the seventies of the last century, and it indicates a slight change in regional climate, but the annual maximum air temperature records not any clear trends, while the annual range of temperature have decreased. The rainfall records that there are not any increasing or decreasing trends and no precipitations indicating climate change in all stations that had been studied. For humidity records no trend in three stations, and in the other three station there was an increasing trend (Hamdi et al., 2009).

1.3 National Water Sources, Supply and Demand

Jordan has a limited fresh water resources, except for some small streams, used for irrigation (Zarqa, Yarmouk and Wadi Shuib rivers), Jordan river used to discharge approximately $1.4*10^9$ m^3 annually into the dead sea (Jaber and Mohsen, 2001).

The renewable fresh water sources from the water storage reservoirs and underground aquifers which are supplied by rainfall, and non-renewable sources like Disi and Shedia sandstone fossil aquifers, they are non-renewable groundwater sources, used for agricultural purposes and domestic purposes (Jaber and Mohsen, 2001).

The amount of available renewable water resources in Jordan is about 750 million m^3 in a year. The safe yield from renewable groundwater in Jordan is about 275 million m^3 in a year, and the amount of safe yield from non-renewable sources of a period of 50 years in Jordan is about 143 million m^3 in a year (MWI report, 2013).

As non-conventional water resources like groundwater had over-extraction, this led to decrease in aquifer yields and reductions in their water quality, led to more demand on other resources of fresh water.

Consequent of all previous data indicates that the non-conventional water resources such as rainwater harvesting are very important and need to be investigated.

1.4 Objectives of The Study

The broad objective of the study is to investigate the possibility of rooftop rainwater harvesting (rooftop RWH), its efficiency and design its components to maximize the harvested rainwater at least cost. The specific objectives are:

1. To study climate change effects and variability on rainfall depth, and distribution along the rainy season and consequently on the amount of rainwater harvesting collected during the rainy season.
2. To introduce scientific tools to design the optimum/smallest volume of rainwater collection tank from rooftop using historic rainfall data rather than the annual average and how rainfall variability in depth and distribution affects the optimal tank volume which should also be related to rate of rainwater consumption and withdrawal from the tank along the season.
3. Prepare a contour map, showing the minimum recommended volume of water tank needed as a function of house roof area and family size.
4. Determine the quality of rainwater and its changes along the season by testing (BOD5, COD, pH, Salinity, Conductivity, Dissolved Oxygen, Alkalinity, Hardness, Total Solids, and Total Coliforms).

Chapter Two: Literature Review

2.1 Water Supply and Demand in Jordan

Hashemite Kingdom of Jordan is one of the middle eastern countries, located in an arid to semi-arid zone, covers an area of about 92,000 Km^2, it is located in the northwestern part of the Arabian Peninsula, bordered by Syria in the north, Iraq to the northeast, Saudi Arabia to the east and south and the West Bank to the west, Jordan is divided into three regions (north, middle, and south), about 28% in the northern region(Irbid, Mafraq, Ajloun, and Jarash), which are the study areas of this research except Mafraq governorate.

In Jordan and like another country which suffer from fresh water shortages, the domestic water supply is not based on the demand. Table (2.1) showed the population of the study area (Irbid, Jarash, and Ajloun governorates, and their districts) (DOS, 2015). Number of population in Jordan is 9,531,712 and 69.4% of them have a Jordanian identity, number of population in Irbid, Ajloun and Jarash governorates is 1770158, 176080 and 237059 persons; respectively, and the percent of people who are not Jordanian is 25.62%, 10.74% and 29.24%; respectively. [DOS report, 2015]

Table 2.1: The Population of the Kingdom by Administrative Divisions, According to the General Census of Population and Housing result 2015 (DOS, 2015)

Administrative Divisions	Population			
	Households	Total	Female	Male
Irbid Governorate	**355597**	**1770158**	**855523**	**914635**
Irbid Qasabah District	151119	739212	355898	383314
Ramtha District	45211	238502	114571	23931
Koorah District	31335	161505	78847	82658
Bani Kenanah District	27596	131797	64971	66826
Aghwar Shamaliyah District	24659	122330	56839	65491
Bani Obeid Distric	40871	204313	100351	103962
Mazar Shamali District	15760	78427	38266	40161

Taybeh District	10269	51501	25228	26273
Wasatiyyah District	8777	42571	20552	22019
Jarash Governorate	**46798**	**237059**	**113814**	**123245**
Jarash Qasabah District	46798	237059	113814	123245
Jarash Sub-District	40990	207997	99879	108118
Mestabah Sub-District	3415	16904	8022	8882
Borma Sub-District	2393	12158	5913	6245
Ajlun Governorate	**34950**	**176080**	**85454**	**90626**
Ajlun Qasabah District	27300	137820	66915	70905
Ajlun Sub-District	16236	81215	39250	41965
Sakhrah Sub-District	6848	34863	17078	17785
Orjan Sub-District	4216	21742	10587	11155
Kufranjah District	6750	38260	18539	19721

In many developing countries, water scarcity is one of the major problems, as it is the source of life and food, the rainwater is a potential source as a fresh water for drinking uses, a proper management could reduce water crisis, (Helmreich and Horn, 2010). One of these countries which have a limited fresh water resources is Jordan, Jordan has a rising demand on fresh water, the rising in demand due to multi variables, the main reason is the population growth, and the other one which is a sudden change in growth rate is the political issues and the refugees from wars. Figure (2.1) represents the sectorial distribution of water consumption during 1998, as it seems that the most consumption sector is the agricultural, it has accounted about 70% of the total fresh water demand (Jaber and Mohsen, 2001).

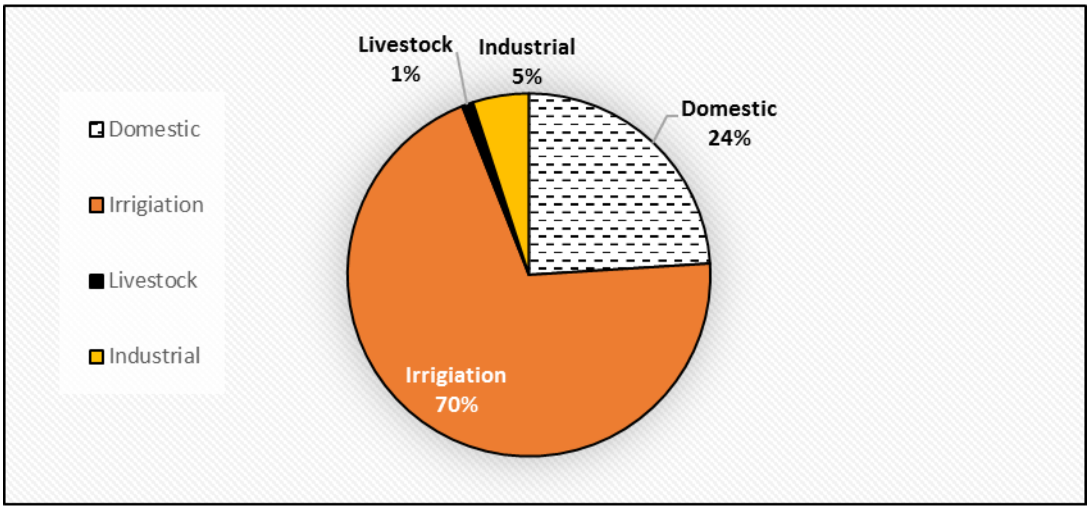


Figure 2.1: The sectorial distribution of water consumption during 1998. (Jaber and Mohsen, 2001)

But Figure (2.2) shows the sectorial distribution of water consumption during 2013, as it seems that the most consumption sector is the agricultural, it has accounted about 53% of the total fresh water demand. (MWI report, 2013). The change in percentages in the two years had affected by the population growth, the domestic share of fresh water had increased, while the agricultural share had decreased.

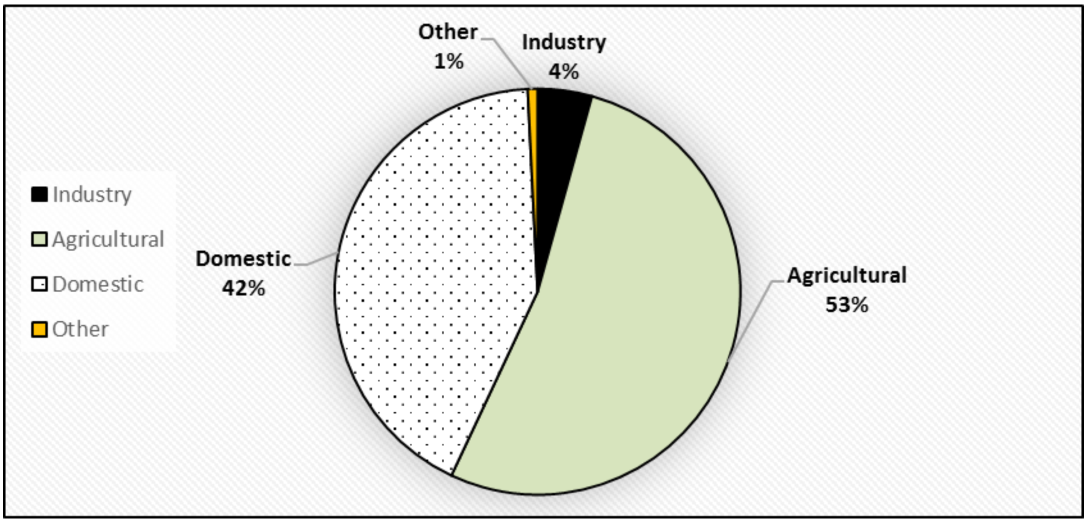


Figure 2.2: The sectorial distribution of water consumption during 2013. (MWI report, 2013)

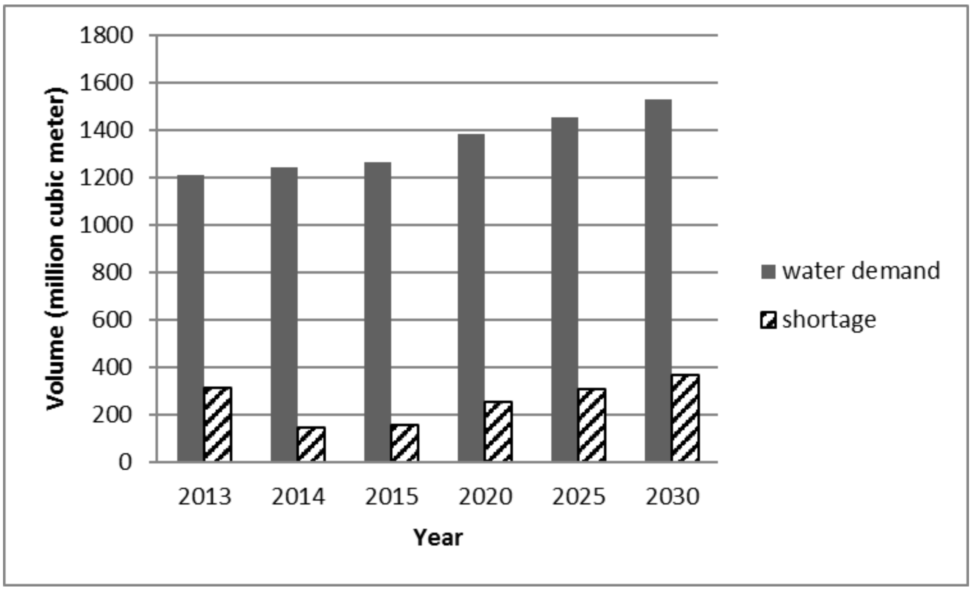


Figure 2.3: The expected needs of water and shortages from the year 2013 to 2030 in million cubic meters. (MWI report, 2013)

Figure (2.3) shows the expected needs of water and shortages from the year 2013 to 2030 in million cubic meters (MWI report, 2013). For year 2015, the expected water demand was 1266 million cubic meter, while the shortages in water was 156 million cubic meter.

2.2 Rainwater Harvesting

Rainwater harvesting is a technology used for collecting rainwater from rooftops or any surface can use it as a catchment area, and storing it in tanks and cisterns and conserving local runoff for agriculture in arid and semi-arid regions. (Hatibu and Mahoo, 1999).

The harvested rainwater is a renewable source of clean water that can use for multi-purposes, such as domestic uses and landscape uses and will reduce water deficit in the country of Jordan. As the rainwater harvesting system is a flexible solution for meeting the needs of new and existing, and it can be developed over time because of it is an ongoing process, the rainwater harvesting system has a great attraction because of the low cost, accessibility and easy maintenance at the house-hold level (Abu-Zreig et al., 2013; Abdulla and Al-Shareef, 2009). Water availability has been a big concern all over the world, rainwater harvesting can play a significant approach in water saving.

2.3 Types of Rainwater Harvesting

Three major forms of RWH, in situ RWH, collecting the rainfall on the surface where it falls and storing in the soil, external water harvesting, collecting runoff and flood water originating from rainfall over a surface elsewhere and stored offside, both are used for agricultural rainwater harvesting, and domestic rainwater harvesting (DRWH), where water is collected from rooftops and streets and courtyards runoffs (Helmreich and Horn, 2010).

2.4 History of Rainwater Harvesting in Jordan

In agricultural sector, there were using surface run-off and rain harvesting techniques, that was practiced as early as 4000 years ago, but also harvesting used to provide water that is suitable for domestic uses (Abdulla and Al-Shareef, 2009), but the most ancient water harvesting scheme in Jordan are Jawa and Umm El-Jimal, there were established 6000 and 2000 years ago; respectively (Al-Ansari et al., 2013).

In Jordan, historically the rainwater harvesting was the main source of drinking water, and were totally dependent on rainwater harvesting for domestic uses, the public water supply network had reached about 97% of household, in 1991. But multi reasons happened have let the traditional in-house rainwater harvesting system to be abandoned, some reasons are: the population increase, so the water demand increased, the improved standard of living, and increased dependence on the easily accessed water through the new supply system (Abu-Zreig et al., 2013).

2.5 Domestic Rainwater Harvesting

A field experiment was conducted to determine runoff coefficient (C) on the campus of the National Taiwan Ocean University, four types of rooftop were used; the inverted-v (iron sheet and frame), the level cement, the parabolic and the saw tooth. The constructed area of the household was approximately 132 m^2, for cement, the C value was 0.81 (Liaw and Tsai, 2004).

A study done at Nanyang Technological University, Singapore, showed that runoff from a roof area of 38,700 m^2 could be collected and used in the north spine of the University for toilet flushing. And a computer simulation has showed that the collected rainwater from the roof would save 12.4% of the monthly cost for water used in the north spine. Also, the study showed that the collected rainwater has a generally high quality except for pH and the total coliforms counts, in comparison with potable water supply and the laboratory storage tanks (Appan, 1999).

Some other examples in a large scale in rainwater collection system are multipurpose stadiums located in Tokyo, Nagoya, and Fukoka, Japan, the collected rainwater is used for flush toilets and watering plants, the tank volumes are 1000, 1800 and 1500 m^3; respectively, for catchment areas of 16000, 25900 and 35000 m^2; respectively. At Fukoka dome, the study showed that rainwater utilization covered about 65% of the volume of low quality water. Approximately 75% of the rainwater was utilized from the total volume of annual rainfall on the roof at Fukuoa Dome, which was 52836 m^3 (Zaizen et al., 1999).

Also in Japan, at Sumida City Office, a roof of 5000 m^3, which rainwater is collected from, and stored in a 1000 m^3 tank. In 1998, the total amount used for toilet flushing was 4658 m^3, which is 36% of the total toilet water consumption (Villarreal and Dixon, 2005).

In Berlin, at Daimler Chrysler Potzdamer Platz, roof of 19 buildings (total area 32,000 m^2), rainwater is collected from it and stored in a tank of 3500 m^3 (UNEP, 2002). Then the collected rainwater is used for flushing toilets and watering gardens. And in the Belss-Luedecke-Strasse building estate. Rainwater from roof area of 7000 m^2 is stored in a 160 m^3 tank with rain runoff from streets, parking places and pathways. A treatment done for the collected water, then the collected water is used for toilet flushing and garden watering. About 58% of the rainwater is retained locally by using this system. A simulation of period of 10 years showed that a 2430 m^3 potable water savings per year can be achieved (UNEP, 2002).

In Sweden, the average annual rainfall in the study area is 508 mm, the study found that using a 40 m^3 rainwater collecting tank of a collection area of 27600 m^2 and use it in toilet flushing will save up to 60% of water consumption from the main supply (Villarreal and Dixon, 2005).

In London, from a roof of 2200 m^2, the rainwater is collected and stored to a 14.56 m^3 tank and used for toilet flushing in commercial building; the overall annual efficiency of the collection system was about 51% (Chilton et al., 1999).

Also in London, at the Millenium Dome is an example of a large-scale rainwater scheme. The surface area of the roof of the dome is approximately 100,000 m^2, the rainwater is collected from the roof using large hoppers. and discharge into a collection ring main that runs around the circumference of the Dome. The collected rainwater is then discharged into a culvert containing an 800 m^3 underground sump, the sump has three storm discharge pumps, these pumps discharge the collected rainwater into the River Thames, or to the treatment plant (Villarreal and Dixon, 2005). A study done to measure the performance of the collection system, the study showed that the collected rainwater provided about 10% of the water demand, there was constrains in the site affected on the storage; thus, a maximum of 100 m^3 a day of rain could be collected (Hills et al., 2002).

Other large example of rainwater harvesting systems in Japan, it has been constructed to reduce local flood problems, decrease dependence on main supplies, reduce water bills, and to provide a backup emergency supply. In Tokyo, at the Kokugikan Sumo Wrestling Stadium, the rainwater is collected from a roof of 8400 m^2 and stored in a 1000 m^3 reservoir in the basement, the collected rainwater is used for toilet flushing and cooling the building.

At the Izumo Dome in Izumo, the rainwater runoff is collected and stored in two storage tanks with a total volume of 270 m^3 from a catchment area of 13.200 m^2.

2.6 Quality of Rainwater

Quality of the rainwater depending on the quality of the atmosphere and the type of the collection surface, the pure rainwater itself mostly is low polluted, and it can neglect the contamination of rain as it falls (Thomas, 1998). Before the rainy season there is the dry season which have the pollutants accumulated on the catchment surfaces like roof top of houses and streets, some of the atmospheric pollutants are: particles, microorganisms, heavy metals and organic substances, these pollutants will wash out from the atmosphere during the rainfall events and from the collection surface (Helmreich and Horn, 2010). So mostly, it is not advised to collect he first flush of the rainfall event if the purpose of rainwater collection for domestic uses. The measured inorganic compounds were found as generally matched the WHO standards for drinking water if the rainwater has collected from the rooftops, while it is higher than the standards for drinking water if the rainwater has collected from the road surfaces (Helmreich and Horn, 2010; Yaziz et al., 1989), the road catchment polluted by heavy metals originating from brakes and tires, and some organic compounds from incomplete combustion processes.

No evidence that pathogens can be picked up, and very lack of dissolved calcium or magnesium accounts for the historical construction of rainwater catchment systems, but what is accumulated on the roof of catchment surface is it the important, most roofs are coated with dust and organic materials; bird droppings are common. Faecal coliforms counts of stored water samples and have rarely exceeded 4 per 100ml, (Thomas, 1998), Bacteria, viruses and protozoa may originate from fecal pollution by birds, mammals and reptiles (Evans et al., 2006; Sazakli et al., 2007).

Chapter Three: Research Methodology

3.1 Location of The Study Area

Hashemite Kingdom of Jordan is one of the middle eastern countries, located in an arid to semi-arid zone, covers an area of about 92,000 Km^2, it is located in the northwestern part of the Arabian Peninsula, bordered by Syria in the north, Iraq to the northeast, Saudi Arabia to the east and south and the West Bank to the west. The study area concentrated on Irbid governorate which is located in the northwestern part of the Jordan, just 65 kilometers north of the capital Amman (GIM website). Figure (3.1) shows a map of Irbid, Ajloun and Jarash governorates and the location of all metrological stations used in the analysis and Table (3.1) shows topographic details of the stations used in the analysis.

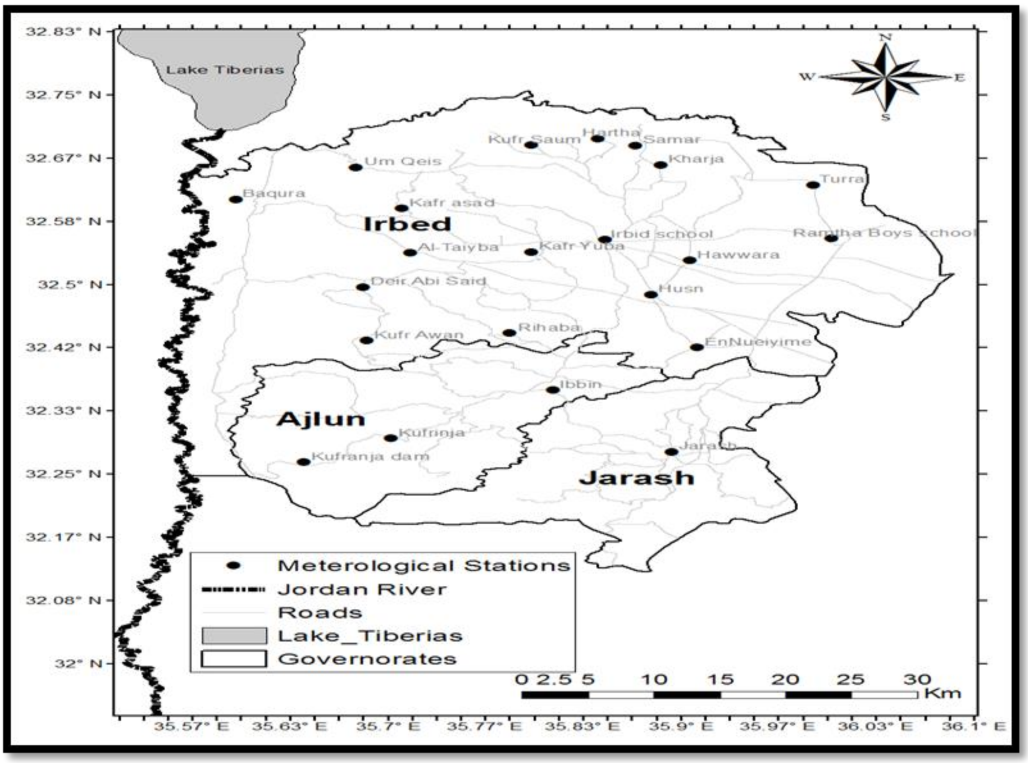


Figure 3.1: Irbid, Ajloun and Jarash governorates map shows the location of all metrological stations used in the analysis.

Table 3.1: Topographic details of the stations used in the analysis, include the altitude and the coordinates of each station in Jordan. (Water Authority of Jordan)

Station	Altitude (m)	PGN	PGE
Al-Taiyiba	365	1216500	217500
Deir Abi Said	330	1211500	214500
Kufr Awan	470	1203700	214800
Hartha	450	1233300	229500
Kufr Saum	455	1232300	225200
Um Qeis	360	1229000	214000
Kharja	455	1229500	233500
Hawwara	560	1215500	235500
Husn	680	1210500	233000
En Nueiyime	785	1202800	236000
Ramtha Boys School	520	1218800	244500
Ibbin	1105	1196500	226800
Turra	450	1226600	243300
Baqura	-205	1224300	206300
Samar	410	1232300	231900
Irbid School	585	1218500	230000
Kafr Yuba	560	1216700	225300
Kafr Asad	350	1223000	217000
Rihaba	925	1204800	224000
Kufranja Dam	228	1185884	210862
Kufrinja	640	1189400	216400
Jarash	585	1187500	234500

3.2 Rainfall of The Study Area

Jordan has a high spatial and temporal rainfall variability due to it is location in the eastern part of the Mediterranean region. The annual rainfall has a large spatial variation from station to another (Ghanem, 2011) and ranges between 50 mm in the eastern and south desert regions to 600 mm in the northern highlands, (AbdelKhaleq and Alhaj Ahmed, 2007; Al-Mashagbah and Al-Farajat, 2013). Most of regions in Jordan received less than 200 mm of annual rainfall (Al-Mashagbah and Al-Farajat, 2013; Ghanem, 2011). The average annual quantity of rainfall which falls on Jordan is approximately $7200*10^6$ m3/y (Abdulla and Al- Shareef, 2009). Table (3.2) shows the study period for each station in Irbid, Ajloun and Jarash governorates, and the average rainfall during the study period.

Table 3.2: The study period for each station and the average annual rainfall during the study period in Jordan.

Station	Study Period (water year)	Average Annual Rainfall (mm)
Al-Taiyiba	(1937/1938)-(2014/2015)	472.41
Deir Abi Said	(1937/1938)-(2014/2015)	459.83
Kufr Awan	(1937/1938)-(2014/2015)	473.92
Hartha	(1951/1952)-(2014/2015)	416.85
Kufr Saum	(1937/1938)-(2014/2015)	475.45
Um Qeis	(1937/1938)-(2014/2015)	446.02
Kharja	(1937/1938)-(2014/2015)	431.66
Hawwara	(1937/1938)-(2014/2015)	352.56
Husn	(1942/1943)-(2014/2015)	372.35
En Nueiyime	(1955/1956)-(2014/2015)	288.51
Ramtha Boys School	(1937/1938)-(2014/2015)	266.15
Ibbin	(1937/1938)-(2014/2015)	539.81
Turra	(1964/1965)-(2014/2015)	273.9
Baqura	(1938/1939)-(2014/2015)	355.9
Samar	(1984/1985)-(2014/2015)	450.16
Irbid School	(1937/1938)-(2014/2015)	411.1
Kafr Yuba	(1937/1938)-(2014/2015)	480.1
Kafr Asad	(1962/1963)-(2014/2015)	461
Rihaba	(1962/1963)-(2014/2015)	544.45
Kufranja Dam	(1989/1990)-(2014/2015)	627.03
Kufrinja	(1937/1938)-(2014/2015)	608.89
Jarash	(1942/1943)-(2014/2015)	354.88

3.3 Public Survey

A survey was done to investigate the status of rooftop rainwater harvesting in Irbid. A questionnaire consisting of twenty-seven questions was designed and distributed to more than five hundred of public participants, but only two hundred and fifty were collected back. The survey was handed out in arabic version, the survey covers multi-subjects to study, included living area (place and area of the house), people awareness of fresh water crisis, water supply from the authority (times of supply, invoice and shortages of supply), people opinions of having a rainwater collection system or not and the uses of collected water, the way of selecting the rainwater collection tank and other information about rainwater harvesting system, and people opinions about the rainwater collection system itself, etc.…. See appendix (A.1) in English language and appendix (A.2) in Arabic language.

3.4 Rainwater Laboratory Test Results

Samples from rain water were collected from a roof top from several storms along the rainy season of 2015/2016. Laboratory tests were conducted to measure various rainwater quality parameters, the quality parameters are: Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Solids (TS), Alkalinity, Hardness, pH, Turbidity, Dissolved Oxygen (DO), Conductivity and Total Coliforms, all tests were measured in the Sanitary Laboratory at Jordan University of Science and Technology except the Total Coliforms was measured in Princess Haya Biotechnology Center at King Abdullah University Hospital.

BOD_5, DO, COD, TS, Alkalinity, Hardness, Total Coliforms test procedures were adapted from Standard Methods for Examination of water and Wastewater.

- Biological Oxygen Demand (BOD): is an empirical test in which standardized laboratory procedures are used to determine the relative oxygen requirements of wastewater, effluents, and polluted water, was measured using 5-Day BOD test, titration method of dissolved oxygen (SMEWW 5210 B), and (SMEWW 4500-O C) for Dissolved Oxygen (DO).
- Chemical oxygen demand (COD): is defined as the amount of a specific oxidant that reacts with the sample under controlled conditions, was measured using closed reflux, titration method (SMEWW 5220 C).
- Alkalinity: Alkalinity of a water is its acid-neutralizing capacity, was measured using titration method (SMEWW 2320 B).

- Hardness: water hardness was understood to be a measure of the capacity of water to precipitate soap, was measured using EDTA- titrimetric method (SMEWW 2340 C).
- Total Solids: is the term applies to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. Total solids include “total suspended solids,” the portion of total solids retained by a filter, and “total dissolved solids,” the portion that passes through the filter (SMEWW 2540 B).
- pH, Turbidity and conductivity where measured by using pH meter, Turbidity meter and conductivity meter; respectively.
- Total Coliforms: The most basic test for bacterial contamination of a water supply, it gives a general indication of the sanitary condition of a water supply. Total coliforms include bacteria that are found in the soil, in water, and in human or animal waste (WHO A5.7).

3.5 Rainwater Trend Analysis

Statistical analysis was performed on the historic rainfall data for each station to detect any trend in rainfall depth along the historic years, the trend analysis was performed to study climate changes effects and variability on rainfall depth, and distribution along the rainy season and consequently on the amount of rainwater harvesting collected during the rainy season. In this research, two trend analysis tests were used namely, linear regression and Mann-Kendall trend test. Minitab Program was used to perform both tests analysis:

3.5.1 Linear Regression

Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data, based on least-square regression analysis of potentially false significance.

One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable, (y, x); y is the meteorological variable in this study and x represents years (Hamdi et al., 2009).

The Equation (3.1) represents the linear regression line:

$$Y = a + bX \qquad \ldots\ldots\ldots\ldots Equation(3.1)$$

Where;

X: the explanatory variable.

Y: the dependent variable.

b: the slope of the line.

a: the intercept (the value of y when x = 0).

Least-Squares Regression is a method for fitting a regression line, it done by minimizing the sum of the squares of the vertical deviations from each data point to the line.

3.5.2 Mann-Kendall Trend Test

The Mann-Kendall test is a non-parametric test for randomness against hydrology and climatology, this test is usually known as Kendall's Ʈ, it is proposed to test the null hypothesis, H_0, that data come from a population where the random variables are independent and identically distributed by letting X_1, X_2, ..., X_n be a sequent of measurements over time (Partal and Kahya, 2006; Longobardi and Vilani, 2009). The alternative hypothesis H_1 is that the data follow a monotonic trend over time. Under H_0, the Mann-Kendall test statistics is:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \qquad \ldots\ldots\ldots\ldots\ldots Equation\ (3.2)$$

$$sgn(x_j - x_k) = \begin{cases} +1\ if\ (x_j - x_k) > 0 \\ 0\ if\ (x_j - x_k) = 0 \\ -1\ if\ (x_j - x_k) < 0 \end{cases} \qquad \ldots\ldots\ldots\ldots Equation\ (3.3)$$

Under the hypothesis of independent and randomly distributed random variables, when n ≥ 10, the S statistic is approximately normally distributed, when zero mean and variance as follows:

$$Var(S) = \frac{[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)]}{18} \qquad \ldots\ldots\ldots\ldots Equation\ (3.4)$$

The notation t is the extent of any given tie and ∑t denotes the summation over all ties. The standard normal variate z is computed by using the following Equation (3.5). In a two-sided test for trend, H_0 should thus be accepted if $|z| \leq z\alpha/2$ at the α level of significance. A positive value of S indicates an ‘upward trend’; likewise, a negative value of S indicates ‘downward trend’:

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(s)}}\ if\ S > 0 \\ 0\ if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}\ if\ S < 0 \end{cases} \qquad \ldots\ldots\ldots\ldots Equation\ (3.5)$$

3.6 Tank Sizing

The tank size is the most expensive part in rooftop rainwater harvesting system and found to be the factor hindering people from harvesting rainwater. Therefore, careful consideration for selecting the smallest tank size that can satisfy a family water need is extremely beneficial. The size of the collection tank could be determined based on supply size, that the maximum rainwater that can be collected from a rooftop area, or the demand size, that is the maximum of water needed to satisfy a family during a period of time, or calculating the minimum storage required to satisfy a supply demand series during a period of time.

3.6.1 Maximum Potential Rainwater

Historic monthly rainfall data of twenty-two stations in north of Jordan were collected from Water Authority in Jordan, the twenty-two stations located at three governorates; Irbid, Ajloun and Jarash; all stations are presented in Table (3.3). The historic data range between 1937 to 2015, all station ends at the water year of 2014/2015 but the beginning of each station defers from the other due to the establish year of the station. The maximum collection of rainwater in one year were calculated as the summation of an average history monthly data of whole years for each station, as a simple calculation, this average was multiplied by the coefficient of concrete (C = 0.8); because of most houses in Jordan from concrete, area of the roof of house and a convergent factor to homogenous the units. This simple calculation will give a one value of maximum potential water for each roof area, and it is the same of the maximum storage tank, where the areas used are (A = 100 m^2, 150 m^2, 200 m^2, 250 m^2, 300 m^2), Equation (3.6) illustrate this:

$$RRV = \frac{C.R_s.A}{1000} \qquad \text{……………… } Equation\ (3.6)$$

Where;

RRV: the annual roof rainwater volume that can be collected from each station (m^3).

R_e: is the average annual rainfall (mm).

A: is the total roof top area of individual house and apartment buildings in each region (m^2).

C: is the runoff coefficient

Table 3.2: station names of each governorate in the study area

Governorate	Station name
Irbid	Al-Taiyiba, Deir Abi Said, Kufr Awan, Hartha, Kufr Saum, Um Qeis, Kharja, Hawwara, Husn, En Nueiyime, Ramtha Boys School, Ibbin, Turra, Baqura, Samar, Irbid School, Kafr Yuba, Kafr Asad, Rihaba
Ajloun	Kufranja Dam, Kufrinja
Jarash	Jarash,

3.6.2 Optimum Storage Tank According to Monthly Demand

The second approach is the supply-demand series analysis, a monthly average value for rainy months (October to May) of the whole years for each station were taken and multiplied by coefficient of concrete (C=0.8), area of the roof of house and a convergent factor to homogenous the units, then a cumulative values were taken among the eight months and subtract from the cumulative selected demand; a demand was selected as (D = 2 m^3, 4 m^3, 6 m^3, 8 m^3, 10 m^3, 12 m^3, 14 m^3, 16 m^3, 18 m^3, 20 m^3, 22 m^3) per month, this will give a negative values for each month describing the lack of rainwater, and to get the maximum need of rainwater with respect of the specific demand, the previous negative value will accumulate over the eight months and take the minimum value, this minimum value represents the needed storage for a specific demand and a specific roof area, thus describes the optimum/ smallest storage tank volume; see Equation (3.7).

$$\Delta S = \frac{A.R}{1000} - O \qquad \ldots\ldots\ldots\ldots\ldots \; Equation\ (3.7)$$

Where;

ΔS: the optimum storage (m^3).

A: the area of rooftop of the house (m^2).

R: average historic rainfall (mm).

O: consumption of family (m^3).

This results of the needed storages of each demand for each roof area may be exceed the real maximum rainwater which can be collected, graphs drown by Excel program showing the optimum tank volume for all roof areas with respect to the maximum collection of rainwater, and contour maps drown by interpolating the storage tank volumes for each station, showing Irbid, Ajloun and Jarash governorates and the twenty-two stations to show the optimum storage with respect of demand control values or the maximum storage tank for each roof area.

Reliability test was done to test the reliability of calculated optimum/ smallest volume of storage tank with respect to the average monthly historical years of each station and for each rooftop area, with a demand of 12 m^3/ month, then were tested on a wet year and a dry year to study the reliability of them, all test starts with an empty tank and ends with no overflow.

Chapter Four: Results and Discussion

4.1 Public Survey

A questionnaire was designed and distributed among more than five-hundred residents in Irbid and surround towns. More than 250. Two hundred-fifty were collected and analyzed. The objective of this survey was to explore the general acceptance of roof top rainwater harvesting among population and how they currently manage with water shortages. The results of the survey are summarized as follows in Table (4.1):

Table 4.1: The percentage results of public survey of Irbid governorate.

#	Subject		%		%
1	Residence	Live in village	42%	Live the city	58%
2	House areas	100 m^2 and less	10%	(more than 100 to 150) m^2	32%
		(more than 150 to 200) m^2	28%	(more than 200 to 250) m^2	19%
		(more than 250 to 300) m^2	8%	350 m^2 and more	3%
3	Awareness of water resources problems that Jordan face in recent years.	Aware of water resources problems in Jordan	87%	Not Aware	13%
4	Having a water supply from the authority	Connected	97%	Not connected to public water supply	3%
5	The water bill for one period (every three months)	Less than 20 JD	30%	Between (20-30) JD	33%
		Between (30-40) JD	18%	Between (40-50) JD	10%
		More than 50 JD	8%		

6	Number of days that water supply houses	One day in a week	58%	Two days in a week	27%
		Three days in a week	10%	Four days in a week	2%
		(5-7) days in a week	2%	One day in couple of weeks	1%
7	Number of hours the municipal supply the house within a day	(5-7) hours	32%	(7-9) hours	22%
		(9-11) hours	23%	(11-13) hours	12%
		More than 14 hours	11%		
8	People have answered the question "How did you manage with water shortages crises?"	Bought water tanks	58%	Gate an emergency supply from the water Authority	6%
		Borrow some water from neighbors	8%	Use stored water in the house	27%
		Said that there are not any shortages	1%		
9	Collecting rainwater	Collecting rainwater	54%	Collecting from the roof	82%
				Collecting from in house courtyard	10%
				Collecting from outside courtyards and streets	8%
		Do not collecting	46%		
10	Materials of the collection tank	Concrete	60%	Plastic or PVC	19%
		Steel	21%	Natural tanks	1%
11	The volume of the rainwater collection tanks	Less than 20 m^3	26%	From (20-24) m^3	21%
		From (25-29) m^3	13%	From (30-34) m^3	10%
		From (35-39) m^3	8%	From (40-44) m^3	4%
		From (45-49) m^3	0.0%	From (50-54) m^3	5%
		From (55-59) m^3	6%	From (60-64) m^3	5%
		More than 65 m^3	4%		
12	The tank size has chosen according to:	Rain depth	22%	Randomly	78%

13	The reason of having a collection system	"There is no water supply from the authority to my house"	5%	To save money on water	22%
		The rain water is best	37%	"I prefer to use rainwater for my garden"	11%
		For other reasons.	19%		
14	The uses of collected rainwater	Drinking	50%	Car wash	9%
		Flushing toilets	1%	Irrigation of gardens and/or lawns	16%
		Livestock watering	4%	For all uses	27%
	Rainwater quality and so why they used it for a specific use	The quality is good enough for drinking	78%	The collected rainwater quality is not good	22%
15	Numbers of times do people clean the roof	(1-2) times in a year	59%	(3-4) times in a year	16%
		(5-6) times in a year	7%	More than 6 times a year	7%
		Once in couple of years	4%	Do not clean	6%
	Numbers of times do people clean the collection tank	Once a year	93%	Once in couple of years	14%
		Once in three years	5%	Once in four years and more	5%
		Do not clean	7%		
16	Using disinfectant in the collecting tanks	Yes	38%	No	62%
	Willingness of adding any disinfectants in the future	Yes	44%	Filtration method	65%
				Chemical treatment	30%
				Ultraviolet	2%
		No	56%		

17	People opinions about not having a collection system	"Lack of awareness about the importance and effectiveness of rooftop rainwater harvesting system"	29%	"Not enough area for storage"	35%
		"Don't believe that I will save any money"	14%	"I live in a property belonging to someone else who won't install one"	24%
		"I don't know how to install one"	10%	"Too expensive to install"	11%
		"I don't believe that the products are reliable enough"	12%	"The water quality isn't good enough"	5%
		"I don't believe that there are any benefits to the environment"	4%		
18	Willingness of having a rainwater collection system, and type of help they need	Will build a rainwater collection system if they get financial/ technical help	70%	Need a technical help	45%
				Need a financial help	73%
				Any other kind of help	11%
		Will not build a rainwater collection system	30%		
19	People opinions about the collection system	Rainwater collection system saves on the water bill	82%	Said not	18%
		Rainwater have w better water quality for drinking, while	80%	Said not	20%
		The rainwater collection system meets the house emergency demand for water	88%	Said not	12%

		The rainwater collection system has a high construction cost	78%	Said not	22%
		The low in rainfall collection efficiency because of high rainfall variability	71%	Said not	29%

4.2 Rainfall Trend Analysis

Rainfall trend analysis performed to detect any changes in rainfall patterns, and the effects on RWH system in the future. Rainfall trend analysis was performed using linear regression and Mann-Kendall trend approach. Twenty- two stations were analyzed using Minitab program, as shown in Table (4.2), that the trend results responded by the slope, and p-value for linear regression, and the Mann-Kendall S-value along with upward or downward p-value for Mann-Kendall trend.

Table 4.2: Trend results of Linear Regression and Mann-Kendall of the rainfall station of Northern Jordan

Station	**Linear Regression**				**Mann-Kendall**			
	Slope	Increasing /Decreasing	P - Value	Trend?	Upward p-value	Downward p-value	z-value	Trend?
Al-Taiyiba	-1.68	Decreasing	0.026	Significant Decreasing trend	0.994408	0.055915	-2.54	No Trend
Deir Abi Said	-0.69	Decreasing	0.337	No Trend	0.901483	0.098517	-1.29	No Trend
Kufr Awan	-1.43	Decreasing	0.058	No Trend	0.987004	0.0129962	-2.23	High significant decreasing trend

Hartha	-0.342	Decreasing	0.708	No Trend	0.7776063	0.223937	-0.76	No Trend
Kufr Saum	-1.83	Decreasing	0.028	Significant Decreasing trend	0.994678	0.0053218	-2.55	High significant decreasing trend
Um Qeis	-1.75	Decreasing	0.009	High significant decreasing trend	0.995533	0.0044668	0.01	High significant decreasing trend
Kharja	-0.998	Decreasing	0.15	No Trend	0.948 542	0.0514576	0.15	No Trend
Hawwara	-0.179	Decreasing	0.756	No Trend	0.643092	0.356908	-0.37	No Trend
Husn	-1.95	Decreasing	0.009	High significant decreasing trend	0.994799	0.0052011	-2.56	High significant decreasing trend
En Nueiyime	-1.14	Decreasing	0.104	No Trend	0.968726	0.0312739	-1.86	significant decreasing trend
Ramtha Boys School	-1.1	Decreasing	0.011	High significant decreasing trend	0.990864	0.0091361	-2.36	High significant decreasing trend
Ibbin	-2.26	Decreasing	0.019	High significant decreasing trend	0.989267	0.0107328	-2.3	High significant decreasing trend
Turra	-0.098	Decreasing	0.903	No Trend	0.615009	0.384991	-0.29	No Trend
Baqura	0.503	Increasing	0.55	No Trend	0.665191	0.334809	-0.43	No Trend

Samar	+0.23	Increasing	0.94	No Trend	0.271943	0.392833	0.27	No Trend
Irbid School	-0.72	Decreasing	0.367	No Trend	0.662216	0.337784	-0.42	No Trend
Kafr Yuba	-1.32	Decreasing	0.117	No Trend	0.978931	0.0210693	-2.03	significant decreasing trend
Kafr Asad	-0.76	Decreasing	0.603	No Trend	0.835016	0.164984	-0.97	No Trend
Rihaba	-0.79	Decreasing	0.642	No Trend	0.813221	0.186779	-0.9	No Trend
Kufranja Dam	-2.92	Decreasing	0.578	No Trend	0.482419	0.517581	0.04	No Trend
Kufrinja	-1.45	Decreasing	0.109	No Trend	0.925218	0.0747824	-1.44	No Trend
Jarash	+0.152	Increasing	0.816	No Trend	0.458278	0.541722	0.11	No Trend

Trend analysis is important to be able to detect the variability of rainfall and the potential effect of rainwater harvesting for domestic uses. Table (4.1) shows that stations (Deir Abi Said, Hartha, Kharja, Hawwara, Turra, Baqura, Samar, Irbid School, Kafr Asad, Rihaba, Kufranja Dam, Kufrinja and Jarash) have no rainfall trend in the historical years by linear regression and Mann-Kendall trend. Other stations, such as Al-Taiyiba station, have a decreasing trend as indicated by linear regression while Mann-Kendall test showed no trend, Kufr Awan, En Nueiyime and Kafr Yuba stations have not any trends by linear regression while they have significant decreasing trends by Mann-Kendall, and Kufr Saum, Um Qeis, Husn, Ramtha Boys School and Ibbin stations have significant decreasing trends in both of linear regression and Mann-Kendall trend.

Trend analysis showed that Um Qeis and Husn stations have the highest significant decreasing trend as indicated by the lowest value of p in linear regression and Mann-Kendall tests; p-value equals 0.009 in both stations in linear regression, 0.0044668 and 0.0052011 in Um Quis and Husn stations; respectively by Mann-Kendall trend.

The Figure (4.1) shows the linear average trend of Um Qeis station, and Figure (4.2) shows the linear trend of Ennueiyime station, Ennueiyime station has significant decreasing trend in Mann-Kendall (p-value equals 0.031) also a decreasing trend in linear regression but this decrease is insignificant at p = 95%. Figure (4.3) shows the linear trend of station Turra, the Turra station has no trend in linear regression and Mann-Kendall.

It can be noted that is not necessary the both test have the same trend result, as an example, Kufr Awan station has a decreasing slope but has not any significant trend at level of significant of 0.05 regarding to Linear regression test, while in the Mann-Kendall test has w high significant decreasing trend at the same level of significant.

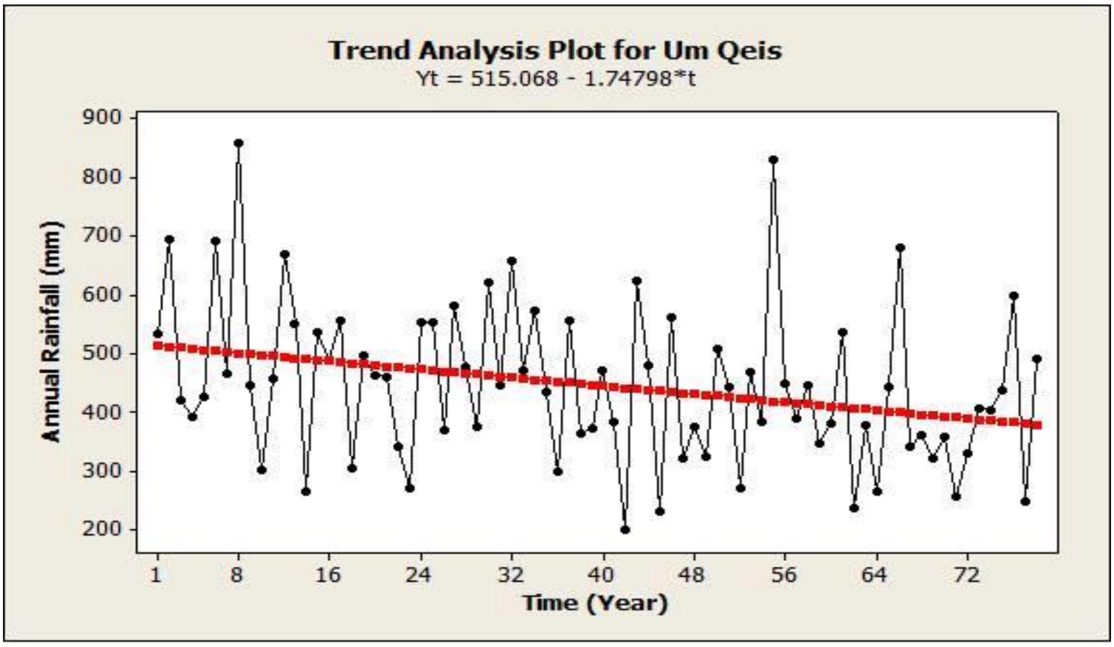


Figure 4.1: linear trend of Um Qeis station.

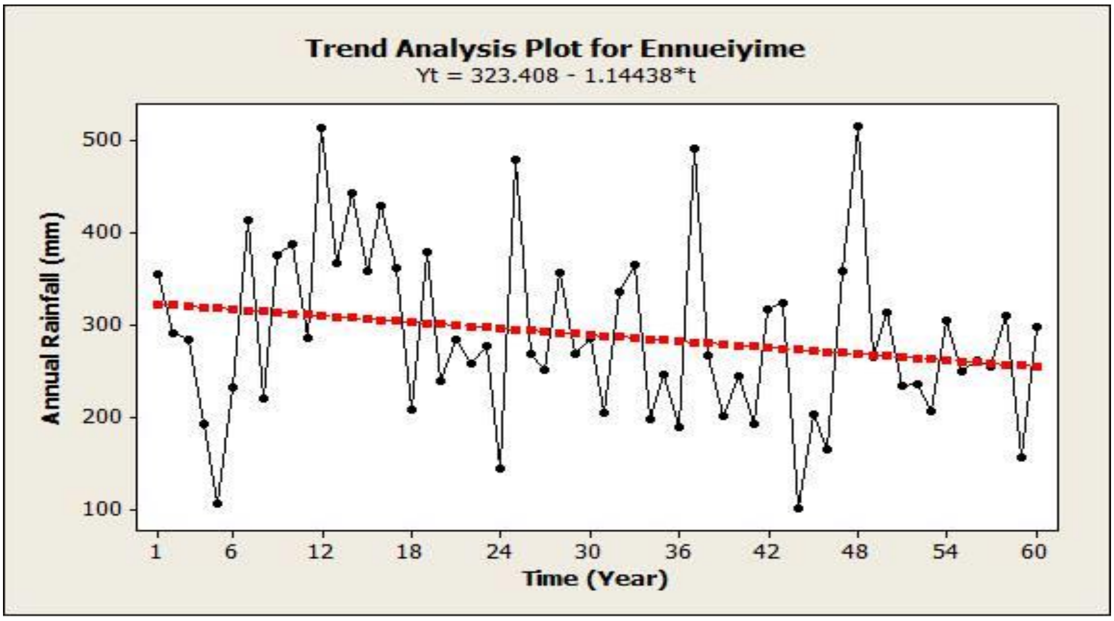


Figure 4.2: linear trend of Ennueiyime station.

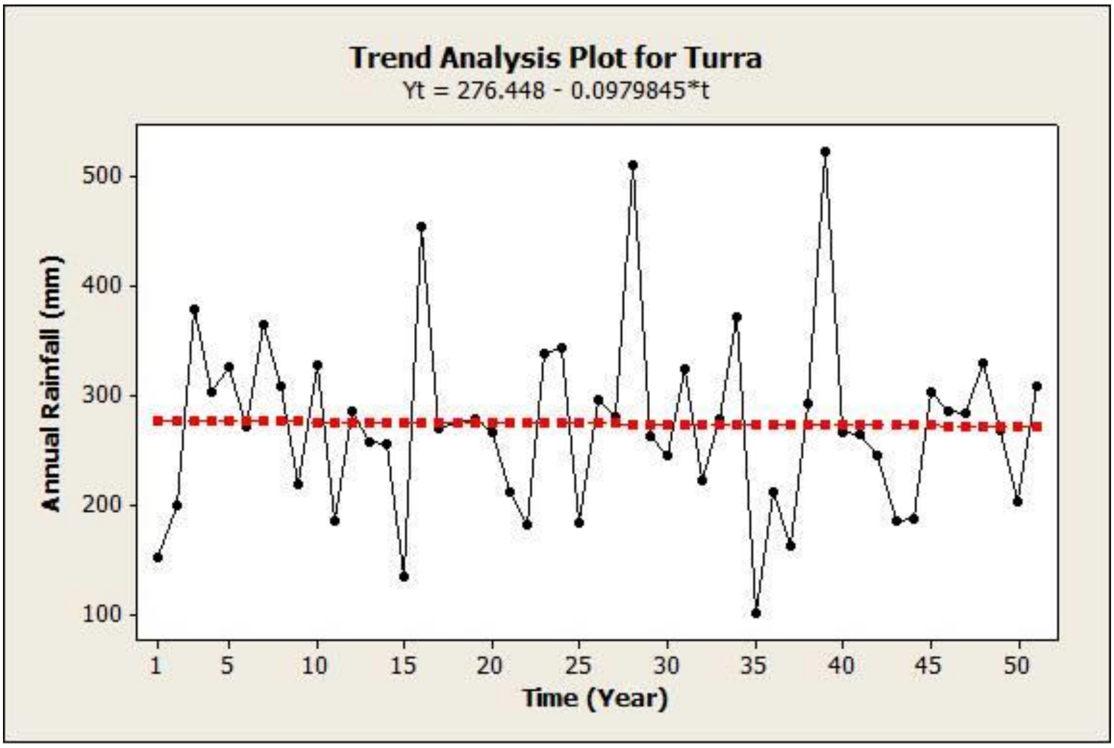


Figure 4.2: linear trend of Turra station.

4.3 Rainwater Laboratory Test Results

Table (4.3) shows the results of rainwater analysis taken in the rainy season of year 2015/2016 from November 16, 2015 to March 28, 2016. Appendixes (B.1-2) contain all the storm events had happened during the water year of 2015/ 2016.

Table 4.3: Laboratory test results of rainwater samples of the water year 2015/2016.

	Nov 16, 2015	Nov 30 & Dec1, 2015	Dec 30 & 31, 2015	Dec 31, 2015 & Jan 1, 2016	Jan 8, 2016	Jan 18, 2016	Jan 24, 2016	Feb 21, 2016	Mar 15, 2016	Mar 28, 2016
BOD5 (mg/ l)	3	0.65	2.5	1.7	0.8	0.6	0.35	2.7	2.25	-
COD (mg/ l)	16	0	0	0	0	22.4	9.6	0	0	48
Total Alkalinity (mg/ l)	134	45.5	22	20	15.5	11.2	8	4	8	11.2
Hardness (mg/ l)	126	194	53	30	40	38.6	36	18	20	28
DO (mg/ l)	9.8	9.15	10	9.9	9.5	9.3	9.85	10.5	10	9.4
pH	7	6.7	7.8	8	7.49	7.76	7.7	5.95	5.8	6.1

Turbidity (NTU)	44.4	6.5	9.4	1.6	38.3	6.54	1.08	1.35	1.61	2.26
Total coliforms (colony/100ml)	0	0	0	0	0	0	0	0	0	0
Conductivity (μs/ cm)	351.53	79.4	137.6	70.1	117.1	95.1	101.1	94.7	81.17	81.1
TS (mg/ l)	0.253	0.093	0.091	0.012	0.091	-	-	-	-	0.055
TDS (mg/ l)	225.33	50.90	88.20	44.93	75.08	60.98	64.84	60.7	52.03	51.98

As shown in the Table (4.3), we have analyzed eleven quality parameters that are relevant to rainwater to be used for domestic purposes. All measured parameters are significantly higher at the beginning of rainy season, compared to the subsequent storms. Alkalinity, hardness, turbidity, conductivity, and TDS are approximately 5-fold higher than subsequent storms.

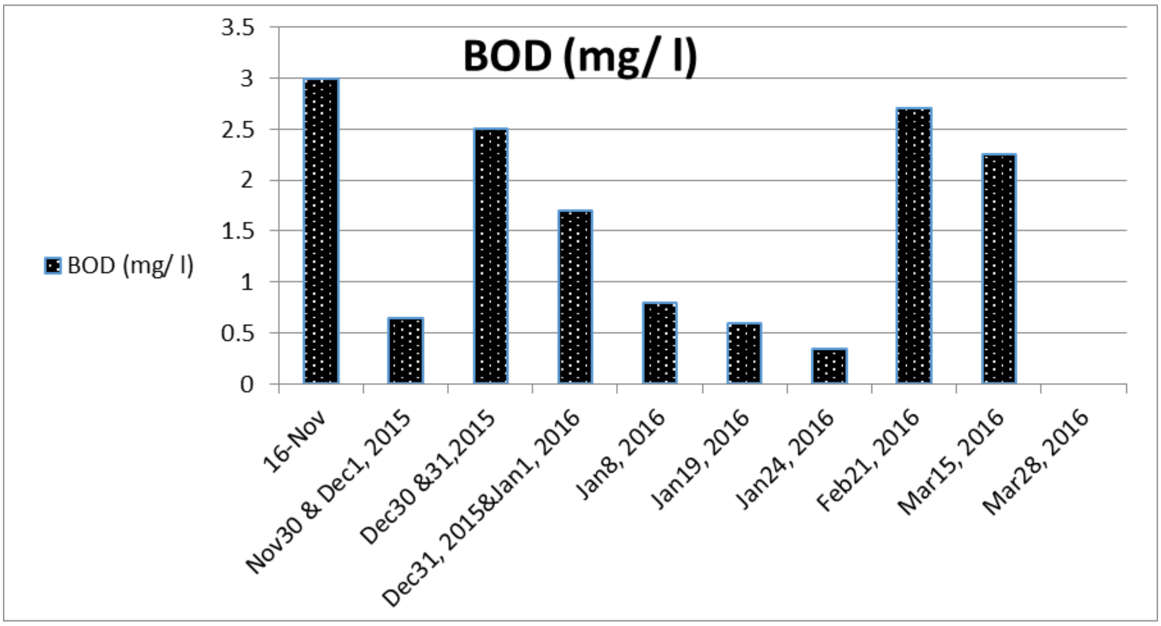


Figure 4.4: BOD test values of water year of 2015/ 2016 samples.

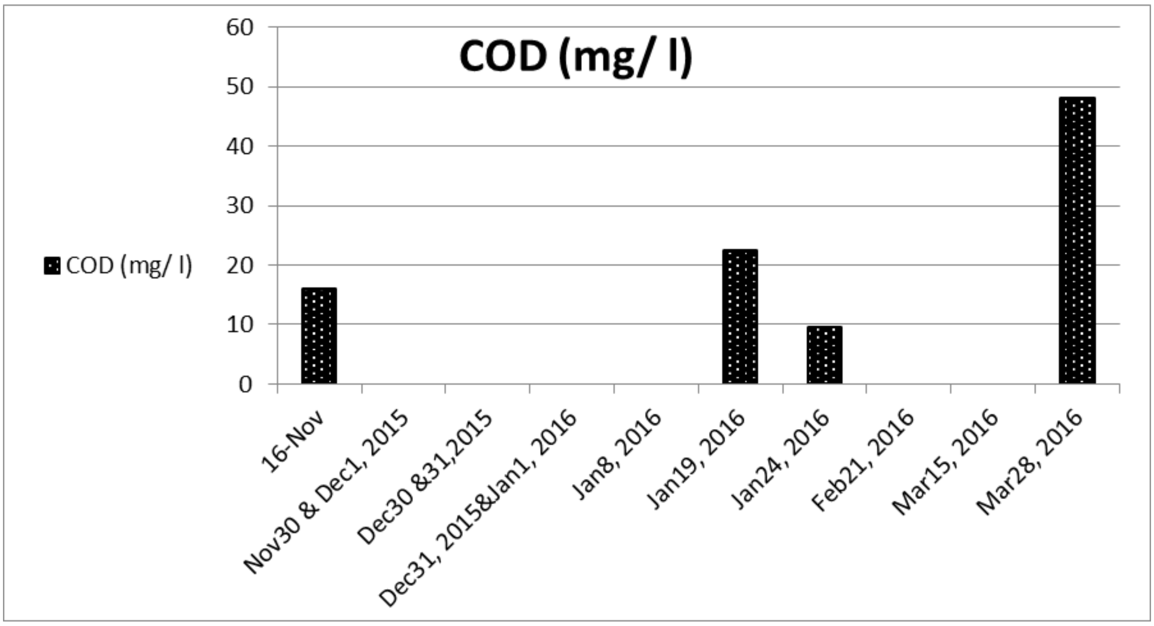


Figure 4.5: COD test values of water year of 2015/ 2016 samples.

Figure (4.4) shows the BOD and Figure (4.5) shows the COD results of rainwater sample of the water year of 2015/ 2016. It seems that for the BOD there is not significant values to be noticed.

Dissolve oxygen has the same range over the water year of average 9.7, maximum value 10.5 and minimum value 9.15. pH values also have the same range among all samples with an average of 7, maximum value 8 and minimum value 5.8, according to JS the pH values range (6.5-8.5). While total coliforms has not been detected in any of the samples collected during this study. Figure (4.6) shows the hardness values and Figure (4.7) shows the total alkalinity values of the water year of 2015/2016 samples. The results showed clearly, that samples taken from the first and second storms had the highest values then there is general decreasing in the values among the year as a timeline, the average values of hardness is 33 and for alkalinity is 12.5 except the first and the second samples due to that at the beginning of the year there are many of dusts in the atmosphere, but the main source to have a high values of hardness cannot be identified.

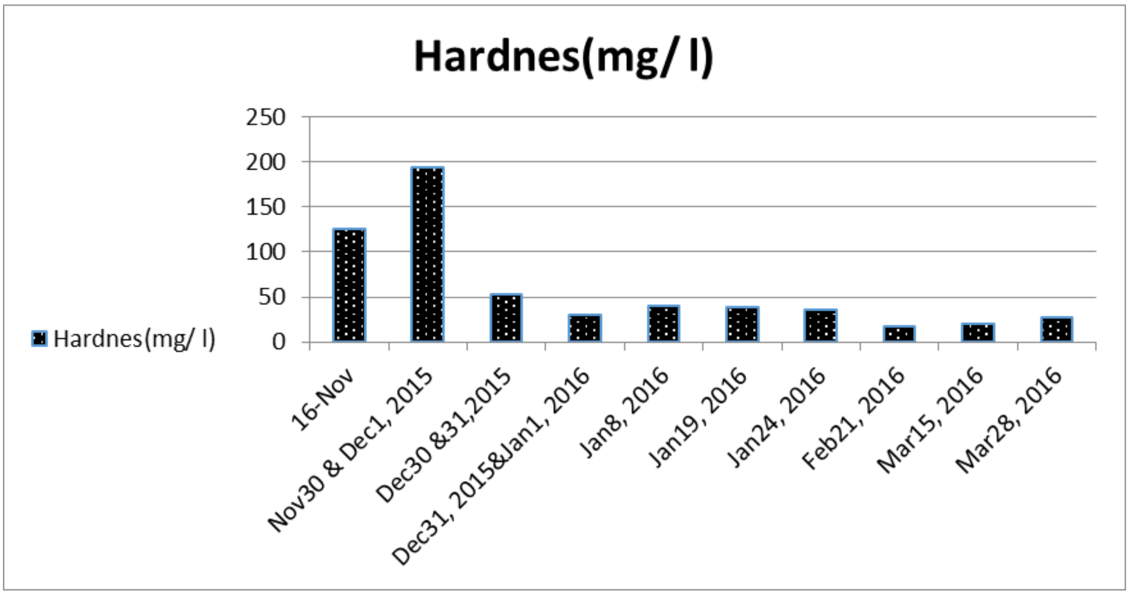


Figure 4.6: Hardness test values of water year of 2015/ 2016 samples.

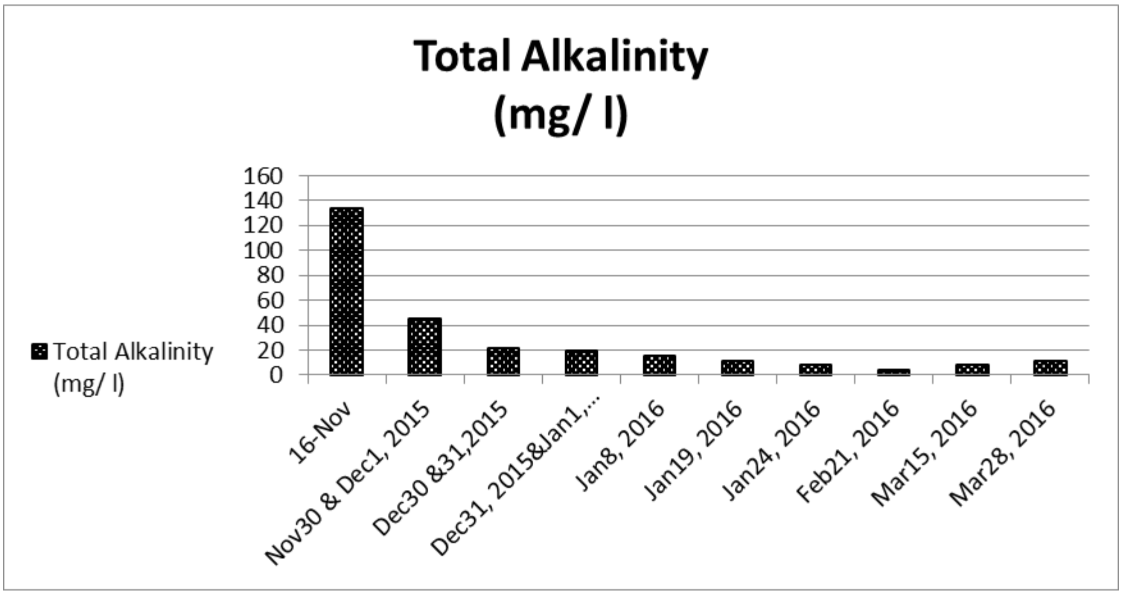


Figure 4.7: Total Alkalinity test values of water year of 2015/ 2016 samples.

Conductivity values shown in Figure (4.8), the highest value is the first one, then the average of conductivity values is 95.3, the TDS was calculated according to the Equation (4.1), all the values are less than the maximum allowable values according to JS. Turbidity got decreasing among the water year and increasing in the end of the year, it is natural that in the beginning of the water year have a high value because of the dust and other scums, and in the end of the water year have increasing because the dust storms among the water year, the water year has discontinuous storms which is represented in Figure (4.9).

$$TDS = Condcutivity * 0.641 \qquad \ldots\ldots\ldots\ldots Equation\ (4.1)$$

Where;

(TDS) Total Dissolved Solids in (mg/l) unit,

Conductivity in (µs/ cm) unit, and

0.641: the conversion factor

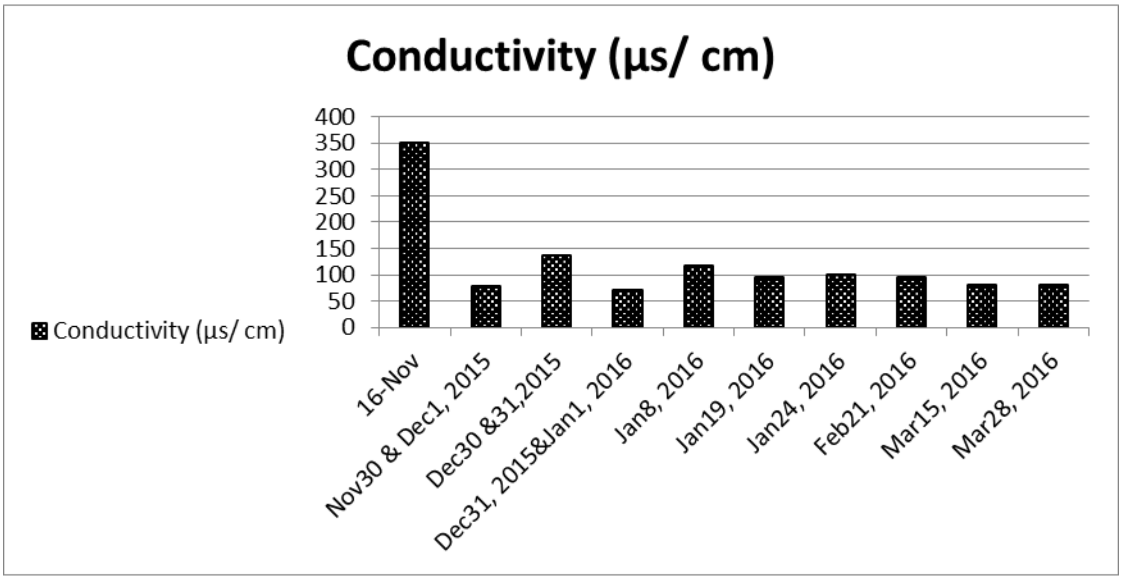


Figure 4.8: Conductivity test values of water year of 2015/ 2016 samples.

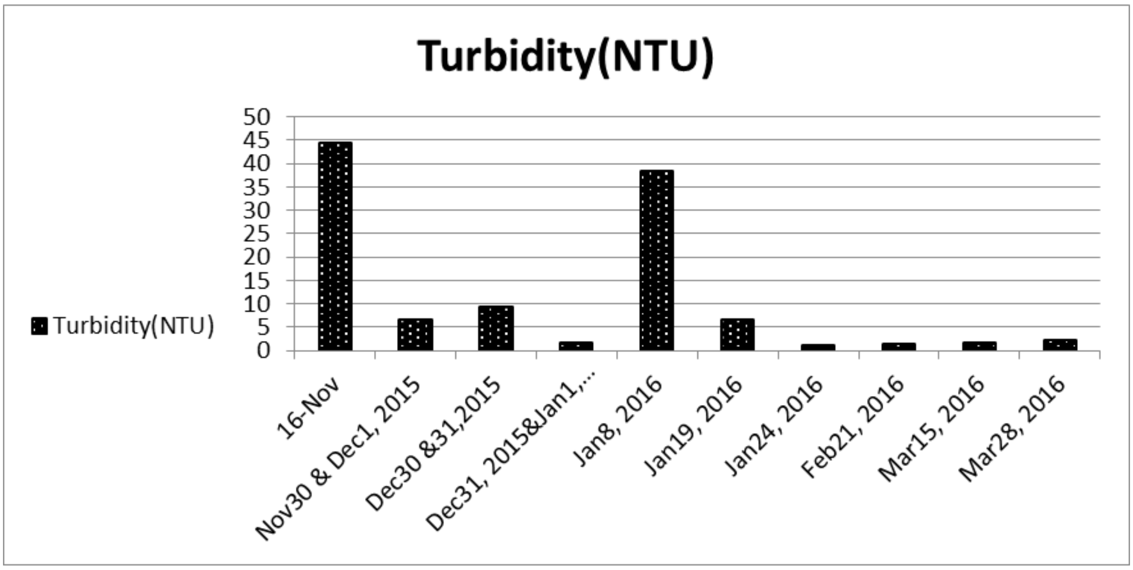


Figure 4.9: Turbidity test values of water year of 2015/ 2016 samples.

4.4 Design of Tank Volume

The optimum tank volumes based on supply-demand series analysis have been calculated for all stations with various combination of rooftop area and demand rate and the results are plotted as a function of demand rate and roof area, the design of the storage tank concluded the eight rainy months only. As assumed for eight months, because if the whole year was taken, the storage will be too much big, and there is no potential rainwater to fill with, and the cost will be very expensive. So why the eight rainy months were taken, and the deficit were calculated to get the smallest tank. While at the non-rainy months, the tank will be filled with fresh water from the authority. So the designed storage tank can be used as an alternative of fresh water (for domestic uses).

Table (4.4) shows an example of tank sizing, in Um Qeis station, rooftop area of 250 m^2 and monthly demand of 12 m^3:

Table 4.4: Example of tank sizing, in Um Qeis station, rooftop area of 250 m^2 and monthly demand of 12 m^3

Rainfall mean value (mm)	**Captured Rainfall of area=250 m^2 (mm)**	**Cumulative captured Rainfall (R) (mm)**	**R-O (O=Monthly Demand of 12 m^3) (m^3)**	**Cummulative (R-O) (m^3)**
11.0615	2.212308	2.212308	-9.78769	-9.78769
51.2872	10.25744	12.46974	-11.5303	-21.3179
91.0474	18.20949	30.67923	-5.32077	-26.6387
110.412	22.08231	52.76154	4.761538	-21.8772
87.3808	17.47615	70.23769	10.23769	-11.6395
65.4205	13.0841	83.32179	11.32179	-0.31769
23.8295	4.765897	88.08769	4.087692	3.77
5.58462	1.116923	89.20462	-6.79538	-3.02538
				$\lvert \text{Minimum} \rvert = 26.6387$

The plotted figures also show the maximum volume that can be collected from a house based on the historic average of rainfall. Therefore, if we need to know the optimum tank volume for a specific rooftop area and a specific demand rate, what we need to do is just to intercept these data on the plotted Figure at the nearest station of the living area. Figure (4.10) shows the maximum tank volume, and the optimum tank volume of Al-Taibah station with respect to the roof area and water usage per month, it can be seen as an example at demand = 12 m^3/month, it exceeds the maximum water which can be collected from rainwater at roof area = 150 m^2 (the optimum volume = 96 m^3, while the maximum volume = 56.7 m^3), but still you can build a large tank, however you know that it cannot get full from rain water, while at same demand but at roof area = 200 m^2, the optimum volume of storage tank is approximately equal of the maximum potential water(the optimum volume = 71.5m^3, while the maximum volume = 75.6m^3), Figure (4.11) shows the maximum tank volume, and the optimum tank volume of Kufranja station with respect to the roof area and water usage per month. Also, it can be seen as an example at demand =

6 m^3/ month, the optimum volume is less than the maximum of rainwater which can be collected at all rooftop areas, Figure (4.12) shows the maximum tank volume, and the optimum tank volume of Ramtha Boys School station with respect to the roof area and water usage per month, it can be seen that maximum demand can be used with respect to the maximum potential rainwater is 10 m^3/ month at area of 250 m^2.

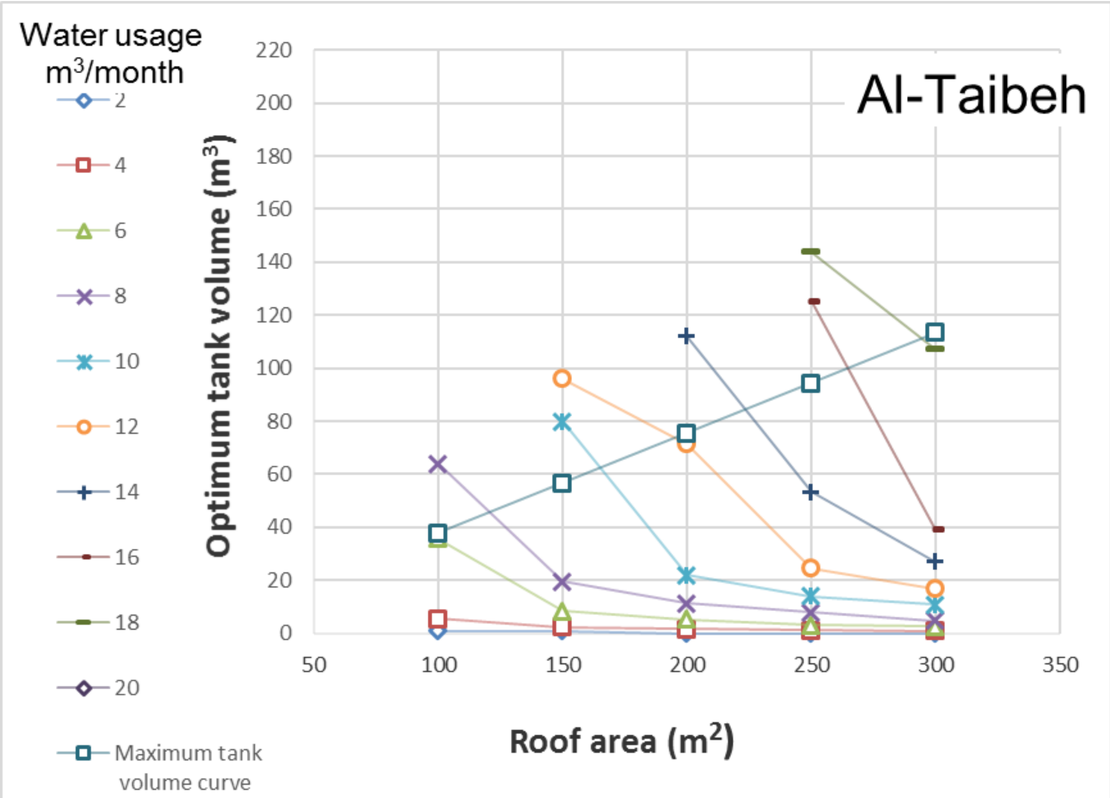


Figure 4.10: The maximum tank volume, and the optimum tank volume of Al-Taibeh station with respect to the roof area and water usage per month.

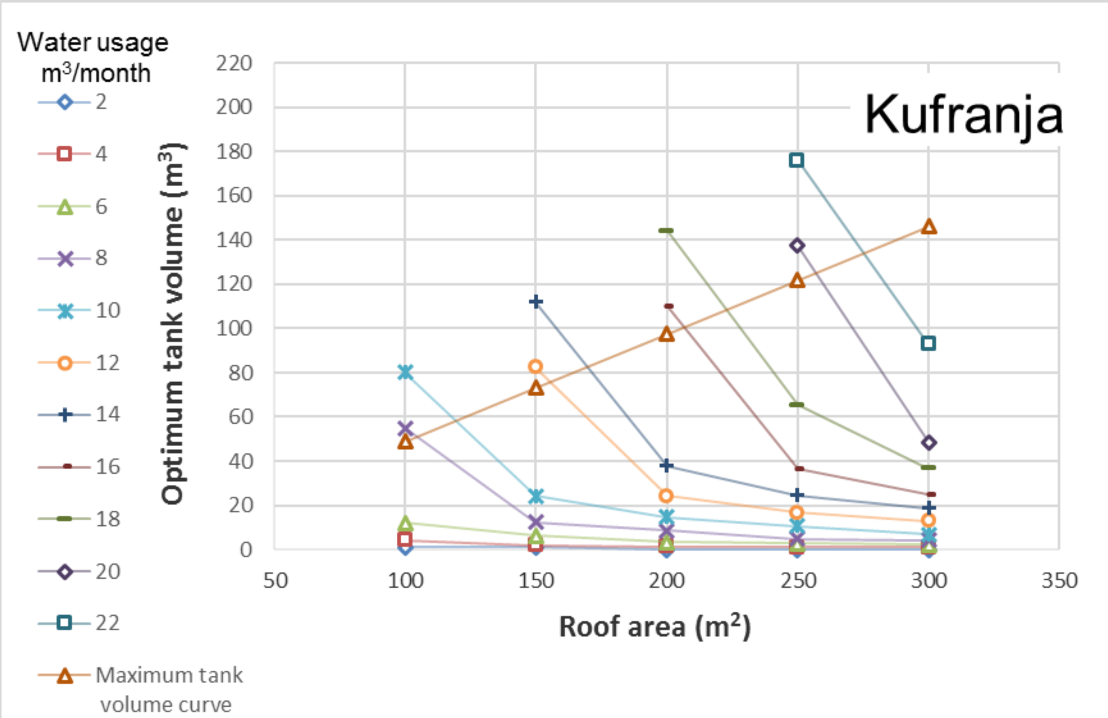


Figure 4.11: The maximum tank volume, and the optimum tank volume of Kufranja station with respect to the roof area and water usage per month.

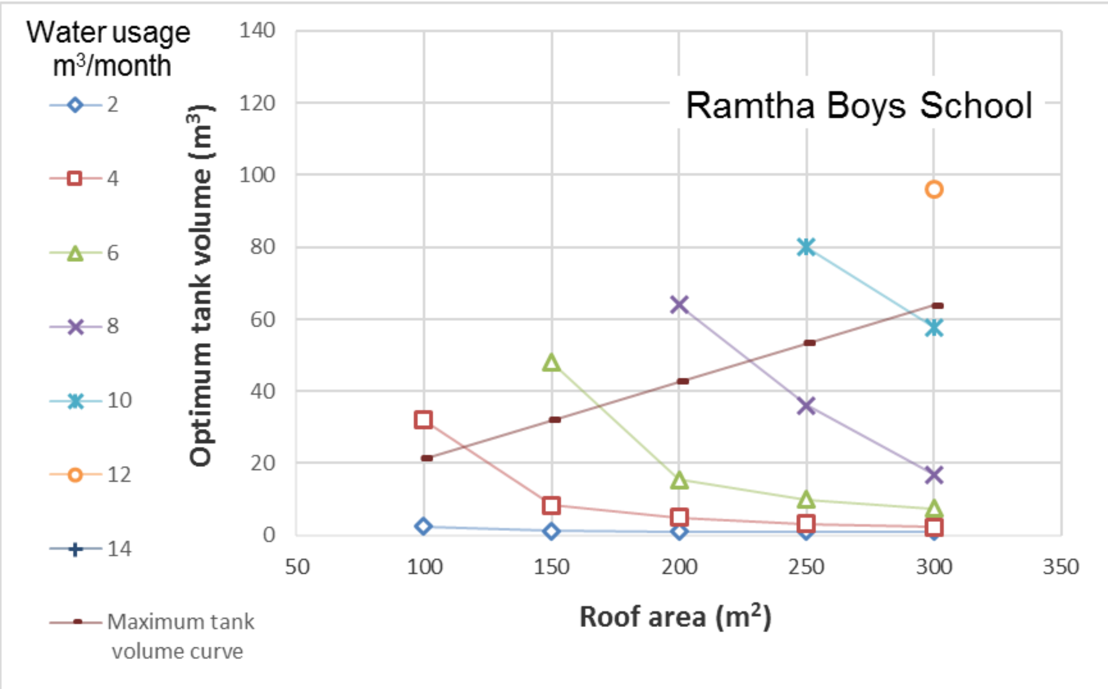


Figure 4.12: The maximum tank volume, and the optimum tank volume of Ramtha Boys School station with respect to the roof area and water usage per month.

Appendix (C) contains the rest of plotted figures of all stations, showing the maximum tank, and the optimum tank volume with respect of the roof area and the demand rate. These results of all stations are interpolated to get contour maps by GIS program, showing Irbid, Ajloun and Jarash governorates, each map contains specific area and a value on each station, to show the maximum potential rainwater (maximum storage tank) and the optimum storage tank according to the water usage per month.

Figure (4.13) shows the maximum storage tank as a contouring map showing the station of the study area, rooftop area of 100 m2, Figure (4.14) shows the maximum storage tank contouring map for rainwater stations of the study area, rooftop area of 150 m^2, Figure (4.15) shows the maximum storage tank as contouring map showing the station of the study area, rooftop area of 200 m^2, Figure (4.16) shows the maximum storage tank as contouring map showing the station of the study area, rooftop area of 250 m^2, Figure (4.17) shows the maximum storage tank as contouring map showing the station of the study area, rooftop area of 300 m^2. Figures (4.13-17) can be used as guidelines for building a storage tank according to the maximum potential rainwater of specific rooftop area and the location of the house.

Figures (4.13-4.17) showed that as we move to the southern west, the maximum storage tank increased for each specific rooftop area, as a s example, take Hawwarra station, the maximum storage tank will increase gradually as the rooftop area increased, so for rooftop area 100 m^2, 150 m^2, 200 m^2, 250 m^2 and 300 m^2 will be the maximum storage tank 28.2 m^3, 42.3 m^3, 56.4 m^3, 70.5 m^3, 84.6 m^3; respectively.

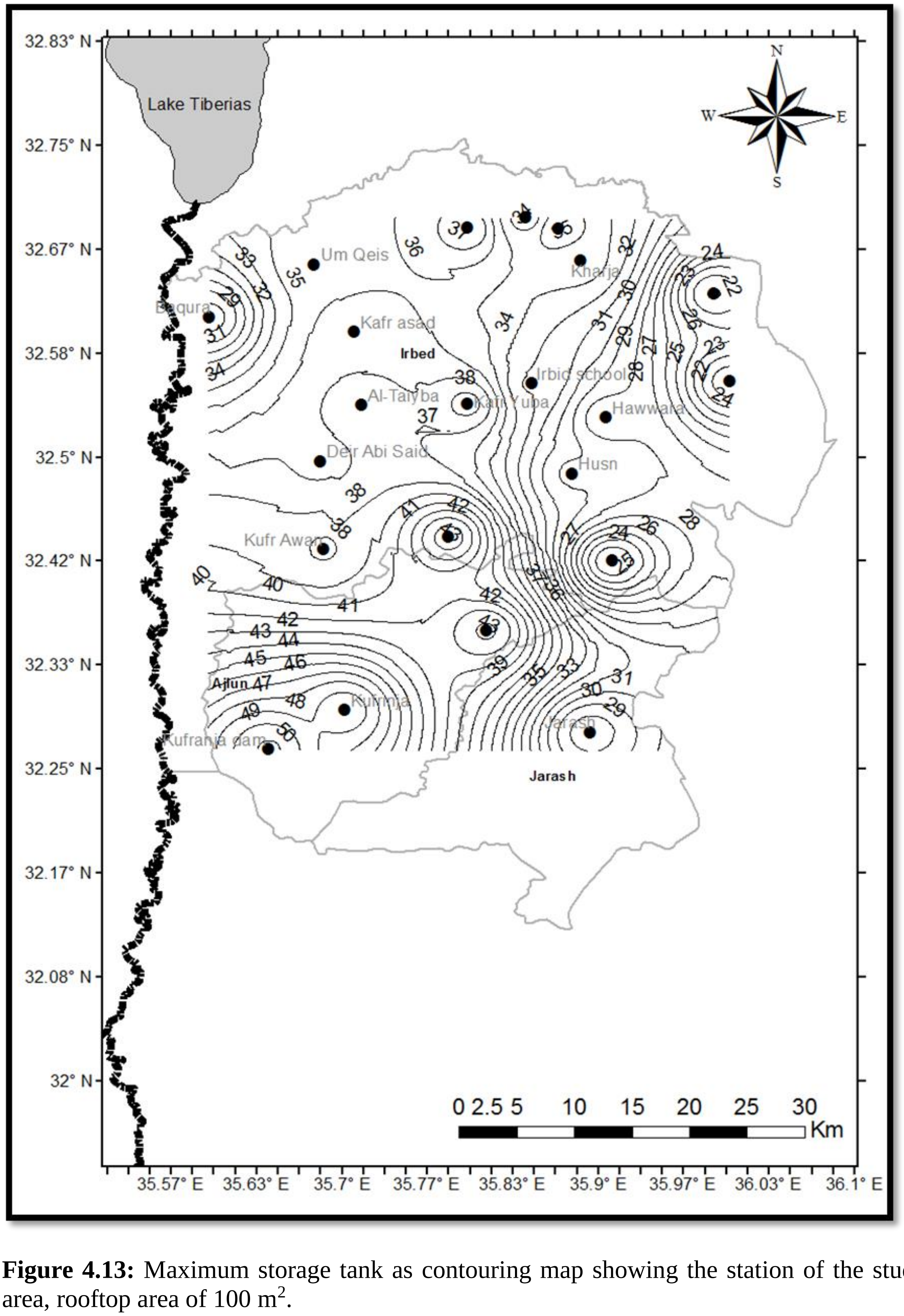


Figure 4.13: Maximum storage tank as contouring map showing the station of the study area, rooftop area of 100 m^2.

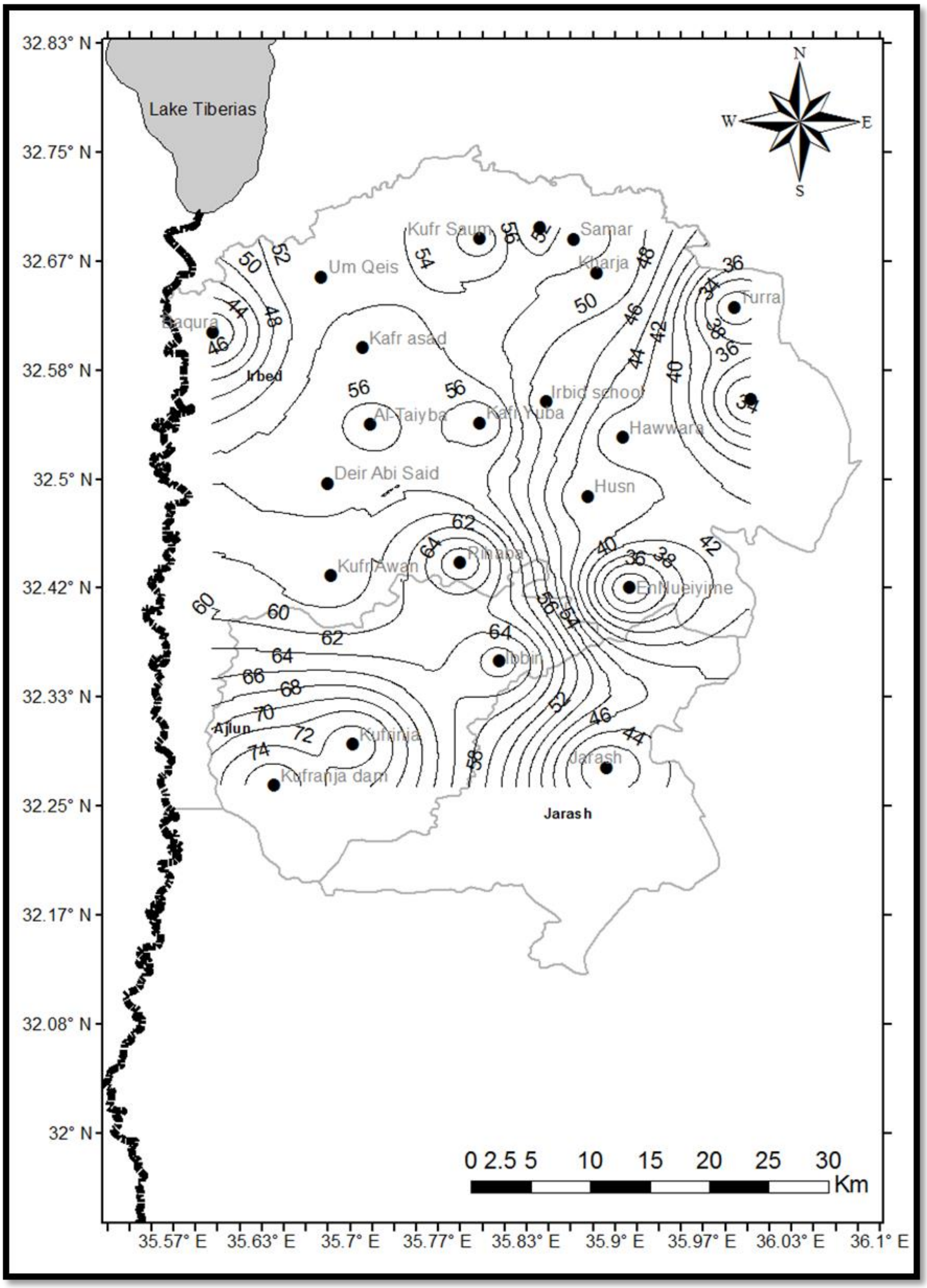


Figure 4.14: Maximum storage tank as contouring map showing the station of the study area, rooftop area of 150 m^2.

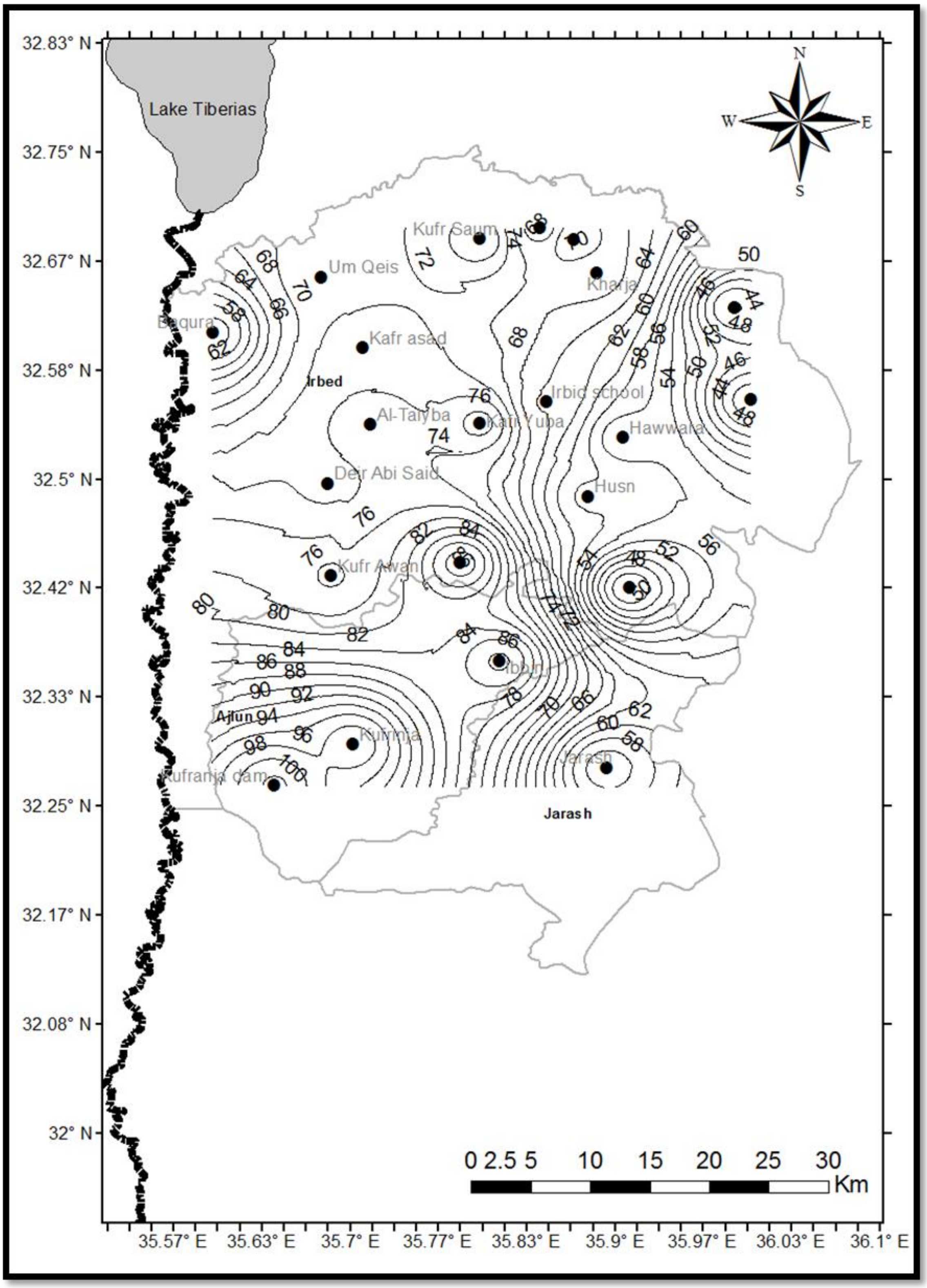


Figure 4.15: Maximum storage tank as contouring map showing the station of the study area, rooftop area of 200 m^2.

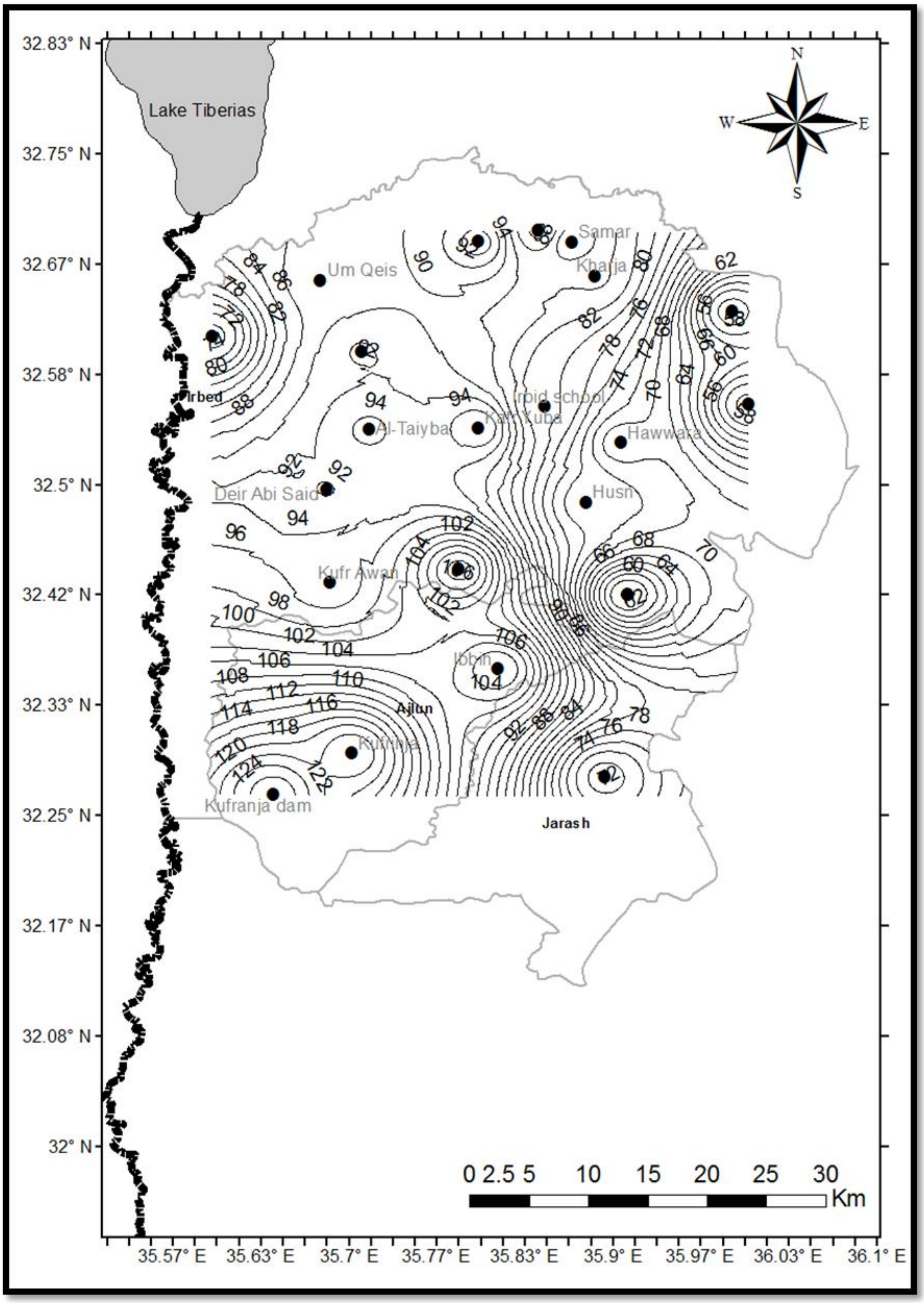


Figure 4.16: Maximum storage tank as contouring map showing the station of the study area, rooftop area of 250 m^2.

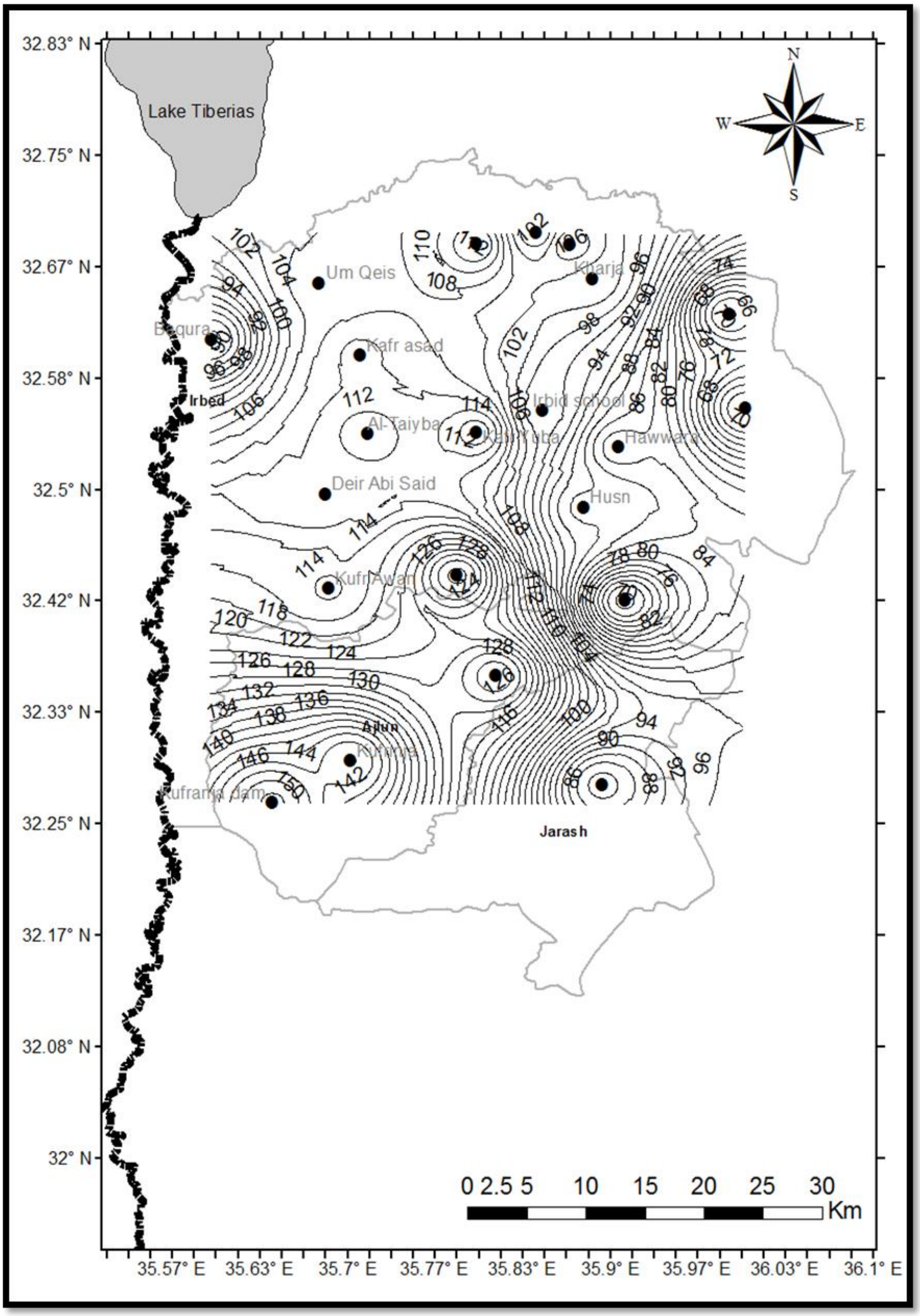


Figure 4.17: Maximum storage tank as contouring map showing the station of the study area, rooftop area of 300 m^2.

Figure (4.18) and figure (4.19) show Optimum/ smallest storage tank as contouring map, showing the station of the study area of rooftop area of 250 m^2, and demand of 10 m^3/month and 12 m^3/month; respectively.

While Figure (4.20) and Figure (4.21) show optimum/ smallest storage tank as contouring map, showing the station of the study area of rooftop area of 300 m^2, and demand of 10 m^3/month and 12 m^3/month; respectively.

Figures (4.18-4.21) can be used as guideline of building a storage tank according to the coordinates of the house with respect to the house area, can be used as maximum storage tank or the optimum/ smallest storage tank according to the water usage per month. And from these figures can be notices that the volume of the optimum storage tank increased when we go to the East direction. As an example, at area of 250 m^2, at Jarash station and demand 10 the optimum volume is 32 m^3, while if the monthly demand increased to 12 m^3, the optimum volume has increased to be 85m^3, and at area of 300 m^2, as an example, take Kufr Awan station and monthly demand 10^3 the optimum volume is 11 m^3, while if the monthly demand increased to 12 m^3, the optimum volume has increased to be 18m^3.

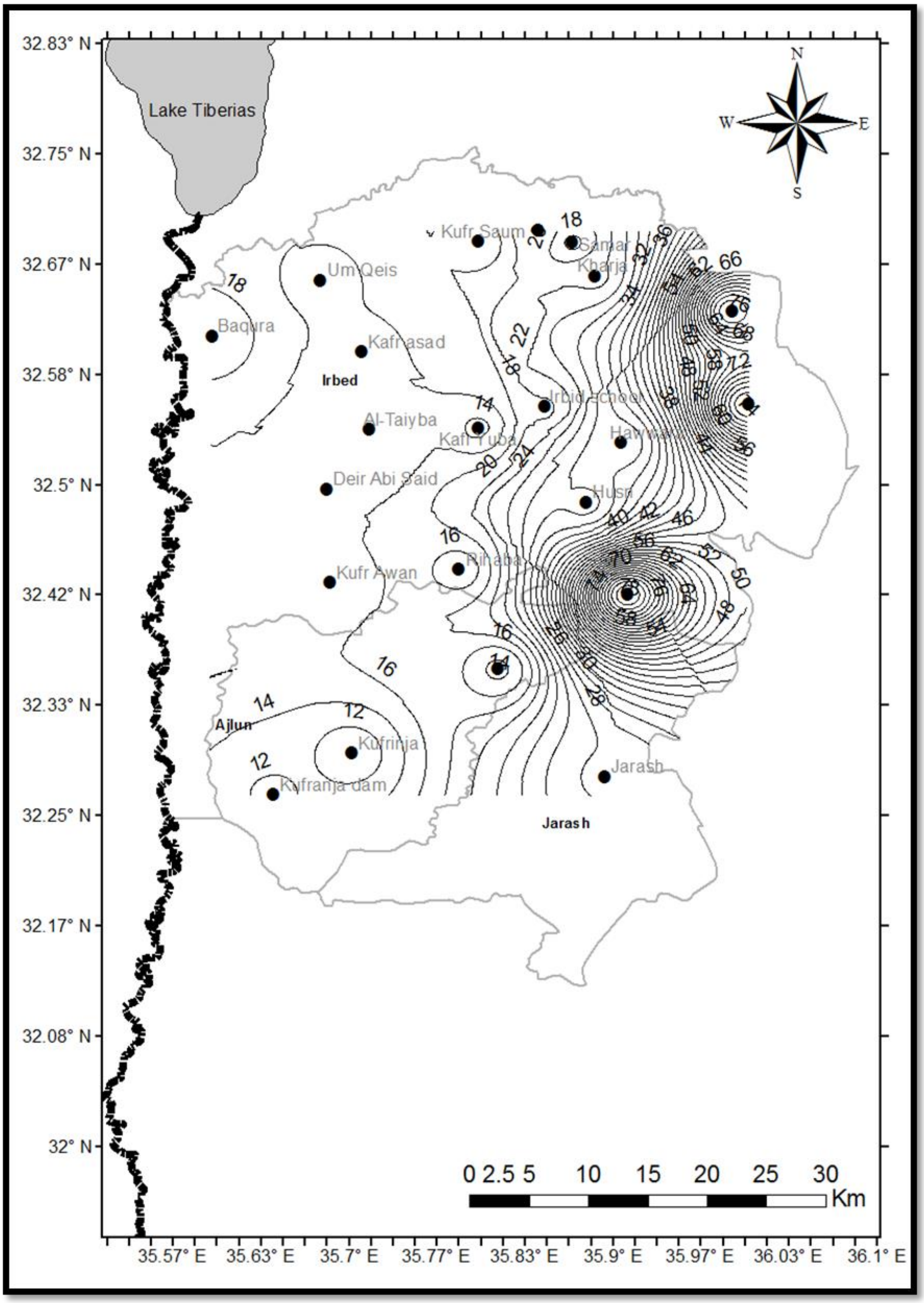


Figure 4.18: Optimum/ smallest storage tank as contouring map showing the station of the study area, rooftop area of 250 m^2 and demand 10 m^3/month.

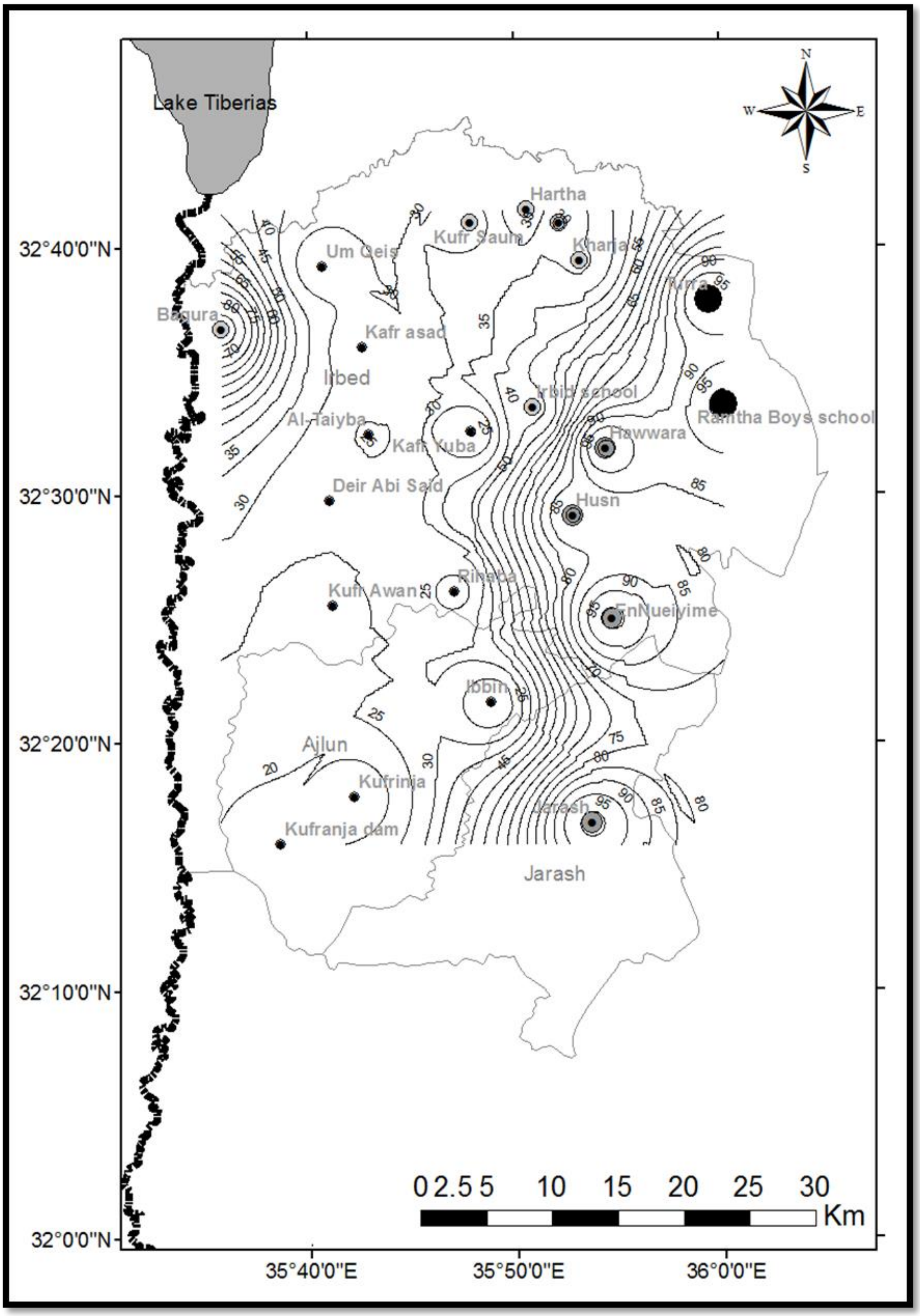


Figure 4.19: Optimum/ smallest storage tank as contouring map showing the station of the study area, rooftop area of 250 m^2 and demand 12 m^3/month.

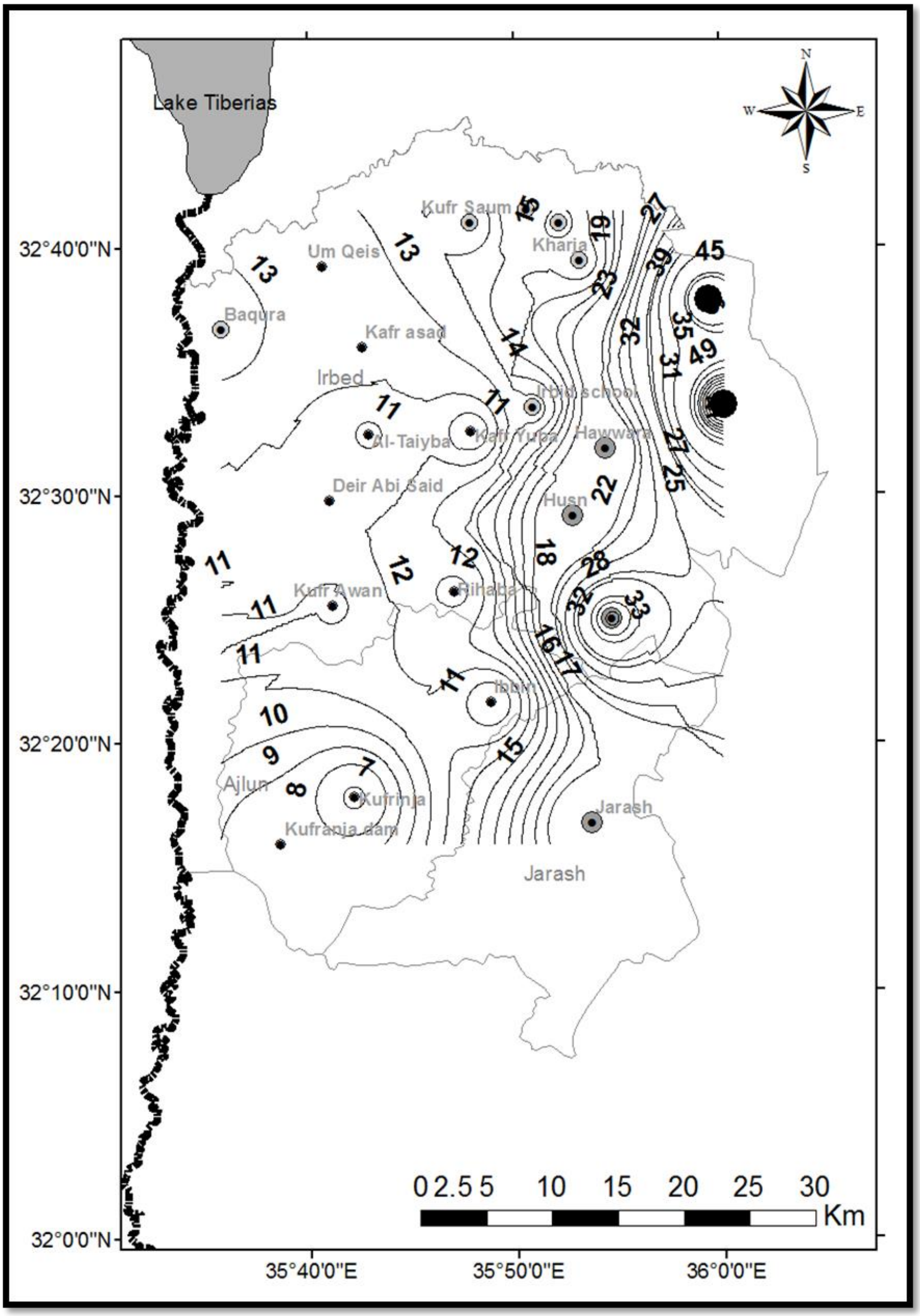


Figure 4.20: Optimum/ smallest storage tank as contouring map showing the station of the study area, rooftop area of 300 m^2 and demand 10 m^3/month.

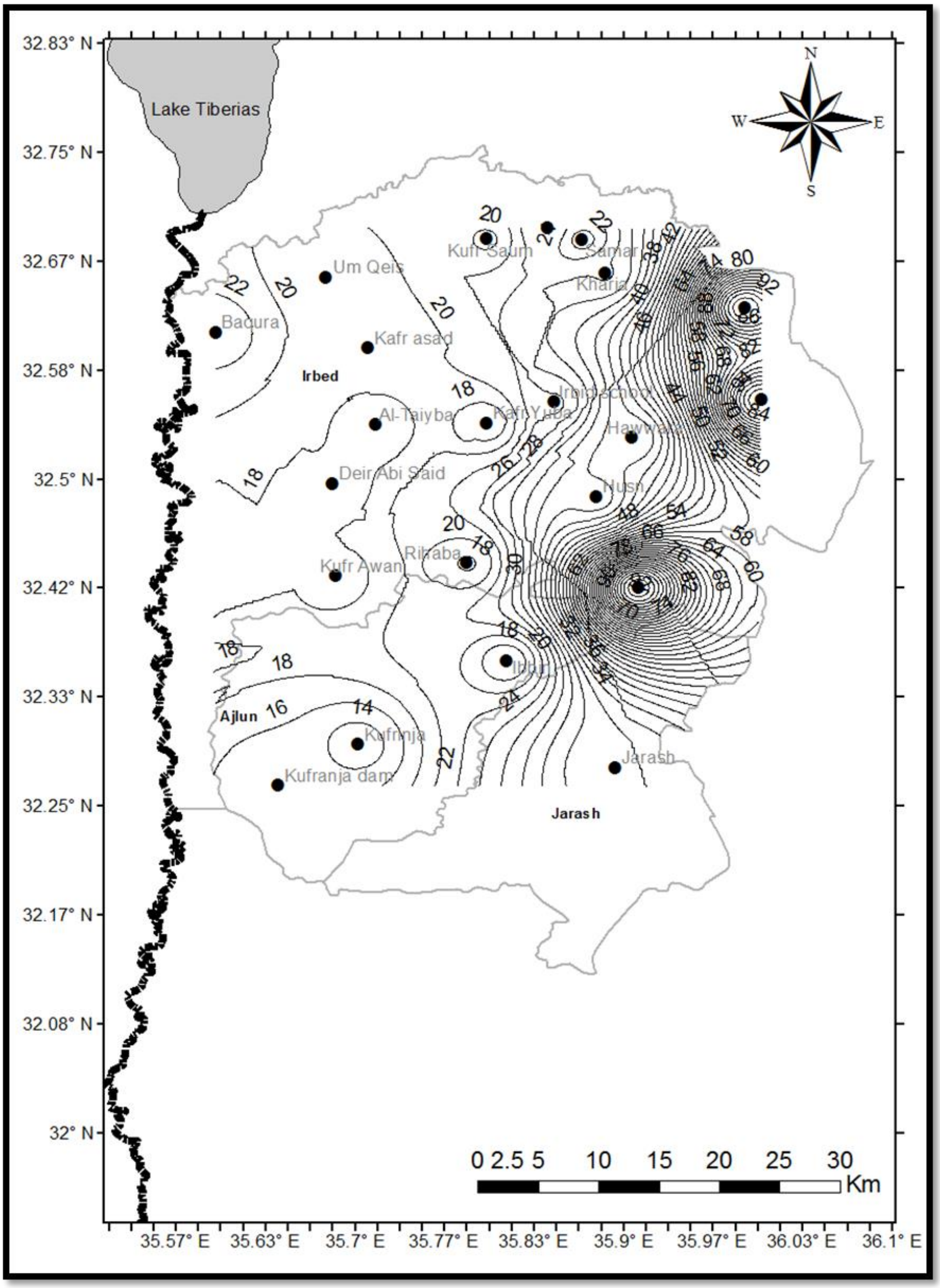


Figure 4.21: Optimum/ smallest storage tank as contouring map showing the station of the study area, rooftop area of 300 m^2 and demand 12 m^3/month.

4.5 Reliability

A reliability test was done, the reliability test can be done for any assumption of monthly demand, number of months, years, etc... in this test, the demand was assumed to be 12 m^3/month, and the monthly average of historic rainfall data of rainy months were used. This monthly demand 12 m^3/ month were used because of in Jordan there is a fresh water crisis and the water supply depends on the amount of water exist not the demand of family, so the number is fair enough to cover the family needs. The reliability was tested for each month by testing the supply-demand of each month, assuming that the water year begins with an empty storage, each month have no overflow and the monthly family demand equal 12 m^3/month, the tested reliability was calculated on the smallest volume of the maximum storage tank (supply side) and the optimum volume tank of demand 12 m^3/month (demand side), so the percentage reliability is calculated by looking at the number of failures the volume in the storage tank of each rainy month would fall below zero when using a specific tank volume. Then the reliability was tested on a wet year and a dry year, the dry year reliability was recorded to be 0.0% at all stations. Equation (4.2) illustrate the percentage reliability equation:

$$\boldsymbol{Relibility\,\% = \left(1 - \left(\frac{Number\ of\ Fails}{Total\ months}\right)\right) * 100\%} \qquad \ldots\ldots\ldots\ldots \boldsymbol{Equation\ (4.2)}$$

As an example of tabular method of the reliability calculation, Table (4.5) shows the reliability testing of Kufranja station, demand =12 m^3/month, rooftop area = 300m^2. The reliability results of all station are in appendix (D).

Column A: Is the average monthly historic rainfall.

Column B: The volume captured in a month in cubic meters is calculated by Equation (3.6).

Column C: Cumulative monthly volumes captured through the year.

Column D: Monthly demand = 12 m^3.

Column E: Cumulative monthly volumes demanded through the year.

Column F: The total amount stored is calculated by subtracting the value in column E from the value in column C.

Column G: It is calculated by subtracting the value in column D from the value in column B.

Column J: equal column F, and the maximum storage tank is the smallest storage volume of supply-demand volumes, the over flow illustrates in column I.

Table 4.5: Reliability calculation of Kufranja station, rooftop area = 300m^2.

	A Month	B Volume captured in month	C cumulative volume captured	D volume demanded in month	E cumulative demand	F Total amount stored C-E	G Deficit/surplus for month B-D	I over flow F-J	J amount actually stored	Fail/OK
Oct	15.93	3.82	3.82	12	12	-8.18	-8.18	0.00	-8.18	Fail
Nov	64.56	15.49	19.32	12	24	-4.68	3.49	0.00	-4.68	Fail
Dec	120.79	28.99	48.31	12	36	12.31	16.99	0.00	12.31	OK
Jan	151.87	36.45	84.76	12	48	36.76	24.45	23.86	12.90	OK
Feb	123.62	29.67	114.42	12	60	54.42	17.67	41.52	12.90	OK
Mar	97.60	23.42	137.85	12	72	65.85	11.42	52.95	12.90	OK
Apr	27.73	6.66	144.50	12	84	60.50	-5.34	47.60	12.90	OK
May	6.79	1.63	146.13	12	96	50.13	-10.37	37.23	12.90	OK
	Total Rainfall =608.89	Total captured = 146.13						Total over flow 203.16	# of Fails=	2

Chapter Five: Summary and Conclusion

The main objective of this study was to investigate the status of rooftop rainwater harvesting at northern Jordan and parameters affecting its use and effectiveness among population at northern Jordan. Therefore, we studied the socioeconomic factors, tank size and water quality parameters of harvesting rainwater.

A five hundred questionnaires has been randomly distributed among residents in Irbid and surrounding villages, only two hundred and fifty have been collected back and analysed, The analysis of the questionnaire indicated that; 87% of people are aware of water resources problems in Jordan and they are looking for a solution, the results also showed that only 54% of people are collecting rainwater and most of them (about 82%) are collecting rainwater from rooftop of their own houses, and use it for drinking (50%), or other purposes like washing and cleaning. There are many reasons why about 46% of people are not practicing rainwater harvesting in their houses despite the obvious needs of it; the most common reason (35%) is there is not enough area for storage followed by (29%) lack of awareness about the importance and effectiveness of rooftop RWH system, and only 11% have not a RWH system because its expensive cost; etc.…, but the other reason to not have a rainwater harvesting system and about 22% of people believe, that they do not believe that the quality of rainwater is good enough, while 70% of the same people who do not use rainwater harvesting system said they will build a rainwater harvesting system if they get finical/ technical or any other kind of help.

One question from the questionnaire must get more focus on it and to be investigated more, that 78% of people who have a rainwater harvesting system had chosen the volume of collection tank randomly, while 22% had chosen it according to the rain depth of the area, in other hand no one of those who had chosen according to rain depth gave a proof of using a scientific way or any other way or help.

Rainwater samples were collected directly from a rooftop and analysed for various quality parameters, the samples were not collected from the rooftop surface of house because rainwater might be affected by rooftop cleanness, and will not represent the correct quality of the rainwater, As general trend for most parameters, the highest values occurred at the in the first few storms at beginning of the winter season. After that there was a noticeable decreasing trends in the values of parameters (Hardness, Turbidity, Total Alkalinity). For some parameters, such as TDS and Turbidity; there increasing then decreasing because of dust storms that occurred during the season. Quality analysis showed that total coliforms was counted 0 CFU/ 100ml for all the samples, thus making rainwater safe for drinking. pH ranges between (5.8-8), BOD ranges between (0.35-3), COD ranges between (0-48), Alkalinity ranges (134-4), Hardness ranges (194-18), TDS ranges (225.3-44.9), turbidity ranges (44.4-1.08) and DO ranges (9.15-10.5).

The trend analysis of annual historical rainwater depth has been investigated using linear regression and Mann-Kendall tests using Minitab program. Analysis of rainfall data showed that the stations (Deir Abi Said, Hartha, Kharja, Hawwara, Turra, Baqura, Samar, Irbid School, Kafr Asad, Rihaba, Kufranja Dam, Kufrinja and Jarash) have no rainfall trend as indicated by linear regression and Mann-Kendall trend, Al-Taiyiba station, has a decreasing trend by linear regression while in Mann-Kendall have not a trend, Kufr Awan, En Nueiyime and Kafr Yuba stations have not any trends by linear regression while they have significant decreasing trends by Mann-Kendall, and Kufr Saum, Um Qeis, Husn, Ramtha Boys School and Ibbin stations have a significant decreasing trends in both of linear regression and Mann-Kendall trend. Um Qeis and Husn stations have the highest decreasing significant.

Mass curve analysis of rainfall data was performed for all stations to find the optimum/smallest tank volume needed for a family having various combination of monthly water demand varied from (2 to 22 m^3/month) and roof area varied from 100 m^2 to 300 m^2. The analysis was based on according to the average annual rainfall of historical data for 8 months (from Oct to May), a mass curve analysis was done for historic rainfall record to determine the smallest/ optimum volume of storage tank, according to the maximum deficit between supply (rainfall) and demand (family consumption) between Oct to May. The results of this analysis were shown in charts for all 22 stations covered in this study and also using contour maps that show the deigned tank volumes at northern Jordan. The results showed that the volume of the water tank can be greatly reduced as compared to simple volume calculation based on the average rainfall depth and rooftop area. For a family living in Irbid in a house with roof area of 250 m^2 and monthly consumption of 12 m^3 then the designed tank volume is equal to 43.7 m^3 compared to 82.2 m^3 if only average rainfall and roof area is taken into account. The results greatly reduce the cost of the tank construction by decreasing the size of the collection tank as possible as it can be, and therefore encourage Jordanian to build water tanks to collect rainwater.

Chapter six: Recommendations

1. This study should be completed to include the whole Jordan.
2. The samples of rainwater should include the storage tank and the rooftop of the house to involve the study of rainwater quality of all elements of RWH system.
3. Treatment methods could be used, like as sand filtration and should be tested on RWH system.
4. Research new materials to be used in building the storage tank to get the minimum cost of RWHS, due to the storage tank is the most expensive element of the system.

References:

AbdelKhaleq R.A. and Alhaj Ahmed I., 2007. Rainwater harvesting in ancient civilizations in Jordan, Water Science and Technology: Water Supply, Vol 7, No 1 pp 85-93

Abdulla F.A., A.W. Al-Shareef, 2009. Roof rainwater harvesting systems for household water supple in Jordan, Desalination 243, 195-207

Abu-Zreig M., Hazaymeh A. and Shatanawi M., 2013. Evaluation of residential rainfall harvesting systems in Jordan, Urban Water Journal, vol. 10, no. 2, 105-111

Al-Ansari N., Al-Hanbaly M. and Knutsson S., 2013. Hydrology of the most Ancient Water Harvesting Schemes, Journal of Earth Sciences and Geotechnical Engineering, vol. 3, no. 1, 15-25

Al-Mashagbah A. and Al-Farajat M., 2013. Assessment of spatial and Temporal Variability of Rainfall Data Using Kriging, Man Kendall Test and the Sen's Slope Estimates in Jordan from 1980 to 2007, Research Journal of Environmental and Earth Science 5(10): 611-618

Appan A., 1999. A dual-mode system for harnessing roofwater for non-potable uses, Urban Water 1, 317-321

Chilton J.C., Maidment G.G., Marriott D., Francis A., Tobias G., 1999. Case study of a rainwater recovery system in a commercial building with a large roof, Urban Water 1, 345-354

DOS (Department of statistics), 2015. The main results of population and housing Census report

DOS (Department of statistics), 2015. The Population of the Kingdom by Administrative Divisions, According to the General Census of Population and Housing result

Evans C.A., Coombes P.J. and Dunstan R.H., 2006. Wind, rain and bacteria: The effect of weather on the microbial composition of roof-harvested rainwater, Water Research 40, 37-44

Ghanem A.A., 2011. Trends in Mean Seasonal and Annual Rainfall Amounts over Jordan, Dirasat, Human Social Science. Volume 38, No. 3

GIM (Greater Irbid Municipality Website), accessed at 31/10/2016:

http://www.irbid.gov.jo/portal/Irbid_history.aspx

Hamdi M.R., Abu-Allaban M., Al-Shayeb A., Jaber M. and Momani N., 2009. Climate Change in Jordan: A Comprehensive Examination Approach, American Journal of Environmental Sciences 5(1), 58-68

Hatibu N. and Mahoo H., 1999. Rainwater harvesting technologies for agricultural production: A case for Dodoma, Tanzania

Helmreich B. and Horn H., 2010. Opportunities in rainwater harvesting, desalination 251, 118-124

Hills S., Birks R. and McKenzie B., 2002. The Millennium Dome "Watercycle" experiment: to evaluate water efficiency and customer perception at a recycling scheme for 6 million visitors, Water Science and Technology, Vol. 46, No. 6–7, pp 233–240

Jaber J. O. and Mohsen M. S., 2001. Evaluation of non-conventional water resources supply in Jordan, desalination 136, 83-92

JS (Jordan Standards) of drinking water, 2008. Fifth edition

Liaw C. and Tsai Y., 2004. Optimum Storage Volume of Rooftop Rainwater Harvesting Systems for Domestic Use, Journal of the American water resources association, no. 03014

Longobardi A. and Vilani P., 2009. Trend analysis of annual and seasonal rainfall time series in the Mediterranean area, Int. J. Climatol., DOI: 10.1002/joc.2001

MWI (Ministry of Water and Irrigation),2014. The annual report of Jordan Authority-Jordan Valley Authority

MWI (Ministry of Water and Irrigation, 2013. Jordanian water sector report

Partal T. and Kahya E., 2006. Trend analysis in Turkish precipitation data, Hydrol. Process. 20, 2011-2026

Sazakli E., Alexopoulos A. and Leotsinidis M., 2007. Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece, Water research 41, 2039,2047

Thomas T., 1998. Domestic water supply using rainwater harvesting, Building Research and Information 26(2), 94-101

UNEP (United Nations Environment Programme), 2002. An Environmentally Sound Approach for Sustainable Urban Water Management: An Introductory Guide for Decision-Makers

Villarreal E. L. and Dixon A., 2005. Analysis of a rainwater collection system for domestic water supply in Ringdansen, Norrköping, Sweden, Building and Environment 40, 1174 -1184

Yaziz M. I., Gunting H., Sapari N. and Ghazali A.W., 1989. Variations in Rainwater Quality from Roof Catchments, Wat. Res., vol. 6, no. 6, pp. 761-765

Zaizen M., Urakawa T., Matsumoto Y. and Takai H., 1999. The collection of rainwater from dome stadiums in Japan, Urban Water 1, 355 – 359

Appendix A

Appendix A.1: The public questionnaire in English language

Public Questionnaire / Rooftop Rainwater Harvesting

This questionnaire is prepared to evaluate social acceptance, concerns and understanding for rooftop rainfall harvesting in Jordan. Please answer all question to the best of you knowledge:

1. Place of resident Village City

2. What is the area of your house in square meter?
(i) 100 m^2 (ii) 150 m^2 (iii) 200 m^2 (iv) 250 m^2 (v) 300 m^2 (vi) 350 m^2
(vii) none, please mention the area of your house …………… m^2

3. Are you aware of water resources problems in Jordan (i.e. shortages of water supply, ground water exploitation, low rainfall, etc..)
Yes No

4. Is there a water supply to your house from the water authority ? Yes No

5. What is the amount of water bell in one period (each 3 months) ?
(i) Less than 20 JD (ii) 20 -30 JD (iii) 30 to 40 JD
(iv) 40-50 JD (v) More than 50 JD

6. How many days do the municipal supply your house in a week ?
(i) once a week (ii) Twice a week (iii) 3 days in a week (iv) 4 days in a week (v) 5 days in a week (vi) 6 days in a week (vii) 7 days in a week

7. How many hours do the municipal supply your house within a day ?
(i) 5-7 hours (ii) 7-9 hours (iii) 9-11 hours (iv) 11-13 hours (v)more than 14 hours

8. How did you manage with water shortages crises?
(i) Bought water tanks
(ii) Gate an emergency supply from the water Authority in my area
(iii)Borrow some water from neighbors
(iv)Use stored rainwater in the house

9. Are you collecting rainwater?
Yes No

10. From where are you collecting rainwater?
(i). Rooftop (ii) In house courtyard (iii) Outside courtyard and streets

11. What is the size of your storage water tank?
(i) less than 20 m^3 (ii) 20-24 m^3 (iii) 25-29 m^3 (iv) 30-34 m^3 (v) 35-39 m^3
(vi)40-44 m^3 (vii) 45-49 m^3 (viii) 50-59 m^3 (ix) 60-64 m^3
(x) More than 65 m^3

12. How did you choose the volume of water tank?

(i) Scientifically, according to rainfall depth (ii) Randomly, according to free space or the cost of building

13. Type of rainfall storage tank

(i) Concrete (ii) Plastic or PVC (iii) Steel

14. Why do you have a rainwater harvesting system? (please select all that apply)

(i) There is no water supply from the authority to my house
(ii) To save money on water
(iii)The rain water is best
(iv)I prefer to use rainwater for my garden
(v) Other (please specify) …………………

15. What do you use the water for? (please select all that apply)

(i) Drinking
(ii) Washing the car
(iii)Flushing toilets
(iv)Irrigation of gardens and/or lawns
(v) Livestock watering
(vi) For all that mentioned above

16. Why do you use the water for this specific uses that you marked at question number (15) ?

(i) The water quality isn't good enough
(ii) The water quality is good enough for drinking
(iii) Other (please specify)……………….

17. Will your rooftop system be you're only source of water at your residence?

Yes No

18. If NO: What the other source will supply water for drinking to your residence? (mark all that apply):

(i) Collected rainwater
(ii) Tap water
(iii) Treated water from water distribution shops
(iv) Bottled water
(v) In house tap water treatment filter

19. Do you clean your roof top in :

(i) 1-2 times in a year (ii) 3-4 times in a year (iii) 5-6 times in a year
(iv) More than 6 times in a year (v) Once in two years (vi) I don't clean it

20. Do you clean your storage tank in :

(i) Once a year (ii) Once in two years (iii) Once in 3 year
(iv) Once in 4 years and more than 4 years (v) I don't clean it

21. Do you add any type of disinfectants in the tank?

Yes No

22. Do you intend to treat the water you collect in your rooftop system prior to use?

Yes No

23. If YES: What type of treatment do you intend to use (mark all that apply):

(i)Filtration (ii) Chemical treatment (iii) Ultraviolet (UV) treatment

24. To those who are not using rooftop rainfall harvesting system; Why?

a) Lack of awareness about the importance and effectiveness of rooftop rainwater harvesting system
b) Not enough area for storage
c) Don't believe that I will save any money
d) I live in a property belonging to someone else who won't install one
e) I don't know how to install one
f) Too expensive to install
g) I don't believe that the products are reliable enough
h) The water quality isn't good enough
i) I don't believe that there are any benefits to the environment

25. If you have given an assistant, such as financial assistant, will you build a rooftop rainfall harvesting system?

Yes No

26. What kind of assistant you will need?

(i) Technical assistant
(ii) Financial assistant
(iii) Any other type of assistant

27. Can you answer with Yes or No on the following questions , please ?

a) Saving water bill : Yes No
b) Better water quality for drinking : Yes No
c) Meet the house emergency demand for water : Yes No
d) High construction cost : Yes No
e) Low rainfall collection efficiency due to high rainfall variability : Yes No

Appendix A.2: The public questionnaire in Arabic language

استبيان عام / حصاد مياه الأمطار عن أسطح المنازل

تم إعداد الاستبيان لتقييم التقبل الاجتماعي, المخاوف والتفهم لحصاد مياه الأمطار عن أسطح المنازل في الأردن.
الرجاء الإجابة عن الأسئلة التالية :
ملاحظة : سوف تستخدم إجاباتك في أغراض علمية فقط .

1. مكان الإقامة : (أ) قرية (ب) مدينة

2. ما هي مساحة منزلك في المتر المربع؟
(أ) 100م^2 (ب) 150 م^2 (ج) 200 م^2 (د) 250 م^2 (هـ) 300 م^2 (و) 350 م^2 (ز)غير ذلك, الرجاء ذكر مساحة منزلك .... م^2

3. هل أنت على علم بمشاكل الموارد المائية في الأردن (أي نقص في إمدادات المياه، واستغلال المياه الجوفية وقلة سقوط الأمطار، الخ...) ؟ نعم لا

4. هل يوجد خط مياه من السلطة يزود منزلك ؟ نعم لا

5. ما هو مقدار فاتورة المياه في الدورة الواحدة (كل 3 أشهر) ؟
(أ) أقل من 20 د.أ (ب) 30-20 د.أ (ج) 40-30 د.أ (د) 50-40 د.أ (هـ) أكثر من 50د.أ

6. كم عدد الأيام التي يتم بها تزويد منزلك بالمياه في الأسبوع؟
(أ) يوم واحد في الأسبوع (ب) يومان في الأسبوع (ج) 3 أيام في الأسبوع (هـ) 4 أيام في الأسبوع
(و) 5 أيام في الأسبوع (ز) 6 أيام في الأسبوع (ح) 7 أيام في الأسبوع

7. عدد ساعات تزويد المياه لمنزلك خلال اليوم الواحد :
(أ)7-5 ساعات (ب) 7 -9 ساعات (ج) 11-9 ساعات (د) 11 -13 ساعة (هـ) أكثر من 14 ساعة في اليوم

8. كيف تمت تغطية النقص بالمياه , إن وجد ؟
(أ) اشترى خزانات المياه (تنك مياه)
(ب) خزانات إمدادات عاجلة من سلطة المياه في منطقتي
(ج) استعارة بعض المياه من الجيران
(د) استخدام مياه الأمطار من خزان التجميع في منزلي

9. هل يتم تجميع مياه الأمطار في منزلك؟ نعم لا

10. من أين تجمع مياه الأمطار؟
(أ) السطح (ب) في فناء المنزل (ج) الفناء الخارجي والشوارع

11. ما هو حجم خزان مياه التخزين الخاصة بك؟
(أ) أقل من 20 م^3 (ب) 20 -24 م^3 (ج) 25-29 م^3 (د) 30-34 م^3 (هـ) 35-39 م^3 (و) 40-44 م^3
(ز) 45-49 م^3 (ح) 50-54 م^3 (ط) 55-59 م^3 (ي)60-64 م^3 (ك)أكبر من 65 م^3

12. كيف اخترت حجم خزان الماء الخاص بمنزلك ؟
(أ) علمياً, حسب نسب هطول الأمطار في منطقتك
(ب) عشوائياً, حسب المساحة المتوفرة لبناء الخزان أو حسب التكلفة المادية

الماء : 13. نوع خزان
(أ) الخرسانة (الاسمنت) (ب) البلاستيك أو PVC (ج) معدن صلب

14. لماذا لديك نظام تجمع مياه الأمطار؟ (يرجى تحديد كل ما ينطبق):
(أ) لا يوجد إمدادات للمياه من السلطة إلى منزلي (ب) لتوفير المال (ج) مياه الأمطار أفضل وأنقى
(د) أنا أفضل أن استخدام مياه الأمطار لحديقتي (هـ) أسباب أخرى

15. بماذا تستخدم المياه المجمعة من الأمطار؟ (يرجى تحديد كل ما ينطبق):
(أ) للشرب (ب) غسل السيارات (ج) تدفق مياه المراحيض
(د) ريّ الحديقة (هـ) سقي الثروة الحيوانية (ز) لجميع ما ذكر

16. لماذا تستخدم المياه المجمعة من الأمطار لهذه الاستخدامات التي حددتها في السؤال رقم (15) ؟
(أ) نوعية المياه ليست جيدة بما فيه الكفاية (ب) نوعية المياه جيدة بما يكفي للشرب
(ج) أسباب أخرى (يرجى التحديد) ....

17. هل سيكون نظام تجميع الأمطار على السطح الخاص بك المصدر الوحيد لتزويد منزلك بالمياه في مكان سكنك؟
نعم لا

18. إذا كانت إجابتك لا في السؤال رقم (17), ما هو المصدر الآخر من شأنه توفير المياه للشرب إلى مكان سكنك؟ (يرجى وضع علامة على كل الخيارات المناسبة لك) :
(أ) مياه الأمطار المجمعة (ب) مياه الصنبور (مياه الحنفية)
(ج) المياه المعالجة من محلات توزيع المياه (د) المياه المعبأة في زجاجات تباع في الأسواق
(هـ) في المنزل فلتر مياه لمعالجة المياه من الصنبور (الحنفية)

19. عدد المرات التي تقوم بتنظيف السطح الخاص بك :
(أ) 1-2 مرة السنة (ب) 4-3 مرات في السنة (ج) 6-5 مرات في السنة (د) أكثر من 6 مرات في السنة
(هـ) مرة واحدة في السنتين (و) لا أنظفه

20. عدد المرات التي تقوم بتنظيف خزان تجميع مياه الأمطار :
(أ) مرة واحدة في السنة (ب) مرة واحدة في غضون عامين (ج) مرة واحدة في 3 سنوات
(د) مرة واحدة في 4 سنوات وأكثر من 4 سنوات (هـ) لا أنظفه

21. هل تضيف أي نوع من المعقمات في الخزان؟ نعم لا

22. هل تنوي معالجة المياه التي تجمعها من سطح المنزل الخاص بك قبل الاستخدام؟ نعم لا

23. إذا كان جوابك نعم في السؤال (22), ما هو نوع المعالجة/التعقيم الذي تنوي استخدامه؟
(أ) الترشيح / الفلترة
(ب) العلاج الكيميائي
الأشعة فوق البنفسجية (ج)

24. لأولئك الذين لا يستخدمون نظام تجميع مياه الأمطار عن أسطح المنازل, لماذا ؟ يمكنك تحديد كل ما ينطبق :
(أ) قلة الوعي حول أهمية وفعالية نظام التجميع لمياه الأمطار
(ب) ليس هنالك مساحة كافية للتخزين
(ج) لا أعتقد أنني سوف أوفر أية أموال
(د) أنا أعيش في ممتلكات شخص آخر لم ينشيء واحد من قبل
(هـ) أنا لا أعرف كيفية إنشاء خزان
(و) عملية إنشاء خزان مكلفة للغاية
(ز) لا أعتقد أن تخزين مياه الأمطار موضوع مفيد بما فيه الكفاية
(ح) نوعية المياه ليست جيدة بما فيه الكفاية
(ط) لا أعتقد أن هناك أية فوائد تعود على البيئة

25. إذا كنت قد أعطيت مساعدة، مثل مساعدة مالية أو تقنية، هل سوف تبني نظام تجميع مياه الأمطار؟
نعم لا

26. ما هو نوع من المساعدة التي تحتاجها؟
(أ) مساعدة تقنية
(ب) مساعدة مالية
(ج) أي نوع آخر من المساعدة

27. هل يمكن أن تجيب بنعم أو لا على الأسئلة التالية بالنسبة لنظام تجميع مياه الأمطار عن أسطح المنازل ، من فضلك؟
(أ) توفير أكثر على فاتورة المياه: نعم لا
(ب) نوعية مياه الأمطار المجمعة أفضل لمياه الشرب: نعم لا
(ج) تلبية النقص المفاجئ للمياه في المنزل: نعم لا
(هـ) ارتفاع تكلفة البناء لخزان تجميع مياه الأمطار : نعم لا
(و) قلة فعالية التجميع بسبب التغير الكبير في نسبة هطول الأمطار : نعم لا

Appendix B

Appendix B.1: Table of Rainfall storms happened (mm) among the water year of 2015/2016 of the studied stations.

	Station										
Date of water year 2015/2016	**Al-Taiyibah**	**Deir Abi Said**	**Kufr Awan**	**Hartha**	**Kufr Saum**	**Um Qeis**	**Kharja**	**Hawwarah**	**Husn**	**Ennuiyime**	**Ramtha Boys School**
OCT 6											
OCT 7	4.8	3.9	18	11	15	0.2	9.8	1.6	2.2	3	0.4
OCT 8										7	
OCT 25	23.3	10.5	10	34	30	18.5	19	5.8	7	0	5.2
OCT 26	19.3	5.2	0.2	3	3.8	2.6	3.2	1	0	0	
OCT 27	0.3	0.5	0	0	0	4.2	0	2.1	0	3	
OCT 28											
OCT 29											
OCT 31	12	9.9	8	7	6	2	6.5	2.6	2	8	
NOV 2	0	0	0	0	0	3	8	0.4	7	3	1
NOV 3	2.6	2.6	1.6	2	1.2	8.4	2	1.8	3.6	3.8	0.7
NOV 4	0	0	0	0	0	0	0	0	0	0	0
NOV 5	0	0	0	0	0	0	0	1	0	0	
NOV 6	1.8	2.7	6	10.3	0.4	0.8	18	3.8	4.4	1	20.1
NOV 7	1	0.2	3	0	0	0	2.5	0.6	0.8	0	
NOV 8	3	0.2	0	1.5	1	0	7	4.2	0	2	9
NOV 9	2.7	6.5	5.5	1.7	1.4	3.4	1.3	0	3.8	1.8	0.2
NOV 15	0	0	0	0	0	0	0	0.4	0	0	
NOV 16	1	8	3.5	2	1.5	0	2	0.4	1.4	0.5	1.5
NOV 17	1	8.5	7.2	1	0	0	3	0	0.8	3.6	1.5
NOV 29	0	0	0	0	0	0	0	8.4	0	0	
NOV 30	5.6	18	6	1.5	3.7	5.6	10.6	0	5	0.2	6.8
DEC 1	0.3	0	0.3	0	0	2.8	0	0.4	0.2	1	
DEC 2	1.2	1	1.4	2	1.5	2	1.3	0	0.2	0	

DEC 3	0	0	0	0	0	0	0.1	0	0	0	
DEC 4											
DEC 5	0	0	0	0	0	0.2	0	0	0.1	0	0.1
DEC 19	1.5	1.3	1.7	2.2	2.6	2.2	1.2	2.8	4.8	0.1	1.3
DEC 29	0	0	0	0	0	0	0	0.2	0.2	0.7	0.7
DEC 30	6.1	7	3.5	1.2	1	3.6	2.1	4.8	3.2	27.3	2.5
DEC 31											
JAN 1	52	37	48.6	47	42	46.8	48.3	41.6	87.4	19.1	38.1
JAN 2	3.5	2.4	2.8	2	0.8	4.8	1.8	26.6	1.8	1.4	0.8
JAN 3	0	0	1.8	0.5	0.4	0.6	0.6	4.4	3.4	17.4	0.9
JAN 7	0	0	0	0	0	0	0	21.8	0	0	
JAN 8	82.3	68.4	33.8	98	97	91.6	76.6	46.8	71.6	20.8	43.8
JAN 9	0.5	0	0	0	0	1	0.1	2.6	1.8	0.1	0.4
JAN 10	0	0	0	0	0	0	0	0	0	0.1	
JAN 11	0	0	0	0	0	0	0	1.4	0	0.2	
JAN 18											
JAN 19	17.1	18	12.8	18.8	18.2	24.4	15.4	12	18.6	1.5	8.5
JAN 21											
JAN 22											
JAN 23	0	0	0	0	0	0	6.5	7.8	0	3.5	
JAN 24	5.7	14	9.5	7.5	7	2.2	18	22.8	9.4	20.8	3.7
JAN 25	15	13.6	12	22	21	13.6	0.4	3.4	26.2	0.8	11.5
JAN 26	0.4	0.2	0.2	0.4	0.2	0	2	0	1.4	3.8	0.2
JAN 27	0.6	2	1.8	1.6	1.4	0.4	0	0	5	0	1.2
FEB 1	0	0	40	0	0	0	0	0	0	0	
FEB 5											
FEB 6											
FEB 7	33	42	0	38	35	35	36	31.2	39	29.5	18.5
FEB 8	15.9	9	8	17	16.6	8	10.5	3.2	9.6	8.9	21
FEB 21	0	0	14	0	12	0	15.2	6.8	0	9.8	
FEB 22	15.6	16.5	17.6	16	18	12.6	14.3	10.8	12.6	16.5	8.6
FEB 23	28.2	17	0	17.5	0	17.8	0	0	17.8	0	3.2
MAR 13	0	0	1.3	0	0	0	1	3.6	0	0.6	0.3

MAR 14	1	2	0	1.2	0.2	0.6	0	0	0.6	0	
MAR 15	0	0	19.2	0	0	0	26.9	24.4	0	22.1	
MAR 16	17.8	25.5	10.7	24	27.2	26.8	14	9	26.8	6.5	9.7
MAR 17	7.6	6.5	0	7.2	6	15	0	0	15	0	6
MAR 20	0	0	0	0	0	0	0	0.4	0	0	
MAR 24											
MAR 26	0	0	2.9	0	2	0	0.2	8,2	0	0.4	
MAR 27	0.2	0.4	5.4	2.5	5.2	0.8	8.5	6.4	0.8	2	0.2
MAR 28	7.6	12	1	7	6	6.6	5.2	0	6.6	4.4	4.4
MAR 29	11.1	1	0	5.8	0	4	0	0	4	0	3
APR 10	0.6	0		0	0	0	0	0	0	0	
APR 12	2.9	3	3	12	11	17.8	10	3.8	17.8	4	6.8
APR 13	9	5	5	3.2	3	4.6	3	1	4.6	0.4	0.5
MAY 24	0	0	1	0	2.5	0.2	0	0	1.4	0	0.9

Appendix B.2: Table of Rainfall storms happened (mm) among the water year of 2015/2016 of the studied stations.

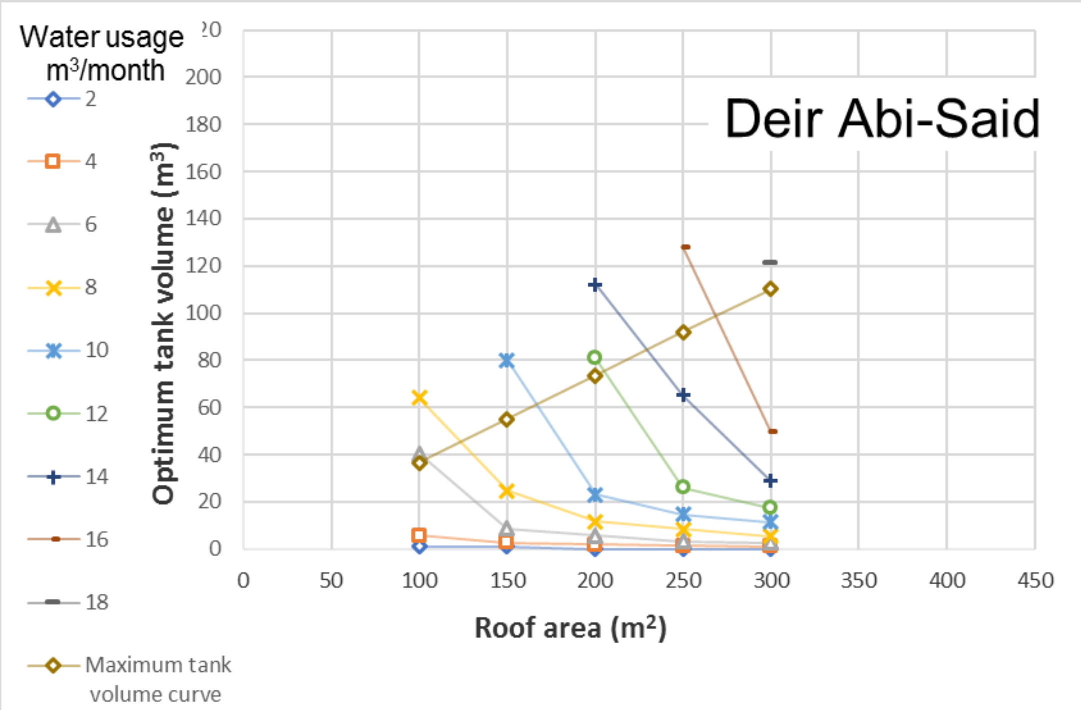
	Station										
Date of water year 2015/2016	**Ibbin**	**Turra**	**Baqura**	**Samar**	**Irbid School**	**Kafr Yuba**	**Kafr Asad**	**Rihaba**	**Kufranja Dam**	**Kufranja**	**Jarash**
OCT 6	4								6	10	2.5
OCT 7	0	0.9	9.4	9	1.8	3.2	3.5	4			
OCT 8											
OCT 25	7	3.5	20	27	5.2	10	36	6.5	10	8	4.5
OCT 26			1.8	4	0.2	9	10		1		4.5
OCT 27		2	0.6	2	9			5	6	9	1.5
OCT 28				3							
OCT 29				3							
OCT 31			5.4			8	6				
NOV 2	21	1			1			48	2	4	
NOV 3	8	1.8	2		1.8	2	4	3.3	3		
NOV 4	4										8.5
NOV 5	5	24			0.6			2.9	7.5	4	
NOV 6		0.9	3	14	1.4	1.2	6	1.9			
NOV 7		2			5.2			3.7			7.6
NOV 8	4	2.2	0.2	3	7.4	4	7	5.2	7	12	8
NOV 9	4.5		2.3	3		3	2		5	10	7
NOV 15		0.9									
NOV 16	2	1	0.7		8	1	2	3	5	3	0.5
NOV 17			0.7		2.4	0.5	2	3			2
NOV 29		2.5									
NOV 30	9		2.1	6	162	5	14	13	11	8	
DEC 1	1	4		6			0.4		2	2	8
DEC 2	4.5	0.4	0.3	4		0.8	0.2	1.3	9	9	3.3
DEC 3											

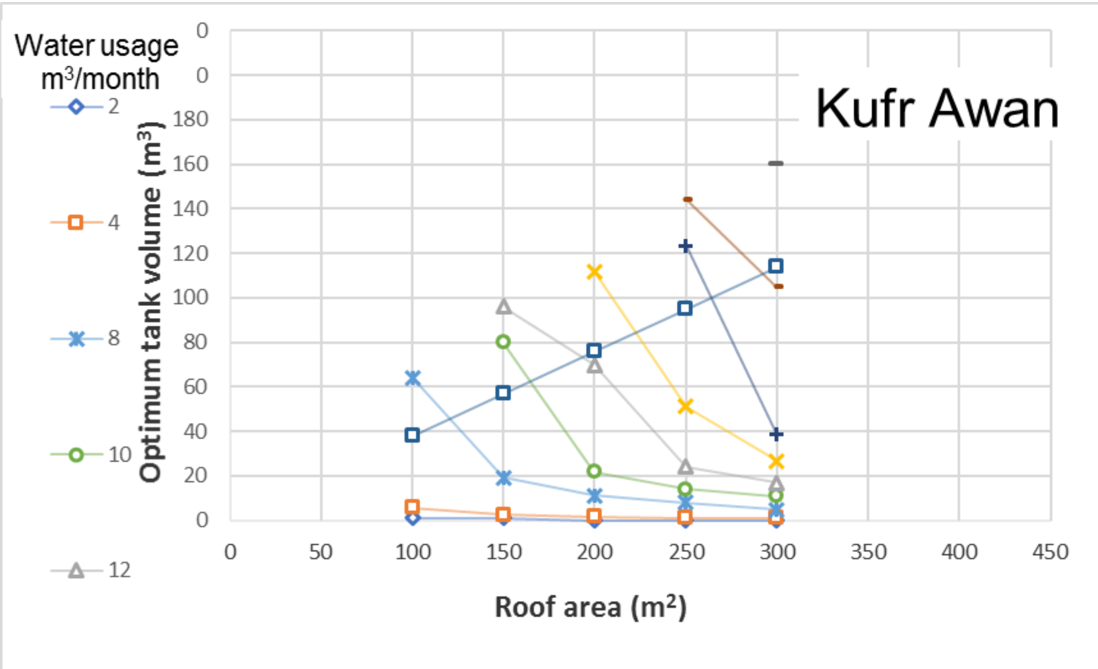
DEC 4							0.3				
DEC 5					0.4	0.2		0.2			
DEC 19		1	4.4	4		1.8	1.1	1.8			
DEC 29	1.3	2							1.4	2	3
DEC 30	4.5	11.1	2.8		6.8	4	5.4	1.5	10	5	3.6
DEC 31	72			25					12	85	
JAN 1		13.5	37.9	30	74.2	50	45.4	44.5			60
JAN 2		0.5	4.9	4	2.2	2	3.2	5			
JAN 3	5.5	0.7			4.6	1	1.1		6	5	4.1
JAN 7		38		35							
JAN 8		18.3	61	63		82	81.8	55			52.7
JAN 9	49				138.4	0.5	0.4		56	45	
JAN 10											
JAN 11		3.9									
JAN 18				3							
JAN 19	15.8	7.1	10.1	16	15	13.5	16	18	13.2	10	
JAN 21	7.5								25	12	
JAN 22											6.3
JAN 23		1.4		7		4.2		0.6			
JAN 24		4.4	1.8	20	5.6	16	5	22			26.4
JAN 25			8.4	4	30.2	0.4	15	1			0.5
JAN 26	13.5	1				1.4	0.4	4.5	34.6	38	4.3
JAN 27					4		1				
FEB 1											
FEB 5				35							
FEB 6	36			15					56	48	34
FEB 7	12.5	9.5	19.7		45	38	37	52	20	20	6
FEB 8		0.7	13.4		10	9	12	8			
FEB 21	26	1.3		8	11.2	14.8	14.8	26	46.2	41	26.5
FEB 22	17.5	0.7	11.9	20	23.8	17.5	37	22	36.6	50	12
FEB 23			10.6						5	10	
MAR 13	2.2	0.5				1	0.8	3.2	3.5	2.5	0.5
MAR 14	6.2				4.8				3		0.2

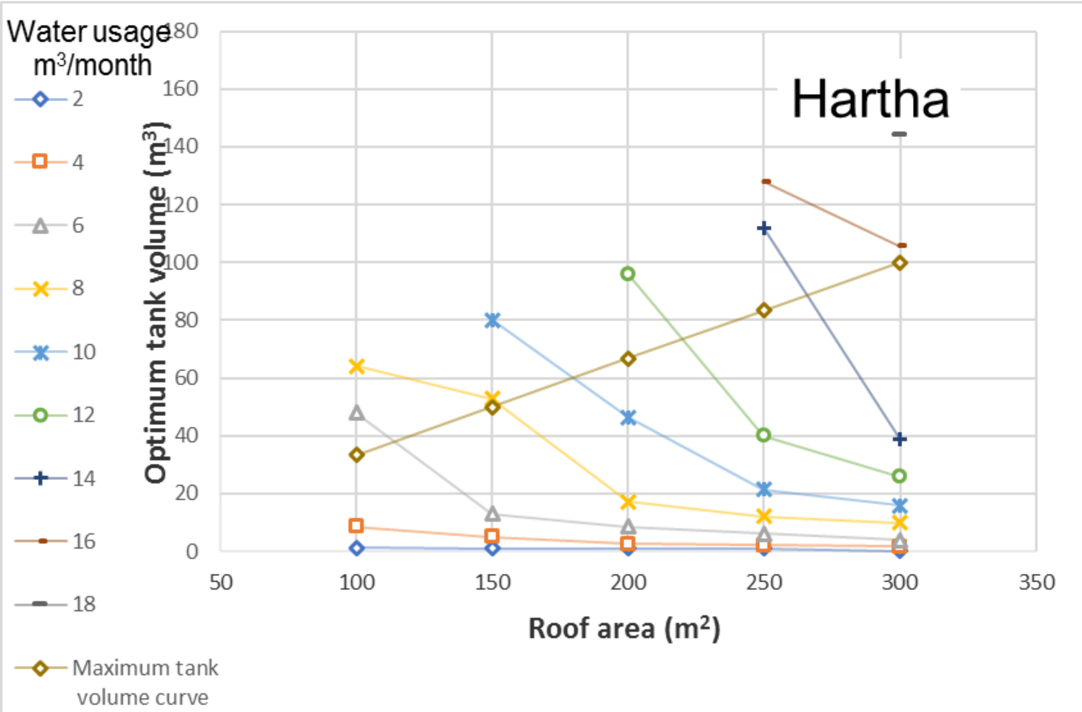
MAR 15	29.3	3.3		2.2		13	34.5	38.4	47	35	10.7
MAR 16	15	3.9	3.6	15	48.6	7	3.7	8.6	7,2	7	5.5
MAR 17			0.6		6.6						
MAR 20		0.2		3							
MAR 24	2								4	1	
MAR 26		2.1		3		0.4	1.8	0.3			
MAR 27	9.1	2.2	0.4	10		6.2	15	12	15	13	10.9
MAR 28	2.5	0.2	8.6		3.2	4	3	6.2	5	2	3.8
MAR 29			2.4								
APR 10	0.8							0.7	2.4	4	3
APR 12	18.8	7.6	8.7	14	4.4	3.8	12	5		22	20
APR 13	9.6	0.5	6.7		1.8	6	3	2.5	9	10	3.3
MAY 24									0.4		0.2

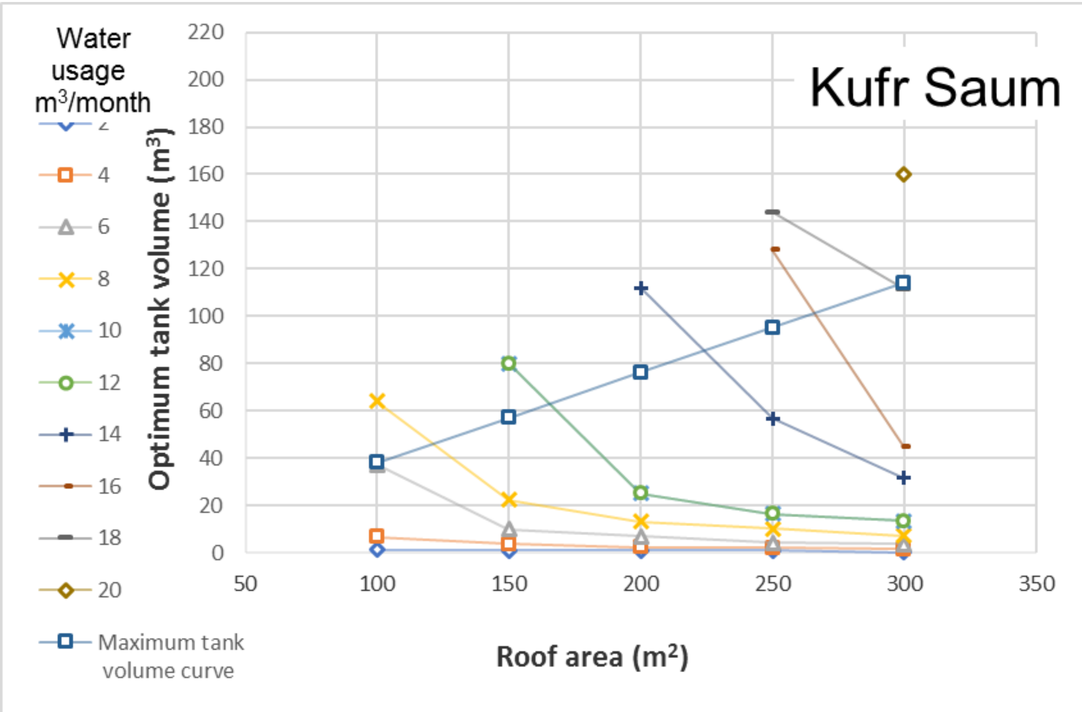
Appendix C

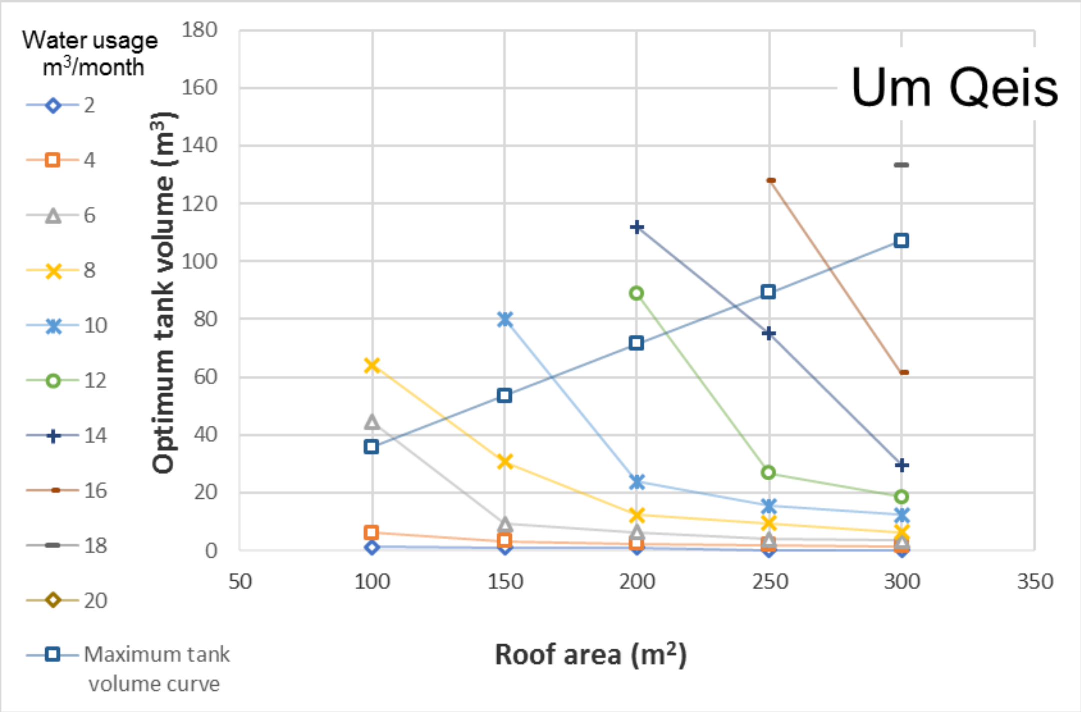
The plotted figures of the rest of metrological stations showing the maximum tank volume, and the optimum tank volume with respect to the roof area and water usage per month.

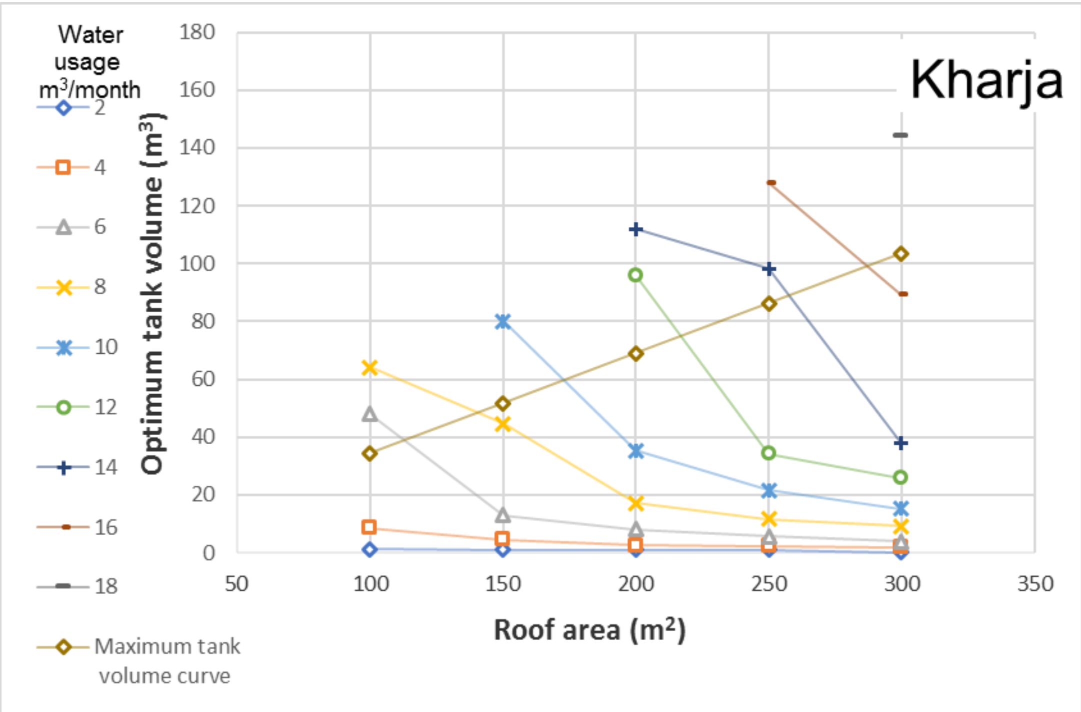


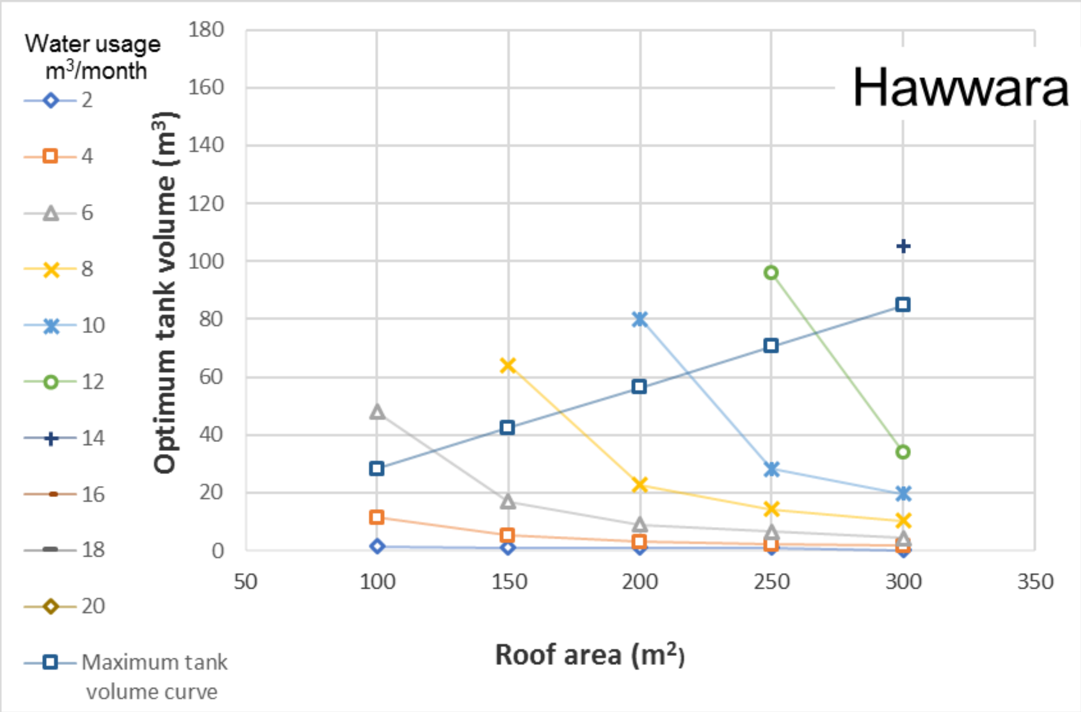


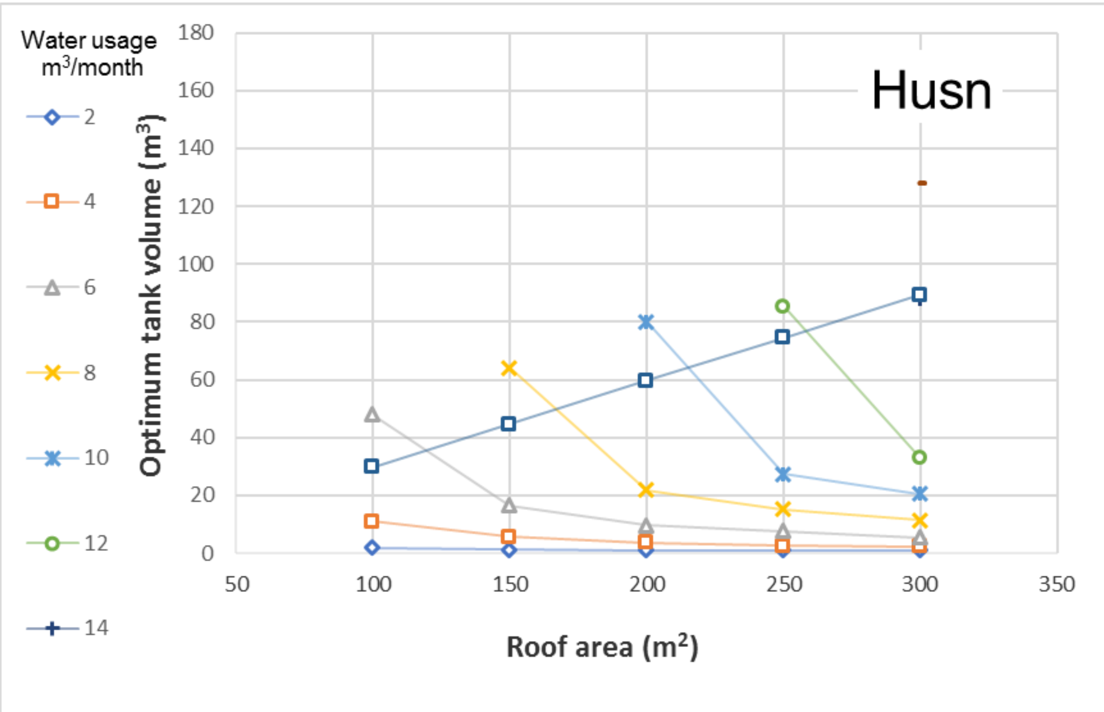

Hartha
Water usage m3/month
2
4
6
8
10
12
14
16
18
Maximum tank volume curve
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350

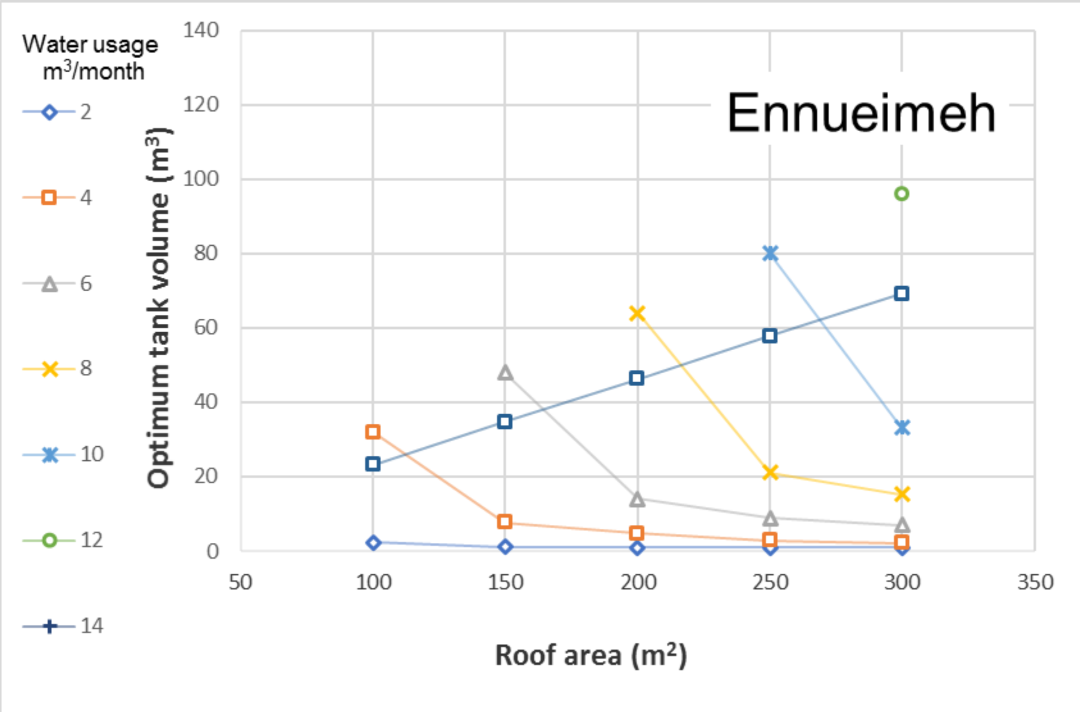

Kufr Saum
Water usage m3/month
4
6
8
10
12
14
16
18
20
Maximum tank volume curve
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
180
200
220
50
100
150
200
250
300
350


Um Qeis
Water usage m3/month
2
4
6
8
10
12
14
16
18
20
Maximum tank volume curve
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350

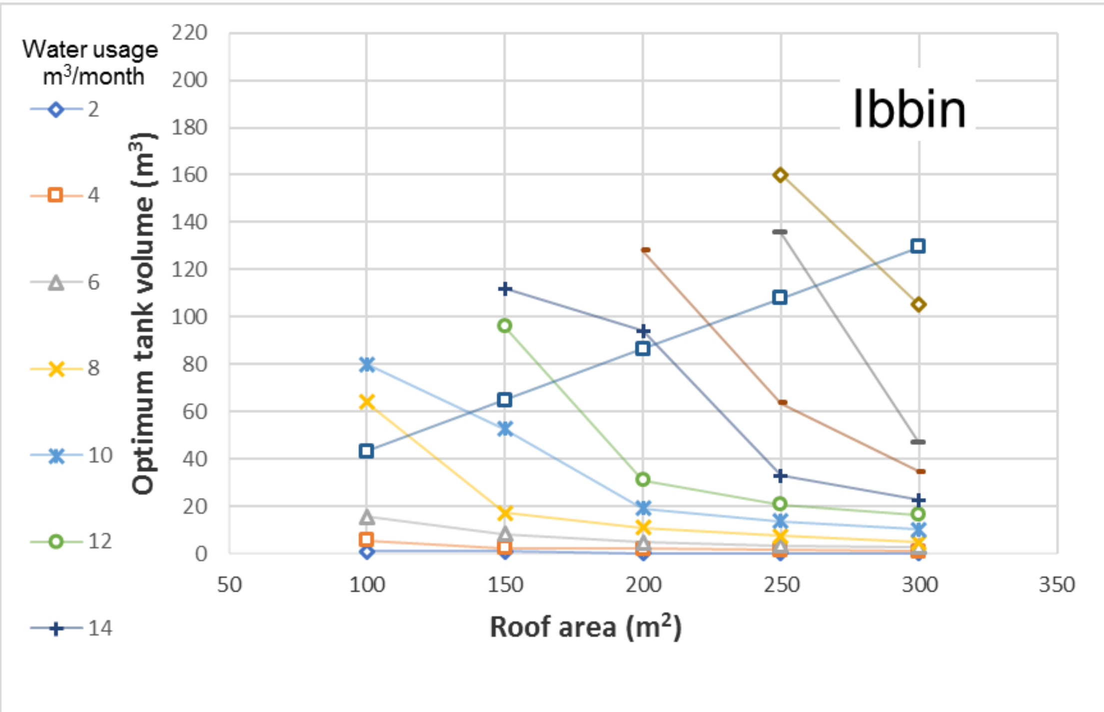

Kharja
Water usage m3/month
2
4
6
8
10
12
14
16
18
Maximum tank volume curve
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350


Hawwara
Water usage m3/month
2
4
6
8
10
12
14
16
18
20
Maximum tank volume curve
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350

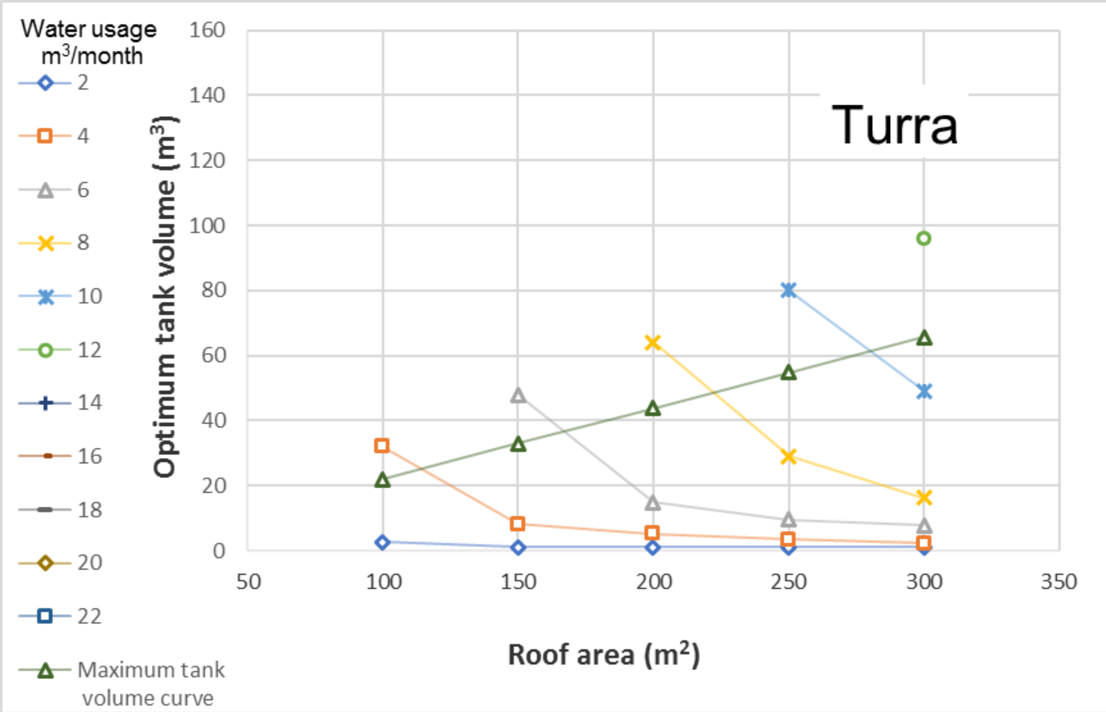

Husn
Water usage m3/month
2
4
6
8
10
12
14
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350



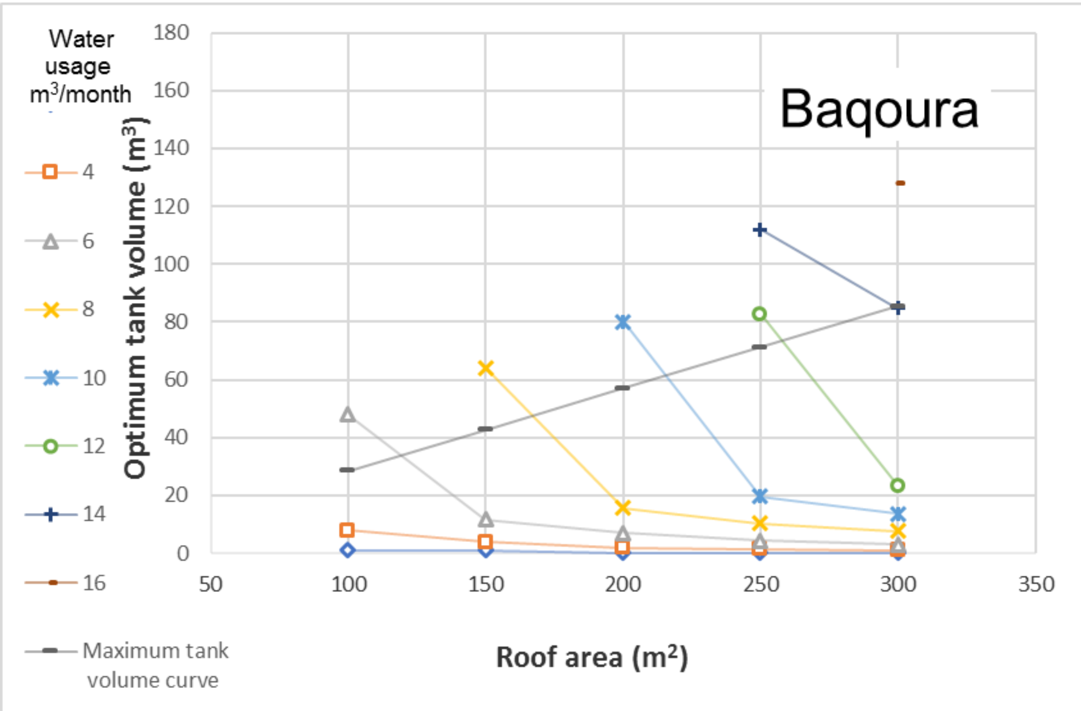
Water usage m3/month
2
4
6
8
10
12
14
Ennueimeh
Optimum tank volume (m3)
0
20
40
60
80
100
120
140
50
100
150
200
250
300
350
Roof area (m2)



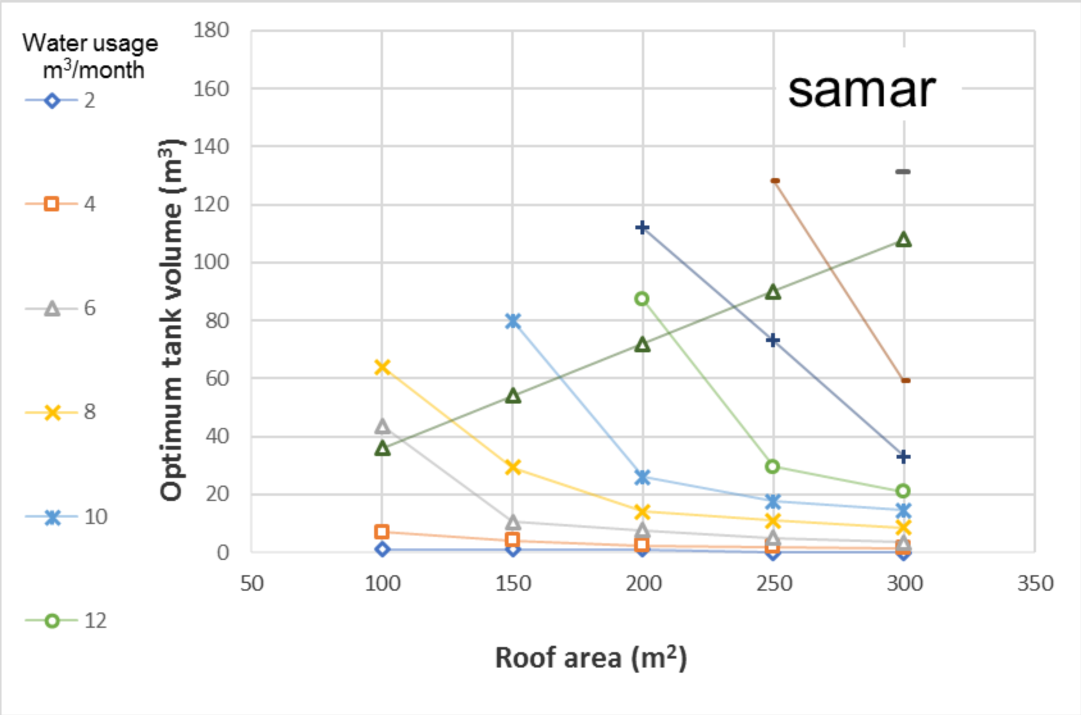
Water usage m3/month
2
4
6
8
10
12
14
Ibbin
Optimum tank volume (m3)
0
20
40
60
80
100
120
140
160
180
200
220
50
100
150
200
250
300
350
Roof area (m2)

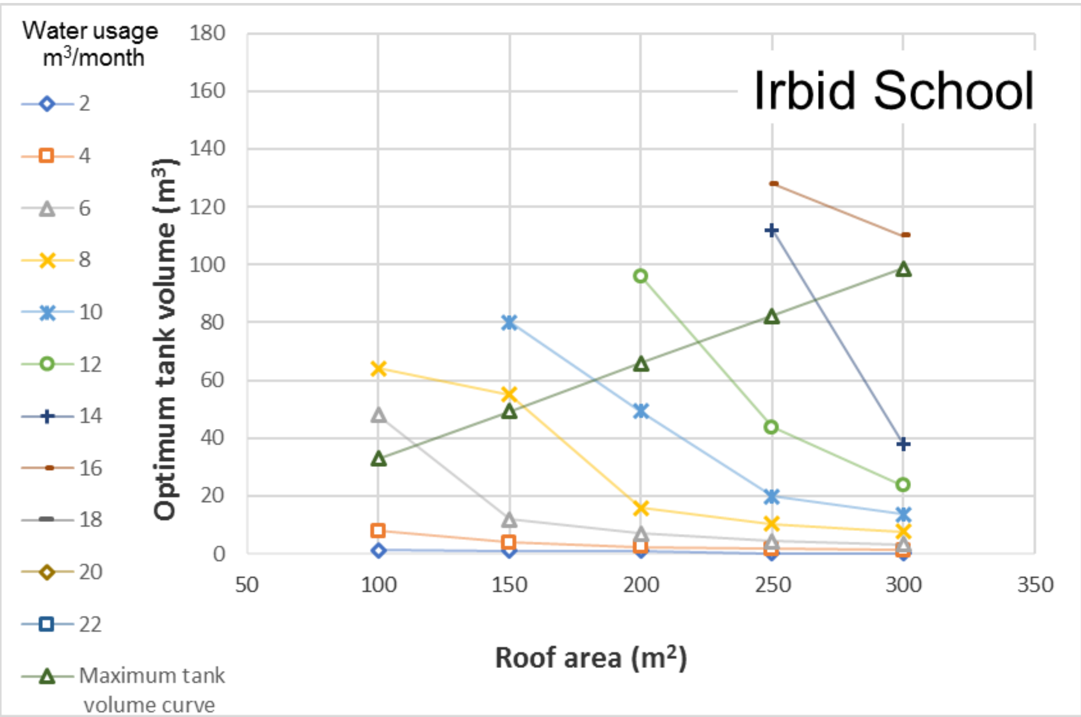


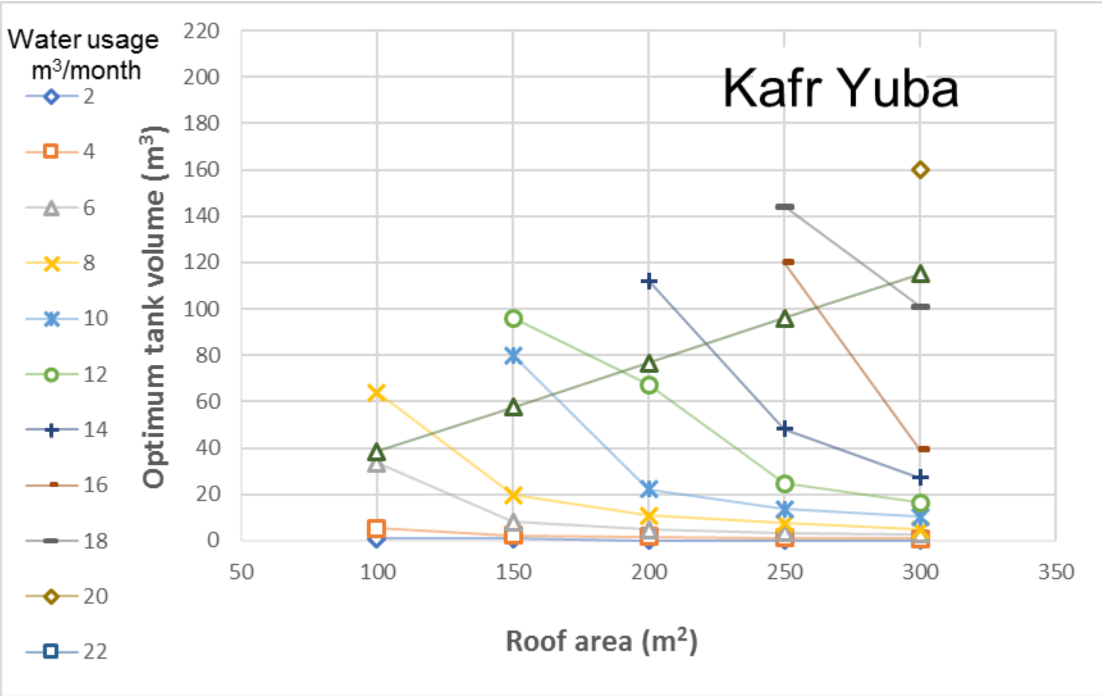
Water usage m3/month
2
4
6
8
10
12
14
16
18
20
22
Maximum tank volume curve
Turra
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
50
100
150
200
250
300
350

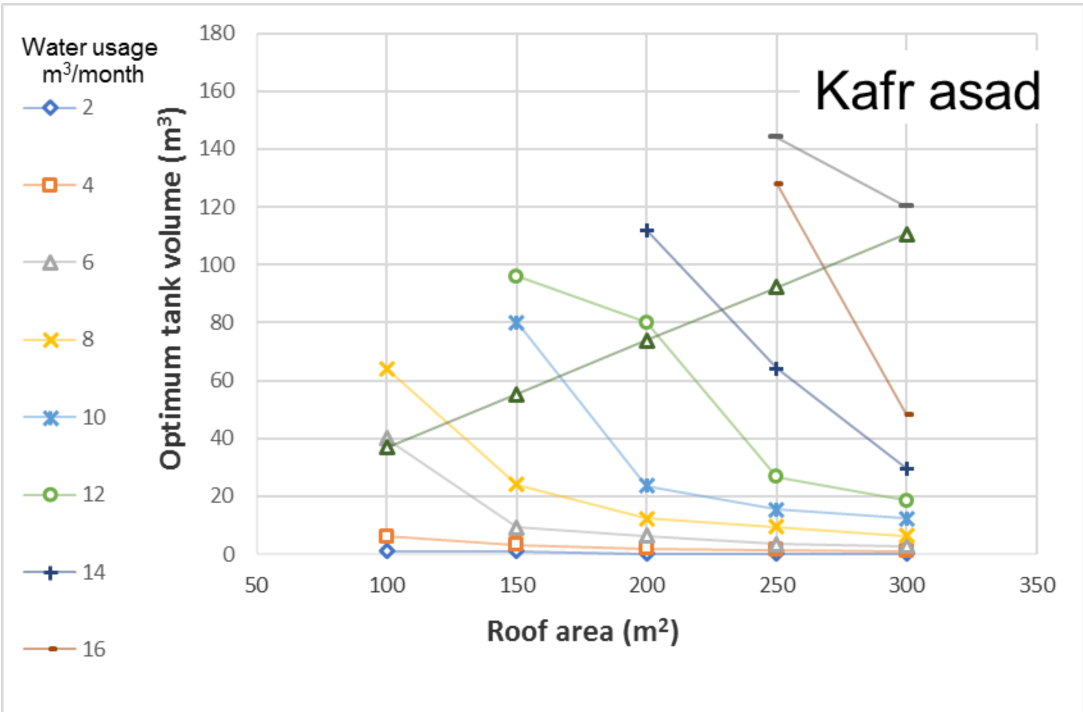


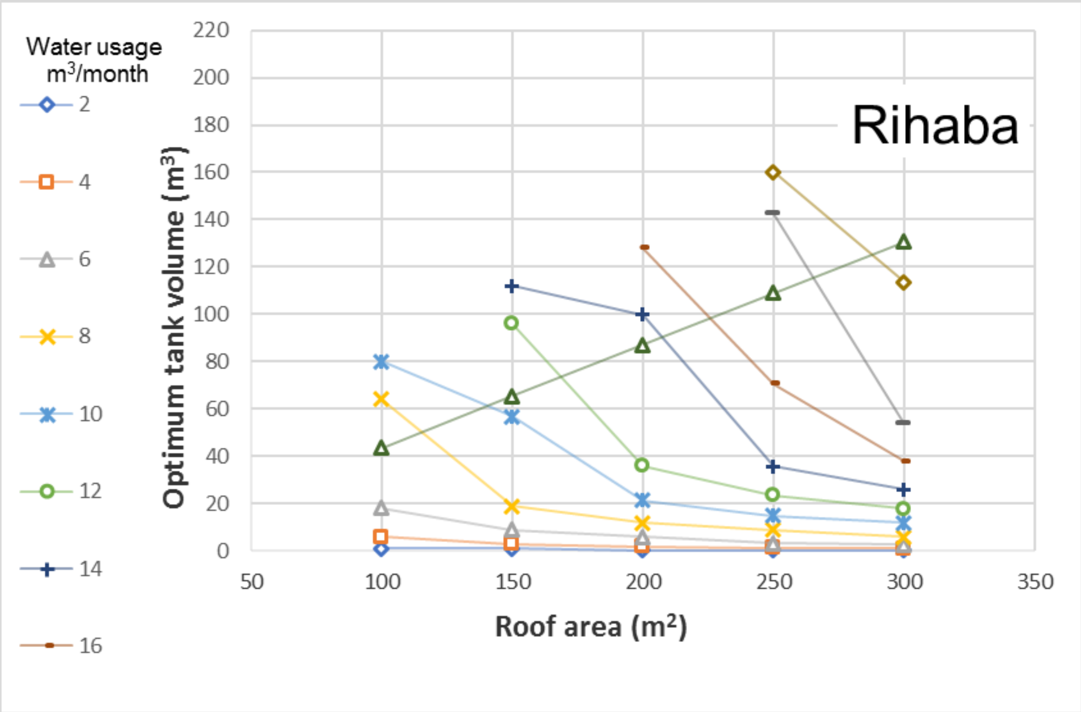
Water usage m3/month
4
6
8
10
12
14
16
Maximum tank volume curve
Baqoura
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350

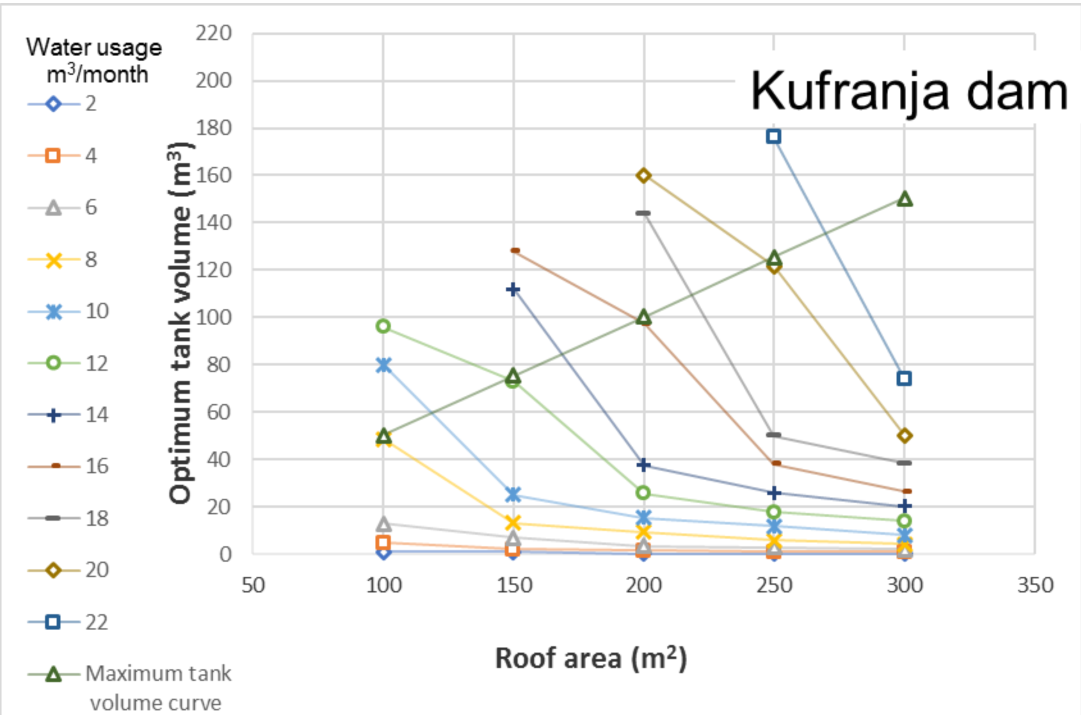

samar
Water usage m3/month
2
4
6
8
10
12
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350

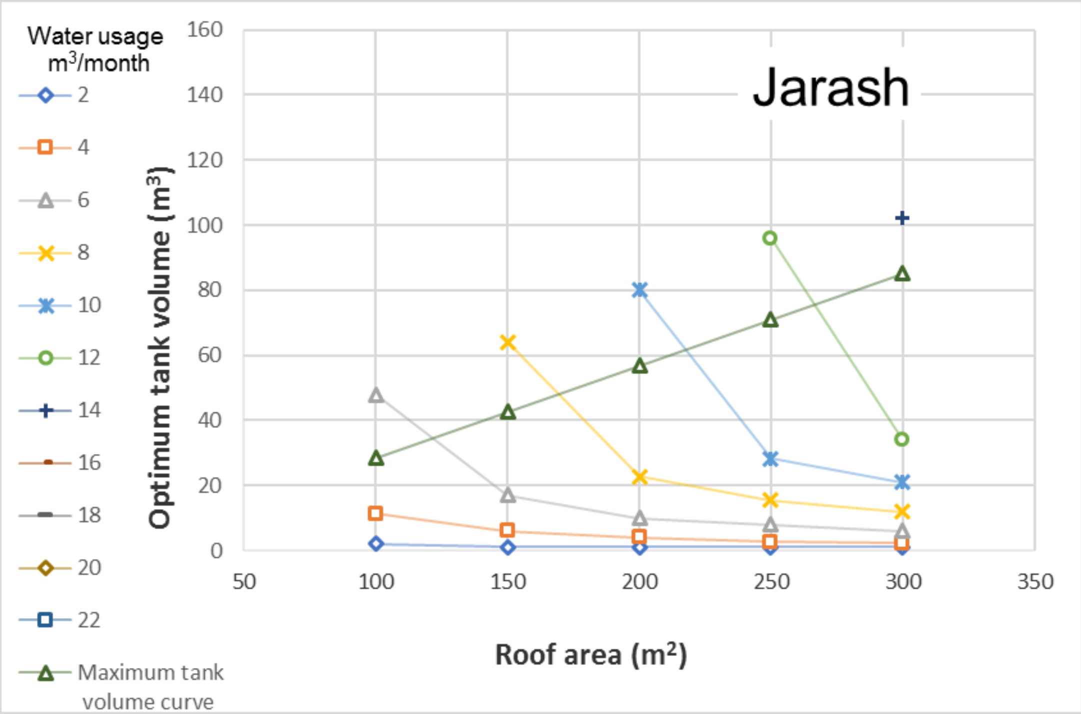

Irbid School
Water usage m3/month
2
4
6
8
10
12
14
16
18
20
22
Maximum tank volume curve
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350


Kafr Yuba
Water usage m3/month
2
4
6
8
10
12
14
16
18
20
22
Optimum tank volume (m3)
220
200
180
160
140
120
100
80
60
40
20
0
50
100
150
200
250
300
350
Roof area (m2)


Kafr asad
Water usage m3/month
2
4
6
8
10
12
14
16
Optimum tank volume (m3)
180
160
140
120
100
80
60
40
20
0
50
100
150
200
250
300
350
Roof area (m2)


Water usage m³/month
2
4
6
8
10
12
14
16
Rihaba
Optimum tank volume (m³)
Roof area (m²)
220
200
180
160
140
120
100
80
60
40
20
0
50
100
150
200
250
300
350


Water usage m³/month
2
4
6
8
10
12
14
16
18
20
22
Maximum tank volume curve
Kufranja dam
Optimum tank volume (m³)
Roof area (m²)
220
200
180
160
140
120
100
80
60
40
20
0
50
100
150
200
250
300
350


Jarash
Water usage m3/month
2
4
6
8
10
12
14
16
18
20
22
Maximum tank volume curve
Optimum tank volume (m3)
Roof area (m2)
0
20
40
60
80
100
120
140
160
50
100
150
200
250
300
350

Appendix D

The reliability tests of all the metrological stations, demand =12 m^3/month, rooftop area = 300m^2.

Station		Rooftop Area (m^2) 100 m^2	150 m^2	200 m^2	250 m^2	300 m^2
Al-Taibah	Maximum storage tank (m^3)	37.79	56.69	75.59	94.48	113.3
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	71.53	24.55	16.86
	Smallest volume (between supply-demand side) (m^3)	37.79	56.69	71.53	24.55	16.86
	Reliability of average historical years (%)	0.00	0.00	0.00	50.00	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	39.60
	Reliability of a wet year (%)	25.00	75.00	75.00	75.00	87.50
	Over flow of a wet year (m^3)	0.00	0.00	0.30	343.60	566.5
Deir Abi-Said	Maximum storage tank (m^3)	36.79	55.18	73.57	91.97	110.3
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	80.90	25.95	17.47
	Smallest volume (between supply-demand side) (m^3)	36.79	55.18	73.57	25.95	17.47
	Reliability of average historical years (%)	0.00	0.00	0.00	50.00	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	30.00
	Reliability of a wet year (%)	25.00	75.00	75.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	0.00	13.20	342.20	570.9
Kufr Awan	Maximum storage tank (m^3)	37.91	56.87	75.83	94.78	113.7
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	69.84	24.14	16.91
	Smallest volume (between supply-demand side) (m^3)	37.91	56.87	69.84	24.14	16.91
	Reliability of average historical years (%)	0.00	0.00	0.00	50.00	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	41.60
	Reliability of a wet year (%)	25.00	75.00	75.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	6.20	78.00	476.80	723.5
Hartha	Maximum storage tank (m^3)	33.35	50.02	66.70	83.37	100.0
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	39.88	25.75
	Smallest volume (between supply-demand side) (m^3)	33.35	50.02	66.70	39.88	25.75
	Reliability of average historical years (%)	0.00	0.00	0.00	25.00	62.50
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	0.00	50.00	75.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	0.00	0.00	143.10	337.2
Kufr Saum	Maximum storage tank (m^3)	38.04	57.05	76.07	95.09	114.1
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	74.26	28.31	19.58
	Smallest volume (between supply-demand side) (m^3)	38.04	57.05	74.26	28.31	19.58
	Reliability of average historical years (%)	0.00	0.00	0.00	50.00	62.50
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	32.20
	Reliability of a wet year (%)	25.00	62.50	75.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	0.00	6.10	309.80	517.5
Um Qeis	Maximum storage tank (m^3)	35.68	53.52	71.36	89.20	107.0
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	88.82	26.64	18.38
	Smallest volume (between supply-demand side) (m^3)	35.68	53.52	71.36	26.64	18.38
	Reliability of average historical years (%)	0.00	0.00	0.00	50.00	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	18.80
	Reliability of a wet year (%)	25.00	87.50	87.50	87.50	87.50
	Over flow of a wet year (m^3)	0.00	0.00	0.00	320.80	562.0
Kharja	Maximum storage tank (m^3)	34.53	51.80	69.07	86.33	103.6
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	34.27	25.81
	Smallest volume (between supply-demand side) (m^3)	34.53	51.80	69.07	34.27	25.81
	Reliability of average historical years (%)	0.00	0.00	0.00	37.50	62.50

	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	0.00	50.00	75.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	0.00	0.00	189.90	351.8
Hawwarah	Maximum storage tank (m^3)	28.21	42.31	56.41	70.51	84.62
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	96.00	33.93
	Smallest volume (between supply-demand side) (m^3)	28.21	42.31	56.41	70.51	33.93
	Reliability of average historical years (%)	0.00	0.00	0.00	0.00	0.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	0.00	37.50	50.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	0.00	0.00	0.00	196.6
Husn	Maximum storage tank (m^3)	29.79	44.68	59.58	74.47	89.36
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	85.40	32.79
	Smallest volume (between supply-demand side) (m^3)	29.79	44.68	59.58	74.47	32.79
	Reliability of average historical years (%)	0.00	0.00	0.00	0.00	37.50
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	0.00	62.50	87.50	87.50	87.50
	Over flow of a wet year (m^3)	0.00	0.00	0.00	0.00	274.7
Ennueimye	Maximum storage tank (m^3)	23.08	34.62	46.16	57.70	69.24
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	96.00	96.00
	Smallest volume (between supply-demand side) (m^3)	23.08	34.62	46.16	57.70	69.24
	Reliability of average historical years (%)	0.00	0.00	0.00	0.00	0.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	0.00	0.00	25.00	50.00	62.50
	Over flow of a wet year (m^3)	0.00	0.00	0.00	0.00	0.00
Ramtha Boys School	Maximum storage tank (m^3)	21.29	31.94	42.58	53.23	63.88
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	96.00	96.00
	Smallest volume (between supply-demand side) (m^3)	21.29	31.94	42.58	53.23	63.88
	Reliability of average historical years (%)	0.00	0.00	0.00	0.00	0.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	0.00	0.00	50.00	87.50	87.50
	Over flow of a wet year (m^3)	0.00	0.00	0.00	0.00	0.00
Ibbin	Maximum storage tank (m^3)	43.18	64.78	86.37	107.96	129.5
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	31.05	20.82	16.27
	Smallest volume (between supply-demand side) (m^3)	43.18	64.78	31.05	20.82	16.27
	Reliability of average historical years (%)	0.00	0.00	50.00	62.50	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	13.40	112.0
	Reliability of a wet year (%)	62.50	75.00	75.00	75.00	87.50
	Over flow of a wet year (m^3)	0.00	11.30	342.0	634.00	892.1
Turra	Maximum storage tank (m^3)	21.91	32.87	43.82	54.78	65.74
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	96.00	96.00
	Smallest volume (between supply-demand side) (m^3)	21.91	32.87	43.82	54.78	65.74
	Reliability of average historical years (%)	0.00	0.00	0.00	0.00	0.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	0.00	0.00	25.00	50.00	75.00
	Over flow of a wet year (m^3)	0.00	0.00	0.00	0.00	0.00
Baqura	Maximum storage tank (m^3)	28.47	42.70	56.94	71.17	85.41
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	82.62	23.45
	Smallest volume (between supply-demand side) (m^3)	28.47	42.70	56.94	71.17	23.45
	Reliability of average historical years (%)	0.00	0.00	0.00	0.00	50.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	50.00	75.00	75.00	75.00	87.50
	Over flow of a wet year (m^3)	0.00	0.86	64.30	170.00	635.5
Samar	Maximum storage tank (m^3)	36.01	54.02	72.03	90.03	108.0
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	87.27	29.53	21.03
	Smallest volume (between supply-demand side) (m^3)	36.01	54.02	72.03	29.53	21.03
	Reliability of average historical years (%)	0.00	0.00	0.00	50.00	62.50
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	16.80
	Reliability of a wet year (%)	12.50	75.00	75.00	75.00	87.50
	Over flow of a wet year (m^3)	0.00	0.00	4.40	302.50	527.8
Irbid scho	Maximum storage tank (m^3)	32.89	49.33	65.77	82.22	98.66
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	43.67	23.64
	Smallest volume (between supply-demand side) (m^3)	32.89	49.33	65.77	43.67	23.64

	Reliability of average historical years (%)	0.00	0.00	0.00	25.00	62.50
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	0.00	50.00	75.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	0.00	0.00	160.50	384.1
Kafr Yuba	Maximum storage tank (m^3)	38.41	57.61	76.81	96.02	115
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	67.26	24.76	16.30
	Smallest volume (between supply-demand side) (m^3)	38.41	57.61	67.26	24.76	16.30
	Reliability of average historical years (%)	0.00	0.00	0.00	62.50	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	49.00
	Reliability of a wet year (%)	0.00	50.00	75.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	0.00	2.20	263.20	467.8
Kafr Asad	Maximum storage tank (m^3)	36.88	55.32	73.76	92.20	110.6
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	80.05	26.58	18.39
	Smallest volume (between supply-demand side) (m^3)	36.88	55.32	73.76	26.58	18.39
	Reliability of average historical years (%)	0.00	0.00	0.00	50.00	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	28.58
	Reliability of a wet year (%)	25.00	75.00	75.00	75.00	87.50
	Over flow of a wet year (m^3)	0.00	4.00	55.00	442.10	690.9
Rihaba	Maximum storage tank (m^3)	43.56	65.33	87.11	108.89	130.6
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	35.79	23.46	17.75
	Smallest volume (between supply-demand side) (m^3)	43.56	65.33	35.79	23.46	17.75
	Reliability of average historical years (%)	0.00	0.00	37.50	62.50	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	7.00	99.30
	Reliability of a wet year (%)	50.00	75.00	75.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	0.0	291.6	581.30	839.5
Kufranja Dam	Maximum storage tank (m^3)	50.16	75.24	100.3	125.41	150.4
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	73.04	25.51	17.68	14.02
	Smallest volume (between supply-demand side) (m^3)	50.16	73.04	25.51	17.68	14.02
	Reliability of average historical years (%)	0.00	0.00	62.50	75.00	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	91.70	218.2
	Reliability of a wet year (%)	62.50	75.00	75.00	75.00	87.50
	Over flow of a wet year (m^3)	0.00	0.00	352.7	625.00	872.6
Kufranja	Maximum storage tank (m^3)	48.71	73.07	97.42	121.78	146.1
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	82.44	24.37	16.72	12.86
	Smallest volume (between supply-demand side) (m^3)	48.71	73.07	24.37	16.72	12.86
	Reliability of average historical years (%)	0.00	0.00	62.50	75.00	75.00
	Over flow of average historical years (m^3)	0.00	0.00	0.00	79.60	203.2
	Reliability of a wet year (%)	0.00	0.00	25.00	50.00	62.50
	Over flow of a wet year (m^3)	0.00	0.00	0.00	27.50	121.7
Jarash	Maximum storage tank (m^3)	28.39	42.59	56.78	70.98	85.17
	Optimum storage tank of monthly demand =12m^3 (m^3)	96.00	96.00	96.00	96.00	33.97
	Smallest volume (between supply-demand side) (m^3)	28.39	42.59	56.78	70.98	33.97
	Reliability of average historical years (%)	0.00	0.00	0.00	0.00	37.50
	Over flow of average historical years (m^3)	0.00	0.00	0.00	0.00	0.00
	Reliability of a wet year (%)	0.00	25.00	75.00	75.00	75.00
	Over flow of a wet year (m^3)	0.00	0.00	0.00	0.00	191.5

دليل لتصميم انظمة الحصاد المائي المنزلي في الأردن

إعداد: فرح محمد خليف عبابنه

المشرف: أ.د. ماجد ابوزريق

الملخص

يعتبر الأردن من أكثر البلدان الشحيحة في موارد المياه. ويعتبر تأمين الاحتياجات المائية من مصادر متعددة، مثل تجميع مياه الأمطار، هو أولوية قصوى للحكومة الأردنية، إن الهدف من هذا البحث هو دراسة إمكانية استخدام حصاد مياه الأمطار في شمال الأردن وحساب كمياته وتحديد الحجم الأمثل لخزان تجميع مياه الامطار في مناطق الدراسة، تم توزيع استبيان لمجموعة من السكان في محافظة اربد للتعرف على واقع المياه وعلى كمية المياه المزودة من السلطة للمنازل واستهلاكها، ومستوى الوعي والصعوبات التي يوجهها الناس في محاولاتهم لجمع مياه الأمطار من أسطح المنازل، أيضا، تم إجراء تحليل رياضي لمعرفة التغيّر في كمية هطول مياه الأمطار عبر السنوات في شمال الأردن من أجل فهم الإمكانية لجمع مياه الأمطار في المستقبل، تم عمل فحوصات مخبرية لمعرفة جودة مياه الأمطار التي جمعت على طول الموسم المطري 2015\2016 ومراقبة التغييرات الحاصلة على نوعية المياه على طول الموسم المطري بسبب بعض العوامل مثل العوامل الجوية والأنشطة البشرية، وتحديد مدى سلامة مياه الأمطار في استخدامها للأغراض المنزلية، وأخيرا، حيث أن تكلفة الخزان المستخدم لجمع مياه الأمطار عالية وهو السبب الرئيسي الذي يدفع الناس الى عدم بناء نظام تجميع مياه الأمطار من أسطح المنارل، فقد تم تطوير منهجية لتحديد أصغر خزان يلزم لمنزل معين في منطقة معينة.

لقد تم دراسة آراء الناس حول أهمية الحصاد المائي ومدى معرفتهم بعوامل التصميم والمشاكل المحيطه بالتزويد المائي، مائتان وخمسون استبيان التي تم تحليلها, فقد تبين أن 87٪ من الناس على معرفه بأن هنالك مشاكل موارد مائية في الأردن، فقط 54٪ من الناس يجمعون مياه الأمطار، 22٪ من الناس لا يعتقدون أن جودة مياه الأمطار هي جيدة بما فيه الكفاية، والسؤال الأهم انه من بين أولئك الذين يجمعون مياه الأمطار والتي تتعلق بحجم خزان التجميع؛ اختار 78٪ منهم حجم خزان التجميع عشوائيا، في حين أن 22٪ قد قالوا إنهم اختاروا حجم خزان التجميع وفقا لنسبة هطول الأمطار في المنطقة، ولكن لم يظهر أي أحد دليلا على استخدام طرق علمية لتحديد حجم خزان التجميع، أظهرت الفحوصات المخبرية لعينات مياه الأمطار لموسم 2015\2016 جودة مياه الأمطار, مثل المواد الصلبة الذائبة, فقد كان كمية المواد الصبة الذائبة تنخفض تدريجياً على طول الموسم المطري، ويلاحظ أن الهطول المطري الأول يملك أعلى القيم في فحص الجودة بسبب وجود الغبار في الجو من مصادر متعددة قبل بداية الموسم المطري, فقد كان في الهطول الأول 225.3 ملغم / لتر في حين كان المتوسط بعد الهطول الأول 61.1 ملغم / لتر، قد تم دراسة العلاقة بين السنوات المسجلة لهطول الأمطار عبر السنوات السابقة ل22 محطة قياس باستخدام الانحدار الخطي واختبار مان-كندال، وأظهرت النتائج أن 13 محطة ليس هنالك أية علاقة بين السنوات المسجلة لكميات هطول الأمطار، وأظهرت 9 محطات أخرى وجود علاقة في اتجاه تنازلي على الأقل في واحد من الاختبارين المستخدمين، و 5 من بين تلك المحطات كانت العلاقة في اتجاه تنازلي كبير كما تبين في الاختبارين المستخدمين.

وقد تم تطوير البرنامج الأمثل لتحديد أصغر خزان تجميع مياه الأمطار بناءاً على المعدل الشهري لهطول الأمطار عبر السنوات السابقة المسجلة، تم تحديد أقل حجم خزان لكل مساحة منزل، لكل محطة ولعدد من الافتراضات للاستخدام الشهري للمياه، تم حساب الخزان لكل حالة وتم رسم النتائج ضمن مستويات بيانية، ومن ثم تحويلها إلى خطوط كنتورية لشمال الأردن، على سبيل المثال، الحد الأدنى لحجم خزان في محطة الطيبة لعائلة استهلاكها الشهري من المياه 12 م3, ومساحة المنزل 300 م2، مع 75٪ امكانية تحقيقه هو 16.9 م3، مع العلم أن الحد الأقصى للمياه التي يمكن جمعها في هذا الموقع هو 113.4 م3، الخرائط الكنتورية لحجم خزان تجميع مياه الأمطار يمكن أن تستخدم كدليل لمعرفة حجم خزان التجميع استنادا إلى موقع المنزل، مساحة سطح المنزل، واستهلاك المياه الشهري.