COMMUNITY WATER HARVESTING SYSTEMS

APPLYING SIMPLE, LOW COST, AND SCIENTIFICALLY BASED WATER HARVESTING SYSTEMS

FINAL REPORT

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FINAL REPORT

USAID JORDAN ECONOMIC DEVELOPMENT PROGRAM

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DELOITTE CONSULTING LLP

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EXECUTIVE SUMMARY

Jordan is classified among countries with limited water resources and in fact is the lowest on a per capita basis. The available water resources per capita are falling as a result of population growth and are projected to decrease from less than 160 m^3 /cap/year at the present to about 90 m^3/cap/year by 2025, putting Jordan in the category of an absolute water shortage. The scarcity of water in Jordan is the single most important constraint to the country's growth and development because water is not only considered a factor for food production but also for economic development. As a result of this scarcity, the demand on Jordan's water resources has far outpaced its supply.. The deficit is made up by the unsustainable use of groundwater through overdrawing of highland aquifers, resulting in lowered water table in many basins and declining water quality in some. In addition, the deficit is overcome by rationing the supply of water to the agricultural sector.

Because of this shortage, a variety of water conservation measures should be pursued. Among these is "water harvesting", which allows for the capture and re-use of water from natural rainfall and man-made sources. The project outlined in this report highlights:

- The application of simple, low cost, and scientifically based water harvesting systems.
- The utilization of harvested water for agricultural production.

The project's selection criteria focused on two themes, which were the geographic-weather parameters and the socio-economic considerations for the target communities. The geographic-weather parameters included:

- The availability of good rainfall volumes, the areas with annual rainfall ranges between 250 mm and 350 mm will be selected. For areas with rainfall more than 350 mm per year, the need for storing water is relatively not essential. On the other hand, areas with annual rainfall less 250 mm has limited rainfall availability and the risk of building projects depends on rainfall harvesting is relatively high, Figures 1 and 2 show the regions that receives annual rainfall volumes between 250 mm and 350 mm for Mafraq and Karak governorates respectively.
- The availability of agriculture land is an important factor in selecting the project site. , The collected water will be used mainly for farming and in some cases for watering animals, so the availability of suitable land for farming or existing farms will affect the selection of project sites,

After the physical parameters were analyzed and suitable regions were defined, the next step in the selection process was working with target communities.

The regions that receive rainfall of more than 250 mm per year were identified within the Mafraq and Karak governorates, after which community organizations and NGOs were identified and consultation conducted with community leaders that could offer support for the project. After careful research, the team found that most of the NGOs have offices in rented building and therefore could not provide space for project implementation. Because of this, the implementatation team decided to initiate the project on public access land in order to create visibility and enhance community support. Ultimately, four sites were identified in Mafraq and two in Karak.

Once the sites were selected, the project team analyzed the best options for placement of a water storage tank, since it constitutes the major investment in a water harvesting system. After exploring several alternatives, the team decided on the placement of a cone cistern based on the geographical features of the project sites.

The per cubic meter cost of the four water harvesting systems varied between 33.5 JD and 38 JD. One of the systems, Mughair Girls School, cost an extra 10 JD for conveying the roof drains into the cistern, which was about 100 meters away. In general, the per unit volume (m^3) cost varied between 35 – 40 JD for the governmental tendering since contractors tended to increase the cost in order to compensate for the delay in receiving their payments.

The prices for cubic meter of water in rural areas varied between 3.5 and 4.0 JD using tankers. And in some dry seasons this price could increase to 5 JD. With these inputs, the water harvesting systems will cover their costs in 4 – 5 years taking into consideration that the system will be filled only two times during a season.

BACKGROUND

GENERAL

Jordan's acute lack of water has become a limiting factor in its economic growth. This being the case, the USAID Jordan Economic Development Program initiated a project in two Governorates to harvest rainwater at targeted locations. One of the project implementation team's collaborating partners was Al al-Bayy University. With its location in the western portion of Mafraq Governorate, the university recognized the importance of its role to promote better use of natural resources.. Since its founding early 1990's, the university established a Water and Environment Research Unit to focus on research and demonstration projects in arid areas.. In late 2008, the research unit was transformed into a specialized center called the "Arid Lands, Water and Environment Research Center (ALWERC)".

The ALWERC's research over the past several years confirms that the lack of water is putting a brake on agricultural development. The country's principle crops, wheat, barley, lentils, tomatoes, eggplants, citrus fruits, olives, and grapes, require consistent water sources, which required irrigation. For instance, in 2005, the total area cultivated to fruit trees was about 861 thousand dunums, from which 32% were irrigated. In the same year, field crops occupied 1,212,000 dunums, from which only 7% was irrigated. Since that time, irrigation of agriculture lands has risen to almost 95% due to lack of rainfall.

Because of increases in population growth, there is a need to incorporate arid and semi-arid land into the agriculture sector. In these areas, surface runoff accelerates soil erosion and depletes the productivity of soils and produces sediment, which is one of the major pollutants of the environment. Therefore, conservation measures to reduce the rate of soil and water losses at tolerable rate are necessary in order to conserve soil fertility, improve crop production, and to sustain productivity of this land for future generations.

Theoretically, proper watershed management and soil practices will reduce the rainfall impact on soil and intensity of runoff and subsequently increase soil moisture storage from rainfall while maintaining low levels of soil erosion and sedimentation.

With this in mind, the water harvesting project focused on:

- Applying simple, low cost, and scientifically based water harvesting systems.
- Utilizing harvested water for agricultural production.

The collected rainwater from this project can be used in the following ways:

- Supplementary irrigation to improve crop productivity
- Drinking purposes, in remote areas, where there is no water network
- Water for livestock

LITERATURE REVIEW

In preparation for implementing the water harvesting project, the team reviewed valumes of literature on the topic, among which were:

- **Ben-Asher, J.et al., 1995**, observed that roof water harvesting is beneficial in semi-arid areas and could generate a significant percentage of the regional water demand for domestic and micro irrigation.
- **Verma et al., 1990,** designed a water harvesting system and calculated a cost benefit ratio. They worked in northern Punjab region in India and found that the cost of the water harvesting system per unit capacity decreased with the increase of storage tank capacity, since the storage tank formed the major cost of the water harvesting system.
- **Gobin et al., 1996**, studied the water harvesting systems in southwestern Nigeria, where rainwater harvesting is a widespread practice to provide water for household consumption. Rainwater harvesting for agriculture use is standard practice while roof top water harvesting is not fully realized de to insufficient storage tanks and roof guttering.
- **Thomas et al, 1998**, indicated that worldwide pressure on water resources is growing as population grows and per capita water consumption increases. The available water resources from fossil water combined with climate change challenge the plans for meeting the growing demand for water. The study highlighted the benefits of rainwater harvesting, as it can offset a significant component of water demand.
- **Chilton et al., 2000**, studied a prototype system to collect rainwater from the roof structure, using it to satisfy part of the domestic cold water requirements of selected supermarkets in the United Kingdom. The results of this monitoring were used to calculate the cost efficiency of the system compared to the local rainfall volumes. Based on this, the study found a twelve year payback period based on a collection efficiency of 57%. The tank size and configuration is the key element in the cost-benefit ratio and with some re-configuration, the study found that the payback period could be reduced to four years.
- **Fewkes, 2000**, investigated the effect of spatial and temporal fluctuation in rainfall on the performance of rainwater harvesting systems. He simulated the performance of the water harvesting systems using a monthly model that incorporated average values of the storage operating parameters. It showed that it correlate well with the corresponding values using the daily interval models. The monthly model provides a simple method of modeling the performance of rainwater harvesting system in the wet areas.
- **Mungekar, N.P., 2003** recommended that a water harvesting system could reduce pressure on a public water distribution system. The rain water could be collected from terraces and roofs and stored in a cistern for the use by neighborhood people during the dry season.

- **Kumar, M.D., 2004,** indicated that roof water harvesting systems are being widely promoted as a source for the growing drinking water in India and many underdeveloped where the technical skills are poor.. The study found that roof water harvesting systems may be economically viable as a supplementary source to already existing public water supply schemes in rural areas with dispersed populations and hilly areas. On the other hand, their physical feasibility and economic viability as a supplementary source of domestic water supply seems to be poor in urban areas, when compared to the good supplies from the public water network.

The background research provided a frame of reference for the project, as well as focused the team on international best practices in the field of water harvesting. Many of the techniques outlined in the material were incorporated into the project design.

STUDY AREA

Jordan is an emerging market situated off the southeastern shores of the Mediterranean Sea between longitudes 35^o and 39^o East and latitudes 29^o and 33^o North. Its area is about 90,000 km^2 and consists of different distinctive topographic units trending in north-south direction. These units are the rift valley, the high lands on the side of the rift valley and the desert region. (Figure 1)

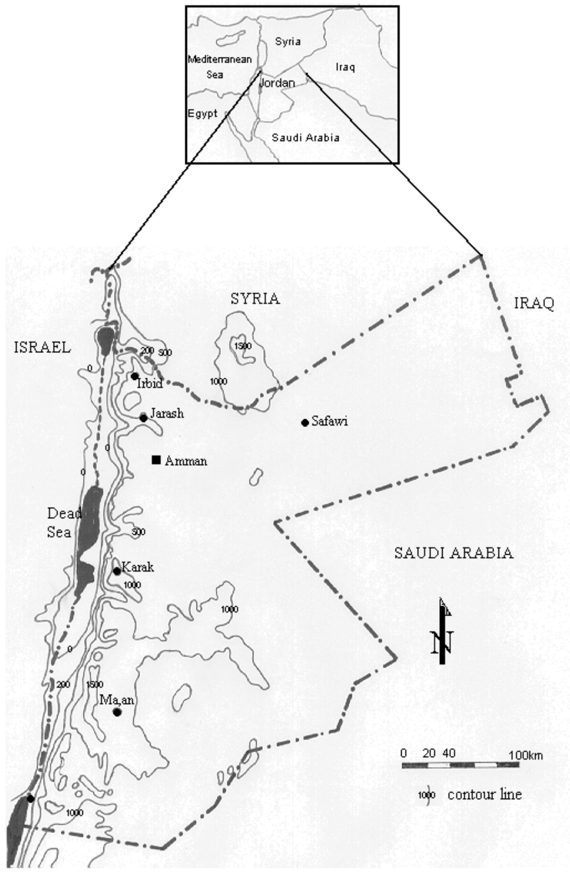
Desert covers more than 80% of Jordan's landmass. This desert has very few urban areas due to the limitation of resources, such as water. Jordan's population is approximately 6.1 million according to the 2004 census, with a population growth rate that exceeds 3.6% per year. Approximately 90% of the population is concentrated on 10% of the country's land, which generates a high demand for resources. Jordan's location has caused it to be impacted by several events over the years, including the 1990 Gulf crises that forced more than 300,000 individuals to leave the Gulf area and resettle in Jordan. These events further increased the demand for water and mineral resources.

CLIMATE AND ENVIRONMENT

Jordan's climate is semi-arid,, characterized by sunny days and cool nights, with an average temperature of 33^{o}C between May and October, and 12^{o}C between November and April. The climate varies with location and physiography. Jordan is divided into three main physiographic regions: the highlands on both sides of the rift valley, the rift valley, and the desert region.

Jordan's geographical location is at the desert edges and in an area where the continental jet stream causes variable climate conditions. Its mean annual rainfall volume is 7.2 billion cubic meters with range of 6 to 12 billion cubic meters (Salameh and Bannayan, 1993). Hydrologic records suggest that the mean annual rainfall varies from year to year. For example, in Amman, the capital city, the average annual rainfall depth varies from 111 mm to 540 mm and at Irbid it varies between 193 mm and 816 mm (Salameh and Bannayan, 1993). Rainfall also changes from one region to another; it decreases very rapidly from north to south and from west to east. The fluctuation in the quantity of rainfall from year to year has resulted in drought in certain regions.

Figure 1: Location Map of Jordan

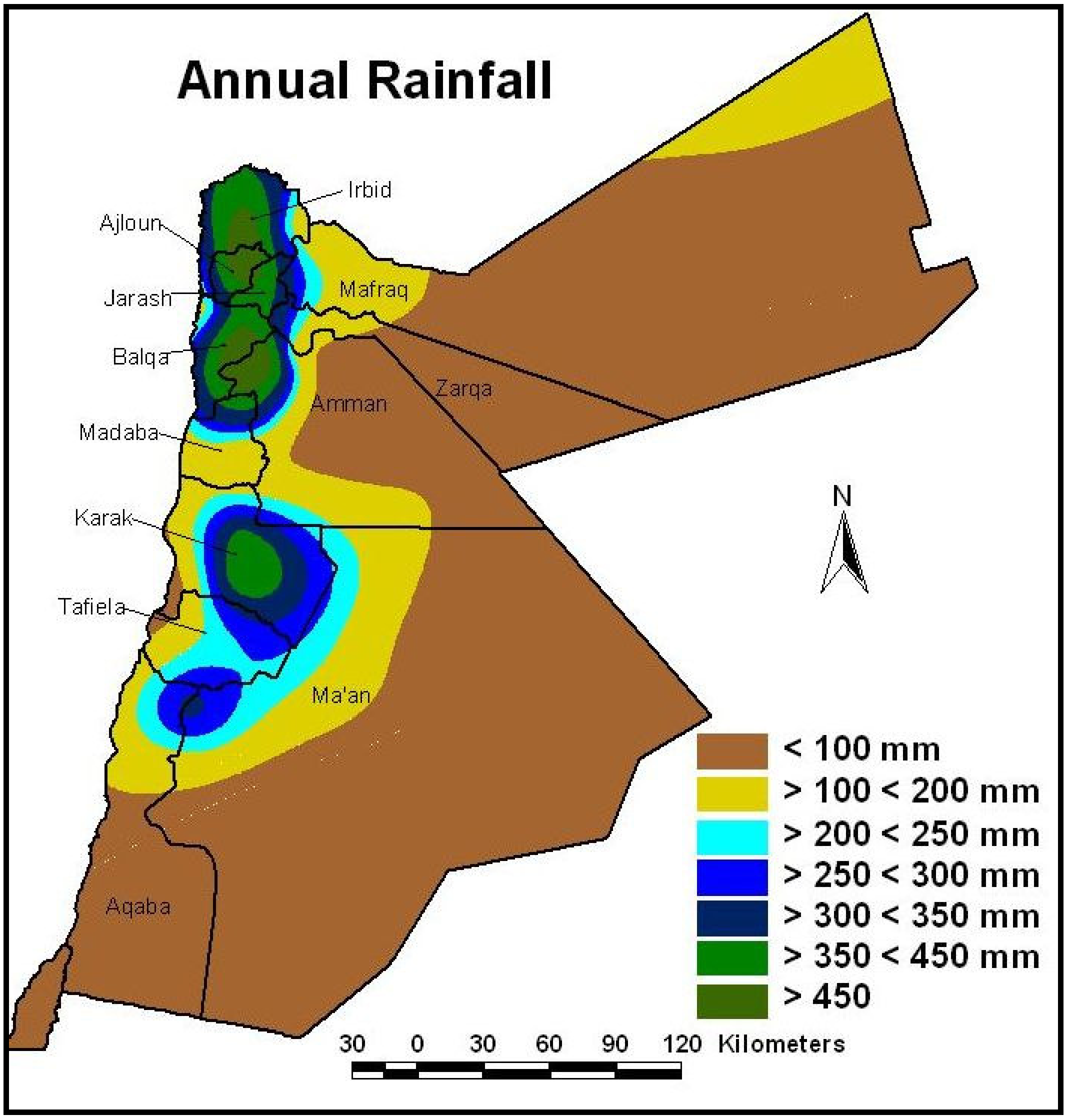


According to rainfall quantities, Jordan may also be divided into four main regions as shown in Table 1, these regions also shown in Figure 2,

Table 1: Variation of average rainfall in the main regions

Region	Average Rainfall (mm)	Area covered (%)
Arid	< 200	90
Marginal	200 – 350	6
Semiarid	350 – 500	1.5
Semiwet	> 500	1.5

Figure 2: Rainfall Regions in Jordan

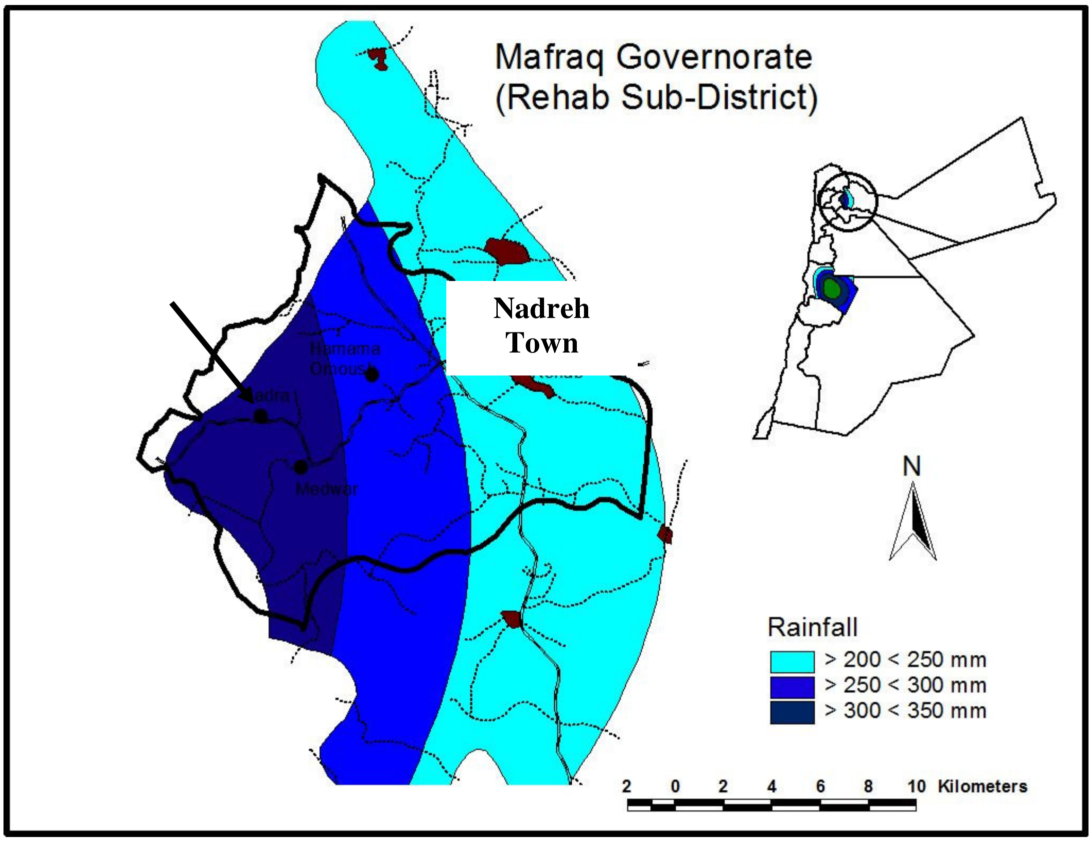


MAFRAQ GOVERNORATE

The Mafraq Governorate is the second largest area in Jordan, covering about 30% of the country's landmass. However, it contains only 5% of its total population. Most of the Mafraq area is considered to be arid land with annual rainfall less than 200 mm. The western part of the governorate receives annual rainfall that could reach about 350 mm as shown in Figure 3.

In the western parts of Mafraq Governorate, one of the major economic activities is farming, especially olive trees. Growing olives depends on consistent rainfall with supplemental irrigation during the dry season.

Figure 3: Rainfall Regions in Mafraq Governorate

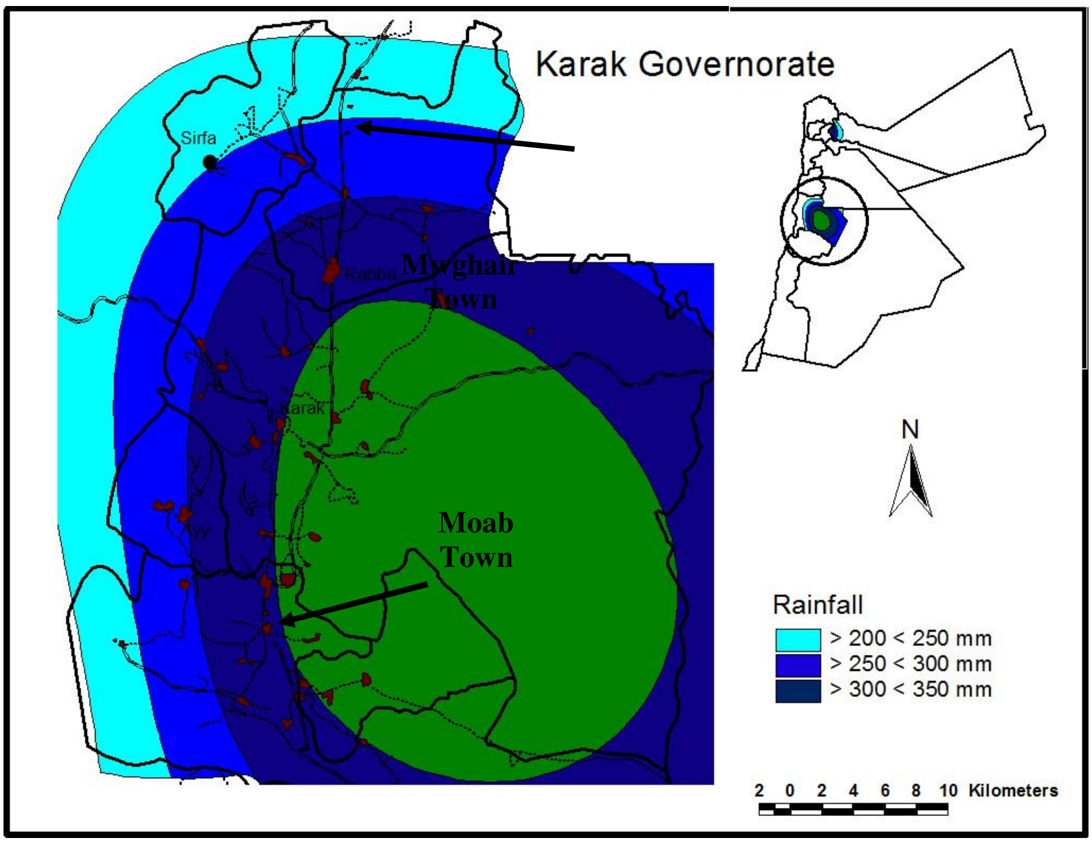


KARAK GOVERNORATE

The Karak governorate is one of Jordan's medium sized Governorates, covering about 4% of the country's landmass and boasting 4% of its population. The Karak area is relatively wet, with annual rainfall reaching,500 mm in some areas with an average of 250 mm Governorate-wide. This is highlighted in Figure 4.

The Karak Governorate depends on rainfall for the growth of its staple crops such as grain, fruit trees, olive production, and grape production.

Figure 4: Rainfall Regions in Karak Governorate



SITE AND SYSTEM SELECTION

SELECTING THE SITES AND PARTNERS

The project's selection criteria focused on two themes, the geographic and weather parameters of the target regions and the socio-economic considerations for the target communities. The geographic-weather parameters include:

- The availability of good rainfall volumes, the areas with annual rainfall ranges between 250 mm and 350 mm will be selected. For areas with rainfall more than 350 mm per year, the need for storing water is relatively not essential. On the other hand, areas with annual rainfall less 250 mm has limited rainfall availability and the risk of building projects depends on rainfall harvesting is relatively high, Figures 3 and 4 above show the regions that receives annual rainfall volumes between 250 mm and 350 mm for Mafraq and Karak Governorates respectively.
- The availability of agriculture land is an important factor of selecting the site of the project, the collected water will be used mainly for farming and in some cases for watering animals, so the availability of suitable land for farming or existing farms will affect the selection of project sites,

After the physical parameters are analyzed and suitable regions are defined, the next step in the selection process was working with target communities. In this step, the human factors that directed the selection are:

- The economical status of the target communities where focus will be on the less fortunate communities and/or individuals. In this stage, help will be asked from local governors, community leaders and NGOs working on these areas,
- Availability of active community organizations with resources available for the project such as land and farms,

The regions that receive rainfall more than 250 mm per year were identified within the Mafraq and Karak governorates (Figures 3 and 4). In those regions, the project team members identified community organizations such as NGOs with which to work and also consulted with community leaders such as the Assistant Governor, mayors, and school principals. Ultimately, the team selected public access sites within the Governorates, with four sites identified in Mafraq and two in Karak.

MAFRAQ SITES

Sites selected in Mafraq were in the Rehab Sub-District in the western part of the Governorate. Both sites were in Nadreh town within the Rehab Municipality. At the first site, the project sought to collect water from the roof and paved areas of the Nadreh Girls' School and use the water to irrigate the school's garden. The other site was a housing area that included six brothers who have houses close together. The project sought to collect water from the roofs of the six houses in order to irrigate nearby olive trees.

According to the 2004 census, The Rehab Sub-District has a population of 16143 forming 2880 families. Nadreh town is a small town with population of 437 forming 77 families.

The major economic activities for the target areas are divided between agriculture, and public employment. Agriculture activities included livestock husbandry and growing olives.

The Nadreh Area is located in the western part of the Rehab Sub-District where annual rainfall ranges between 300 and 350 mm. This makes the area suitable for rainfall water harvesting.

The following individuals were consulted during the selection of project sites:

- Mafraq Assistant Governor for community development,
- Mayor of Rehab Municipality,
- Principal of Nadreh Girls' school,
- Principal of Nadreh Boys' school,
- Community leaders in the town of Nadreh..

KARAK SITES

The sites selected in Karak were in the Qasser District north of Karak-- one in the Mujeb Sub-district and the other in the Qasser Sub-district. The Mujeb Sub-district site was located in the town of Mwghair within the Talal Municipality where the water was to be collected from the roof and paved areas of the Mwghair Girls' School and used to irrigate the school's garden. The Qasser Sub-District site was located in Qasser town where water was to be collected from the roof and paved areas of the Qasser Girls' school and used to irrigate the Shehan Municipality Park next to the school.

After starting the work at the second site in Shehan Municipality Park, the team realized that the sites geology was not consistent for the project's design so it found another site in the Moab area south of Karak, where the water was collected from the roof of the Iskan Moab NGO building complex that included a school and multipurpose hall.

According to the 2004 census, the Qasser district has a population of 20,849, consisting of 3,696 families; there are two sub-districts in Qasser District, the Mujeb and Qasser Sub-Districts with population of 5,810 and 15,039 respectively. The town of Mughair has a population of 1,523, consisting of 161 families and the town of Qasser has a population of 4,441 consisting of 807 families.

The area's economy is largely dependent on agriculture, trading and public employment. Agriculture activities include animal husbandry and growing fruit trees.

The first site in the Mughair area was located in the southern part of Mujeb Sub-District in an area that receives an average annual rainfall between 250 and 300 mm, which provided good potential for rainfall water harvesting. The other site in the Qasser area was located in the northern part of Qasser Sub-District in an area that receives an annual rainfall around 300 mm, which is also favorable for rainfall water harvesting.

Key people who are consulted in the project site selection process are:

- Mayor of the Talal Municipality,
- Mayor of the Shehan Municipality,

- Head of the Amro Women's Society,
- Principal of the Talal Primary School,
- Municipality engineers in both the Talal and Shehan Municipalities

SYSTEM SELECTION

Rooftop water harvesting systems have various designs and configurations, the primary of which are the catchment, which is the rooftop in this case; the conveyor from the catchment to the storage tank; the use of PVC pipes from the roof drains to the storage tank; and the the most expensive system which is the storage tank. There are many types of storage tanks, the most basic of which made from plastic or metal containers that connect to roof drains. This system is limited by its low volume of collections and the relatively high cost per cubic meter of collection. Another alternative is the construction of overland or underground concrete reservoirs. This option is considered the most expensive option for rooftop water harvesting. A third option is digging a cistern underground with cone geometry to make use of ground as cover of the tank. This option requires special geology such as soft sedimentary rocks.. There are other options that provide less efficiency, such as open ponds lined with concrete or plastic or large plastic balloons. The next table summarizes the various alternatives for water harvesting systems.

Based on the cost per cubic meter, the advantages and disadvantages of each option for storage tanks:

READY MADE PLASTIC TANKS:

Cost = 50 – 60 JD per cubic meters

Advantages:

- Easy to install,
- Ready made,
- Installed above ground to use flow by gravity for irrigation puproses

Disadvantages:

- Limited volume, available in 2 m^3,
- Needs about 1.4 m^2 of area per cubic meter,
- Low durability.

READY MADE METAL TANKS:

Cost = 75 – 80 JD per cubic meters

Advantages:

- Easy to install,
- Ready made,

- Installed above ground to use gravity flow for irrigation

Disadvantages:

- Limited volume, available in 2 m^3,

SPECIALLY MADE METAL TANKS:

Cost = about 100 - 120 JD per cubic meters for 4 m^3

Advantages:

- Easy to install,
- Installed above ground to use gravity flow for irrigation

Disadvantages:

- High cost per cubic meter

ABOVE GROUND CONCRETE TANKS:

Cost = 80 – 100 JD per cubic meters for volumes 10 – 15 m^3

Advantages:

- Installed above ground to use gravity flow for irrigation
- Low footprint per cubic meter.

Disadvantages:

- High cost for volumes above 15 m^3,
- Needs professional engineering to design and supervise implementation.

UNDER GROUND CONCRETE TANKS:

Cost = 80 – 100 JD per cubic meters for volumes 20 – 30 m^3

Advantages:

- Low footprint per cubic meter.

Disadvantages:

- High cost for volumes less than 20 m^3,
- Needs professional engineering to design and supervise implementation.
- Needs pumping for water use,

CONE CISTERNS:

Cost = 35 – 40 JD per cubic meters

Advantages:

- Relatively low cost per cubic meter,
- Small footprint,
- Doesn't need professional engineering to install

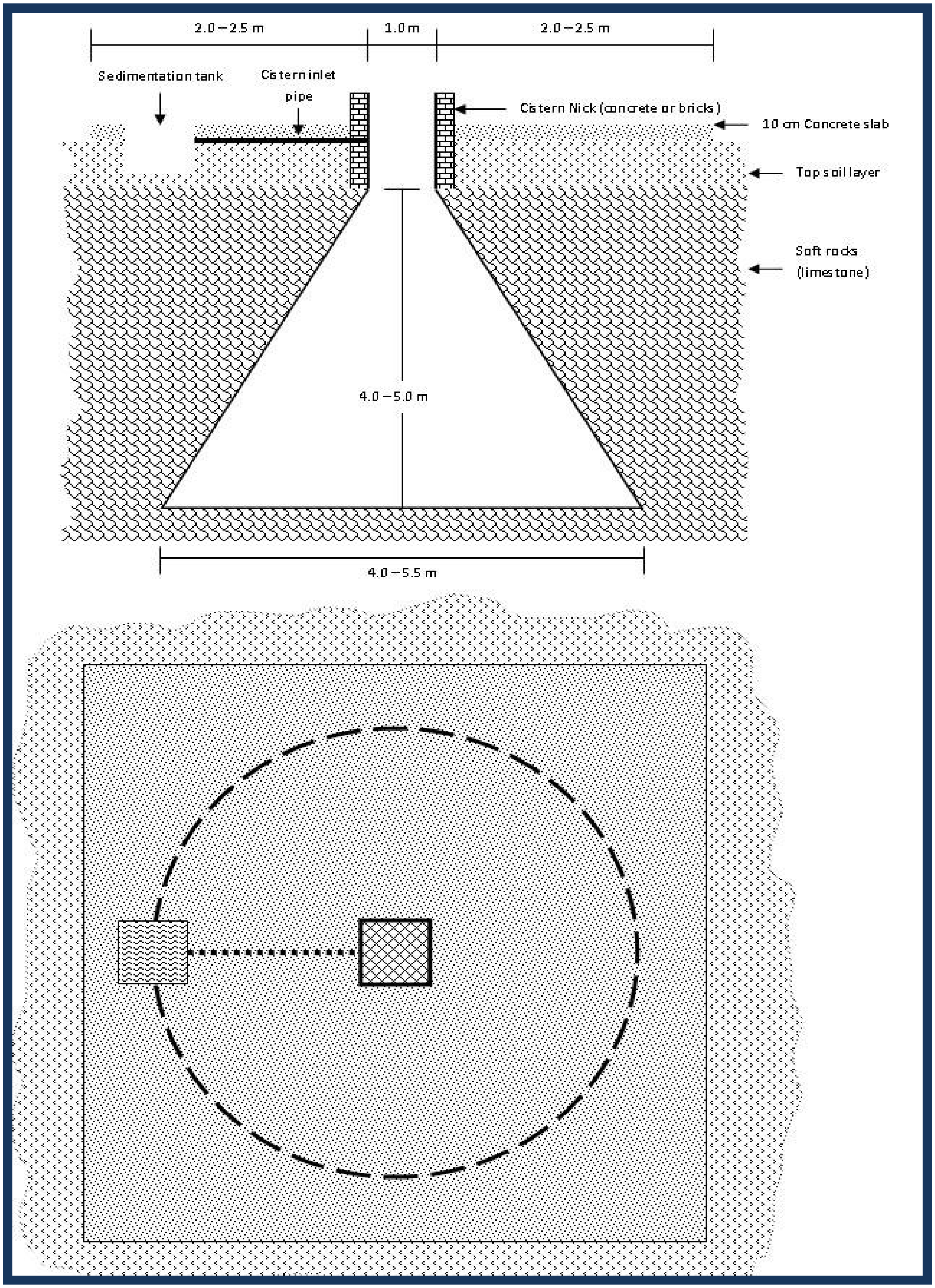
Disadvantages:

- Needs specific geology,
- Needs pumping for water use,

After analyzing the available options, the project team determined that the cone cistern was the best choice, since most of the geology in the selected regions is suitable for this system Figure 5 shows sketch of the cone cistern system.

In the case of Shehan Municipality Park, the site was located in an area with high soil sedimentation and the rocks were more than 2 meters below ground. To implement a cone cistern system with low cost the soil above the rocks where the cistern will be placed were removed so as not to exceed one meter high.

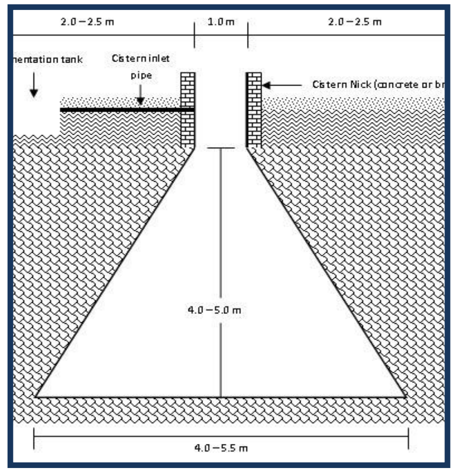
Figure 5: Sketch of cross section and top plan of cone cistern system



DESIGN AND IMPLEMENTATION

As mentioned in the previous section, the cone cistern was selected to be the storage tank option. In this type of system, the cistern takes a cone shape where it widens as digging goes down. Figure 6 shows sketch of a cone cistern. Cost for digging the cisterns was reduced through the use of a compressor to excavate rocks and by limiting the cistern's depth. Initially, the contractors determined that the optimum depth for each cistern should be 3.5 meters, which would hold about 20 cubic meters of water.

Figure 6: Sketch of Cone Cistern



The discussion with contractors led to the decision that the cistern size need to be as maximum as possible compared to the unit cost. The volume of the cisterns was controlled by the subteranian characteristics of the site. After discussion it was agreed that the cisterns should be 5 meters in depth to hold a volume of 50 cubic meters of water.

Table 2: Typical Cone Cistern Dimensions and Volumes

H (m)	D_1 (m)	Volume (m^3)
3	3.0	10
	3.5	13
3.5	3.0	12
	3.5	15
	4.0	19
4.0	3.5	17
	4.0	22
	4.5	27
4.5	4.0	25
	4.5	30
	5.0	36
5.0	4.5	34
	5.0	40
	5.5	48
5.5	5.0	45
	5.5	53

H

D_1

MAFRAQ SITES

MAFRAQ SITE 1: NADREH GIRLS' SCHOOL

The school's area was approximately 650 m^2 in addition to about 1300^2 of paved area. The building roof was well connected to guttering pipes that drain the roof runoff into the paved area. The paved area slope directed all the water into the northeastern corner where it emptied into a field without proper utilization. Figures 7 and 8 show Google location image of Nadreh girls' school and rainwater runoff direction.

As shown in Figure 3, the town of Nadreh is located in an area that receives average annual rainfall between 300 and 350 mm. Assuming that approximately 70% of the rainfall is runoff, this would result in excess of more than 200 mm of water per year. From these values the available rainfall floods volume that is available for collection can be computed from the following parameters:

Catchment area = 1600 m^2 (half of the buildings roof drains into the other side)

Excess rainfall = 200 mm

The annual runoff volume available for collecting = 320 m^3

The location of the storage tank is selected next to the northeastern corner of the paved area where all the rainfall floods end. The dimensions of the cistern are:

The depth from the bottom of the cistern neck = 5.4 meters

The diameters of the bottom of the cistern = 5.6 meters

The opening diameter = 1 meters

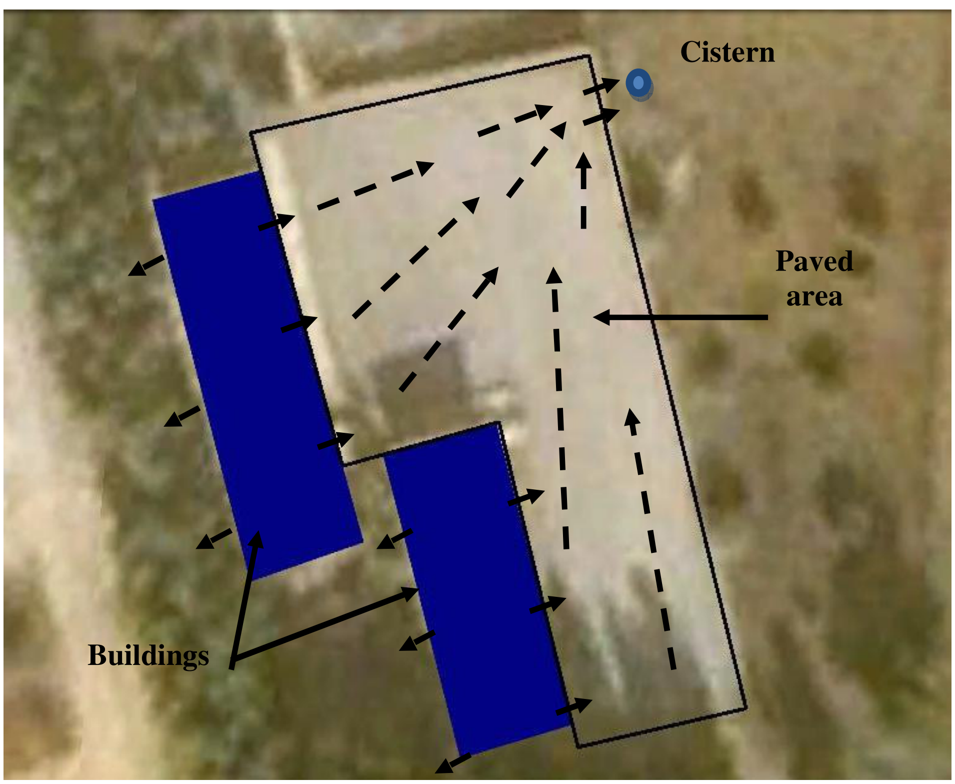
The volume of the cistern = 54 cubic meters

The cost of the unit volume of the cistern = 33.5 JD per cubic meters

With the available rainfall flood volume of 320 m^3, the cistern can be filled about six times a year, but the actual practice, the water usage in the rainy season is very low and in the best cases, one full volume of the cistern can be used before the end of the rainy season allowing the system to be filled another time in the same season. In this case the total utilized volume of rainfall floods will be about 108 cubic meters per season.

Figure 7: Google Image of Nadreh Town and Nadreh school location

Figure 8: Nadreh Girls School rainfall flood direction



MAFRAQ SITE 2: AYYASH OMOUSH FAMILY LAND

The Ayyash Omoush family is an extended family houses consisting of five buildings with a total area of about 750 m^2. The five buildings have a guttering system drain the facilitates rainfall flood from the roof into the field next to the houses. The field is cultivated by rain-fed olive trees with supplemental irrigation during dry periods. The area slopes to the north where it directs all the floods into the olive trees field without efficient use. Figures 9 and 10 show Google location image of the site and the location of the cistern and olive trees field.

As shown in Figure 3, Nadreh Town is located in an area that receives average annual rainfall between 300 and 350 mm. with the assumption that about 70% of the storms generate runoff this results on excess rainfall of more than 200 mm per year. From these values the available rainfall floods volume that is available for collection can be computed from the following parameters:

Catchment area = 600 m^2 (only four houses are connected to the system)

Excess rainfall = 200 mm

The annual runoff volume available for collecting = 120 m^3

The location of the storage tank is selected next to the olive trees field downstream of the houses in the northern side (Figure 10) where all the rainfall floods flow. The dimensions of the cistern are:

The depth from the bottom of the cistern neck = 5.1 meters

The diameters of the bottom of the cistern = 5.0 meters

The opening diameter = 1 meters

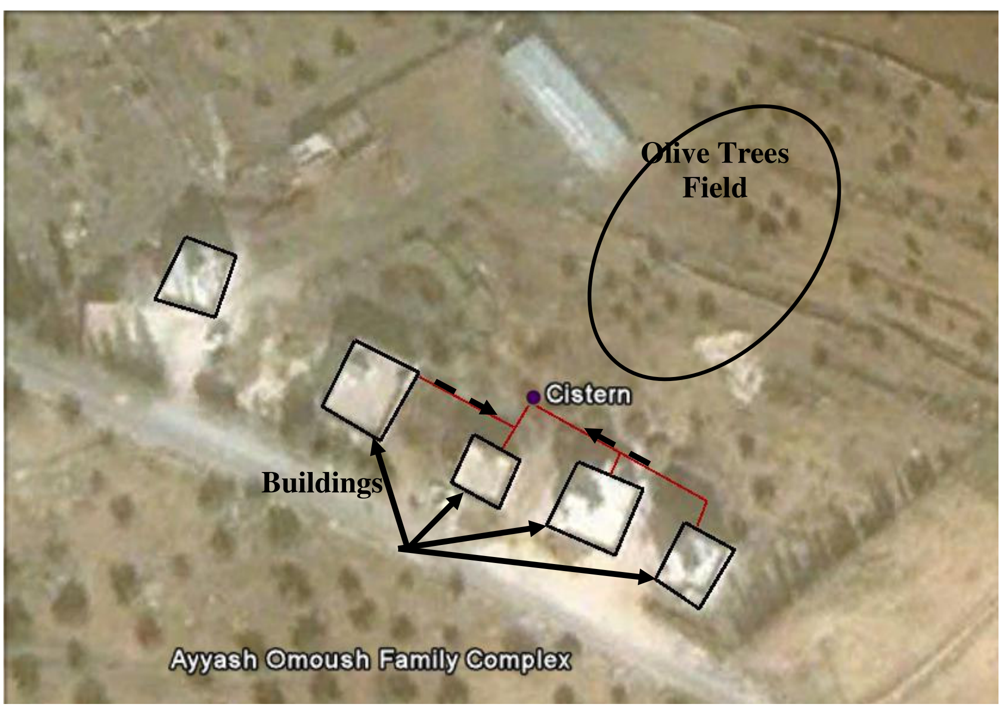
The volume of the cistern = 42 cubic meters

The cost of the unit volume of the cistern = 33.75 JD per cubic meters

With the available rainfall flood volume of 120 m^3, the cistern can be filled for three times a year. The water usage in the rainy season is very low and in the best cases, one full volume of the cistern can be used before the end of the rainy season allowing the system to be filled another time in the same season. In this case the total utilized volume of rainfall floods will be about 84 cubic meters per season.

Figure 9: Google Image of Nadreh Town and Ayyash Omoush houses

Figure 10: Ayyash Omoush houses rainfall flood direction



KARAK SITES

KARAK SITE 1: MUGHAIR GIRLS' SCHOOL

The building area of the school is about 1000 m^2 in addition to about 700^2 of paved area. The building roof is well connected to guttering pipes that drain the roof runoff into the paved area and the back of the buildings. The paved area slope directs all the floods into the western corner between the south and west buildings where water ends into the field without good utilization. Figures 11 and 12 show Google location image of Mwghair girls' school and rainfall floods directions.

As shown in Figure 4, Mughair Town is located in an area that receives average annual rainfall of about 250 mm. with the assumption that about 70% of the storms generate runoff this results on excess rainfall of about 175 mm per year. From these values the available rainfall floods volume that is available for collection can be computed from the following parameters:

Catchment area = 550 m^2 (only the south building is connected to the system)

Excess rainfall = 175 mm

The annual runoff volume available for collecting = 96 m^3

The location of the storage tank is selected on the southern corner of the school area close to the field planted with olive trees. The dimensions of the cistern are:

The depth from the bottom of the cistern neck = 5.1 meters

The diameters of the bottom of the cistern = 5.4 meters

The opening diameter = 1 meters

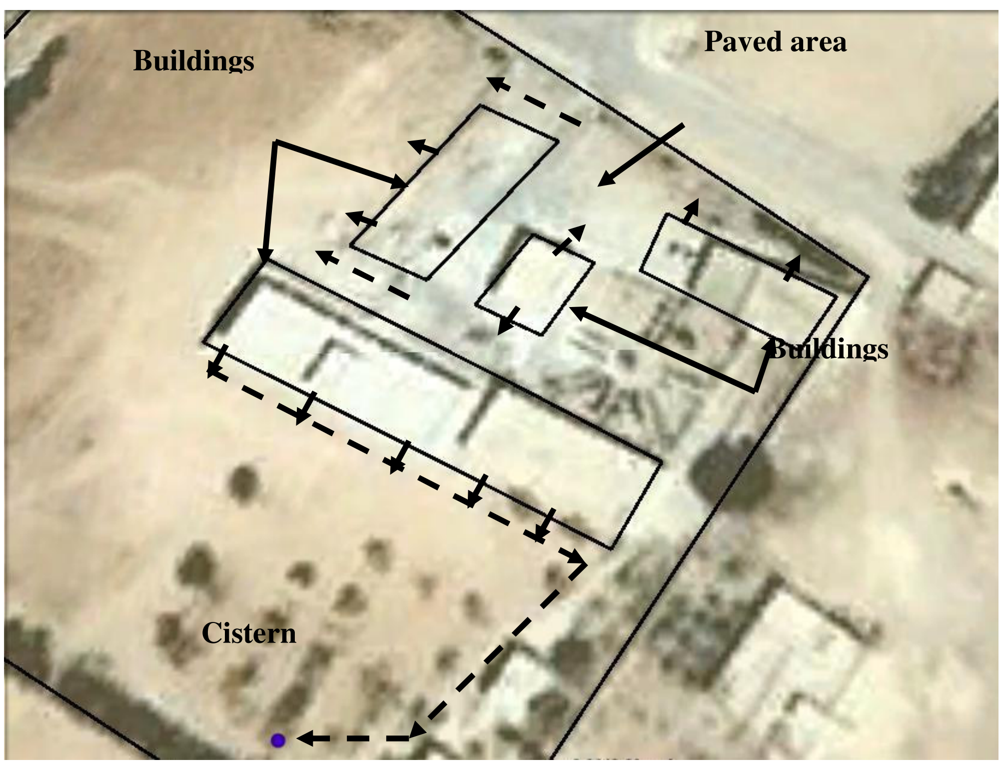
The volume of the cistern = 48 cubic meters

The cost of the unit volume of the cistern = 38 JD per cubic meters

With the available rainfall flood volume of 96 m^3, the cistern can be filled two times a year. the water usage in the rainy season is very low and in the best cases, one full volume of the cistern can be used before the end of the rainy season allowing the system to be filled another time in the same season. In this case the total utilized volume of rainfall floods will be about 96 cubic meters per season.

Figure 11: Google Image of Mwghair Town and Mwghair Girls School

Figure 12, Mwghair Girls School rainfall flood direction



KARAK SITE 2: ISKAN MOAB COOPERATIVE

The Iskan Moab Cooperative is an NGO working in the area of Moab,. The Cooperative has a building complex with roof area of about 750 m^2. The buildings have two guttering direction, one for the main building which is used as school and drains into the west open area, the other building drains rainfall to the south into the nearby street. Figures 13 and 14 show Google location image of Moab Town and Iskan Moab Coop and the buildings and cistern location on the site.

As shown in Figure 4, Moab Town is located in an area that receives average annual rainfall of about 350 mm. with the assumption that about 70% of the storms generate runoff this results on excess rainfall of more than 240 mm per year. From these values the available rainfall floods volume that is available for collection can be computed from the following parameters:

Catchment area = 450 m^2 (only the west building is connected to the system)

Excess rainfall = 240 mm

The annual runoff volume available for collecting = 108 m^3

The location of the storage tank is selected in the corner of the open area where the coop is planning to have small garden and playground for school children. The dimensions of the cistern are:

The depth from the bottom of the cistern neck = 5.4 meters

The diameters of the bottom of the cistern = 5.4 meters

The opening diameter = 1 meters

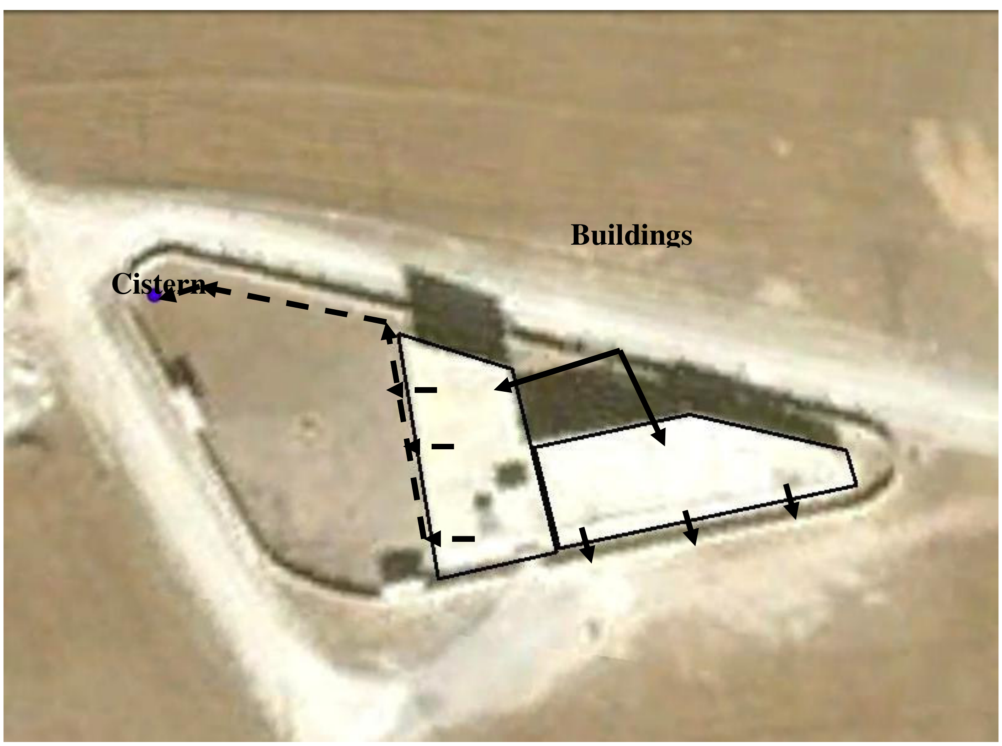
The volume of the cistern = 50 cubic meters

The cost of the unit volume of the cistern = 38 JD per cubic meters

With the available rainfall flood volume of 108 m^3, the cistern can be filled for two times a year. The water usage in the rainy season is very low and in the best cases, one full volume of the cistern can be used before the end of the rainy season allowing the system to be filled another time in the same season. In this case the total utilized volume of rainfall floods will be about 100 cubic meters per season.

Figure 13: Google Image of Moab Town and Iskan Moab Cooperative

Figure 14: Iskan Moab Cooperative Building rainfall flood direction



COST-BENEFIT ANALYSIS

The per cubic meter cost of the four water harvesting systems varied between 33.5 JD and 38 JD. One of the systems, Mwghair Girls School, cost extra 10 JD for conveying the roof drains into the cistern which is about 100 meters away. In General, the per unit volume (m^3) cost varies between 35 – 40 JD for the governmental tendering since contractors tend to raise the cost to compensate for the delay in getting their payments. The individual negotiable cost of the cubic meter could go down to 25 – 30JD.

The prices for cubic meter of water in rural areas vary between 3.5 and 4.0 JD using tankers. And in some dry seasons this price could go up to 5 JD. With these inputs, the water harvesting systems will cover their costs in 4 – 5 years taking in consideration that the system will be filled two times only during the one season.

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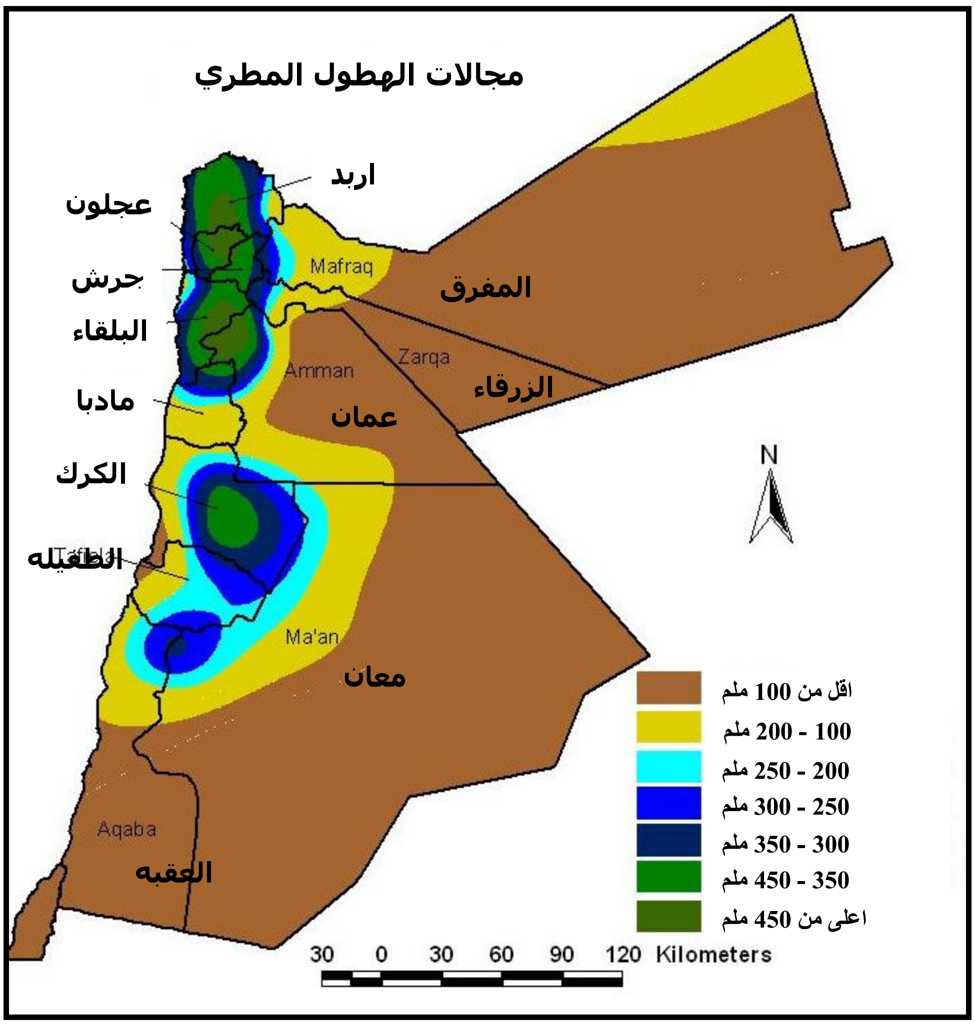
APPENDIX

GUIDELINE FOR SELECTING AND SIZING WATER HARVESTING SYSTEM (ARABIC)

مراحل تحديد حجم الخزان الممكن لجمع مياه الامطار

الخطوة الأولى:

تحديد الموقع من الخارطة التالية وتحديد كمية الأمطار التاحة حسب المجال المطري. أذا كان الموقع ضمن المجالات المطرية 200 ملم الى 350 ملم فهذه المناطق التي ينصح بعمل الحصاد المائي فيها بينما المجالات التي تقل عن 200 ملم فأن الحصاد المائي غير مضمون ولا يعتمد عليه أما المجال المطري الذي يزيد عن 350 ملم فأن المياه متوفرة وقد لا تمون عملية الحصاد المائي ضرورية.



الخطوة الثانية:

أولاً: حساب كمية الهطول المطري المتاح لعملية الجمع ويساوي الحد الادنى للمجال المطري الذي تم تحديده من الخطوة الاولى مضروباً ب 75% ويمكن تحديدها من الجدول التالي:

المجال المطري (ملم)	الهطول المطري المتاح (ملم)	حجم المياه التي يمكن جمعها من كل 10 متر مربع (متر مكعب)
اقل من 100	0	0
100 – 200	70	0.7
200 – 250	140	1.4
250 – 300	175	1.75
300 – 350	210	2.1
350 – 400	245	2.45
اعلى من 400	280	2.8

ثانياً: حساب حجم المياه التي يمكن جمعها من كل 10 متر مربع من مساحة السطح وذلك بضرب 10 في الكمية المحسوبة من (أولاً) اعلاه وقسمة الناتج على 100 لتكون النتيجة بالمتر المكعب

الخطوة الثالثة:

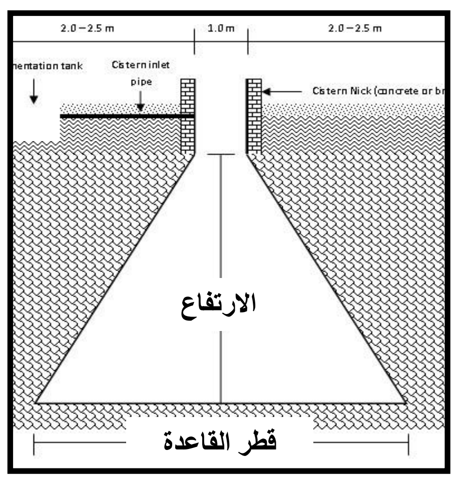
تحديد مساحة السطح الذي سيتم جمع مياه الامطار منه وحساب حجم المياه التي يمكن جمعها من هذا السطح وذلك بقسمة مساحة السطح على 10 وضرب الناتج بحجم المياه التي يمكن جمعها من كل 10 متر مربع المقابل للمجال المطري في الجدول اعلاه

الخطوة الرابعة:

تحديد حجم الخزان المطلوب على ان لا يتجاوز هذا الحجم نصف الحجم الذي تم حسابه في الخطوة الثالثة اعلاه

اختيار ابعاد الخزان المطلوب من الجدول التالي:

الارتفاع (متر)	قطر القاعدة (متر)	الحجم (متر مكعب)
3	3.0	10
	3.5	13
3.5	3.0	12
	3.5	15
	4.0	19
4.0	3.5	17
	4.0	22
	4.5	27
4.5	4.0	25
	4.5	30
	5.0	36
5.0	4.5	34
	5.0	40
	5.5	48
5.5	5.0	45
	5.5	53



PICTURES FROM THE PROJECT SITES

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