Rainwater Harvesting and Management under Arid Climatic Zone: A Case Study of El Managil Area, Gezira State, Sudan

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September/2012
Rainwater Harvesting and Management under Arid Climatic Zone: A Case Study of El Managil Area, Gezira State, Sudan

By:

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Date of Examination: 30th/09/2012
To

My Parents, Father Abdelbagi and Mother

My Sisters and

My Friends and Brothers And

All those who helped with this Work.
ACKNOWLEDGEMENT

I'm deeply indebted to my supervisors Dr. Shamseddin Musa Ahmed and Prof. Dr. Ali M. Adeeb for their valuable support and advice.

Thanks also are extended to the staff of the water management in El Managil locality. Special Thanks to my Colleagues who helped with this work.

Finally, I would like to acknowledge my brother Mohamed for his patience in tolerating my preoccupation with lengthy manuscripts on work.
ABSTRACT

In arid zones the imbalance between water supply (rainfall) and demand necessitates efficient and better water use. Rainwater harvesting practices are promising for bridging the gap in water supply and in improving crop yields. The specific objective of this study is to evaluate the performance of rainwater harvesting techniques (RWHT) in crop production and domestic water supply purposes, in El Managil area, Gezira state. The data collected using three approaches, viz: field surveying for the actual dimensions of the adopted RWHT, statistical designed questionnaire (from five different villages) and time series data. The collected data were analyzed using SPSS and Excel sheets. The study found that there is an increasing trend in rainfall since 1992. However, the area witnessed a drought cycle of 12 years (1980-1991), disturbed the livelihood generation and deteriorated the vegetation cover. The hydroclimatological analysis showed that the rainfed agricultural production is limited unless RWHT is adopted in scientific pillars. Terraces were found the dominant (100%) RWHT in the crop production i.e. increased the yield by 333%. Haffir water and boreholes were the dominant domestic water supply. The design dimensions, especially the depth of Haffir were deformed due to silt accumulation (soil erosion), reducing the storage capacity and in turn caused water deficit problems. From water management perspective, the existed Haffir waters may remain 5-3 months, however, the actual functioning period was found 3-5 months due high evaporation losses (47%) and deep percolation (22%); thus, water deficit is a water mismanagement aspects rather than physical water availability. The study recommends the increasing of Terraces adoption on scientific pillars, restoring design Haffir dimensions and restoring the vegetation cover in order to combat soil erosion, increasing capacity building trainings in water management and extending the education umbrella.
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CHAPTER ONE
INTRODUCTION

1.1 General:

Water resources are getting a large attention throughout the world especially in arid and semi arid areas since water has a vital role in sustaining life and development. However, water is limited and vulnerable resource. Therefore, managing water resources in a sustainable manner is utmost important, especially where water is scarce.

1.2 Water Resources in Sudan:

1.2.1 The Nile System:

The Nile River receives its water from two major sources the equatorial lakes and the Ethiopian plateau. The flow contribution of the main tributaries of the Nile River from the Ethiopian highland is 86% (Blue Nile system, Sobat and Atbara) and that from equatorial lakes is 14% (White Nile). According to the 1959 Nile water agreement Sudan has the right to use 18.5 km$^3$ (Eldaw, 2003).

1.2.2 Groundwater:

The renewable groundwater in Sudan is estimated at 4.1 km, the bulk of it is found within the Nubian sandstone aquifer that is covered about 28% of Sudan (Eldaw, 2003). The main constraint associated with the use of groundwater is the high cost of exploration and abstraction, especially in remote areas where the groundwater table is deep (Adeeb, 2002).

1.2.3 Rainfall:

The average rainfall amount in Sudan (Sudan and Southern Sudan) is estimated at 1050 km$^3$ and on the basis of 80% probability it is estimated at
875 km³ (Adam et al., 1999). Variability of rainfall in space and time is the main constraint of using rain water in Sudan.

1.2.4 Non Nile Streams and Wadis:

The major four streams which fall under this category are Gash and Barka (shared with Eritrea) and Azum and Hawar (shared with Chad), the annual estimated flow of these non-Nilotic rivers is 5.5 km³ (Eldaw, 2003).

1.3 The Problem:

Most of arid and semi arid regions suffer from rainfall variability, therefore, managing rainwater is indispensable. The semi–arid climate influences rainfall patterns in the El Managil area. Very intense rainfall in the El Managil area results from convective storms. Storms whose intense periods are less than one or two hours in duration, causes most of the flooding problems (Eltaib, 2010).

Groundwater resources are limited in El Managil area due to geological formation problems (Abdelrahman, 2003), leaving rainwater as the sole source of drinking water for many parts, especially those far from Gezira scheme canalization system. Moreover, the livelihood generation in this area is mainly rainfall dependent, i.e. livestock. Albeit with its importance, rainwater management in this area is poorly studied.

1.4 Objectives:

The general objective of this study is to promote the harvested rainwater management in a sustainable manner in arid climatic zone.

The specific objective is to evaluate the hydro-climatic performance of rainwater harvesting techniques that were adopted for crop production and domestic water supply, in El Managil area, Gezira state".
2.1 Definition of Rain Water Harvesting (RWH):

The United Nations Environmental Programme (UNEP, 1983) defined rainwater harvesting as “the deliberate collection of rain water from surface (catchments) and its storage to provide supply of water” (UNEP, 1983). It is also defined as “the concentration of precipitation through runoff storage for beneficial use” (Oweis. et al., 2001). Similar definition was given by International Water and Sanitation Center (IRC, 1992), in which rainwater harvesting is considered as “the collection, concentration and storage of water that runs off a natural or man mad catchments surface”. The common factor in these definitions is that RWH is the capture, diversion, and storage of rainwater for many uses”.

2.2 Conditions for RWH:

2.2.1 Climate

Water harvesting is suitable in arid and semi arid regions (100-300 and 300-700 mm average annual rainfall respectively). In most tropical regions the main rainfall period occurs in the summer period, when evaporation rates are high, resulting in high risk of crops failure (FAO, 2006).

2.2.2 Topography:

Drainage characteristics, slope gradient, slope length are some important topographic factors influencing rainwater harvesting, since they are affecting the runoff, water storage etc. Oweis et. al. (1999) stated that there is an inverse relationship between the catchment size and runoff quantity in Syria. Investigations on experimental runoff plots have shown that steep slope plots yield more runoff than those with gentle slopes. In addition, it was observed
that the quantity of runoff decreased with increasing slope length (FAO, 2006).

2.2.3 Soils:

Soils in the cultivated area should be deep enough to allow sufficient moisture storage capacity and be fertile. The type of soil also largely affects the amount of runoff through its effect on the infiltration process that separates hydrologically the received rainfall into green water (soil moisture) and blue water (runoff) (FAO, 2006).

2.2.4 Crops:

One of the main criteria for selection of water harvesting technique is its suitability for the type of plant one wants (FAO, 2006). The design of irrigation scheme, in terms of area to be cropped, the cropping pattern, canal capacities, depended to a large extent on accurate figures of crop water requirement. The ratio of transpiration to soil evaporation depended on crop cover (Adam, 2005).

2.2.5 Socio-economic Aspects:

In developing countries most of the rainfed farmers are poor. Thus, the recommended rainwater harvesting techniques should consider the socioeconomic aspects. For example, many rainwater harvesting schemes in the western region of Sudan failed due to inconsideration of socioeconomic aspects (FAO, 2006).

2.3 Rainwater Harvesting Techniques:

Rainwater harvesting has many types with various classification, forms and names worldwide one of the famous classification of water harvesting techniques is given in Table (2.1).
2.4 Rainwater Harvesting in Sudan:

Sudan is endowed with many water resources. Total precipitation on the country is estimated roughly at 450 km\(^3\). Rainfed agriculture is the dominant source for Sudan food supply since 85% of the Sudanese cultivated area is rainfed (Shamseddin and Lars, 2011). Therefore, rainwater harvesting is very important for Sudan food security, poverty reduction, development, etc. The most important natural resources in the drier environment are rainfall. Despite its scarcity rainfall is generally poorly managed, and much of it is lost through runoff and evaporation (Rockstroem et al., 2002).

Historically, various rainwater harvesting techniques were widely practices in Sudan. Terraces, Bunds, Haffir and small dams are the dominant RWH techniques in Sudan. Shamseddin (2009) proved the suitability of rainwater harvesting techniques for sustaining agricultural practices in arid and semi arid climatic zones of Sudan. Rockstroem and Steiner (2004) used the parallel earth bunds (0.40 m height and 10 m distance) as RWH techniques in Kordofan State and obtained good results. Pitting and spreading of water techniques were also carried out in west of Sudan for natural resources conservational purpose showed good results (Abualgasim and Mohamed, 2003).

In Gedarif area, using RWH resulted in positive effects on sorghum grain yields (Salih et al., 2003).

2.5 Types of Catchments Rain Water Harvesting:

Mainly, there are three types of catchments, depending on the scale:

2.5.1 Micro Catchments Water Harvesting:

Micro rainwater harvesting systems is the method of collecting surface runoff from small catchments area and storing it in a tank or in the root zone. This infiltrated water have may be planted with single tree, bush or with annual crops (Boers and Ben-Asher, 1982).
2.5.2 Medium –sized Catchments:
Water harvesting from medium sized catchments are typically $100 \text{ m}^2 - 20 \text{ ha}$ is defined by many authors as water harvesting long slop as macro catchments water harvesting or harvesting from external catchments system (Prinz, 2001).

2.5.3 Large Catchments Water Harvesting:
Comprises systems with large catchments being many square kilometers, and a complex structure may be needed (small dams, water diversion structures, etc).

2.6 Haffir for Domestic Water Supply:
The ‘Haffir’ is the local name in Sudan for a natural pond or man-made (excavated pond). The Haffir is a hollow dug in the ground designed to store runoff water beyond the rainy season basically for domestic uses; Lack of design aspects, high evaporation rate, pollution, and rainfall variability are the main obstacles facing Haffir water management.

2.6.1 Haffir Scheme Components Comprise:
Rice (1992) described the following components for any Haffir scheme in Sudan:

2.6.1.1 Water Input:
Either a canal is constructed from a nearby irrigation canal, or diversionary dykes are raised to lead rain water into a Haffir.

2.6.1.2 Haffir (pond):
The pond is excavated to a designed size to receive water and store it. A surrounding fence is needed so as to control contamination.

2.6.1.3 Water Treatment Works:
A three-stage system is needed: sedimentation tank where silt is
deposited; from the sedimentation tank the water flows by gravity into a slow sand filter tank where it is purified, and from the slow sand filter by gravity into a clean water tank, the clean water tank is roofed to prevent introduction of pollutants (Rice, 1992).

2.6.2 Design and Planning:

The appropriate design of any Haffir scheme may need the following information:

- The current and future projected Population
- Water daily consumption (A consumption of 20 liters per person per day is usually applied under rural areas).
- Haffir capacity: dry season periods (without inflow) of 5 and 10 months are assumed for canal–fed and rain-fed Haffirs, respectively.
- Water losses: mainly evaporation, deep percolation and seepage losses. For rainfed Haffir a 2.0 meter annual evaporation is generally used (Rice, 1992).

2.7 Rainfall:

2.7.1 Rainfall characteristics

The amount and spatio-temporal distribution of rainfall are very important characteristics, which are independent of locations. For instance, Precipitation in arid and semi-arid zones results largely from convective cloud mechanisms producing storms typically of short duration, relatively high intensity and limited a real extent (FAO, 2006). Eltaib (2010) reported the experiments carried out in Saudi Arabia that, on average, around 50% of all rain occurs at intensities of greater than 20 mm/hour and 20-30% occurs at intensities of 40 mm/hour. Moreover, this relationship appears to be independent of the long-term average rainfall at a particular location as reported in (Eltaib, 2010).
2.7.2 Rainfall Analysis:

The analysis of the relationship between rainfall-runoff is very crucial in rainwater harvesting management. The term mean rainfall is very deceptive; it is therefore the term probability is preferably used instead in designing rainwater harvesting techniques (Shamseddin, 2009). However, rainfall data in a good quality is very difficult to exist, especially in developing countries. Annual rainfall amount may be the only data available. For Rainwater harvesting techniques, the rainfall analysis of 2-3 years may be used (Nuhu and Mahoo, 1999). Generally, for designing any rainwater harvesting systems the following information may be needed: the number of rainy days, the probability and recurrence period, intensity distribution (Oweis et al., 1999).

2.8 Runoff:

2.8.1 Definition:

One of the main theories that described the initiation of runoff was set by Declan (1994) who stated the following condition for the development of runoff that "the precipitation should exceed the potential evapotranspiration and satisfies the soil moisture content deficit".

2.8.2 Factors Affecting Runoff:

Generally, factors affecting runoff may be categorized into factors associated with topography (slope, slope length, catchment size), land use, soil moisture, etc, and that associated with rainfall (amount, intensity and duration).

2.8.3 Estimating Runoff:

There are several models developed for estimating runoff such as soil conservation service (SCS), rational method...etc. Mays (2001). Among them, the SCS is the easiest, less data demanding, and preferred for agricultural catchments (Shamseddin, 2009).
Table (2.1): Classification of water harvesting techniques.

<table>
<thead>
<tr>
<th>Micro-catchment Techniques</th>
<th>Macro-catchment Techniques</th>
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<tr>
<td>On-farm Systems</td>
<td>Rooftop Systems</td>
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<td>Contour Ridges</td>
<td>Water Harvesting Techniques</td>
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<td>Contour Bench Terraces</td>
<td>Rural Systems</td>
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<tr>
<td>Semi-Circular/Trapezoidal Bounds</td>
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<td>Small Runoff Basins</td>
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<td>Small Pits</td>
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<td>Runoff Strips</td>
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<td>Inter-Row Systems</td>
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<td>Meskat</td>
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<tr>
<td>Wadi-bed Systems</td>
<td>Small Farms Reservoirs</td>
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<tr>
<td>Off-wadi Systems</td>
<td>Water-Spreading</td>
</tr>
<tr>
<td>Wadi-Bed Cultivations</td>
<td>Large Bound</td>
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<td>Jessour</td>
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<tr>
<td>Haffir, tank</td>
<td></td>
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<tr>
<td>Cisterns</td>
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<td>Hillside Conduits</td>
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Source: Oweis et al. (2001)
CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Area:

The study area is the El Managil Locality (32° 25´- 33° 18´ E and 13° 35´- 14° 37´ N) as shown in Figure (3.1). The locality belongs to the Gezira state. According to 2008 census, the population of the locality is about 906,216 inhabitants, distributed to eight smaller administrative units known locally as mahalias, consisting of 415 villages. Livelihood generations in the area depend largely on agriculture and livestock breeding.

3.2 Topography:

The area belongs to the central clay plain of Sudan. The slope is generally gentle (Abdelrahman, 2003). The soil is clay and characterized by very low infiltration rate, deep profile and high total available water. The area suffering ground water resources due to the geological formation (rock basement).

3.3 Climate:

The climate is dry with a short rainy season (July-September). Annual rainfall ranges between 200-300 mm (measured at Wad Medani station). This is coupled with an annual evapotranspiration of 2500 mm, yielding a negative annual water balance (Abdelrahman, 2003).
**Source:** El Managil Survey Office, reported in Fathelrahaman (2003)

**Figure (3.1):** El Managil location map.

### 3.4 Methodology:

Data were collected using three approaches, viz. questionnaire, field survey and official time series data.

#### 3.4.1 Questionnaire:

The questionnaire is distributed in five randomly selected villages, namely; Elazaza, Omjen, Hilet Khalid, Hilet Elhaj and Elamara Elkanab. The sample size was 50.

#### 3.4.2 Field Survey Data:

A field survey was carried out primarily for estimating the current storage capacity of Haffirs. Therefore, measuring tapes were used for collecting the dimension of Haffirs, including: the internal and external diameters, and depth. The dimensions were used for estimating the storage capacity as follows:
\[ V = \frac{(A_1 + A_2)}{2} \times D \] \hspace{1cm} (3.1)

**Where:**

\(V\) is water volume \((m^3)\), \(A_1\) and \(A_2\) are the top and bottom areas, respectively and \(D\) is the water depth.

The water consumption was estimated as follows:

\[ C = \sum_{i=1}^{n} N_i \times R_i \] \hspace{1cm} (3.2)

**Where:**

\(C\): total water consumption
\(N\): Total population
\(R\): Rate of water consumption per capita per liter/day

**Assumption:**

- Population water consumption per capita per day in Arid zone rural area is 20 liters/day (WHO and UN standard figure).
- The existing daily water consumption are much lower than the recommended according to the international standard, 50-80 liter/day for rural, and 100-120 liter/day for urban in Sudan.
- Cows and donkeys consumption per day = 72 liter/day
- Sheep’s and goats consumption per day = 18 liter/day (Ministry of Animals Wealth, 2011).
- Evaporation \((E_{\circ})\) was estimated using evapotranspiration-CROPWAT based \((ET_{\circ})\).

\[ E_{\circ} = ET_{\circ} \times \text{period} \times \text{correction factor} \] \hspace{1cm} (3.3)

\(E_{\circ}\) = Evaporation \((m/\text{month})\)
\(ET_{\circ}\) = Evapotranspiration \((m/\text{month})\)
Correction factor = 15\%
\( E_v = \text{Average } E \times \text{Top Area} \) ........................................... (3.4)

\( E_v = \text{Evaporation volume (m}^3\) \\

\( Z_v = (A \times B) \times FC \) ......................................................... (3.5)

**Where:**

\( Z_v = \text{infiltration volume of the Haffir (m}^3\) \\
\( A = \text{Bottom area of the Haffir (m}^2\) \\
\( B = \text{Infiltration depth} = 1.5 \text{ (m)} \\
\( FC = \text{Maximum soil water retention(Maximum soil moisture)} = (0.45m^3/m^3) \\

**Note:** The study assumed negligible seepage. Thus, the total losses:

\( V_1 = E_v + Z_v \) ................................................................. (3.6)

**Where:**

\( V_1 = \text{total water volume losses} \\
\text{This volume was cross evaluated based on the questionnaire observations and field survey. Accordingly, the Haffir water potential residence period (P}_{re} \text{ was:} \\

\( (P}_{re} = (\text{Available water ÷ Total consumption}) \) ....................................... (3.7)

**3.5 Data Analysis:**

The computerized based program SPSS and Excel Sheets were used to analyze the collected.
4.1 Rain Water Harvesting Techniques (RWHT) in Crop Production:

According to the results of the questionnaire, terraces is the dominant RWHT as 100% of the people using it. This is very high adoption rate, compared with that found in Sennar state (0.5%) as stated by Adeeb et al. (2005). About 74% of the people believe that RWHTs have good impact on crop production. The estimated increase ranged between 180-720 kg/fed, where the highest percentage found as 560 kg/fed (Table 4.1). On the other hand, 46% stated that the crop production could be stable at 270 kg/feddan without adopting RWHT (Table 4.2) if there is a good rainfall.

Among the questioned factors that could affect the crop yield, rainfall ranked first with 54% and the adoption of RWHT is ranked second (42%) shown in Table (4.3). This reveals that local people have very low knowledge on benefits of RWHT since RWHT could stabilized yield in arid and semi arid climates conditions as been widely stated worldwide (Rockstrom et. al., 2003; Shamseddin, 2009). About 44% believes that there is enough rainfall but the problem is dry spells. Shamseddin (2009) found that the poor crop yield under dry conditions of central Sudan is attributed partially to mismanagement of water as well as physical water availability.
Table (4.1): Yield increase (kg/fed) due to the adoption of RWHT in El Managil.

<table>
<thead>
<tr>
<th>Yield (kg/fedan)</th>
<th>Percent %</th>
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<tr>
<td>180</td>
<td>8.0</td>
</tr>
<tr>
<td>270</td>
<td>12.0</td>
</tr>
<tr>
<td>360</td>
<td>10.0</td>
</tr>
<tr>
<td>450</td>
<td>24.0</td>
</tr>
<tr>
<td>560</td>
<td>32.0</td>
</tr>
<tr>
<td>720</td>
<td>14.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
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Table (4.2): Crop yields (kg/fed) under non–rainwater harvesting condition.

<table>
<thead>
<tr>
<th>Yield kg/fed</th>
<th>Percent %</th>
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<tbody>
<tr>
<td>180</td>
<td>50.0</td>
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<tr>
<td>270</td>
<td>46.0</td>
</tr>
<tr>
<td>360</td>
<td>4.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table (4.3): Factors affecting production as stated by the respondents

<table>
<thead>
<tr>
<th>Factors</th>
<th>Percent %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rains</td>
<td>54.0</td>
</tr>
<tr>
<td>Techniques used</td>
<td>4.0</td>
</tr>
<tr>
<td>Rain and techniques</td>
<td>42.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

4.2 Rainfall analysis in El Managil Locality:

The average annual rainfall is found at about 180 mm for the period 1980-2009 (Figure 4.1). This is coupled with a very high standard deviation of 85.4 mm. Therefore, the crop production is hydroclimatologically limited unless rainwater harvesting techniques are scientifically practiced.
Hydrologically, the area found experienced a long dry period of consecutive eleven years (1980-1991). Generally, the central Sudan has witnessed repetitive drought cycles, the severe one is witnessed during the period 1980s. However, the area is currently under wet conditions since the rainfall showed increasing pattern from 1992 and onward (Figure 4.2).

4.3 Managing Haffir Water for Domestic Water Supply Purposes:

Haffir is the main source of drinking water supply in the area as the majority (60%) is found using Haffir and boreholes for domestic water supply as shown in Figure (4.3).

From hydro-climatic perspectives, the Haffir start its filling on 1st of July at the northern part and on 20th of July at the western part (Table 4.4). Haffirs reached their full capacity on 30th of August at the northern part and on 15th of September at the western part (Table 4.5). The water storage of the Haffir found to range between 29 and 30 thousand cubic meters. These differences show the temporal variability of rainfall and that some Haffirs received water from a macro catchment, especially those peaked in September as the area monthly rainfall showed very little amount in September 24 mm at 80% probability with a coefficient of variation of 0.5 (Shamseldin, 2009).
Calculated from Adam (2005)

Figure (4.1): Annual rainfall amount of El Managil area (1980-2009).

Figure (4.2): Annual rainfall trend of El Managil area (1980-2009).
Figure (4.3): The adopted Rainwater harvesting techniques (RWHT) in El Managil area for domestic water supply purposes.

Table (4.4): Time of water flows to enters the Haffir.

<table>
<thead>
<tr>
<th>Period</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>10(^{th}) of July</td>
<td>92.0</td>
</tr>
<tr>
<td>20 of July</td>
<td>8.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table (4.5): The periods when the Haffir reaches its full capacity.

<table>
<thead>
<tr>
<th>Month</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>30(^{th}) of Aug.</td>
<td>90.0</td>
</tr>
<tr>
<td>15(^{th})-sep</td>
<td>10.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Haffir water is found to last for 3-5 month depending on the location, Haffir characteristics and Haffir water management. 100% of the surveyed people believed that the current storage capacities of the Haffirs were quite enough for meeting their water need. Moreover 80% believed that the water of the Haffir is clean and safe from a qualitative perspective. However rainfall variability and the far distance of the Haffir from the villages, which averaged 400-600 m as shown in (Table 4.6),were the main obstacles regarding water availability and access in the region. About 70% of the people suggested the introduction of drinking water networks, while 30% refused this suggestion because of cost pertaining issues.

Generally, the Haffirs dimensions are found stable. The width and depth of the Haffirs however were reduced, resulting in reduction in the storage capacity and in turn in available water (Table 4.7). These reductions attributed to soil erosion problems (silt accumulation). Thus, the vegetation cover and land resources are under stress and need rehabilitation plans.

Table (4.8) showed the current water consumption, based on equations (3.1 and 3.2). The current Haffir available water may last for 3-5 month shown in Table (4.9), this residence period is same to the actual observed residence period that is 3-5 month. This period is too short due to high evaporation (21%) and deep percolation losses (47%) let alone the mismanagement problems. Therefore, mismanagement aspects exaggerated the water stress in the El Managil area (Table 4.9).

It is found that the local communities are responsible for the Haffir water management. However, the education levels of those communities are poor as shown in Table (4.10). Therefore, spreading of the education umbrella is crucial.
Table (4.6): Haffir distance from villages.

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>80.0</td>
</tr>
<tr>
<td>600</td>
<td>20.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table (4.7): Comparison between actual and design Haffir dimension.

<table>
<thead>
<tr>
<th>Location</th>
<th>Length (m)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Designed</td>
<td>Actual</td>
<td>Top</td>
<td>Bottom</td>
<td>Top</td>
<td>Bottom</td>
</tr>
<tr>
<td>Helat elhag</td>
<td>124</td>
<td>114</td>
<td>124</td>
<td>114</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elazara</td>
<td>130</td>
<td>112</td>
<td>131</td>
<td>112</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elamara elknanab</td>
<td>124</td>
<td>114</td>
<td>124</td>
<td>114</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omjen</td>
<td>130</td>
<td>110</td>
<td>130</td>
<td>110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helat Khalid</td>
<td>124</td>
<td>114</td>
<td>124</td>
<td>114</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Width (m)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Designed</td>
<td>Actual</td>
<td>Top</td>
<td>Bottom</td>
<td>Top</td>
<td>Bottom</td>
</tr>
<tr>
<td>Helat elhag</td>
<td>62</td>
<td>54</td>
<td>62</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elazara</td>
<td>70</td>
<td>54</td>
<td>70</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elamara elknanab</td>
<td>70</td>
<td>54</td>
<td>62</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omjen</td>
<td>70</td>
<td>56</td>
<td>70</td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helat Khalid</td>
<td>62</td>
<td>54</td>
<td>62</td>
<td>54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (m)</th>
<th>Capacity (m³)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Designed</td>
<td>Actual</td>
<td>Designed</td>
<td>Actual</td>
</tr>
<tr>
<td>Helat elhag</td>
<td>4.3</td>
<td>3.8</td>
<td>29764.6</td>
<td>26995.8</td>
</tr>
<tr>
<td>Elazara</td>
<td>4</td>
<td>3.5</td>
<td>30296</td>
<td>26631.5</td>
</tr>
<tr>
<td>Elamara elknanab</td>
<td>4.3</td>
<td>4</td>
<td>29764.6</td>
<td>27688</td>
</tr>
<tr>
<td>Omjen</td>
<td>4</td>
<td>3.8</td>
<td>30520</td>
<td>28994</td>
</tr>
<tr>
<td>Helat Khalid</td>
<td>4.3</td>
<td>4.1</td>
<td>29764.6</td>
<td>28380.2</td>
</tr>
</tbody>
</table>
Table (4.8): Water consumption.

<table>
<thead>
<tr>
<th>Location</th>
<th>Animals Numbers</th>
<th>Population</th>
<th>Total consumption m³ per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cows</td>
<td>Donkeys</td>
<td>Goats</td>
</tr>
<tr>
<td>Helatelhag</td>
<td>250</td>
<td>150</td>
<td>500</td>
</tr>
<tr>
<td>Elazaza</td>
<td>200</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>ElamaraElknanab</td>
<td>300</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>Omjen</td>
<td>500</td>
<td>300</td>
<td>600</td>
</tr>
<tr>
<td>Helat Khalid</td>
<td>700</td>
<td>400</td>
<td>650</td>
</tr>
</tbody>
</table>

Source: Calculated from Animal wealth, 2012

Table (4.9): Monthly Haffir water balance.

<table>
<thead>
<tr>
<th>Location</th>
<th>Available Water</th>
<th>Residence Period (month)</th>
<th>E%</th>
<th>Z%</th>
</tr>
</thead>
<tbody>
<tr>
<td>HelatElhage</td>
<td>2700</td>
<td>5</td>
<td>22</td>
<td>48</td>
</tr>
<tr>
<td>Alazaza</td>
<td>26631</td>
<td>5</td>
<td>26</td>
<td>53</td>
</tr>
<tr>
<td>ElamaraElknanab</td>
<td>27688</td>
<td>5</td>
<td>22</td>
<td>51</td>
</tr>
<tr>
<td>Omjen</td>
<td>29000</td>
<td>4</td>
<td>20</td>
<td>43</td>
</tr>
<tr>
<td>Helat Khalid</td>
<td>28300</td>
<td>3</td>
<td>17</td>
<td>39</td>
</tr>
</tbody>
</table>
Table (4.10): Education level in the selected villages, El Managil area.

<table>
<thead>
<tr>
<th>Level</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>38.0</td>
</tr>
<tr>
<td>Primary</td>
<td>38.0</td>
</tr>
<tr>
<td>Secondary</td>
<td>16.0</td>
</tr>
<tr>
<td>University</td>
<td>8.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>
5.1 Conclusions:

- The rainfall analysis of the last 30 years indicated increasing trend in the annual rainfall since 1992. However, the trend in monthly rainfall is not investigated and should be studied. The region suffers from a long drought period of eleven consecutive years (1980-1991). This drought cycle deteriorated the vegetation cover and disturbed and jeopardized the livelihood generation.

- From hydroclimatology perspective, rainfed agriculture is very difficult to be practiced unless, rainwater harvesting techniques are adopted.

- Terraces are found the dominant rainwater harvesting techniques in the region. Rainfall variability, dry spells are the main reasons behind low crop yield.

- Haffir is the dominant rainwater harvesting system for domestic water supply purposes in the region.

- The current designed dimensions of Haffirs were deteriorated due to silt accumulation, indicating soil erosion problems.

- High evaporation and infiltration resulted in poor Haffir water management, leading to short functioning period of Haffirs, not exceeding 5 months, which may be extended using good water management perspectives.

5.2 Recommendations:

- Designing terraces on the basis of scientific pillars.

- Increase education umbrella to raise the awareness regarding Haffir water management

- Using sedimentation trap to reduce silt accumulation in the Haffir.

- Restoring the vegetation cover so as to combat evaporation.

- Regular training programs in water management for the related governmental staff, and local communities.
REFERENCES


QUESTIONNAIR

Name or the subject of the Questionnaire: Rain Water Harvesting Techniques.

Section (1):

1. Population approximately

1.1 Social status:

The head of the household:

Male ( ) Female ( )
Married ( ) Unmarried ( ) Divorced ( ) Widow ( )

1.2 Education level

None ( ) Primary ( ) Secondary ( ) University ( )

1.3 Family

How many people currently live in your household?

<table>
<thead>
<tr>
<th>Numbers</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3.1 Under 5 years old</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3.2 6 – 15 years old</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3.3 16 – 60 years old</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3.4 More than 60 years old</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. What is your main work?

Farming ( ) grazing ( ) others ( )
3. How many animals currently you have?

<table>
<thead>
<tr>
<th>Animals</th>
<th>Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camels</td>
<td></td>
</tr>
<tr>
<td>Cows</td>
<td></td>
</tr>
<tr>
<td>Sheep’s</td>
<td></td>
</tr>
<tr>
<td>Goats</td>
<td></td>
</tr>
<tr>
<td>Donkeys</td>
<td></td>
</tr>
</tbody>
</table>

**Section (2):**

2. Occupation:

2.1 Water harvesting techniques:

2.1.1 Types Used:

- Embankments ( )
- Terraces ( )
- Dams ( )
- Hafirs ( )
- Others ( )

2.1.2 If not used. Why?

________________________________________________________________________

________________________________________________________________________

2.1.3 Why the types used? (Reasons). Explain?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

2.2 What is the impact of using or applying that specific technique?

- Yield increasing/fed- No ( ) yes ( )

From ___________ To ________________

2.3 Without applying that technique the yield is _______ /fed
2.4 Factors affect in production increase?
Rains ( ) Rains and Techniques applied ( ) Techniques applied ( )

2.5 Is the quantity of rainfall enough or not?

Section (3):

3. Drought Topping Strategies:

3.1 Water storage
Hafirs ( ) Embankment ( ) Terraces ( )

[In relation to water availability]

3.2 Drinking Water:
Hafirs ( ) Boreholes ( ) shallow well ( ) Dams ( )

Other (Specify) 

3.3 If drinking water source is Hafirs:
3.3.1 When the first water will enter the Hafirs?

3.3.2 When it will be full of water?

3.3.3 How long time period?

3.3.4 Source of water entries the Haffirs:
   Rains ( ) khors ( )

3.3.5 Is the Haffirs water clean and safe?
   Yes ( ) No ( )

3.3.6 Is the capacity of the Hafirs is enough?
   Yes ( ) No ( )

3.3.7 If not what do you suggest?
Increase capacity ( ) Construct another source ( )

3.3.8 What is the main problem (Users of the Haffir)?

--------------------------------------------------

3.3.9 What is the distance to the Hafir (home)?

--------------------------------------------------

3.3.10 What do you suggest for distance issue?

--------------------------------------------------

3.3.11 The responsibility of the Hafirs. (Operation-maintenance and inspection)?

--------------------------------------------------

Section (4):

4. Water consumptions (Rural Water Corporation):

4.1 Family --------------- Liter/day
4.2 Animals --------------- Liter/day
  4.2.1 Sheep’s --------------- Liter/day
  4.2.2 Goats --------------- Liter/day
  4.2.3 Cows --------------- Liter/day
  4.2.4 Camels --------------- Liter/day

Section (5):

5.1 What means or methods used to conserve Haffirs water?
Polyether (Evaporation or Infiltration).

--------------------------------------------------

5.2 What methods are used to clean water?
The Haffir: (Filling - Refine - Desalination). (RWC)

5.3 How is it done? (The methods) (RWC)

5.4 Technical specification of the Hafirs. (RWC)
   (Design - Location - Soil type and Physical - Chemical properties)

5.5 Capacity, how is it calculated?

5.6 Population need?

5.7 Physical condition?