Evaluating the potential of road rain water harvesting in Yemen – Rural Roads

A case study of the Maghrabah Manakah Bab Bahil Road and the linked rural road Jabal Ekbari and Jabal Awi Road, Sana'a Governorate

Prepared by: Eng. Mohamed Abdullah Al-Abyadh

Supervise by:
Main supervisor: Dr. Sharaf Adeen Abdullah. Saleh
Co-supervisor: Dr. Abdullah Ahmed Al-Maswari
Abstract:
Farmers and people living in Manakah area are suffering from water scarcity and limited water resources. The objective of this research is to optimize the benefits of water harvesting from roads for the local communities in socio-economic development (water storage volume and the beneficial reuse of it). In addition to the environment protection for roads, this is focusing on the road of Maghrabah Manakah Bab Bahil Road and the linked rural feeder road Jabal Ekbari and Jabal Awí Road Sana’a Governorate. It discussed the role of geometric design of the road to enhance the water harvesting from the road. The research approach concentrated on a reconnaissance survey through field walk to record the farmers’ initiatives for water harvesting and drainage structures, with random explanatory farmers’ sample interviews, and semi-structured questionnaire, to evaluate the awareness, water rights, rainwater variability with climate change, pollution, women role and activities in rainwater harvesting along the study road sections. Finally, a calculation of the potential rainwater harvesting for main road and sub-road and water harvesting balance for the water harvesting structures were conducted. The case study road sections were two kinds: the first one is non-asphaltic road under construction, start from Souk Maghrabah Manakah to Bab-Bahil with length about 36 km, the second is rural feeder road stone paved in critical sections.

The research output is reported as the farmers benefits from Road Rain Water Harvesting (RRWH), which are water saving, increase production, supplementary irrigation and cover needs in dry season. In addition the harvested water is used in drinking, agriculture, domestic and livestock breeding. moreover, the results obtained show that women play a main role in water resource and water harvesting which will help to reduce the effort and time for fetching water from the nearby water resource. In the other hands road engineers’ awareness on the concept of water harvesting and water for irrigation from road surface and road structures was not considered by most of the road engineers unless were requested by farmers. While about two thirds of the engineers represent the possibility to use roads for groundwater recharge. And the potential RRWH will be a renewable source of water if the water management is applied and farmer’s initiatives were supported. Also in general the road drainage structures were designed and implemented by different ways such as experience, cost, terrain nature and project type.

The research concluded that the main road catchment yield affected by the natural road catchment, the culverts catchments, and the road surface geometric properties (profile distances between drainage points, cross slope, super-elevation method, number of horizontal curves). And the estimated potential RRWH quantity from the main road natural catchment is 1,662,729.25 m³, also the total RRWH which generated from 10 km length at 40 culverts location equal to 529,178.31 m³. The amount of potential harvested water in suitable locations (22 culverts) equal to 188,446.87 m³, that represents 36% from the total generated amount of water.

The research recommended encouraging and improving farmer's initiatives technically and institutionally, and also it should be supported from government's agencies and donor programs. Moreover awareness and training workshops should be arranged for road engineers with hydrologic and watershed specialist.

Key words: Roads Rainwater Harvesting, Culverts, Road Engineers, Farmers.
1. Introduction

Water scarcity, limited water resource and climate change are the main problems facing Yemen farmers. Drought has been a common occurrence as rainfall has decreased and temperatures have risen. Droughts affect the livelihoods of farmers in particular, and contribute to a lack of food security for most population.

In Yemen there is no perennial surface water resources, and the country depends entirely on rainfall, groundwater and flash flooding. The challenge facing the Government with water is defending the best way to control and manage the replenishment and depletion of groundwater resources by improving water harvesting and raise the efficiency of water uses. For millennia, farmers have practiced sustainable agriculture using available water and land. Through a lot of mountain terraces, elaborate water harvesting techniques, spring irrigation systems and community-managed flood.

Furthermore, Yemen’s topography is known through its rich variety, which is varying from vast plains to steep mountain slopes. It was stated that Yemen has 71,300 kilometers of roads according MOPWH, where some of Yemen roads located in mountainous areas or along the wadis, while road system design is adapted to each environment. Also, the rainwater harvesting potential changes accordingly to each road’s stretches.

In Yemen, surface water is estimated to be about 1,500 Mm\(^3\)/year - Meanwhile, some roads are subjected to severe damages as a result of flash flood events throughout the country. So by accelerated growth in road industry, the negative impact of road industry is modified the natural flow of surface water by concentrating flows at certain points and, in many cases, increasing the speed of flow. These changes can contribute to flooding, soil erosion, channel modification, and siltation of streams depending on local conditions.

In Manakha area along Al-Maghrabah - Bab Bahil road and it’s rural feeder road at Sana’a Governorate, “people face recurrent droughts, and lack of green cover, while rainwater is the sole source of water, rainwater harvesting establishments have been deployed by local inhabitants as an effective water development and management technique”, Accordingly, any road rainwater harvesting is necessary to be adapted to climate change by integration road construction and findings, which can be up-scaled easily.

Based on the previous, all efforts are required to conserve Yemen water resources and find alternative water resource for irrigation and other uses. Where surface water is considered to be an important source for irrigation in Yemen.

On the other hand, a highlight should be rise to benefit from the harvested surface water running on the roads and its uses in agriculture or livestock breeding to minimize the negative impacts caused by water running in the roads.

1.1 Objectives of the research

The main objective of this research is to optimize the benefits from rainwater harvesting which is collected in tanks and side ditches cisterns, and to determine the effect of road construction and drainage structures on the water harvesting and recharge from road in Yemen especially in mountainous areas. Focusing on the road of Maghrabah Manakah Bab Bahil Road and the linked rural road Jabal Ekbari and Jabal Awi Road Sana’a Governorate

a. Sub-objectives:
- Check the awareness of roads engineers whom are responsible for design, supervision and maintenance on the importance of **Integrated Water & Roads Management**.
- Development water storage volume and the beneficial reuse of additional captured water to improve socio-economic of local communities and for the environment protection

### 2. Research Approach

#### 2.1 Methodology

In order to achieve the objectives of this research a comprehensive approach has been done to formulate and include:

1- Literature review
   - Study all previous reports, studies, and researches.
2- Field works which consist of:
   a- A reconnaissance survey to record the farmers’ initiatives for water harvesting structures and constructed culverts, with random explanatory farmers’ sample interviews, and semi structured questionnaire, to evaluate the awareness, water rights, climate change, pollution, women role and rainwater harvesting activities along the study road sections.
   b- Collecting data and calculating to study the potential rainwater harvesting from road
   c- Questionnaire:
      A questionnaire have been implemented and filled by the specialist's engineers who are responsible for the design, supervision and maintenance of roads, including information about RRWH concept and how to benefit from it and design standards of road water drainage structures.

#### 2.2 Study area

##### 2.2.1 Location

The study area is a part of rural road at Manakhah district which is located at the west highlands of Yemen which is called Haraz Mountain, that locates at distance about 120 km from Sana'a along Sana’a – Hodiedah road. It is a part of Sana’a Governorate with total area of 700.2 square kilometer. The study road area was choosing in the route from Maghrabah – Manakah to Bab Bihil with a catchment area of 73.13 km², which represent a small part of Wadi Surdud catchment 2700 km², which is part of the Tihama plain catchment, Figure (1) shows the location of the study area.

![Figure 1 study area location](image)
2.2.2. Topography

Manakhah district consists of a large, dissected plateau marked with rugged volcanoes mountains. The western escarpment, which forms a transitional zone between the Tihama and the upland plateau, it is steep and rugged. Where thousands of small villages are situated on rocky outcroppings of this slope, which supports crop cultivation via an elaborate terracing system. Figure (2) shows the topographic map of the study area.

Figure 2 Topographic map of the study area

2.2.3. Study Road Sections

The study roads consist of two routes: main road which is under construction and the sub-study road which is rural feeder tertiary road with stone paved sections; both of them are described below:

2.2.3.1. Main Study Road

The selected main road is Maghrabah Manakah Bab-Bahil Road in the Sana'a governorate, a crosses part of Haraz highlands and linked with the Sana'a – Hodida main road at the start and end points. It has a length about 36 Km and start from the Souk (Market) of Maghrabah Manakah (latitude: 15.097250°, longitude: 43.736450°) and elevation of 2000m (asl) and passed through several villages (Bait Shiabah, Bani Katab, Bait Hadad, Draj Al-Gail, Al-Tabyan, Al-Me'an, Al-Dhola'a, Al-Darmy, Bait Al-Hood, Bait Al-Thobani, Al-Zaih, Al-Ghawanima, Al-Jazabah), and end at Bab-Bahil (latitude: 15.123880°, longitude: 43.657072°) at an elevation of 1200 m (asl).

The road is earth road surface under construction phase to be an asphalted road and the road surface is in subgrade phase. It is deteriorated by the water erosion that forms some longitudinal gullies. The road passes through multiple topography change from steep to moderate with different slopes and crosses some sub plateau and several small water’s fall streams and wadi’s such as wadi Bani Khatab, wadi Tabyen, Bait Thowbani, wadi I’ryaha and Howiad wadi. The land use along the road contains scattered villages, agriculture terraces, rock outcrops, hill slopes, and pastures & regional plants cover.

2.2.3.2. Sub Study Road

The sub study road is a feeder rural road (Jabal Ekbari and Jabal Awi Road – Hasaban subdistrict – Manakah district – Sana'a Governorate). It has a length about 16 Km and starts from Bani Khatab (latitude: 15.127734°, longitude: 43.715219°) and elevation of 1861m (asl), and intersect the main study road at a station of 5 km from the start station and intersect it at kilometer 20.5 in the end (latitude: 15.190629°, longitude: 43.683351°) at an elevation of 1877m (asl).

The road is earth dirt surface in semi flat sections with scattered stone paved section (cumulative paved length about 8 Km) at the steep, hard and rough slopes. The road passing in a mountainous terrain vary from moderate to steep slopes and it pass in the top of mountain (Jabal Al-Awi) with different slopes.
This road passes near the terraces which have been planted with coffee, qat and other rain-fed plants. In general the road alignment follows the existing landscape of the surrounding mountains and cross multi agriculture terraces.

2.2.4. Hydrogeological characteristics
The hydrogeological map produced by the (Ministry of Oil and Mineral Resource) classified the hydrogeological characteristics of the study area as follow:

**Tertiary Volcanic** considered moderately or poorly productive aquifers in which fissure flow is dominant.

**Tertiary Intrusive**: is considered as strata with essentially no groundwater resources which consist of granites, granodiories and gabbros, mostly cropping out in a broad band along the western margins of the Yemen highlands region. Primary permeability is likely to be negligible in the intusives because of the close crystalline structure of the rock, but limited groundwater flow may occur in shallow cracks and joints opened by weathering. However, it is not likely to be generally sufficient to sustain flow to a well. Figure (3) shows the hydrogeological map of the study area.

![Figure 3 hydrogeological map (source: Ministry of Oil and Mineral Resource)](image)

2.3. Field Work Results

2.3.1. Reconnaissance survey of farmers initiatives and rainwater harvesting structures and techniques
A long the study main and sub roads sections there are a number of water harvesting structures with multiple sizes either opened or roofed with single skin panels roofs, old corrugated zinc panels roofs, wood shrubs roofs or with natural soft rock cave roofs which found in dig cisterns. Figure (4) shows the location of water harvesting structures along the study roads.

![Figure 4 Water harvesting structures along the main and sub-road](image)
At the present time, people already have been harvested water from roads surface and from culverts outlets by different ways such as: earthen humps and small cascade steps - to divert the harvested water from road surface water, either to water harvesting structures or to the farms. The farmers used sand and dry stone check walls to build humps and cascade steps. Some of the water harvesting structures along the main and sub road are shown in Figures (5) to (11).

Figure 5 Left: Open water harvesting tank near coffee terraces, Right: Under construction water harvesting tanks

Figure 6 Left: shrubs roofed water harvesting tank the farmer use an earth hump to divert the water from the road surface. Right: old corrugated roofed tank the farmer use parallel side ditch to divert the water from the road.

Figure 7 Left: Two roofed tanks the farmers use an earth hump to divert the water from the road, Right: Roofed tank with old corrugated panels and the farmer dry check wall and intercept running water from the road surface.

Figure 8 Roofed Dug Cistern near the main road
There is a lot of water harvesting techniques which have been already used for water harvesting from the road such as:

1. Water harvesting from Road surface: by using the road surface as main catchment channel to collect and divert water to the purposed location with using the (inward slope) of the cross section or the rolling dips and humps.

2. Water harvesting using Rolling Dips: there are a lot of stone paved rolling dips or earth rolling dips (humps), which built from sand and dry stone check walls to divert and collect road surface water to the proposed locations.

3. Water harvesting from Channels: there are dry stone channels to transport the surface water from rolling dips and spillways to the proposed location, these are longitudinal channels parallel to the road alignment. Figures (12) to (15) show some water diverting techniques along the sub-road.
2.3.2 Potential road rainwater harvesting

The catchment area for the study watersheds were computed using GIS tool. The study watersheds area consist of 27 sub catchment areas with total area of 73.13 km².

Figure (16) illustrate the sub-catchment of the study watershed area with culverts locations.
Main assumptions: The formula of Ben Kubbinga, 2012 (4) was used to calculate the harvested rainwater.

\[
\text{Water Harvested} \, (\text{m}^3) = \text{Catchment Area} \, (\text{m}^2) \times P_d \, (\text{m}) \times K \times E
\]

Where: \( P_d \, (\text{m}) \): The average annual rainfall, it is estimated 371 mm as predicted from SAM SAM tool.

\( K \): Runoff coefficient which depend on the slope and soil type.

\( E \): Efficiency Factor which will be 0.7

The potential road rainwater harvesting were calculated for the main and sub-road based on the above outcomes and as follows:

2.3.2.1 Main Road

Three methods were used to predict the potential rainwater harvesting quantity and show the farmer’s initiative for main road as follows:

1. Through the whole road length 36 km and with the whole road natural catchment areas (catchment above the road surface).
2. At culverts points through 10 km of the road and with reference to culverts catchment characteristics and cross section.
3. A detailed case for farmer initiative and benefits of road rainwater harvesting structure.

The following steps summarize the general calculation methodology:

- The main road passed through 17 sub catchment areas with total area of 53.58 km²
- The 97 design culverts coordinates for the main road were modified to be adapted with the UTM and projected to the study main road and the 36 executed culverts were surveyed using GPS and projected accordingly. Figure (17) shows culverts location along the study main road.
- All the data set from GIS for sub catchment areas of the study watershed including culverts and water harvesting structures were projected to GOOGLE EARTH, after that the area tool was used to define the road natural catchments and culverts catchments area.
In this study several cases are conducted as follows:

**Case 1 road natural catchment**

- The road natural catchment areas - can be defined as part area from the sub catchment areas which is affected on the road rainwater harvesting. This catchment is consisting of the culverts catchment and strip catchment. Figure (18) shows a sample of culverts and strip catchment of the road natural catchment.

In addition Table 1 shows the detailed calculations of the sub-catchment areas and road natural catchment areas with the culverts number and type in each sub-catchment.
Table no. 1 Road and intersected sub-catchment areas and road natural catchment area with number of culverts and culverts type in each sub catchment.

<table>
<thead>
<tr>
<th>No.</th>
<th>Sub-Catchment Category</th>
<th>Sub-Catchment Area (Km²) (1)</th>
<th>Road Natural Catchment Area (Km²) (2)</th>
<th>Percentage of (2) from (1)</th>
<th>No. of Culverts</th>
<th>Culvert Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>5.71</td>
<td>0.38</td>
<td>6.65%</td>
<td>10</td>
<td>Executed</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>3.41</td>
<td>0.11</td>
<td>3.23%</td>
<td>4</td>
<td>Executed</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>3.84</td>
<td>0.26</td>
<td>6.77%</td>
<td>4</td>
<td>1 Executed / 3 Design</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>1.81</td>
<td>0.22</td>
<td>12.15%</td>
<td>3</td>
<td>Design</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>12.46</td>
<td>2.54</td>
<td>20.39%</td>
<td>23</td>
<td>Design</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>6.59</td>
<td>2.86</td>
<td>43.40%</td>
<td>15</td>
<td>Design</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>1.48</td>
<td>0.36</td>
<td>24.01%</td>
<td>10</td>
<td>Design</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>0.78</td>
<td>0.09</td>
<td>11.54%</td>
<td>2</td>
<td>Design</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>4.28</td>
<td>0.64</td>
<td>14.95%</td>
<td>16</td>
<td>Design</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>7.93</td>
<td>0.66</td>
<td>8.32%</td>
<td>10</td>
<td>5 Executed / 5 Design</td>
</tr>
<tr>
<td>11</td>
<td>8</td>
<td>0.08</td>
<td>0.02</td>
<td>25.00%</td>
<td>1</td>
<td>Executed</td>
</tr>
<tr>
<td>12</td>
<td>11</td>
<td>0.53</td>
<td>0.16</td>
<td>30.19%</td>
<td>3</td>
<td>Executed</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>0.22</td>
<td>0.02</td>
<td>8.00%</td>
<td>1</td>
<td>Design</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>0.1</td>
<td>0.07</td>
<td>70.00%</td>
<td>1</td>
<td>Design</td>
</tr>
<tr>
<td>15</td>
<td>17</td>
<td>1.55</td>
<td>0.31</td>
<td>20.00%</td>
<td>5</td>
<td>Design</td>
</tr>
<tr>
<td>16</td>
<td>19</td>
<td>0.65</td>
<td>0.49</td>
<td>75.38%</td>
<td>6</td>
<td>Design</td>
</tr>
<tr>
<td>17</td>
<td>21</td>
<td>2.16</td>
<td>0.66</td>
<td>30.56%</td>
<td>19</td>
<td>12 Executed / 7 Design</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>53.58</td>
<td>9.85</td>
<td>18.38%</td>
<td>133</td>
<td></td>
</tr>
</tbody>
</table>

The potential RRWH which generated from the road natural catchment by assuming its using runoff coefficient of 0.65 with the (Main assumptions) is 1,662,729.25 m³.

**Case 2: for 10 km from the main road.**

In this case study 10 km length of the main road was selected to compute and estimate the potential of rainwater harvesting at culverts location, total culverts exists in this length are 40 culverts.

Two catchments were defined as follows:

A- **Road catchment:**

The catchment width of the road surface was computed for 10 m width and catchment length and slope were calculated for each culvert by using the road profile and culverts location to define the accumulated catchment length at each culvert location.

B- **Culverts catchment:** which represent the concentrated flow from the catchments upper the culverts. These catchments areas were calculated using GOOGLE EARTH area tool or as strips areas.

The following assumption were taken to calculate the potential rainwater harvesting to culverts

- **Runoff coefficient**
  
  I- Road surface runoff factor of 0.85,
  
  II- Culverts catchment runoff factor of vary according to catchment characteristics and slopes, the details is given in table no. 2 as a sample calculation.

The total potential RRWH which generated from 10 km at 40 culverts location equal to 529,178.31 m³ (from culverts catchment 516,474.44 m³ &from road catchment 12,703.87 m³).

The detailed results were presented in table no. 2. The culverts outlets type were defined according to the land use of the surrounding area to find out the potential locations of RRWH

- According to the culverts outlet characteristics there are only 22 culverts locations is appropriate for potential water harvesting, while the 18 culverts located either in stream ways, steep slopes or stepped the road alignment.
- The amount of potential harvested water at the appropriate culverts locations equal to
188,446.87 m³ (from culverts catchment 180,908.43 m³ & from road catchment 7,538.44 m³) which represent 36% from the total generated amount for the 10 km length case.

- There are 13 water harvesting structures along the 10 km length: three at executed culverts outlets at station (800, 1400 and 3025), two are at design culverts locations at station (5675 and 6325), and the remaining 8 are near the road which use the road surface, humps, channels, spillways to divert and harvest road rainwater.

Table no. 2 shows a sample of calculation for the Potential RRWH at culverts locations for the main road and culvert outlets potential type.

**Case 3 Water Harvesting Tank Calculation**

In this case a detail study for farmer initiative to use rainwater from box culvert outlet and store the harvested water in a tank, the farmer uses the harvested water to irrigate Qat terraces.

At station 1+400 a (1*1) box culvert outlet ends with an earthen pond as temporary sedimentation and storage facility where the farmer transfer the water to the water harvesting tank by gravity using a plastic tube. Figure 19 shows the water harvesting tank at the culvert outlet and the temporary sedimentation & storage pond with the plastic tube which used to transfer the water to the harvesting tank.

Tank’s volume = (20 * 10 * 5) = 1000 M³

Catchment area: The catchment is 75 m length from station 1475 to station 1400.

1- Road catchment area is 750 m²
2- Culvert catchment area is 21,898 m²

Potential harvested rainwater: The annual rainfall is 0.371 m, runoff catchment coefficient is 0.75, and efficiency factor is 0.7.

Potential harvested rainwater = 4430.742 m³

Qat Terraces Area: (1) New Terraces area = 3174 m² with about 260 trees, (2) Old terraces area = 7726.92 m² with about 330 trees, Total area = 10,900.92 m² and total trees = 590.

Qat Crop Requirements: Per tree 100 liter per irrigation as each season about three irrigations where conducted. For this location qat water requirement by assuming the trees irrigated three times per season (farmers is estimated the needs about 100 liter for each tree in each irrigation).

= 100 * 590 * 3 = 177,000 liter = 177 m³

Qat Yields: Yield [Tons/ha] = 1 (Source: Agricultural Statistics Year Book)

Terraces Qat Yields = 1.090092 * 1 = 1.090092 tons = 1090.092 kg

Total RRWH = 4430.742 m³

Qat Needs = 177 m³
Water harvesting balance calculation for main road

For the main road the water harvesting balance calculation for the water harvesting structures exist in the main road was estimated by assuming the average volume of each structure to be 660 m$^3$ from questionnaire.

The total structures along the study road = 33
Average potential water harvesting in structures = 33 * 660 = 21,780 m$^3$.

From case 2: if we consider the result of potential suitable location as a percent of 36% and use it to calculate the potential RRWH which will harvested from road natural catchment

Calculated potential WH from road natural catchment = 36% * 1,662,729.25 m$^3$ = 598,582.53 m$^3$

This amount is supposed per year if we divided it by two (the two rain seasons) = 299,291.265 m$^3$

Water Harvesting Potential Ratio = 21,780 m$^3$/299,291.265 m$^3$ = 7.28%

Water Harvesting Potential structures needed = 299,291.265 m$^3$ - 21,780 m$^3$ = 277,511.265 m$^3$/660 = 420 structures

2.3.2.2 Sub road

Two methods were used to predict the potential rainwater harvesting quantity and show the farmer’s initiative for the sub road as follows:

(1) Through the road length 16 km.

(2) Detailed study of the underground cisterns initiatives.

Case 4: Through the road

In this case and as the sub-road lay at the top border line of the sub-catchments area, so only the road surface of 4 m and strip natural catchment of 4 meter will be used to predict the potential rainwater harvesting quantity from sub road 16 km length. And the runoff factor is assumed 0.75 with the (as in Main assumptions) above.

The potential RRWH which generated from 16 km is 24,931.2 m$^3$.

Case 5: Underground Cistern

In this case a detail study for farmers initiatives related underground cistern in the sub road were selected to show farmer’s indigenous harvesting techniques.

This underground cistern excavated manually in the soft tuff rocks as caves or use arched stone roof. Sediments traps, stone spiral stairs and steel bars doors or steels panels doors were used in some cisterns.

Problem:
The main source of water in this area is rain and the farmers face water scarcity during dry periods of the year. Therefore, the farmers dug a number of 16 underground cisterns in natural tuff soft rocks in the
inner edge of the mountain or under/near the houses to collect runoff and store it to dry season along the sub-road section which located in the upper catchment border. Figure (20) shows the typical drawing sections for some cisterns. Figure (21) shows some photos of constructed cisterns near the houses, under the house and beside/along the road in the inner side of the mountain.

![Typical drawing sections for some cisterns](image1)

**Figure 20 Typical drawing sections for some cisterns (Source: Dr. Ali Al-Ghail)**

![Cisterns along the sub road](image2)

**Figure 21 Cisterns along the sub road**

The catchment area: The main catchment area is the road surface and the adjacent mountainous slopes by the road which located at the top catchment of the study area.

Average Volume: The average volume varies from small to large cisterns and can be estimated from four samples to be 60 m³.

Cost: the cistern mostly dug by the beneficiaries efforts and the estimated cost according to some beneficiaries were exaggerated and not reliable.

Social benefits: the dig cistern is used for domestic water requirement and sometimes for irrigate cash crops during drought periods where the cash crop depends on the markets demands such as tomatoes.

Water harvesting balance for sub road

For the sub road the water harvesting balance calculation for the already and surveyed water harvesting
structures along the sub road was estimated by assuming the average volume of each structure to be 60 m$^3$ for cisterns from case 5 and an average of 660 m$^3$ for tanks.
The total structures along the study road = 57 (21 underground cisterns & 36 tanks)
Average potential water harvesting in structures = 21* 60 + 36* 660 = 25,020 m$^3$

2.3.3 Stakeholders interview analysis and results

During the field visit a number of interviews were conducted with farmers and beneficiaries along the road.
The SPSS and Excel software program had been used to analyze the collected data obtained from the stakeholder interviews.
Figure (22) shows some photos of the interviews with the stakeholders.

![Figure 22 Some photos of the interviews with the stakeholders](image)

The interviews show different and varying results especially for the multiple closed choices (farmers choose more than one choice), Thus the researcher use the multi response analysis tool to calculate the statistical of the sample cases percent and the responses frequency which is used in result analysis as it give a real percent of each multiple choice, (this clarifies the use of two bar charts analysis in some charts).

1. Water Resource
Almost all the samples rely on rainwater as main source of water, in adjacent to other sources. The multiple responses of the farmers questionnaires were 41 out of 22 sample case.
The results from questionnaires analysis have designated that the available water resource are : 53.7% rain; 4.9% local water network; 24.4% wells; 7.3% water trucks; 7.3% springs and 2.4% fog harvesting. Figure (23) shows data analysis of water resource.

![Figure 23 Data analysis of water resource in the study area](image)

2. Water Scarcity Issues and Adaptation
The farmers raise their concerns of water scarcity as clarified from the samples 95% of the farmers face water scarcity, while 5% don’t face water scarcity. Figure (24) shows data analysis of water scarcity issues.
The farmers used to face the water scarcity by using different adaptation measures as follows: convey water from the water sources, from rainwater harvesting, purchase water trucks, harvest rainwater from roofs, share spring water turns, fog water harvesting, water saving, and hand wells.

3. Climate change risks and rain season change
The farmers face climate change risks as explained from the samples 27% of the farmers face water scarcity, 36% face drought and lack of agriculture & pasture, and 23% their income were reduced, while 14% don’t face any risks due to climate change. Figure (25) shows data analysis of climate change risks.
The change of rain season from farmer’s point of view 86% said there are lack of rain, while 14% said the rain season delayed. Figure (26) shows data analysis of rain season change.

4. Roads & Water Harvesting
   
a. Data analysis of land ownership nearby road and running floods water use
   The land ownership adjacent to the road side indicate that about 91 % of the sample farmers have lands adjacent to the road side and use the floods water running from road to irrigate their farms and 9 % of the sample farmers don’t use the floods water running from road and don’t have lands adjacent to the road. Figure (27) shows data analysis of land ownership & running roads floods use.

   b. Data analysis of road rainwater harvesting techniques:
The multiple responses of the farmer’s questionnaires were 33 out of 22 sample case. The questionnaires have indicated that farmers used to harvest the floods water running from road surface and road structures by using different techniques as: 57.6% using humps across the road; 15% from channels; 9.1% from side ditches; and 3% from (culverts; spillways; terraces and WH structures), while 6.1% don’t use any techniques. That means all the above techniques available are used to harvest rainwater from road. Figure (28) shows data analysis of road rainwater harvesting techniques.

5. Data analysis of water rights
All farmers consider rainwater running on the road their right. From their point of view about why they consider rainwater running on the road their right: 59% of them said it is a well-known right, 18% said it is priority and well known water ways (MARAHEG), 18% said water streams ways remain as they were, and 5% said it is father and grandfather MANHAL. Figure (29) shows data analysis of water rights from roads.

   Some farmers claimed that water channels were abandoned after the road excavation and the road profile
were not appropriate to divert water and they used humps and pumps to transfer the water to the tank.

6. Usage & Benefits of RRWH
a. Data analysis of roads rainwater harvesting usage:
The multiple responses of the farmers questionnaires were 61 out of 22 sample case. The questionnaires showed that farmers are using the harvested water running from road surface and road structures for different proposes as follows: 14.8% for drinking; 31.1% for agriculture; 26.2% for domestic & livestock, and 23% for supplementary irrigation; while 4.9% don’t use it. Figure (30) shows data analysis of RRWH usage.

b. Data analysis for benefits from harvested rainwater from road:
The multiple responses of the farmers questionnaires were 48 out of 21 sample case. The questionnaires indicated that the benefits of harvested road rainwater are as follows: 43.80% water saving; 35.40% increase production, 8.30% reduce buying water; 6.20% supplementary irrigation, and 6.20% had other views such as cover needs in dry seasons. Figure (31) shows data analysis of RRWH benefits.

8. Main problems prevent flood water delivery to farms and solution:
About 55% think that there is no problems, while 36 % thinks that the problems are water blockage by road excavation debris and huge floods, and 9% thinks that the problem is road construction as the road design level is below the farm land. Figure (32) shows data analysis of problems prevents flood water delivery to farms. About 27 % of the inhabitants showed that the problems were resolved by understanding, and 18% thinks that road structures and construction regulation will solve the problems especially the use of dynamite, while the rest have no problems to be solved. Figure (33) shows data analysis of solution of main problems related flood water delivery.

9. Roads water damages & mitigation
The data showed that about 64% roads damages and farm lands ruined and buried, 9% disturb and damaged water ways, 14% erosion, 4% transmit of sediments, erosion, and flood accumulation and 9% no damages. Figure (34) shows data analysis of damage caused by water from roads.
Based on the interview questionnaire and from farmer's point of view about the mitigation of damages they suggested the following measures are: the uses of spillways, humps, channels, ponds, sedimentation checks, check walls in water streams, water retention, diversion structures near roads, and check dams to collect water. Others think that the contractor excavation debris must haulage the allocated locations and contractor should maintain water channels and old water ways. Others think that maintenance for agricultural terraces should be conducted by farmers, also paving road by stones and protection works may prevent erosion.

10. RRW Contamination, source, solution and purify techniques
The results indicated that 50% think that the water from road is contaminated and 50% think that the water from road is not contaminated. Figure (35) shows data analysis of RRW contamination.

Contamination source: the result indicated that half of the inhabitants think that the contamination of harvested water from road surface is due to clay, those represent 32 %, while 9% think the contamination is from animal waste, and 9% think the contamination is from clay, animal waste and tires residues. Figure (36) shows data analysis of contamination source.

Solution of contamination: about 86% think that there is no solution as the harvested water were used in agriculture, while 9 % suggested using filters and 5% suggest using sedimentation basins. Figure (37) shows data analysis of contamination solution.

Purify techniques: about 64% don’t use any purification techniques, while 14 % using silver filters, 9% using metal filters, 5% using sedimentation basins, 4% using sand filters, and 4% using chlorine and filters. Figure (38) shows data analysis of purify techniques.

Almost all the sample thinks that RRWH will help women in agriculture and households works. From farmer's point of view on the rule of women in water resource and rainwater harvesting. 77% of them said that women bring the water from the water sources to the house, 14% said that women bring the water from the water sources to the house and harvest rainwater from roofs, and 9 % said that women bring water from the source to the house and divert flood water in the absence of the man & believe that woman is beside the man under rain and sun. Figure (39) shows data
2.3.4. Road engineers questionnaire analysis and results

A structured questionnaire was distributed among 45 random road engineers in MOPWH, RMF, GCRB, and RAP that filled by them to find out the general methods used for water related structures designs in roads, and to measure their awareness of water harvesting aspects from roads. Also the Excel program and SPSS had been used to analyze these data.

The results from the engineer’s questionnaire are different and vary from engineer to engineer. Moreover, there are number of multiple closed choices, with the possibility to add other views to the closed choices. The analysis in this research used the multi responses analysis tool to calculate the statistical of responses frequency for each individual choice, and the other views were listed separately. This clarifies the two percentage of the bar chart and the responses percent were used in result analysis in multiple choices questions.

1. Road Engineers awareness on water harvesting from roads:

The analyzed results indicated that about 58% of the engineers have experience about the effect of roads on water harvesting, while 42% of them do not have any experiences in this field. Figure (40) shows data analysis of engineers experience about the effect of RRWH.

Several results were extracted from the engineer’s questionnaires about the impact of roads on water harvesting as follows:

- The roads construction may affect the mechanism of natural water ways, drainage pattern, springs, water collection basins, distributing water for agriculture lands. Also the road construction affect the concentration of the water in culverts, divert water from road by ditches or side drain, where some locals use skew earth humps or agricultural pipes to divert road rainwater to their farms while in some cases a culvert is installed to divert the water to the farms if requested by farmers.
- All this will be achieved after conducting hydrological study; define the road catchment area; define the collection method and storage or distribution technique for recharge, drinking, agriculture, irrigation and domestic use. So, the road is maintained and the farmers benefited.

The roads protection works and gateways use in bridges and big culverts can be adapted to serve community, control water and recharge by coordination with agencies and considering the total cost of the project and the landscape of the area.

2. Groundwater recharges from roads:

69% of the engineers, it is possible to use roads to collect water for groundwater recharge, while 31%, it is not possible to do that. Figure (41) shows data
analysis of engineers experience about groundwater recharge from roads.

Those who answered yes described the possibility to use roads for groundwater recharge as follows:

The runoff from road both from culverts, ditches, roadsides, channels and road catchment could be diverted, directed and collected to an appropriate location (such as: surface water basin areas, open recharge earth ponds, by digging recharge wells, recharge dams specially in flat areas and by check dams at the end of the ditches) which can contribute as groundwater recharge and water retention in the area or at the wadies. Also roads will act as surface recharge structure (when the body of road is the same body of water dam and the spillway is the asphalt surface or if there is a dam nearby the road). Finally, the groundwater recharge from roads should be considered in the BOQ as an item (build masonry walls, protection works or dams in wadis) which may add additional cost to road projects, and in case there is a strategic planning by coordinating with related agencies. Those who answered no, said no consideration were taken to use roads for groundwater recharge and others said that dams were used for groundwater recharge.

3. Water harvesting for irrigation or groundwater recharge from the culvert:

Only 22% considered water harvesting for irrigation or groundwater recharge from the culvert outlet by coordination and strategic cooperation between agencies which consider project cost and channels used to divert water from culverts outlets to areas of groundwater recharge basins or construct small dams at the culverts outlets, also particular design of culverts wings was used to direct the flow if requested by farmers, moreover the type of soil play a rule in groundwater recharge. The rest 78% of engineers don’t consider water harvesting from culverts due to the following reasons: not recognized; it need high cost and social & environmental study to serve the stakeholders, where only road protection were considered, except self-initiative from farmers. It is not taking in designs; and the insufficient use of this water which discharged away from the road without taking consideration to take advantage of this water which sometimes cause erosion in farmers lands near the outlets of drainage structures. Others suggest the following: construct deep water ponds at culverts inlets to collect water and make use of it in the areas that suffer from water shortage, and they also suggest that water harvesting must be taken in consideration and defined water ways to facilitate water collection. Figure (42) shows data analysis of engineers point of view about consideration of water utilization from culverts.

4. Water harvesting for irrigation or groundwater recharge from road side drainage structures:

Only 29% considered water harvesting for irrigation or groundwater recharge from road side drainage structures by the coordination with agencies and conduct the feasibility study of the project depending on the amount of rain in the region, in some international project which prepare integrated
hydrological study, as in some places channels were constructed at the end of side drainage to direct the discharge to the purpose location (pond or tank) for the beneficiary use, by keep the path of water way for the adjacent land, and sometimes if people request a smaller diameter steel or concrete pipes installed or ditches were used to direct water from the inner side ditch to the farms as the traditional way which is canceled due to the road construction. While 71% don’t consider water harvesting for irrigation or groundwater recharge from road side drainage structures. As they have no idea, and the only practice is self-initiative from people as small ponds filled for later use as well as irrigation for agricultural land. Figure (43) shows data analysis of engineers point of view about consideration of water utilization from road side ditches.

5. Current culvert design understanding

5.1 Location of culverts in road projects:
The multiple responses of the questionnaires were 96 out of 45 sample cases. Figure (44) shows data analysis of location of culverts in roads projects. They have indicated that: 36.5 % due to water ways and streams crossing the road, 32.3% details hydrologic study, 14.6 % at each vertical sag curve, 3.1% at equal intervals, and 13.5% had other views.

Those who add others indicator to their views were as follows: Beneficiary participation (the elderly), design engineer opinion, land survey for natural stream and calculate the catchment area, a distance between the culverts should not exceed 700 m, to transform water from side to side, in multi curves sections to alleviate the accumulated water from the ditches, obligated in some agricultural land, places of water gathering on the surface of the road, and in international projects according to detailed hydrologic study.

5.2 The culverts type selection in road projects:
The multiple responses of the questionnaires were 90 out of 45 sample cases. Figure (45) shows data analysis of culverts type selection in roads projects. They have specified that: 17.8 % technical standards, 24.4 % detailed hydrologic study, 30% typical designs from MPWH & the experience of the consultant, 12.2% cost analysis alternative for the available materials in the project location, and 15.6% had other views.

Those who add others indicator to their views are as the following: nature of the region/site, social factors, hydraulic study, consultant engineer experience, culvert dimensions, estimation of the water course and floods flow volume, typical of the Ministry of Public Works is used, cost of materials and budget availability.

5.3 The size of culverts design in road projects:
The multiple responses of the questionnaires were 65 out
of 45 sample cases. Figure (46) shows data analysis of culverts size design in roads projects. The questionnaires have designated that: 38.5% due to detailed hydrological study, 41.5% the available width and height of the stream line, and 20% add other views. Those who had different views add the following: experience, hydrologic & hydraulic study in the strategic / international projects, estimate the catchment, width of road section, elderly, and available width & height of the stream line, and the height of fill, to calculate the amount of water

5.4 Culvert Inlets Design:
The multiple responses of the questionnaires were 70 out of 45 sample cases. Figure (47) shows data analysis of culverts inlet design. According to the questionnaires: 45.7% due to typical drawings and the inlet type in cut or fill section; 32.9% onsite structural designs as needed; 18.6% detailed hydrological study; 2.9% other views such as: typical drawings approved by the MPWH for all projects, function of retained embankment, structure skew and overflow requirement, and no designs for the inlets as there is no real design for the culverts.

5.5 Culvert Outlets Design:
The multiple responses of the questionnaires were 62 out of 44 sample cases. Figure (48) shows data analysis of culverts outlet design. According to questionnaires: about 46.8% due to typical drawings and the outlet type, 35.5% onsite structural designs as needed, 16.1% detailed hydrological study, and 1.6% depending on the nature and type of soil.

5.6 Culvert Outlet Spill-Way Design:
Different points of view were defined according to questionnaires as follows: riprap, gradual steps or graded saclobyan protection works up to the solid rock end, the hydraulic models should be used according to ground slope, height, discharge, and soil type, and outlet flow volume and direction, to avoid erosion.

6. Current Ditches design understanding

6.1 The dimension and shape of side ditches in road projects:
The multiple responses of the questionnaires were 68 out of 44 sample cases. Figure (49) shows data analysis of dimension and shape of side ditches. It defined according to questionnaires that 42.6% typical designs from Ministry of Public Work and Highway (MPWH) and the experience of the consultant, 20.6% due to detailed hydrologic study, 16.2% due to an offset distance from the asphalt edge to the cut side, 20.6% had other views such as: depending on the road nature & classification, the amount of water flow, catchment area, type of cut section or the outer edge (rock, steep), the longitudinal slopes, according to economic view beside the shape and size of the landscape. Moreover, in most roads it is defined according the available width after the cut excavation.
6.2 The longitudinal slope of ditches:
The multiple responses of the questionnaires were 65 out of 45 sample cases. Figure (50) shows data analysis of defining longitudinal slope of side ditches. It defined according to questionnaires that: 20% technical standards, 4.6% according to detailed hydrologic study, 13.8% typical designs from MPWH and consultant experience, 49.2% parallel to the slope of the main asphalt profile with a drop of the ditch depth, 12.3% had other views such as: subgrade slopes and cross section slope (super-elevation and widening), due to minimum/required slope for discharge and quick on site decision.

6.3 The exit of side ditches:
The multiple responses of the questionnaires were 61 out of 44 sample cases. Figure (50) shows data analysis of defining the exit of side ditches. It defined according to questionnaires that: 16.4% at the end of every horizontal curve, 50.8% following the natural water ways by using culverts or irrigation pipes to divert water; 32.8% add other views which are: According to: landscape, hydraulic study, amount of water; typical; road site nature (cut or fill), a quick on-site study, engineer experience, at appropriate outlet, at the end of cut sections, at curves allow discharge safely, (50% to 75%) from ditches full capacity, after excavation phase, and it transferred to the other edge to the next curve if there is no agriculture lands or houses.

6.4 Choose the type of the ditches (Riprap – Concrete – Earthen):
The multiple responses of the questionnaires were 66 out of 41 sample cases. Figure (52) shows data analysis of choosing the type of side ditches. It specified according to questionnaires that: 15.2% due to detailed hydrologic study, 25.8% typical drawings and according to X-section type in cut or fill, 31.8% in site structural designs as needed, 27.3% had other views such as: longitudinal slope of the road; class of road, contract BOQ items, project budget, availability of materials and skills, amount of rainwater, flow volume, outlet flow intensity, velocity & topography and according to the consulting and contractor engineers experience.

2.3.5 Geometric design role
Geometric design is a technical matter which considers a lot of design parameters such as horizontal radius, cross slope, super-elevation, gradient, sight distance, stopping sight distance and design speed. In this study to define the role of geometric design in water harvesting the research discussed some geometric parameters that may affect the road drainage and conducted a review of the main road.
2.3.5.1. Effect of some road geometric parameters on drainage

1. Vertical alignments

The longitudinal gradient improves the road surface drainage and facilitates the discharge of water from sections of the road surface with limited cross-slope. In some cases the road gradient is replicated in the side drains,\(^{(18)}\). As well as the DMRB, May 2006,\(^{(8)}\) reported that drainage is a basic consideration in the establishment of road geometry and vertical alignments should ensure that outfall levels are achievable; and subgrade drainage can discharge above the design flood level of watercourses outfall.

2. Camber and (Cross-slopes or Super-elevation).

The camber is the slope from either side of the center line towards the road shoulders. The minimum rate of cross-slope is determined by drainage needs which range from 1.5 percent to 2.5 percent\(^{(1)}\). On sharp curves, the camber is often substituted with a super-elevation which leads the water to the inside of the curve. The super-elevation is installed with a gradual change of the road cross section from a camber shape to a road surface shaped with a cross slope\(^{(18)}\).

Areas of super elevation change require careful consideration. As four methods are used to transition the pavement to a super-elevated cross section also the profile reference line controls the roadway’s vertical alignment through the horizontal curve. Two potential pavement surface drainage problems are of concern in the super-elevation transition section.

I- The potential lack of adequate longitudinal grade which occurs when the grade axis of rotation is equal to, but opposite in sign to, the effective relative gradient. Its results in the edge of pavement having negligible longitudinal grade, which can lead to poor pavement surface drainage.

II- Inadequate lateral drainage due to negligible cross slope during pavement rotation which occurs in the transition section where the cross slope of the outside lane varies from an adverse slope at the normal cross slope rate to a super elevated slope at the normal cross slope rate. This length of the transition section includes the tangent run out section and an equal length of the runoff section.

Two techniques can be used to alleviate these two potential drainage problems, provide a minimum profile grade in the transition section and provide a minimum edge of pavement grade in the transition section.

Both techniques can be incorporated in the design by use of the following grade criteria:

A- Maintain minimum profile grade of 0.5 percent through the transition section.

B- Maintain minimum edge of pavement grade of 0.2 percent through the transition section.

2. Other Field Observations:

1. The geometric design were of relaxed standards where there is high number of horizontal curves which represent an average of one curve per 45 m in the main road and steep vertical slopes.

2. The road drainage structures (culverts) in main road are not installed in the design drawing except the location of culverts in the profile and the dimension and type are mentioned in separate table.

3. The ditch dimension is defined at cut sections of the cross sections at equal intervals of 25 m for the road alignment stations and neglects the lead out points.

4. The cross section vary according to the topology and there are box cut section or one cut side (left or right), while the design cross sections were at equal intervals (stations) there is neglecting of the discharge points of these ditches when the section changed from cut to fill especially in the outer side of the section.
Most protection works of the road defined after the asphalt layer construction.

3. Results and Discussion

3.1. Potential RRWH Results

3.1.1 (case 1).

The estimated potential RRWH quantity from the main road natural catchment is 1,662,729.25 m$^3$. The road natural catchment represent about 18.38% (9.85 km$^2$) from the total sub catchments (53.58 km$^2$) of the watershed, which give an indication of the little effect to the downstream stakeholders if the whole road natural catchment yields were water is harvested and used by the upstream stakeholders.

3.1.2 (case 2).

- The total RRWH which generated from 10 km length at 40 culverts location equal to 529,178.31 m$^3$, the amount of potential harvested water in potential suitable locations (22 culverts) equal to 188,446.87 m$^3$ which represent 36% from the total generated amount.
- There are only 22 culverts locations is suitable for potential water harvesting, while the 18 culverts located either in stream ways, steep slopes or in the stepped road alignment.
- There are already 5 WH structures at the culverts outlets along the 10 km which represent only 22.7% of the potential suitable locations.
- The culverts catchment and outlets type show the different potential locations which vary according to the land use and landscape steepness of the surrounding area, beside land ownership and farmer’s attitude.
- The culverts catchment could be a sub-catchment, stream line, sub-stream or from another upper culvert. While the culvert outlet could be a sub-catchment, stream line, sub-stream, road section, terraces, steep slope and tanks.

3.1.3 (case 3).

- The potential rainwater harvesting from the road surface and culvert catchment at station 1400 (case 1) is 4430.742 m$^3$ per year, while the tank capacity is about 1000 m$^3$ this will provide supplementary irrigation for about 260 of Qat trees with a total area of 3174 m$^2$.
- The temporary earthen pond at the culvert station 1400 outlet act as sedimentation and erosion control structure and water harvesting support structure.
- The potential RRWH is exceeding the farmer tank capacity and the Qat irrigation requirement which give an opportunity to invest in water harvesting activities.
- Social and economic benefits: (1) Increase the farmer income by increasing the Qat yields. (2) Create work as labor opportunities to alleviate poverty. (3) Provide additional water resources and water storage infrastructure. (4) Avoid the high cost of buying water from the nearest source by trucks tanker which cost approximately 4600 Y.R for one cubic meter of water.
- Environmental benefits: (1) Reduce the runoff and consequently the road embankment erosion. (2) Maintain the general landscape of the road surrounding area. (3) Reduce the road maintenance cost which caused by runoff water.

3.1.4 (case 4).

The potential RRWH which generated from the sub road 16 km length is 24,931.2 m$^3$.

3.1.5 (case 5).

- The road location on watershed catchment especially the upper catchment needs more attention to benefit from the harvested rainwater.
- Environmental benefits: the harvested water act as water source for the local inhabitance
during drought periods and the cisterns roofs either natural (cave) or stone arched (dome) will minimize the water prone diseases and the evaporation losses. Also the underground cisterns locations play a role in the general landscape of the agriculture terraces which consist of small arable pieces due to the mountainous ridges of the area.

3.1.6 Factors affecting the potential RRWH
In general the potential RWH depends on: characteristics of the catchment, rainfall/runoff ratio, evapotranspiration rates, land use and other human interferences. For the roads the potential RRWH depends on: the road natural catchment; road surface catchment; road geometric and drainage structures characteristics.

3.2 Stakeholders' Results
The farmers in the study area suffer from water scarcity and they face that by using different adaptation measures such as convey water from the water sources, from rainwater harvesting, purchase water trucks tanker, harvest rainwater from roofs, rationalize water use, avoid extravagance or share spring water turns, fog water harvesting, water saving, hand wells, and immigrate from their village to another internal place. That means all the above measures are adapted to cope with the water scarcity issues in the study area.

There are some claims observed during the field interviews such as:
1- The water channels were abandoned and water blockage occurred by the road excavation debris.
2- The road design profile was below the farmlands level which cause difficulty to divert water.
3- The road produces huge floods at some locations that lead to erosion and transport sediments to farmlands.
4- The use of dynamite in some cut rock sections affect the natural spring line and damages some indigenous old ponds near the explosion location.
5- There is lack of communication between the locals and engineers.
- All farmers consider rainwater running on the road their right. Because water streams ways should remain as they were before road construction, and it is a well-known right and priority, with well known water ways (MARAHEG), as it is for father and grandfather (MANHAL).
- The main effect of water from roads from beneficiaries point of view are: ruin & bury farmlands, disturb & damage water ways, erosion, transmit of sediments and flood accumulation.
- These damages can be mitigated by use (spillways, humps, channels, ponds, sedimentation checks, check walls in water streams, water retention, diversion structures near roads, and check dams to collect water) by oblige the contractor to haulage the excavation debris to allocated locations and maintain water channels & old water ways, by prevent erosion by road stone paving and protection works, by rehabilitate the agricultural terraces by farmer’s.
- Women usually bring the water from the sources to the house and harvest water from roofs beside divert the floods in the case of the absence of the man, thus the RRWH will help the women to save their effort and time consumed in bringing water.

3.3 Roads Engineers Results
Engineers have practiced a number of possible drainage design procedures and consideration to the general road drainage structures such as culverts, ditches and Irish crossing. The differences in design are often forced by changes in geology & terrain, experience, use of typical drawings, lack of hydrologic and hydraulic studies, absence of integrated water resource approach, and the restraint cost. Although, some drainage designs are not always economically, socially, environmentally and technically justifiable for rural roads drainage. It is apparent that certain drainage designs are inherently focused on alleviating and shed the runoff from the road surface. Therefore, an understanding of the integrated road and water
drainage will result a sustainable and cost effective designs.

### 3.4 Geometric and Drainage Design Results
Almost all Yemen rural roads had adapted design standard to reduce the high construction cost and to sidestep the social conflicts that may occur in case of changing the existing route alignment so the designer try to enhance the existing route and exerted great care in order to avoid any damage to the roads by costly design.

Another challenge is poor quality of design in locally funded projects, there is a considerable difference between the implementation processes used in 100% locally funded projects and those in projects with donor assistance, (42). That is noticed through the engineer’s points of view about the hydrological studies.

### 4. Conclusions

#### 4.1 Potential RRWH
- The main road catchment yield affected by the natural road catchment, the culverts catchments, the road surface geometric properties (profile distances between drainage points, cross slope, super-elevation method, number of horizontal curves which affect the lead out discharge points).
- There is a wide range of small scale road rainwater harvesting structures.
- Each RRWH location is unique and need special technical, social, environmental and cost adoption to cope with integrated design for road and water.
- The RRWH locations were already observed at the culverts outlets, humps, channels, spillways, rolling dips and at the inner side of the road. And it could be at curbs outlets and lead out ditches.
- The RRWH is affected by road location on watershed especially upper/border catchment and affect the attitude of farmers on rainwater harvesting.

#### 4.2 Stakeholders:
- The practical farmer’s in-field road rainwater harvesting initiatives could be an effective learning and documentation tool.
- Farmers used to harvest the flood water from the roads using different techniques or methods such as: temporary humps across the road or rolling dips, channels, side ditches, spillways, cascade steps and culverts.
- Rainwater running on the road were farmers right.
- There is negative effect of water from/along roads, and some of the mitigation measures are by means of use resilience structures that regulate flood, appropriate road debris haulage and conservation techniques.
- The benefits of RRWH are: water saving, increase production, reduce buying water and supplementary irrigation.

#### 4.3 Roads Engineers & geometric design
- There is a gap in knowledge among roads engineers about the rainwater harvesting from roads.
- There are a number of possible drainage design procedures and considerations for general road drainage structures and often forced by multiple factors.
- More than half of Engineers response used typical drawings from MPWH in drainage structures.
- The water harvesting concept and practice from roads is not recognized by most of the road engineers.
Some road geometric parameters such as vertical alignments, camber and (cross-slopes or super-elevation), had effect on road drainage and consequence the rainwater harvesting system.

5. Recommendations

5.1. RRWH & Stakeholders
- The RRWH knowledge and experience which had been practiced in different countries should be triggered in road investment in Yemen.
- Farmer's initiatives should be encouraged and improved technically and institutionally, and also should be supported from government's agencies and donor programs.
- The RRWH should be adapted by taking advantage of previous experience locally and across the World.
- The road and culverts catchment should be compared with the total study area catchment to avoid social conflicts in case of RRWH.
- Social communication mechanism between engineers and stakeholders should be developed in all road projects in all phases.
- Detailed road rainwater harvesting balance studies and models should be considered for further research from different background specialist to reach the optimum results.

5.2. Roads Engineers
- Awareness and training workshops should be arranged for road engineers with hydrologic and watershed specialist.
- Procedures and technical and operational manuals should be prepared for road design, procurement, and supervision beside the integrated RRWH should be in Arabic and adapted to the conditions in Yemen and reflect best international practices in road rainwater harvesting by different ways and techniques.
- The knowledge gap challenges related the rainwater harvesting from roads, road landscape, watershed, catchment area, community-based water rights and resources, conservation management plans need enhancement and more attention from IWRM approach for roads engineers.

5.3. Geometric Design
- A careful consideration of coordination and combination the horizontal and vertical alignments and drainage structures with reference to road catchment and natural drainage pattern which may be best indicated by:
  1. Contoured drawings of the required carriageway surface with water stream lines, culverts locations, land use map and potential RRWH locations to serve the road rainwater harvesting facilities.
  2. Details drawings of drainage structures (culverts, ditches, etc..) plan and profile especially when the cross section changed from cut to fill and at the outlet.
- Staged co-financed integrated approach (design and implementation) is suggested to cope with the cost factor (taking advantage of road construction equipment’s) to achieve the sustainable rainwater harvesting in the road vicinity.
- MPWH typical drawing should be updated and reviewed according to Yemen Hydrologic studies and RRWH integrated approach.
- Road drainage structures and protection works in the main road section should take in consideration the integrated design for water harvesting, water rights, erosion control,
environment sustainability and social and gender expectations.

- Routine road maintenance activities should consider the social involvement in some activities as community participation during maintenance.
6. References

5. Diego Garcia-Landarte Puertas, et al. (2014), Roads for water: the unused potential
8. DMRB, HD 33/06, (Surface and Sub-Surface Drainage Systems for Highway), May 2006,
9. DMRB 6.1.1 (TD 9)
10. DMRB 6.2.3 (TD 16)
21. Kithinji Mutunga and Will Critchley with P. Lameck, A. Lwakuba and C. Mburu , 2001,
FARMERS’ INITIATIVES IN LAND HUSBANDRY - Promising technologies for the drier areas of East Africa by – Published in partnership between: UNDP – Office to Combat Desertification and Drought (UNSO/ESDG/BDP) and Sida’s Regional Land Management Unit, 2001.


23. Lichtenthaeler, Gerhard, 2014, MER254, "Water Conflict and Cooperation in Yemen".


28. Ministry of Oil and Minerals Resources.


32. Nama’a NGO papers 2013.


35. Steenbergen, F. van (MetaMeta); Woldearegay, K. (Mekelle Univeristy); Beusekom, H.M.van (MetaMeta Circular Economy); Garcia Landarte, D. (MetaMeta Ethiopia) and Al-Abyadh, M.(Road Maintenance Fund, Ministry of Infrastructure and Highways, Government of Yemen). 2014. How to do Roads for Water – IFAD. Visit [www.roadsforwater.org](http://www.roadsforwater.org/)


