Potential of Road Rainwater Harvesting in Yemen – Its Social, Environmental and Economic Benefits: A Case Study of Sana›a – Hodeida Road, Yemen

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https://doi.org/10.20428/JST.25.1.2

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Abstract:

In Yemen, farmers and people living along the roads are suffering from the lack of utilization of rainwater runoff from road surface & surrounding area and road water structures. The objectives of this research is to optimize the benefits of Road Rainwater Harvesting (RRWH) to the beneficiaries during road design, construction and operation & maintenance; to suggest a technical outlines; to induce the awareness of road's engineers on the importance of Integrated Water Harvesting Management (IWHM), in addition to discussing the Environmental and Social Impact Assessment (ESIA). The research approach focused on conducting field visits and applying a reconnaissance survey to document the current and potential road rainwater structures along the pilot section of 24 km as part of Sana'a – Al-Hodiedah road between Al-Masajed village and Sooq Al-Aman; Designing and applying questionnaires and interviews for farmers & beneficiaries, and road engineers. The SPSS software program was used to analyze the collected data. From the conducted interviews along the road, it was revealed that almost all the stakeholders have land adjacent to the roadside, and their farms are irrigated from rainwater collected from road structures. All inhabitants considered water floods running from/on the road surface and structures as their rights, and it is distributed at the moment according to the field's water rights which exist before the road construction. The research found that almost all farmers considered the water from roads as contaminated water. The source of contamination comes from residual oil on the road, diesel, oil from oil shops and suspended soil particles. On the other hand, according to the road engineer's questionnaire, the concept of water harvesting, groundwater recharge and water for irrigation from road surface and road structures were not considered during design. In addition, the results obtained showed that water-harvesting techniques in the pilot road section is in the form of farmers' initiatives implemented by directing water to their farms for irrigation. The study conclude applying RRWH to protect the road sections from erosion and damage; increase the availability and utilization of water in the areas nearby roads; minimize the erosion of landscape especially in mountainous areas as well as in road embankments; improve the stabilization of the road slopes;

https://doi.org/10.20428/JST.25.1.2

and maintain esthetic value of landscape nearby roads. It is recommended that road drainage structure should be located in a proper place to avoid conflicts among farmers and fulfill their water rights. To avoid soil and water contamination by oil, grease and fuel from vehicles along the road, the research recommends that oil workshops should be implemented and forced to collect and recycle oil instead of disposing it on the road surface. RRWH is recommended to be applied to mitigate the damage of terraces during the heavy runoff. The study urges the joint efforts from all stakeholders and road engineers to apply the suggested technical outline in this paper by including rainwater harvesting from roads as part of road design, implementation and maintenance.

Keywords: rainwater harvesting, road design, culverts, engineers, stakeholders, farmers, ESIA, Yemen, social and economic benefits.

إمكانية حصاد مياه الأمطار من الطرق في اليمن – المردود الاجتماعي والبيئي والاقتصادي – دراسة حالة: طريق صنعاء الحديدة – اليمن

الملخص:

في اليمن، يعاني المزارعون والأشخاص الذين يعيشون على مسار الطرق من عدم الاستفادة من جريان مياه الأمطار من سطح الطريق والمنطقة المحيطة بهم ومنشآت المياه في الطرق. تتمثل أهداف هذا البحث في تعظيم فوائد حصاد مياه الأمطار من الطرق (RRWH) للمستفيدين وذلك أثناء تصميم الطرق وتشغيلها وصيانتها؛ لاقتراح الخطوط العريضة لدليل الدراسات والتصاميم (الفني)؛ لتحفيز وتوعية مهندسي الطرق بأهمية الإدارة المتكاملة لحصاد المياه (IWHM)، بالإضافة إلى مناقشة تقييم الأثر البيئي والاجتماعي (ESIA). ركزت منهجية البحث على إجراء زيارات ميدانية وتطبيق مسح استطلاعي لتوثيق منشآت حصاد مياه الأمطار الحالية والمحتملة على طول الجزء البحثي من الطريق والبالغ طوله 24 كم كجزء من طريق صنعاء - الحديدة بين قرية المساجد وسوق الأمان، تصميم وتطبيق الاستبيانات والمقابلات للمزارعين والمستفيدين ومهندسي الطرق. تم استخدام برنامج SPSS لتحليل البيانات التي تم جمعها من المقابلات التي أجريت على طول الطريق. اتضح من خلال الاستبيانات أن جميع أصحاب المصلحة تقريبًا لديهم أرض محاذية لمسار الطريق، ويتم ري مزارعهم من مياه الأمطار التي يتم جمعها من منشآت الطرق. يعتبر جميع السكان أن مياه الأمطار التي تمر على سطح الطريق ومن خلال المنشآت المائية من ضمن حقوقهم، ويتم توزيعها في الوقت الحالي وفقًا لحقوق المياه المتبعة في المنطقة قبل إنشاء الطريق. اتضح من خلال هذا البحث أن جميع المزارعين تقريبا يعتبرون المياه من الطرق أنها ملوثة، وأن مصدر التلوث ينتج من الزيوت المتبقية أو المتسربة، الديزل والزيوت من محلات تغيير الزيوت اضافة الى جزيئات التربة العالقة. من ناحية أخرى، وفقًا لاستبيان مهندسي الطرق، فإن مفهوم حصاد المياه، وإعادة تغذية المياه الجوفية واستخدام المياه من سطح الطريق ومنشآت الطريق في الري لا تؤخذ في الاعتبار أثناء التصميم. بالإضافة إلى ذلك، أظهرت النتائج أن تقنيات حصاد المياه في قطاع الطريق التجريبي كانت عباره عن مبادرات من قبل المزارعين يتم تنفيذها وذلك بتوجيه المياه إلى مزارعهم للري. خلصت الدراسة إلى ضرورة تطبيق RRWH لحماية الطريق من النحر والأضرار؛ زيادة توفير المياه واستخدامها في المناطق القريبة من الطرق؛ تقليل تعرية التربة وخاصة في المناطق الجبلية وكذلك في ردميات الطرق؛ تحسين استقرار منحدرات الطريق؛ والحفاظ على القيمة الجمالية للمناظر الطبيعية المحاذية للطرق. يوصى هذا البحث بتنفيذ منشآت تصريف الأمطار في الطرق وذلك في مكان مناسب لتجنب النزاعات بين المزارعين وحفظ حقوقهم المائية. لغرض تجنب تلوث التربة ومياه الأمطار بالزيت والشحوم والنفط من المركبات على مسار الطريق، يوصي البحث بضرورة تنفيذ ورش تغيير الزيوت وإجبارها على جمع الزيت وإعادة تدويره بدلاً من التخلص منه على سطح الطريق. يوصى بتطبيق حصاد مياه الأمطار من الطرق للتخفيف من الأضرار بالمدرجات أثناء الجريان السطحي الشديد. تحث الدراسة على بذل الجهود المشتركة من قبل جميع أصحاب المصلحة ومهندسي الطرق لتطبيق الدليل الفني المقترح في هذه الورقة من خلال إدراج حصاد مياه الأمطار من الطرق كجزء من تصميم الطرق وتنفيذها وصيانتها.

الكلمات المفتاحية : حصاد مياه الأمطار، تصميم الطرق، المنشآت المائية، المهندسين، أصحاب المصلحة، المزارعون، اليمن، تخفيف الأثر الاجتماعي والبيئي، الفوائد الاجتماعية والاقتصادية.

https://doi.org/10.20428/JST.25.1.2

1. Introduction

In Yemen there are a lot of rainwater harvesting structures from ancient time when they started to establish the terraces systems. A lot of road rainwater harvesting initiatives had been implemented either by farmers who own lands using the water rights of runoff from road or by road engineers. For example, a large borrow pits are excavated as a consequence of earth works which would be used as water harvesting structures. Farmers and people living along the roads are suffering from the lack of utilization design, construction and maintenance to improve irrigation in the nearby road areas of rainwater runoff from road surface, surrounding area and road water structures. The objective of the pilot research is to optimize the benefits of rainwater harvesting from roads. In addition to suggest a technical outlines aspect from the pilot study and to induce the awareness of roads engineers (designers and supervisors), decision makers and donors on the importance of IWHM, and to demonstrate to local communities' benefits of the road water harvesting structures. The ESIA for the road rainwater harvesting and its structure will be discussed.

2. Research Methodology

Field visits were conducted to the pilot section at Hodiedah road, to investigate and map the adjacent catchments to calculate run-off potential, collect data on current situation, and the potential of rainwater harvesting structures along the study road section. This was implemented by means of Google earth map to illustrate the road plan and calculate the catchment area for part of road surface to find out the harvesting rainwater quantity. Data collection were collected from the landowners and farmers by means of Designing of questionnaires for farmers and road engineers. Two questionnaires were designed and filled by both farmers and the specialist's road engineers who are responsible for the design, supervision and maintenance of roads.

Meeting and interviews were conducted with landowners, farmers, related departments, authorities, and local communities.

Location of the study area: The study road section is situated at Sana'a – Hodeida main road located at the south-west of Sana'a at about 220 km long, single two-lane asphalt carriageway road, constructed between 1958 and 1962 by the Chinese government, as a macadam road surface. The pilot study road area is located at the beginning of Sana'a – Hodeida main road, where most parts of the roads passes in a mountainous area. This pilot sub-section of the road with length of 23.8 km starts from Al MASAJED area (at 12 km from Asser Intersection in Sana'a) at latitude of 15.309954 and longitude of 44.085965 up to Al-Aman market at 35.8 km at latitude of 15.180085 and longitude of 43. 974324.

Terrain: This pilot road section runs in rolling to flat terrain from the beginning to 2.2km with vertical profile grade varies from 3% to 7.5%, then from 2.2 km to 9 km it runs in flat terrain with vertical profile grades varies from 0.1% to 2%. It passes through congested market area of Matnah Town at 7 km to 8 km. Furthermore, from 9 km to the end of pilot section at 23.8 km, the road runs in mountainous terrain till the section end at Al-Aman market, the grades vary from 1% to 7%, with an average of 4- 5%.

Villages and towns: this sub-section road passes through villages and markets such as Mind at 2 km from the pilot start point, Souk Matnah at 7 km, Souk Boua'an at 17 km, Souk Al-Aman at 23.8 km, in addition to other small Souks. The path of the pilot study section is shown in Figure 1.

Figure 1: Location Map of the Pilot Study Section of Sana`a – Hodeidah Road

3. Hydrology of the pilot section road

The general climatic pattern of the catchment area is concerned as sub-tropical arid to semi-arid, where the rainfalls are low in most lower lands in the region, while the rainfall amounts are getting much higher at the mountainous areas, especially in the western parts of the catchments. The mean annual precipitation depends on the orientation of the topography towards the wind direction. The rainfall along the road varies from less than 100 mm in the lower catchment areas to about 500 mm in the higher hills.

https://doi.org/10.20428/JST.25.1.2

While along the study area road ranges from 300 to 400mm. Relative humidity and average wind speed decreases in Yemen, from the sea in the west near Hodeida till it reaches higher elevations of the study area where higher speed of wind exists. The monthly rainfall is found by WWW. SAMSAMWATER.COM Program for the coordinates of the starting and end points of the pilot road section of Al-Masajed and Sooq Al-Aman for year 2002. The total annual rainfall ranged 598437-mm /year (Figures 2a and 2b). The average rainfall for the pilot section is considered as 517.5mm/year

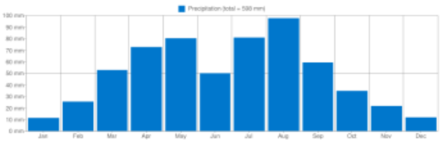

Figure 2a: Monthly Rainfall Depth for the Starting Point of the Pilot Road Section at Al-Masajed

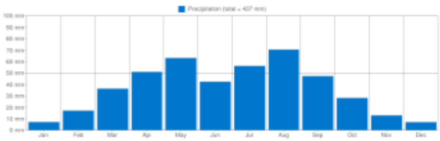

Figure 2b: Monthly Rainfall Depth for the End Point of the Pilot Road Section at Sooq Al-Aman

3.1 RRWH Hydraulic Structures

During the field visits for the pilot road section a lot of water ways structures, water harvesting techniques with water management structures and water impact on roads were found. Several road drainage / water ways structures of various sizes and shapes are available at this road section, it consist of 2 pipe culvert with diameter 60 cm, two stone arch culverts of span around 2 – 3 m with variable height, three bridges of spans vary from 4 to 8 m and about 36 box culverts of variable sizes varies from 60 cm to 4m span. Also, several retaining walls, protection walls, stone lined ditches and side water spillways are encounter through this road section. Generally, when the road runs in mountainous terrain, the cut side is protected with stone lined ditch and the fill side on steep natural slope or passing in cultivated agricultural lands, is retained on a stone walls and side spillways.

3.1.1 Bridges

There are unique bridges in this road one of them is wadi Osfarah bridge it is arched bridge constructed from large concrete blocks with stone walls as illustrated in Figure 3 and part of the terraces at the outlet start eroding.

Figure 3: Wadi Osfarah Bridge

3.1.2 Culverts

A lot of culverts were found with different types and shapes such as stones girders slab and arched culverts, and concrete such as box and pipe culverts. The stone girders slab culverts were unique structures were neglected in the recent culvert's construction; it was made by local stone. Its spans range 0.6-1.2m, with approximate dimension of 0.6 width and 0.6 height, as shown in Figures 4a and 4b.

Figure 4a: Girder Stone Slab Culverts

Figure 4b: Arched Stone Culverts

3.1.3 Side Ditches and Side Spillways

A long the road path a lot of side ditches have been constructed and usually directed either to a watercourse via culverts or to steep slope or to terraces with the outer horizontal curve edge (Figure 5a). There are also spillways at the outer edge of the asphalt pavement road either in the sag vertical curves or as needed in the steep embankments (Figure 5b).

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Figure 5a: Side Ditch

Figure 5b: Side Spillway

A unique water manage

ment structure was found as a stone beams culvert with a unique outlet which is a stone arched roof building with about 12-meter long and 1.5-meter width and used to divert the flood water with right angle direction to a water course parallel to the road alignment. It protects the surrounding agriculture terraces from erosion and keep the water rights for the downstream as it was before constructing the road (Figure 6).

Figure 6: Culvert with Right Angle Direction, Used as Diversion Structure

3.2 Water Harvesting techniques through the pilot Road section

During the field visit, several water-harvesting techniques were found, used for direct and indirect irrigations such as:

Cases 1: Water Harvesting through Side Ditches to earthen pond:

For example, in Mend village, there is an earthen pond was constructed to collect the runoff from road side ditches, where the harvested water from the side catchment area of the Right of the Way (ROW) is collected and transported throw the side ditches of the road to the pond. This Mend pond catchment area consist of the road surface with an area of 6300 m2 with an approximate annual rainfall of 517.5mm/year and runoff coefficient in about 0.7, the potential harvested water will be about 2282m3. In addition, the catchment area of the mountain is estimated to be about 40,000m2, the potential harvested water will be about 14490m3. Therefore, the total harvested water to Mend's pond from road's surface and surrounding catchments is about 16772 m3 (Figure 7).

Figure 7: Location of Mend Pond and its Catchment Area

https://doi.org/10.20428/JST.25.1.2

Case 2: Water harvesting through culverts to the farm using earthen canal:

Due to the scarcity of water and the high cost of extracting or getting water, a farmer along the road used an earthen canal to divert the water from the culvert outlet to irrigate his Almond terraces land with approximate area of 2700 m2 in the rain season. This technique is illustrated in Figure 8.

Figure 8: Harvested Water from Culvert by Earthen Canal to Almond Farm

Case 3: Water harvesting through culverts to the farm directly:

The farmer, during harvesting the rainwater, he partially closes the culvert outlet by mud, stones and shrubs to reduce the speed of running flood and to catch the accumulated solid wastes away from his farm, as shown in Figure 9a. As a result, he suffered from soil erosion in the farm edge (terrace wall). Therefore, he rebuilt the eroded dry wall as shown in Figure 9b. In another site, to avoid soil erosion, the farmer protected his farm by stone bund forming canal to direct flood water away from the almond farm and used intakes openings for irrigation as shown in Figure 9c.

Figure 9a: Culvert Outlet and Inlet

Figure 9b: Soil Erosion Problem

Figure 9c: Soil Erosion Protection by an Earth Bund

Case 4: Water harvesting through roadside shoulders:

The water running in the road surface and side shoulder is collected and diverted to the farms near the roadside either by spillways or directly across the road embankments. It was noticed during the field visit that some farmers plant new almonds trees across the steep road embankments within the ROW to benefit from the collected water during the rainy season as shown in Figure 10a. It is also noticed that road maintenance for side shoulder by grading the side soil -using equipment such as grader and compactor- and leaving the outer edge to access the fill material used in grading process have caused obstacles for the running water and also closed the side spillways by this access fill material (Figure 10b).

https://doi.org/10.20428/JST.25.1.2

Figure 10a: Water Harvesting from Road Shoulders

Figure 10b: Blocked Roadside Spillways in Shoulders

Case 5: Water Harvesting through Inner and Outer Roadside Shoulders:

Farmer direct the water running in the inner side of the road to the other side of the road as shown in Figure 11.

Figure 11: Water Harvesting from Inner and Outer Roadside Shoulders

Case 6: Almond farming:

Almond trees were planted in the fill section with using semi-spherical bund to collect and retain more water for the tree. Almond trees have been spread in new terraces land along the pilot road section sides. Almond tree is a drought tolerant and had a little water requirement, it can drop some leaves as drought resistance mechanism. Most farmers harvest the road rainwater to their almond farms during different periods. Farmers depend on rain harvesting to irrigate the tree, there are three main irrigation periods should be maintained if the rain have been delayed. The first period in the inoculation period which is November, the second period during the flowering period in February, and third period after holding the fruit. Almond tree is one of the cash crops as the price of each tree costs the farmer about one US $, while the cost of almond crop produced is US $ 50/kg.

In this pilot study road section, 11 almond farms were found. They are cultivated near some culverts outlets where water is diverted to almond farms, while two other almond farms are irrigated from the running water diverted from road surface and shoulder by spillway as summarized in Table 1, with total area of 12,125 m2. These farms are shown in Figure 12.

able 1: Almond Farms nearby the Case Study Section Road

.Almond Farm No	Approximate Area (m2)	Location
Almond Farm 1	2700	CULVERT No. 14
Almond Farm 2	2800	CULVERT No. 15
Almond Farm 3	855	CULVERT No. 17
Almond Farm 4	1000	CULVERT No. 18
Almond Farm 5	4096	CULVERT No. 19
Almond Farm 6	1925	CULVERT No. 26
Almond Farm 7	319	CULVERT No. 27
Almond Farm 8	720	CULVERT No. 28
Almond Farm 9	1450	CULVERT No. 33
Almond Farm 10	420	Side Shoulder
Almond Farm 11	240	Side Shoulder
Almond Farm 12	1200	CULVERT No. 34
Almond Farm 13	2400	CULVERT No. 37
Total Area	12,125	

Figure 12: Almond Farms 1-13 near the Road

3.3 Estimation of RRWHS cost

The estimated RRWHS construction and maintenance costs, were obtained by collected cases from Social Fund for Development (SFD) for five water harvesting tanks in different areas and with various volumes. The average cost per cubic meter was calculated for the five RRWHS. The average estimated cost was approximately US $90 /m3 of water as shown in Table 2.

Table 2: RRWHS Construction and Maintenance Costs

Project Name	Total Cost $US	Volume m3	Cost US$/m3
Water Harvesting Tank for Bait Ga'ef village / Almansor / Arhab/ Sana'a	80,586.47	1040	77.49
Water Harvesting Tank for Kitamah village/ Bilad AlQaba'el/ Haimah Dakhelia / Sana'a	140,866.00	1610	87.49
Roofed Water Harvesting Pond for Lakamah village/ Bani Suliaman/ Haimah Kargiah / Sana'a	90,839.24	950	95.62
Water Harvesting for Kaisa'a village/Joba'a/ Milhan / Al-Mahweet	88,863.84	900	98.74
Water Harvesting for Masna'a village/ Gharbi/ Al-Tawellah / Al-Mahweet	134,774.07	1500	89.85

Source: Social Fund for Development, Sana`a Branch (SFD- Unpublished).

Furthermore, the cost of routine maintenance including the cleaning of water culverts and side ditches drains, reconstruct shoulders, remove trees from ROW and falling slides. All routine maintenance is supervised and financed by Road Maintenance Fund (RMF) depends on the road class as mentioned in table 3. This pilot road section of 23.8 Km is classified under category A which will cost about 299.1 US $/Km.month which will be 7118.58 US $ / month for routine maintenance for the whole length of the pilot section.

This cost of routine maintenance will improve the RRWHS which will lead to maximize the benefit of water harvesting for the beneficiaries nearby the road. At the same time this will encourage the beneficiaries to contribute in maintenance activities.

Table 3: Cost of Routine Maintenance

Routine Maintenance Cost / Month / Km		
Road Class	**YR**	**$ US**
A	64,306.00	299.1
B	45,456.00	211.4
C	35,789.00	166.5

Source: Road Maintenance Fund (RMF- Unpublished)

3.4 Rainwater Impact on Road

There is a lot of erosion / sediments deposit problems recorded in some culverts' locations as follows:

A. Water erosion and gullies:

Rainwater is the main cause of soil erosion and road degradation if it is not considered (Frank et al., 2018; Frank et al., 2015); it may erode the arable lands at the culverts' outlets or side embankments of the road. In Figure 13a, the culvert is located at a stream way of seasonal runoff in plain slope, which reduce the erosion impact. However, when the culvert outlet located near steep slopes, the erosion impact will be more if there is no active rehabilitation and soil conservation of the arable terraces near the culverts' outlets. This is presented in Figure 13b.

Figure 13a: Water Erosion inulvert Outlet Located in Plain Slope

https://doi.org/10.20428/JST.25.1.2

Figure 13b: Water Erosion in Culvert Outlet Located in Steep Slope

B. Water ponding:

Water ponding occur in road section by different ways such as the transmitted sediments in the side drain or culverts inlets with no proper maintenance and clean these sediments. Figure 14a, illustrates water ponding which is induced by the stakeholders near the road to reduce the effect of erosion on their farms. Also Figure 14b illustrates water ponding caused by dropping waste garbage near the culverts.

Figure 14a: Water Ponding at Side Drain due to Poor Maintenance

Figure 14b: Water Ponding near the Culverts due to Poor Maintenance

3.5 Interview and Questionnaires

A. Stakeholders interview and questionnaires:

The interviews and group discussion with 15 structured questionnaire were conducted for some farmers and beneficiaries along the road from different villages (Al-Masajed – Mend – Yazil – Baoa`an – Bait AlGaramani…..) with various educational backgrounds and ages along the pilot road section. The results obtained from analyses using SPSS software program were as follows:

About 93.33% of the sample farmers have lands adjacent to the road side and their farms are irrigated from rainwater collected from surface road and shoulders as shown in Figure 15a. About 87 % of the sample farmers use the floods water running from road, as shown in Figure 15b.

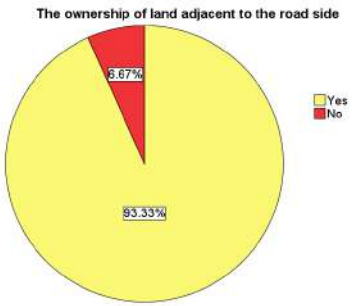

Figure 15a: Land Ownership nearby Road

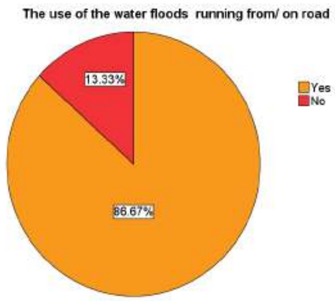

Figure 15b: Harvest Floods Water Uses

Results from different techniques were used for road water harvesting showed that 27% of the farmers used to harvest the flood water from the roads culverts, 7% from side ditches, 20% from side ditches and culverts, 27% from side ditches and temporary hump across the road, and 7% from side shoulders by spillways, side ditches and temporary hump across the road. That means all the above techniques available are used to harvest rainwater from road, as shown in Figure 16.

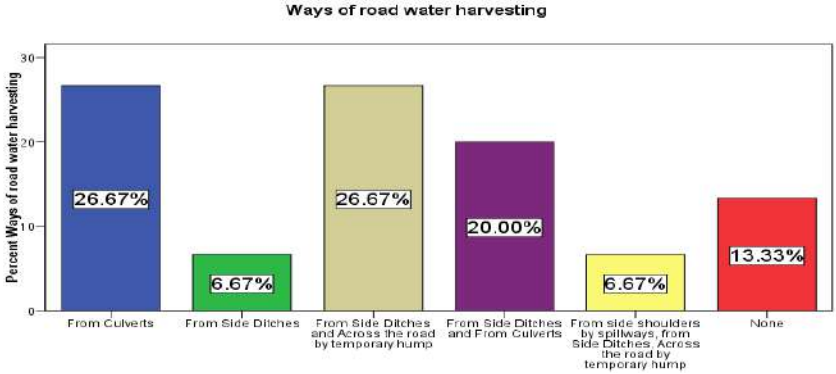

Figure 16: Data Analysis of Ways of Road Water Harvesting

The farmers are using the harvested water running from road surface and road structures for different proposes as follows: 60% for agriculture, 7 % for agriculture and recharge, 13 % for agriculture, domestic and livestock, and 7 for recharge, as shown in Figure 17.

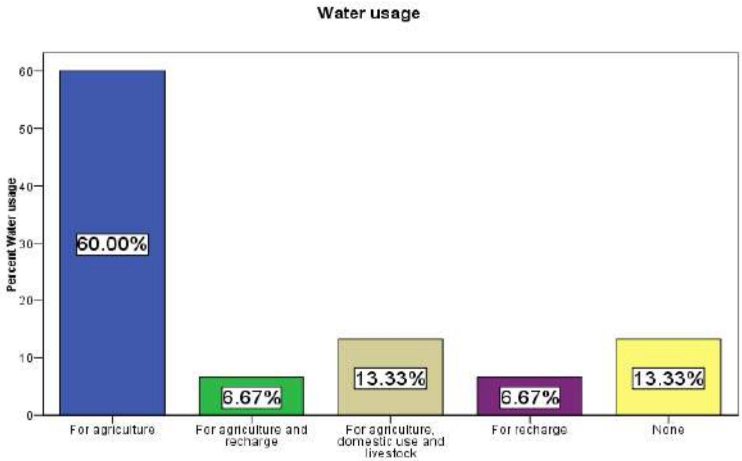

Figure 17: Data Analysis for Water Usage

Based on the questionnaire, specifically at Al-Masajed section, there is a water right problem appears after upgrading this section of the road. The problem was raised due to replacing the six culvers by only one culvert which ignored the distribution of the rainwater equally among the beneficiaries. Therefore, they suggested a need of constructing spillways to overcome this problem and bring back the water right as shown in Figure 18.

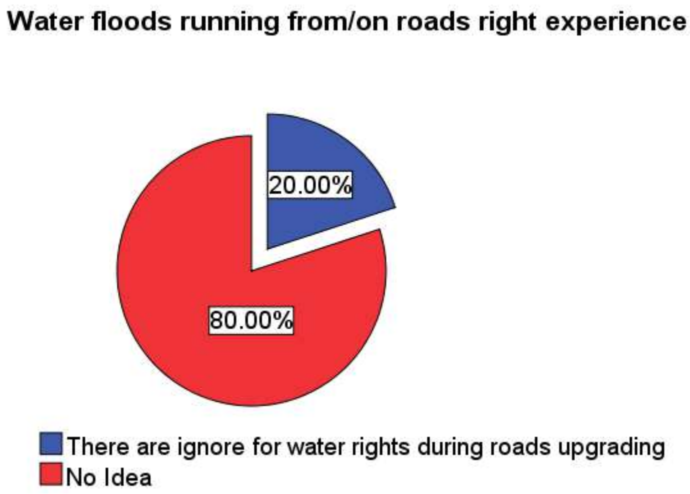

Figure 18: Data Analysis of Water Rights from Roads as Experienced by the Farmers

During the field visit, it was noticed that the people have benefited from harvested rainwater from road (RRWHS) by planting new cash crop trees namely almonds farms near the road culverts with reducing the pumping cost. These trees depend mainly on seasonal irrigation with some supplementary irrigation as needed. The results of the questionnaires showed that 66.67% were benefited for harvested water from roads for agriculture, 13.33% for domestic, 13.33% for recharge and 6.67% for water storage as shown in Figure 19.

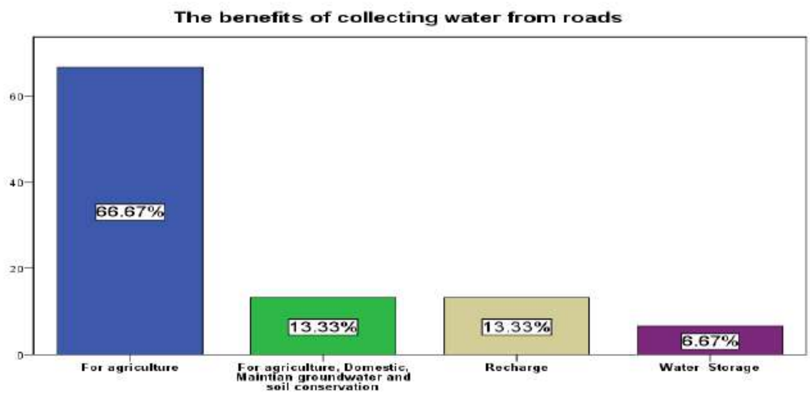

Figure 19: Data Analysis of Benefits from Harvested Rainwater from Road

Regarding the damages on the farms caused by water from roads, the results

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showed that about 53.33% no damages, 33.33% soil erosion damages and 13.33% damage of the arable land and cause gullies as shown in Figure 20.

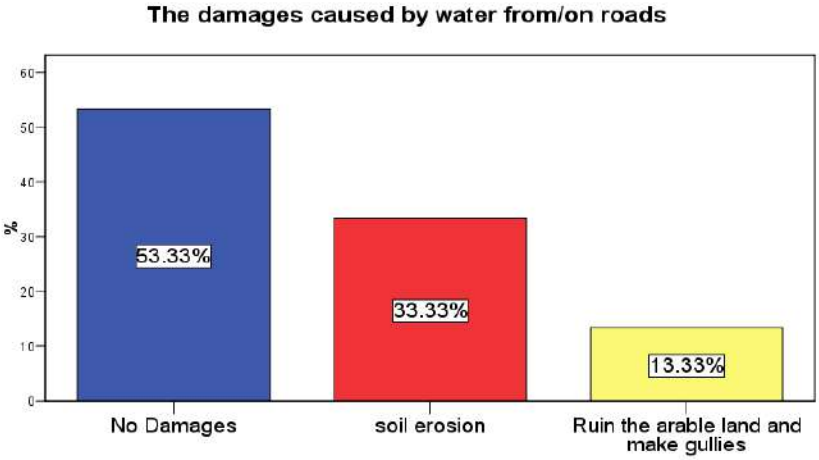

Figure 20: Data Analysis of the Damage Caused by Water from Road

From farmer's point of view on how damage can be mitigated or avoided. 33.33% suggested the following measures: maintenance, use spillway branching, floods drains, ponds and check dams to collect water. 6.67% think that it's difficult to mitigate or avoid the damage, 6.67% using ponds, 53.33% have no answer as shown in Figure 21.

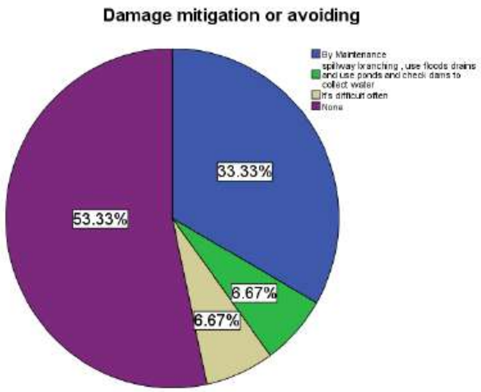

Figure 21: Road Damage from Rainwater

Regarding the water contamination, the results indicated that 93.33% think that the water from road is contaminated, as shown in Figure 22a. 66.67% of the inhabitants think that the contamination of harvested water from road surface is due to residual oil and diesel on the road, while 20% think the contamination is from residual oil on the road and oil from oil shop, and 6.67% think the contamination is from residual oil on the road and soil, 6.67% have no idea, as in shown Figure 22b.

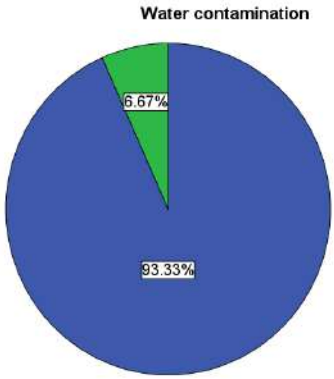

Figure 22a: Rainwater Contamination from Road

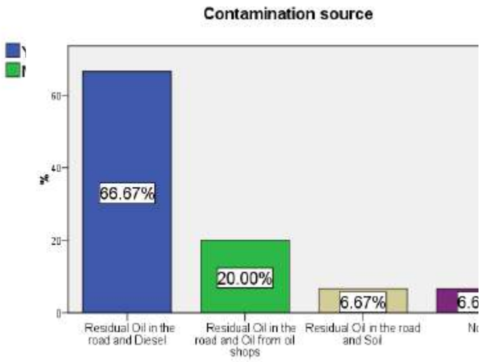

Figure 22b: Contamination Sources of RRWHS

Effect of road path on waterways pattern: 86.67 % of the inhabitants said that the road path changed the waterways pattern, 6.67% said no effect of road on water way pattern as shown in Figure 23a. Regarding the solution, about 80% think that there is no solution but the problem can be adapted by farmers, while 6.67 % suggested the problem can be solved by using culverts. The rest (13.33%) have no idea, as shown in Figure 23b.

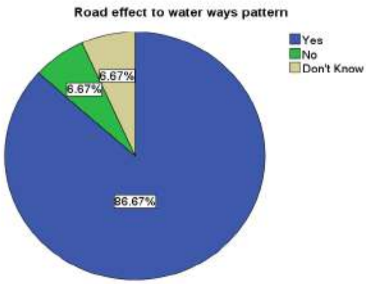

Figure 23a: Effect of Road Path on Waterway Pattern

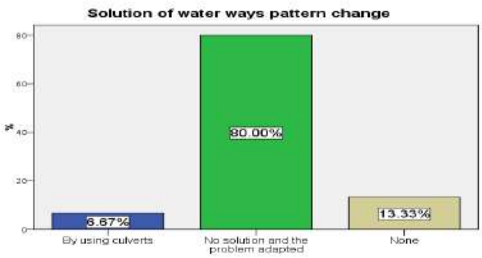

Figure 23b: Solution to the Change of Waterways Pattern

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b. Road Engineers questionnaires and analysis:

A structured questionnaire was designed and distributed among ten random road engineers to find out the general methods used for water related structures designs in roads, and to measure their awareness of water harvesting techniques from roads. The Excel program had been used to analyze this data as follows:

- The effect of roads on Water harvesting from roads:

The analyzed results indicated that about 40% of the engineers have experience about the effect of roads on water harvesting, while 60% of them do not have any experiences in this field, as shown in Figure 24.

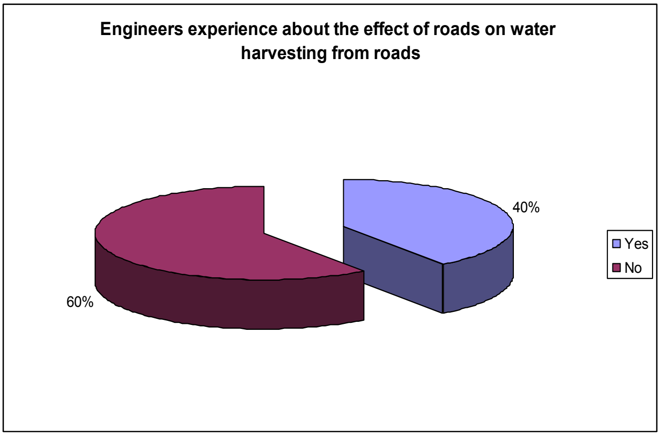

Figure 24. Engineers Experience about the Effect of Road on RRWH

Some of the engineers described their experience about the impact of roads on water harvesting as follows: the roads may have positively impact on water harvesting, where it increases the amount of water captured to the ponds. The agricultural pipes & humps are used to divert the water from road surface to the farms as the case in Amran – Al-Sawdah – Al-Ahnoom Road. The gateways are suggested to control water in bridges and big culverts, in order to maximize the benefit from the floods water running in the wadis crossing the roads. Further, the roads protection works design mainly focus on two factors: the first one, is to protect road surface from water impact and erosion, the second one is to save the water discharge to serve community and water recharge. Several results were extracted from the questionnaires as follows:

- Groundwater recharges from roads:

80% of the engineers said, yes, it is possible to use roads to collect water for groundwater recharge, while 20% said, no it is not possible to do so, as shown in Figure 25.

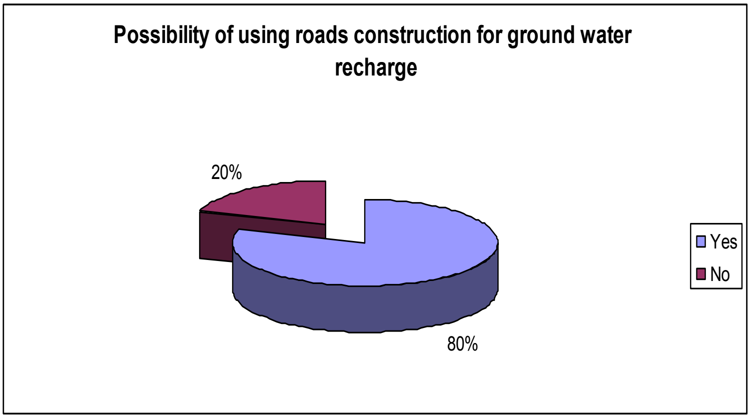

Figure 25. Groundwater Recharge from Roads

- Water harvesting for irrigation or groundwater recharge from the culvert:

Only 10 % considered water harvesting for irrigation or groundwater recharge from the culvert outlet by diverting water to areas of groundwater recharge during the road design. The rest (90%) of engineers don't consider that due to the following reasons: is not recognized; very costly; required social and environmental study to serve the stakeholders needs; and it depends on the strategic cooperation and coordination between beneficiaries, as shown in Figure 26.

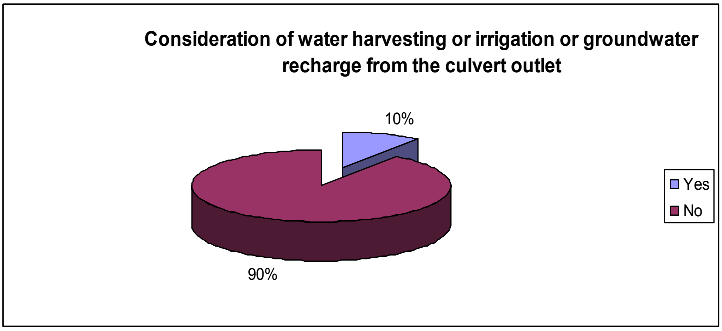

Figure 26: Rainwater Harvesting Utilizations from Culvert from Engineers Point of View

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- Water harvesting for irrigation or groundwater recharge from roadside drainage structures:

Only 20 % considered water harvesting for irrigation or groundwater recharge from roadside drainage structures by agriculture pipes (waterway) which is used to divert the water from the inner side ditch to the farms. This waterway maybe canceled through the road construction, if it is not used by farmers. While 80% don't consider water harvesting for irrigation or groundwater recharge from roadside drainage structures, because this issue depends on the strategic cooperation and coordination between roads authority and agriculture authorities, as shown in Figure 27.

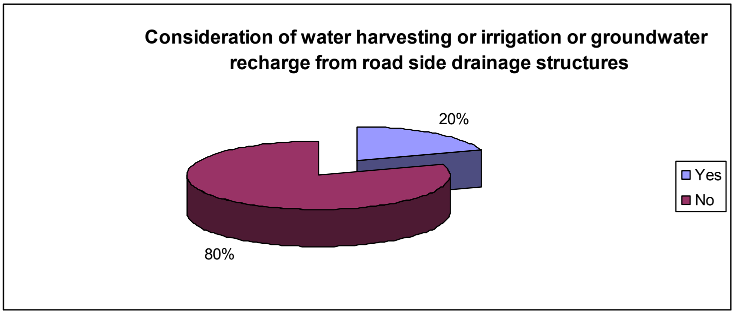

Figure 27: Rainwater Harvesting Utilizations from Roadside Drainage Structure from Engineers Point of View

Based on the questionnaire, the current culverts design understanding was discussed based on the following design elements:

The culverts location, type and size were defined based on the following: The experience of the engineers; types of roads; the culverts inlets and outlets design; the scour in inlet and outlet; the sedimentation transmitted in sediment basin before the inlet; and water velocity in the surrounding land at the outlet. Further, the outlets spillway design was differed from engineer to another as follows:

- Location of culverts in road projects:

The questionnaires indicated that 20% of the engineers think that the location of culverts is based on water ways and streams crossing the road only, 40% said: it is based on water ways and streams crossing the road with details hydrologic study, 10 % said: It is based on water ways and streams crossing the road with details hydrologic study and each vertical sag curve, and 30% said: it is based on details hydrologic study. While 10% reported that in case of international projects, details hydrologic study is used. The last method of design is used in local projects in water ways & streams crossing the road and at equal intervals.

• The culvert's type selection in road projects:

The questionnaires specified that 30% of the engineers said, typical designs from MPWH are used with selection based on the experience of the consultant; 20% of the engineers said, technical standards and detailed hydrologic study are used; 20% of the engineers said: in areas where the rocks is rare, the box culverts replaced by pipe culvert and the rest large culverts are made of stones according to budget availability; 10% of the engineers indicated that they used one of the above methods based on cost analysis for the available materials in the project location, road elevation and Maintenance and durability; 10% of the engineers used detailed hydrologic study and typical designs from MPWH and the experience of the consultant; and 10% of the engineers used detailed hydrologic study only.

• The size of culverts design in road projects:

The questionnaires designated that according to the design engineers, 50% is based on detailed hydrological study; 30% is based on the available width and height of the stream line; 10% based on both detailed hydrological study and the available width and height of the stream line; and 10% according to judgement by the design engineer.

• Culvert inlets design:

According to the questionnaires, 40% of the design engineers are applying typical drawings with selecting the inlet type based on whether the section is cut or fill section; 30% of the engineers are applying structural designs as needed on site; 20% are based on detailed hydrological study; 10% based on both detailed hydrological study & typical drawings while the inlet type is based on whether the section is cut or fill section. In addition to onsite structural designs as needed & function of retained embankment, structure skew and overflow requirement should be considered.

• Culvert outlets design:

According to questionnaires, 40% of the design engineers are applying typical drawings with selecting the outlet type; 30% of the engineers follow detailed hydrological study, typical drawings and the outlet type and onsite structural designs as needed; 20% of the engineers are applying on site structural designs as needed; and 10% follow detailed hydrological study.

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• Culvert outlet spillway design:

Different points of view were defined according to questionnaires as follows: The outlet spillways formed/designed as gradual steps with the protection work at both sides; riprap protection reaching up to the solid rock end. In All previous cases, hydraulic models should be used, in addition to applying the required protection works will depend on ground slope, height, discharge and soil type and to outlet flow volume.

• Engineers specific opinions/experience in culvert design/implementation problems:

– Most culverts do not drain the designed amount of water because the culverts locations are sometimes incorrect;

– Sometimes local beneficiaries ask for additional pipes (for irrigation canals crossing the road) which lead to disturbing the design and location of the culvert;

– There are typical designs drawings are used without considering the nature and site hydrology; which lead to lack on the design and location of the culverts.

– Some design engineers don't determine the specific station for the location of the culvert on the drawings, which led to create a problem in determination of the correct location. This problem might lead to implementing the culvert at wrong location which does not cope with the culvert design.

– If the culvert size is not enough the water will flow over the asphalt surface which may cause scouring & damage of culverts inlet and outlet walls and road embankments. It may also cause settling of sediments at the culvert inlet.

– Reclamation of new farms in the area may cause culvert blockage.

– Culverts dimension may not comply with the final design profile elevation which implies lifting the design level.

► Ditches design:

• The dimension and shape of side ditches in road projects were designed according to the questionnaires as follows: 20% of the Engineers answered that the ditch design is based on both typical designs from Ministry of Public Work and Highway (MPWH) and the experience of the consultant; while 30% is based on typical designs from MPWH, the experience of the consultant and according to detailed hydrologic study; 10 % is based on detailed hydrologic study but in general it is defined after the excavation; 20% is based on an offset distance from the asphalt edge to the cut side; 20% according to the economic point of view. In addition to the shape and size of the landscape. In most roads it is designed according to the available width after the cut excavation.

- The longitudinal slope of ditches were designed according to the questionnaires as follows: 30% of the design engineers answered that they adopt the technical standards; 50% designed it with the same slope as of the main asphalt profile with a drop of the ditch depth; 10 % designed it according to both detailed hydrologic study and technical standards; and 10% designed it according to detailed hydrologic study, technical standards and parallel to the slope of the main asphalt profile with sticking to minimum/required slope for discharge.
- The exit of side ditches were placed according to questionnaires as follows: 20% at the end of every horizontal curve if there is no agriculture lands or houses or it transferred to the other edge to the next curve; 40% following the natural water ways by using culverts or irrigation pipes to divert water; 20% after the excavation phase and according the landscape and needs which maintain work and discharge safety; and 20% following the natural water ways by using culverts or irrigation pipes to divert water, and at the horizontal curve that allow this safely.
- Selection of the type of the ditches construction material (Riprap or Concrete or Earthen): It is specified according to the questionnaire's answers as follows: 40% of the questionnaires reported that the deigned is based on onsite structural designs as needed; 30% due to the availability of rocks in the area with cost consideration and according to the road class and section type and the discharge volume; 10% due to detailed hydrologic study & typical drawings and according to X-section type in cut or fill & in site structural designs as needed & ditch longitudinal slope and type of soil; 10% due to detailed

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hydrologic study & typical drawings and according to X-section type in cut or fill; and 10% detailed hydrologic study.

- Calculation of scour depth in spillways: 70% of the questionnaire reported that they do not calculate scour depth as fixed depth but it is estimated without calculating the flow velocity, slopes or any other elements, while only 30% of the questionnaire engineers calculate the scour depth and they explain that Spillways executed to ends up in a solid edge and to not exceed a maximum length of 25 m, and it ends up with a cyclopean concrete toe, based on hydrology study, and by calculating the scour length in order to define the spillway protection works.

- Using curbs at road sides, and the way to defined the outlet: 80% use curbs at road sides and they explain that is done due the experience of the consultant to select outlet, Stone masonry work with 0.40 m width and 0.5 m height is used in case of there is no stones concrete curbs is used. The outlet diverted to a solid edge or to the nearest culvert according to road curves, water flow and movement, road edges in critical sections, which needs edge protection and divert water to appropriate location where it required, and function of cross slope and safety. Rarely the outlet is defined according to the distance, road slope and the expected water flow. While 20% reported that they do not use curbs at roads sides.

- Engineers Specific Opinions/experience in ditches and roadside drainage design/implementation problems:

– Sometimes, it is not enough to drain the runoff water in design safety volume; Sometimes the side ditch dimension is not enough to drain the side flow with the accumulated debris. This caused blockage of the side ditch which force the flood to run over the road surface causing erosion and damage. Therefore, the ditches should be designed to accommodate water flow in ditches and side drainage;

– Only the structural design is considered due to the absence of hydrological and hydraulic studies;

– Ditches and roadside drainage structures should be designed to maintain sustainability which would avoid high maintenance cost for frequent damaged and collapse.

– Most of side drainage and ditches are earthen, except in locations prone to scour where it is lined as a function of longitudinal slope and soil type.

– The wider drain has a high cost and apparently not accepted if the ratio between the drain width to the road width is high. Therefore, the amount of water at side drainage and ditches is discharged by using additional culverts if it is required by the hydrological study;

– The typical ditches design is not considering the flow velocity and slopes.

► Irish Crossing structure design:

The concept of the Irish crossing design was according to both typical designs from MPWH and the experience of the consultant, or based on hydrologic study in case the time of the flow in the wadi does not exceed one hour. This will depend on the flow volume, slope of the riverbed, scour in the inlet and outlet, the sedimentation.

3.6 Environmental and Social Impact assessment (ESIA) for the pilot road section during design and operation

In this part of the study, ESIA for the pilot road section of about 23.8km of the existing road of Sana'a Hodeida road was conducted. ESIA will be applied for the intended rehabilitation/ maintenance of this rural roads. It has been screened and classified environmentally as class B, as it is an existing road but with no enough water harvesting practice from this road. Moreover, some engineers are not aware of including such water harvesting concept during their design. It could also be considered as Environmental Auditing.

The environmental issues discussed are only those related to rainwater harvested from the pilot road section roads according to the field visits and questionnaires filled by 10 road Engineers and 15 farmers through the pilot road section. The most important related environmental issues in this pilot road section can be listed as follows: Land Use and Siting; Surface Hydrology; Water quality; Public Consultation; Institutional strengthening; and Land acquisition & Grievance Redress Mechanism (GRM).

In general, roads by necessity alter drainage patterns and increase impervious surface area, which serves to increase net run-off and therefore exacerbate erosion and other natural processes (Frank et al., 2018; Frank et al., 2015).

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In conjunction with infrequent heavy rains, a road project may exacerbate flash flooding conditions unless mitigation measures for such rare events are incorporated in project design.

A prediction of the changes in the environment resulting from project operation and maintenance are to be considered, and an assessment of the effect on the surrounding physical, biological, and human systems, should be presented. Among the issues to be investigated are the following:

- Hydrology: modification of natural drainage patterns; changes in groundwater elevation; flash flooding.
- The road Engineer should make sure that the design considered the drainage systems. Without proper drainage system during the operation phase, it is expected that this will cause accidents in the road and stopping the traffic flow for long time.
- Water quality: stream and lake sedimentation; use of pesticides; fuel and oil spills; water pollution from spills or accumulated contaminants on road surfaces.
- Public consultation has not traditionally been strong in Yemen. Therefore, It is important that ESIA for this study take the necessary measures to ensure adequate public consultation. People in the area have been informed.
- Land and Property Acquisition: The degree to which people will accept the influence which the pilot road section will have on their livelihood, such how the beneficiaries will use the harvested stormwater. Compensation can be in the form of monetary /income or new agricultural land. An overriding aspect for the potential acceptance of the proposed project is the potential benefit, which the project will bring in terms of social and economic upliftment to the communities involved. In most instances the communities should be well informed and are aware of the impending development.

From the field visit, the land use survey indicated a multi land use in the vicinity of the pilot road section. From the output of the questionnaires the following were concluded:

- 14 out 15 farmers think that the runoff is polluted. This negative impact is due to some long vehicles and cars that are evacuating the used oil on the roadside, which would pollute the rainwater. Since this rainwater is harvested and used by the farmers along the road for domestic, livestock, irrigation and recharge, the mitigation measure could be that the oil, grease are collected and reused, as well as oil shops are installed along the road. Moreover, a small pond- apart from harvesting pond- is constructed to divert the first flush of this rainwater which is polluted with oil, grease and dust (suspended soil) scavenged by runoff.

- All 15 farmers along the pilot road section of about 23.8km think that the flood water running on the road is their right. While 13 of 15 think that when constructing the road, the waterways pattern is changed. This entails arranging water diversion structures to maintain the water rights. Finally, 13 farmers out of 15 benefitted economically from the RRWH. The Ministry of Public Work and Highways (MPWH), Ministry of Agriculture and Irrigation (MAI), Local Authority and the suggested formed WUAs are responsible to monitor this issue (Frank et al., 2018; Frank et al., 2015).

The possible impact of the rainwater runoff is also soil erosion in heavy rain season, Ruin the arable land, and make gullies. The mitigation measure could well be by preventing clogging of culverts, construct more culverts to decrease the flow rate, install water dissipation energy structure such as cascade spillway at the outlets and basins at inlets of the culverts and ditches with lining the shoulders or constructing riprap.

Table 4 summarizes the ESMP for the pilot road section during operation and maintenance.

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Table 4: ESMP for the Pilot Road Section during Operation and Maintenance

Impact subjects	Impact	Mitigation	Responsibility
Site hydrology and Surface water quality	Erosion of lands below the roadbed receiving concentrated outflow from covered or open drains	.Increase number of drain outlets - Place drain outlets so as to avoid - cascade effect, Line receiving surface with stones, concrete Increase the farmers awareness - about the RRWH and support their initiatives (Canals, tanks, ponds (and direct irrigation from culverts the slopes should be planted - by trees for stabilization. The plantation could be using new almond trees which will maintain the sustainability of agricultural ;land stabilization Construction of retention ponds, - to retain the runoff during the rainy seasons, which might cause soil erosion from the disturbed soil. The role of those ponds will be to retain the runoff for a certain time to allow for precipitation of the eroded soils so as to prevent them from polluting water bodies or reducing the capacity of hydraulic ;structures such as culvert Conserve the eroded soil at the - culvert's outlets and at the streams water ways with land owners .coordination	MPWH, MoA, Local Authority, EPA, WUAs

	Soil erosion, terraces and flooding	- Road facilities (culvert, shoulders, slope orientation, construct harvesting ponds and maintain the water rights) - Widening and paving of shoulders - Proper design, operation and maintenance for culvert or distributing the flood in more culverts; - Implement water harvesting ponds Appropriate inlet and outlet - Proper road maintenance for potential RRWH by cleaning the blocked drainage ditches and side spillways - Widening and stabilizing of embankments - Improvements of culverts outlets, and side drainage - By proper lining protection works, rehabilitation of terraces above/below the culverts inlets/outlets and by building flood breaker (dry wall, canals and diversion channels) - Raising the pavement grade in areas subject to frequent flooding design maintained regularly
Public health	Creation of temporary breeding habitats for mosquito vectors of disease, e.g. sunny, stagnant pools of water	Assess vector ecology in work areas and take steps where possible to avoid creating habitats

Socio-economic and cultural issues and health issues	Involuntary land acquisition for the stormwater harvesting structures, some lands will be affected by the flash flood from the harvesting structure	Involuntary land acquisition is not expected. The local farmers should apply unprecedented mechanisms and procedures to arrive at equitable and adequate arrangements, and a companion effort to develop the capacity may be required
		Regular meetings with project affected people sign agreement for the land acquisitions approve it for the court
	Induced development: roadside commercial, industrial, residential and 'urban 'sprawl	Involve land-use planning agencies at all levels in project design and EIA and plan for controlled development.
water and soil pollution	Soil and water contamination by oil, grease, fuel and paint in equipment yards and asphalt plants	Collect and recycle lubricants
	Roadside litter	Provide for disposal facilities. Encourage anti -littering laws and regulations
slopes and terraces erosion	Landslides slumps, slips and other mass movements during flash flood	Stabilize road cuts with structures (concrete walls, dry wall masonry, gabions, …..etc.).
	damage of terraces by erosion	Regulated through the maintenance concessions
	instability of slopes and road width	Regular maintenance

4. Discussion

4.1 Related to farmers interviews

The interviews were conducted along the road and almost all those who have land adjacent to the roadside, and their farms irrigated from rainwater collected from all road structures. They are harvesting running water from/on the road by a simple structure, such as temporary hump, canal to transport water from culvert outlet to the farms, or from side shoulders by spillways to the farms. The harvested water from road is used for agriculture, domestic use, recharge and livestock.

- Water Rights:
  - All farmers are considering water floods running from/on roads surface and structures as their rights, and it is distributed according to the field's water rights, which exists before the road construction. In case of the road change some of the waterways nature the farmers accept to adapt with the new situation.
  - In one case through the pilot road section, the farmers complained that when the road was widened from one rural lane to two lanes separated by median path, there were about six culverts closed and replaced by only one culvert which made inequity in the harvested water rights;
  - In other cases, they requested to construct spillways. They also suggested a mitigation measures by means of maintenance, constructing spillway branching, floods drains, ponds and check dams, to avoid the damages caused by water from/on roads such as soil erosion, ruin the arable land, and gullies;
- ESIA:
  - Almost all farmers considered the water from roads as contaminated water and the source of contamination is from residual oil in the road, diesel, oil from oil shops and suspended soil particles (Frank et al., 2018).

4.2 Related to Engineers interviews

- The concept of water harvesting, groundwater recharges and water for irrigation from road surface and road structures among most of the road engineers were not considered, while only considered in some cases.
- There are different points of views among road engineers related to location and design of road drainage structures. Knoop et al. (2012) reported that water collected through a road drainage system needs to be carefully discharged from the road, avoiding any damages to the adjacent land. Also, the drainage system of a road needs to be carefully adjusted, so it does not conflict with the drainage systems on adjacent farmlands.

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- The indicators of the best practice of road drainage structures design are the experience and the skills of the engineers. In addition, the main restrictions are the cost and their awareness related of the hydrological and hydraulic studies;
- The available typical design drawings for drainage structures are useful and reflect a long-term experience. However, the hydrological characteristics should be defined to fit the specific locations to avoid damages, failure and high maintenance cost;
- The experience of the engineers is important, and it should be enhanced by focused training related to water harvesting and drainage structures and its reflectance to the road geometric design. According to Erik Nissen-Petersen (2006), Water from roads described four types of rainwater harvesting structures, namely earth dams, tanks, subsurface dams and run-off farming.

4.3 Rainwater Harvesting from roads in other countries

- In Brazil water Way initiative, groundwater recharge increased from 25% to 31% and the surface runoff decreased from 65% to 57%. The main constraints are to avoid the using of water harvested from roads for domestic purposes, as it could be polluted by motor oil, tar, rubber, …. etc.; and road-side structures such as culverts can turn into large gullies (Knoop et al., 2012).
- Other indirect advantages of water harvesting from roads is the uses of water volumes supply from roads such as: The tree nurseries, woodlots, orchards and vegetative fencing of fields and homesteads, manufacturing of burnt bricks, concrete blocks, culverts and other building materials that can be sold, (Erik Nissen-Petersen, 2006).
- Musyoka Muindu from Mwingi District, Kenya, harvested the water from tar road near his farm from a culvert under the road throw a main-channels crossing neighbor land with another channel that leads runoff from hillside (Mutunga and Critchley, 2001).
- Ms Florence Akol from Bukedea County, Kumi District, Uganda, (Mutunga and Critchley, 2001) harvested water from roadside ditches using diversion ditches and stored in semi-circulated infiltration ditches first then water flows to infiltration basins for banana plantation and conserved by mulching. With an increasing in banana yields.
- In Kenya, 'murram' pits are situated next to roads as the murram (excavated soil) is used in the road construction. Using murram pits (also known as borrow pits) is the most common technique to harvest runoff water from roads in the region.
- In China, over 50,000 rainwater harvesting tanks were constructed for irrigation purposes during dry periods. The underground tanks have been built along roads and use drainage water. (Knoop et al., 2012).
- in Brazil, where over 500 infiltration ponds were built along highways to collect road runoff to recharge groundwater under the so-called "Water Way" initiative. The soil in these ponds filters the water and

removes pollutants. The average capacity of the ponds is 4000 m3 (Knoop L. et al., 2012).

- Rainwater run-off from the Nairobi-Mombasa highway is diverted into an earth dam at Salama, which provides water for livestock, brick-making and forestry without any erosion (Erik Nissen-Petersen, 2006).

5. Conclusions and Recommendations

5.1 Conclusions

- There are a lot of water harvesting techniques in the pilot road section in the form of initiatives from farmers by directing water to their farms for irrigation. This issue needs encouragement and support from government's agencies and donor programs to establish water harvesting tanks near their farms along the road to collect and stored water to be used for irrigation and other proposes when needed.
- The almond trees in the pilot road section need to be wide-spread by giving more supporting the farmers to spread and plant almond trees as a cash crop and able to resist drought.
- The uses of RRWH from road surface and nearby areas must be implemented according to water right exist before the road construction.
- Road protection works in this pilot section were unique and serviceable such as side shoulder, curbs and spillways. Unfortunately, it is not considered during the routine road maintenance activities, where they ignore the cleaning of side shoulder, curbs and spillways which lead to blocked unconsciously during shoulder repairing and leveling.
- The water harvesting concept and practice from roads is not recognized by most of the road engineers. There are different views and ideas among the engineers in the design methods of road drainage structures such as culverts, side ditches and Irish crossing, which should to be appropriate for RRWH from road surface and nearby areas.
- The RRWH traditional structures along roads should be rehabilitated maintained and utilized.
- Applying RRWH will protect the road sections from erosion and damage and minimize the erosion of landscape especially in mountainous areas as well as in road embankments.
- The RRWH will increase the availability and utilization of water in the area's nearby roads.
- RRWH will help planting the area which would improve the stabilization of the road slopes and maintain esthetic value of landscape nearby roads.

https://doi.org/10.20428/JST.25.1.2

5.2 Recommendations

5.2.1 Technical Recommendations

- During design and construction of roads, surface water resources such as springs should be protected.
- Road drainage structure should be located in a proper place to avoid farmers conflicts
- More attention should consider to road protection works during design, construction and maintenance and consider the potential of water harvesting from road with the assistance of local stakeholders and recorded initiatives of RRWHS from different roads.
- RRWH should be applied to prevent damage of terraces during the heavy runoff.

5.2.2 ESIA Recommendations

- In the areas of RRWH, A vector ecology should be assessed and take steps to avoid creating habitats
- To avoid soil and water contamination by oil, grease and fuel from vehicle along the road, oil workshops should be implemented and forced to collect and recycle instead of disposing on the road. This is the responsibility of collaborated EPA and MPWH and MoA. A mitigation measure to such problem is by flushing out the first runoff of every season because the heavy pollution accumulated during the dry season.

5.2.3 Social Recommendations

- More attention should be considered in roads investment with water harvesting, watershed management, agriculture, poverty alleviation and infrastructure development agencies.
- Farmer's initiatives should be encouraged and improved by technical and institutional support by conducting training, capacity building and awareness workshops.
- Road maintenance activities should take a pilot participation project after social study on how to merge and benefit from stakeholders to conduct the routine cleaning of culverts and side drains with the emphasis of water harvesting practice.

5.2.4 Training Recommendations

- Awareness campaign and capacity building for road engineers in integrating road design with RRWH.
- Disseminate rainwater harvesting from roads concept to wider engineer's cluster.

5.2.5 Institutional Recommendations

- The water harvesting concept and practice should be included in road construction and maintenance investment plan by decision makers and related government agencies in collaboration with road engineers, watershed specialists, irrigation engineers and soil conservation specialists.
- It is recommended that the MPWH help WUA in formulate and document the local traditional water right rules to reflect this issue and monitor it during design and operation.

5.2.6 Future Recommendations:

- To develop a technical outline for the road design associated with water harvesting, more workshops, participation, and initiatives should be organized with the help of Ministry MPWR, Ministry of Agriculture, Ministry of Water and Environment, WUAs. It should include the following:
  - Construct water harvesting structures (ponds, pits, tanks, etc.) at potential location (at the lead out ends of side ditches, at culverts outlets and at water logging sites) with participation of the local communities to avoid social conflicts.
  - Ditches water flow can be diverted to the farms nearby the road.
  - Build conveyance channel/canals at the culvert's outlets to the farms near to the road.
  - Spillways and guidance curbs should be used to discharge water in embankments from road surface and road shoulders.
  - Almonds trees can be grown in small pits built off in the embankment which allows harvesting water in the planting small pit and reduce erosion.
  - More attention to divert and turn away the accumulated water from new road construction to protect the existing roads.
  - borrow pits location should be utilized after adaptation as water harvesting retention structure and recharge groundwater.
  - Irish crossing should be used as sand dam in wide wadis streams and used to recharge and retention water.
  - Construct water flow energy dissipation structures to control the erosion at the culvert's outlets.

https://doi.org/10.20428/JST.25.1.2

- Gates can be installed at culverts inlet to control water flow.
- Maximize the social benefits by harvest more water for different use, increase the farmer's income by planting cash crops such as almonds, reduce efforts for searching water and conserve the soil from degradation and erosion.
- The financial benefits: by increase the farmer's income by planting yield cash trees such as almonds, reduce consumption for buying water, reduce the soil conservation, terraces rehabilitation and reduce the road maintenance cost.

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