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Rain Water Harvesting Potential from Roads in Yemen, its social and economic benefits on national scale

A case study: Pilot section at Sana'a Al-Hodiedah Road

إمكانية حصاد مياه الأمطار من الطرق في اليمن. المردود الاجتماعي والاقتصادي على المستوى الوطني.
دراسة حاله: مقطع تجريبي على طريق صنعاء الحديدة

A Combination WEC Pilot Research With Roads and Highway Authority by:
Dr. SharafAddin Abdulah Ahmed Saleh
Dr. Abdullah Ahmed Maswari
Dr. Fadhl Ali Al-Nozaily
Eng. Mohamed abdullah Al-Abyadh

Water and Environment center
RMF & Road Highway Authority
Faculty of Engineering
RMF & Road Highway Authority



From Culvert by Canals



From Culvert Directly



From Side Ditch to Pond



Locations RRWH

From Road surface
and Side Shoulder



■ Problem statement

- Yemen positioned as the first country to run out of water due to the coupled enormous consumption with poor management and a growing population
 - Scarce water resources in Yemen are becoming increasingly precious, as per capita availability is falling steadily with growing population.
- The annual per capita water availability in Yemen is 115 m³; this is less than 10% of the regional average and 2% of the world average.
 - Annual groundwater withdrawal (from wells and springs) exceeds recharge at an alarming rate. Approximately 90% of all water consumed is in the agricultural sector
 - Rainfall exist annually in two seasons summer and autumn, and its intensity varies widely across the country, from less than 50 mm along the coast and desert interior , rising with the topography to between 500 and 800 mm in the western mountainous areas
- From the previous experience, RRWH is not considered by road engineers during the design, construction and O&M
 - Surface water is considered to be an important source for irrigation in Yemen, which consists of seasonal spate water and springs, with differing quantity & quality depending on the area.
 - Most of soil erosion problems in roads sides are caused by water floods in rainy season

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Main Objectives

Optimize the benefits of rain water harvesting from road construction / improvement to nearby areas for irrigation, by demonstrating the benefits to local communities (farmers), authorities and road engineers, so private and public initiatives can be developed.

SUB- objectives

- To suggest a technical outlines aspects from the pilot study
- To induce the awareness of roads engineers (designers and supervisors), decision makers and donors on the importance of IWHM.
- To study the ESIA for the road rainwater harvesting and its structures.
- To demonstrate to local communities benefits of the road water harvesting structures.

Objective of the pilot research

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1. Road Water Structures
Reconnaissance
Survey

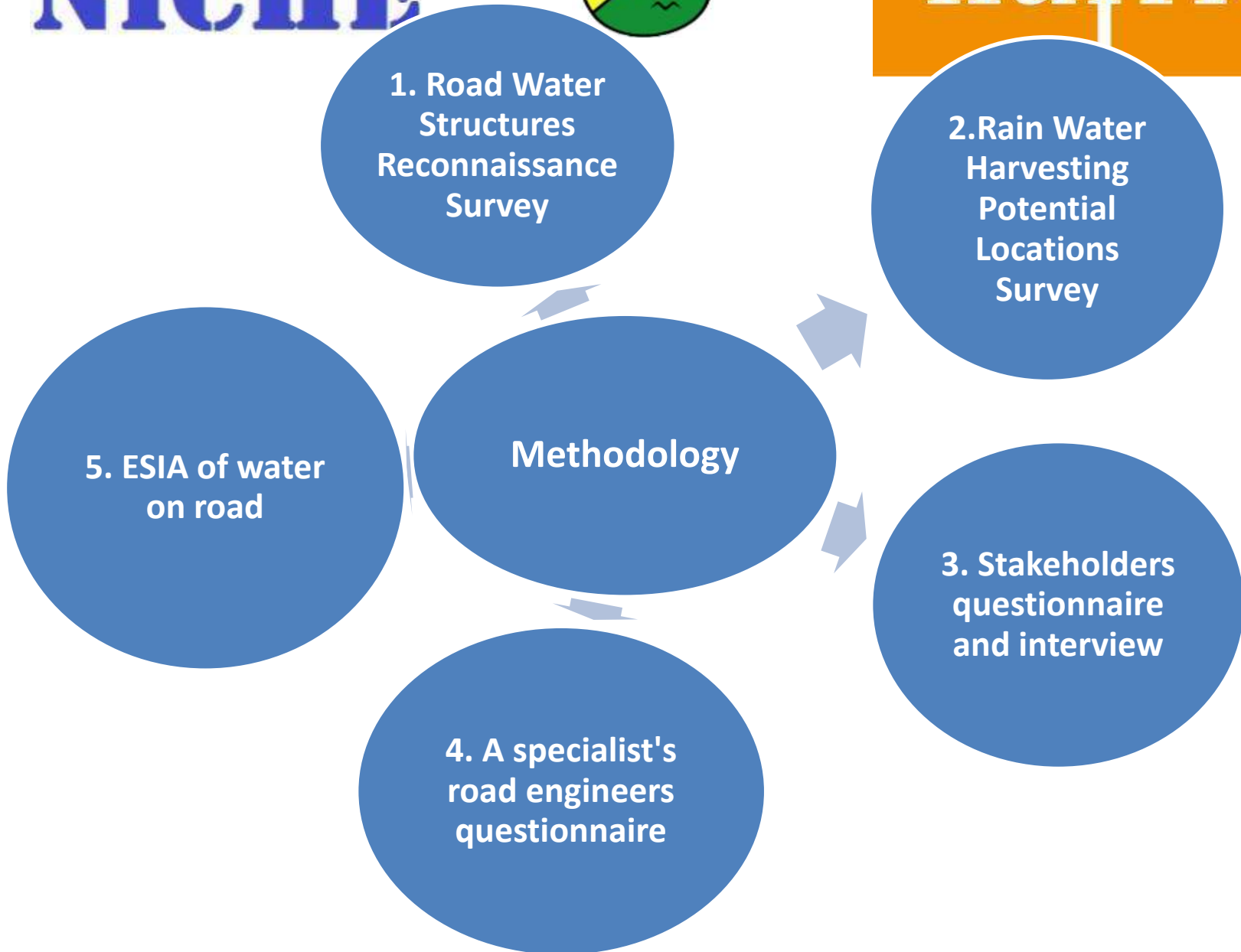
2. Rain Water
Harvesting
Potential
Locations
Survey

5. ESIA of water
on road

Methodology

3. Stakeholders
questionnaire
and interview

4. A specialist's
road engineers
questionnaire



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■ Pilot Study Road Section



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Field Work

1- Road
Water
Structures

Bridges

Culverts

Side Ditches and
Side Spillways

Water
Management
Structures

*Mis-Improvement
and Maintenance of
Water Structures*



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Field Work

2. Water Harvesting potential from Roads

Water Harvesting from Side Ditches to Pond

Water harvesting from culverts using earthen canal to the farm

Water harvesting from culverts to the farm directly

Water harvesting from road side shoulders and surface

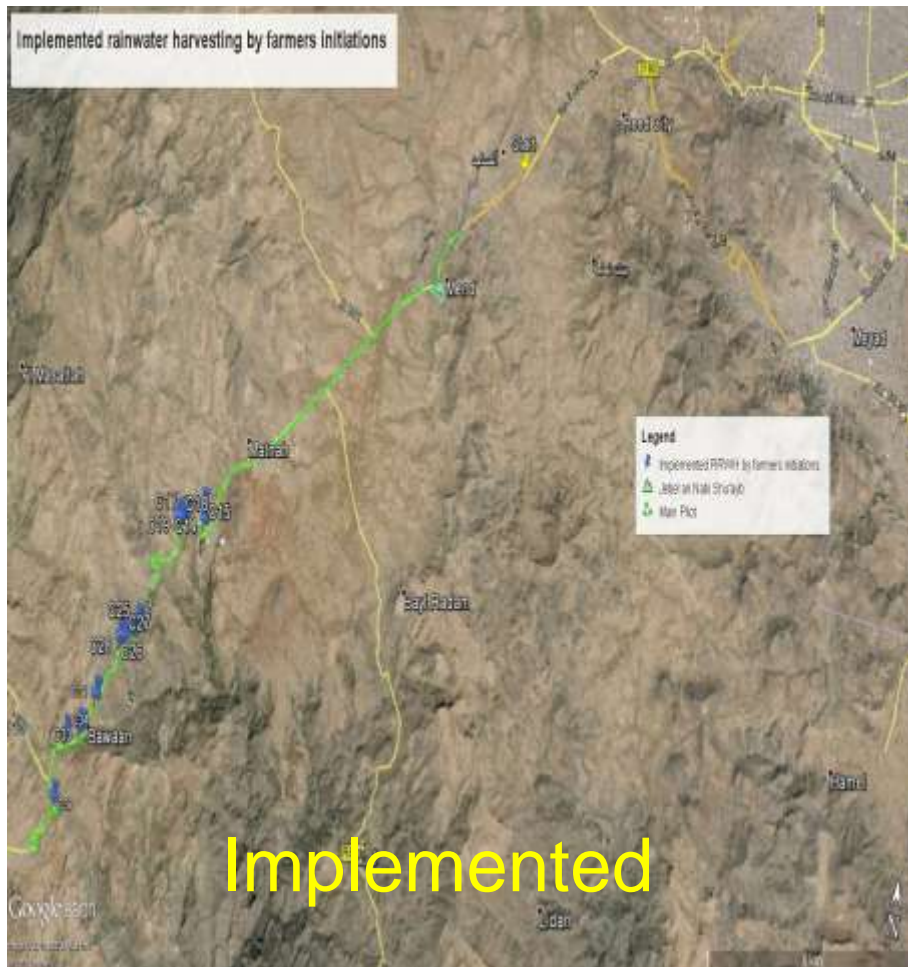


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Implemented and Potential RRWH with erosion and bridge locations



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The RRWH potential



1. Catchment of Mend pond:

road surface catchment = 900 meter long * 7 meter width = 6300 m² Approximately annual rainfall = 150 mm/year

Runoff coefficient is about 0.7

The potential harvested water = 661.5 m³.

The catchment area of the mountain side = 40,000m² ,
the potential harvested water = 4200 m³ .

The total harvested water = 4861.5 m³.

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2. Almond Farms irrigated from 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	



The RWH construction and road maintenance costs

1. The RWHS construction cost

Project Name	Total Cost US\$	Volume M ³	Cost US\$/M ³
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
Average RWH construction Cost			90

2. The road routine maintenance costs

The pilot section is classified under category A.

The total length of 23.8 km will cost about 7118.58 US Dollar /month for routine maintenance.

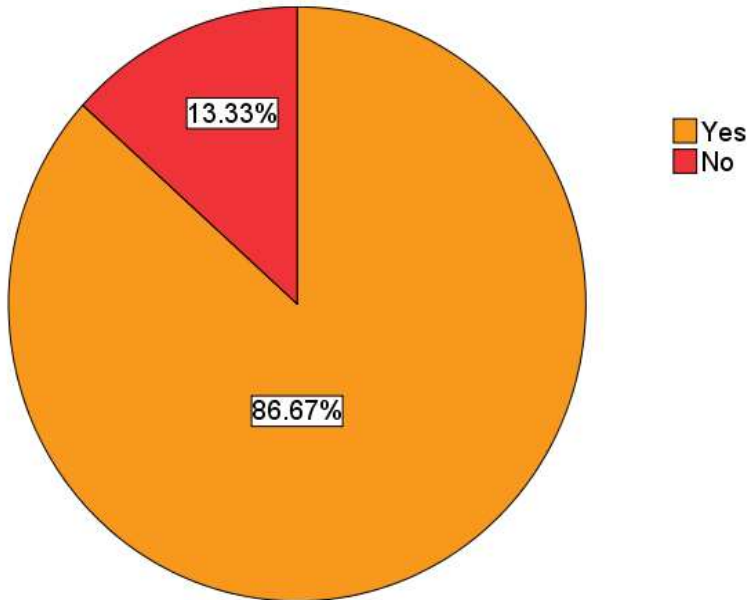
Routine Maintenance Cost / Month / Km		
Road Class	YR	US \$
A	64,306.00	299.1
B	45,456.00	211.4
C	35,789.00	166.5

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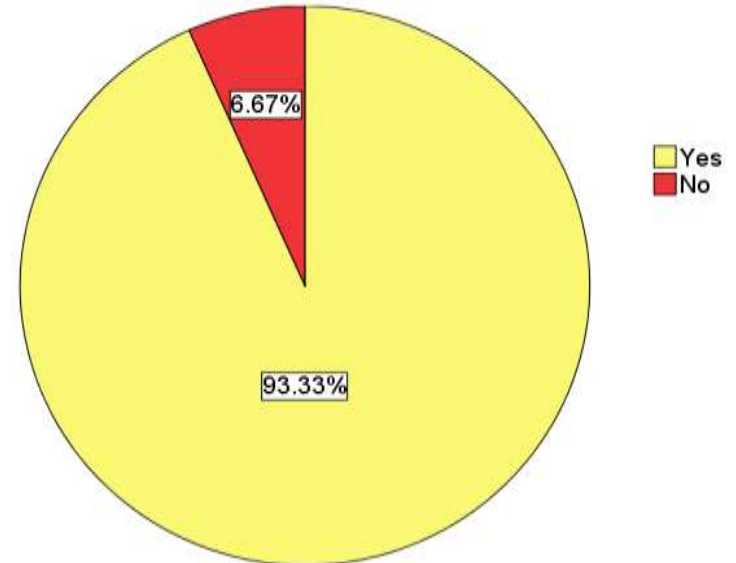


3. Stakeholders Data Collection and Analysis Cont.

The use of the water floods running from/ on road



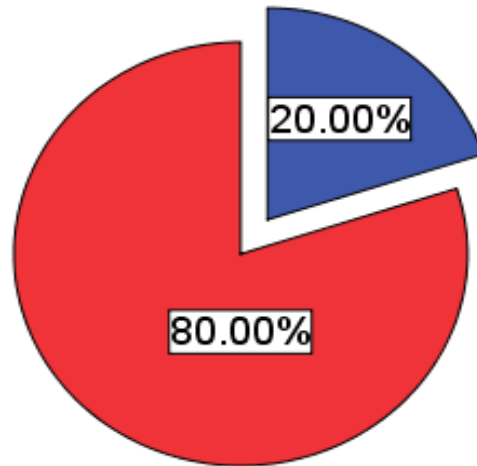
The ownership of land adjacent to the road side



3.Stakeholders Data Collection and Analysis Cont.

Water Rights

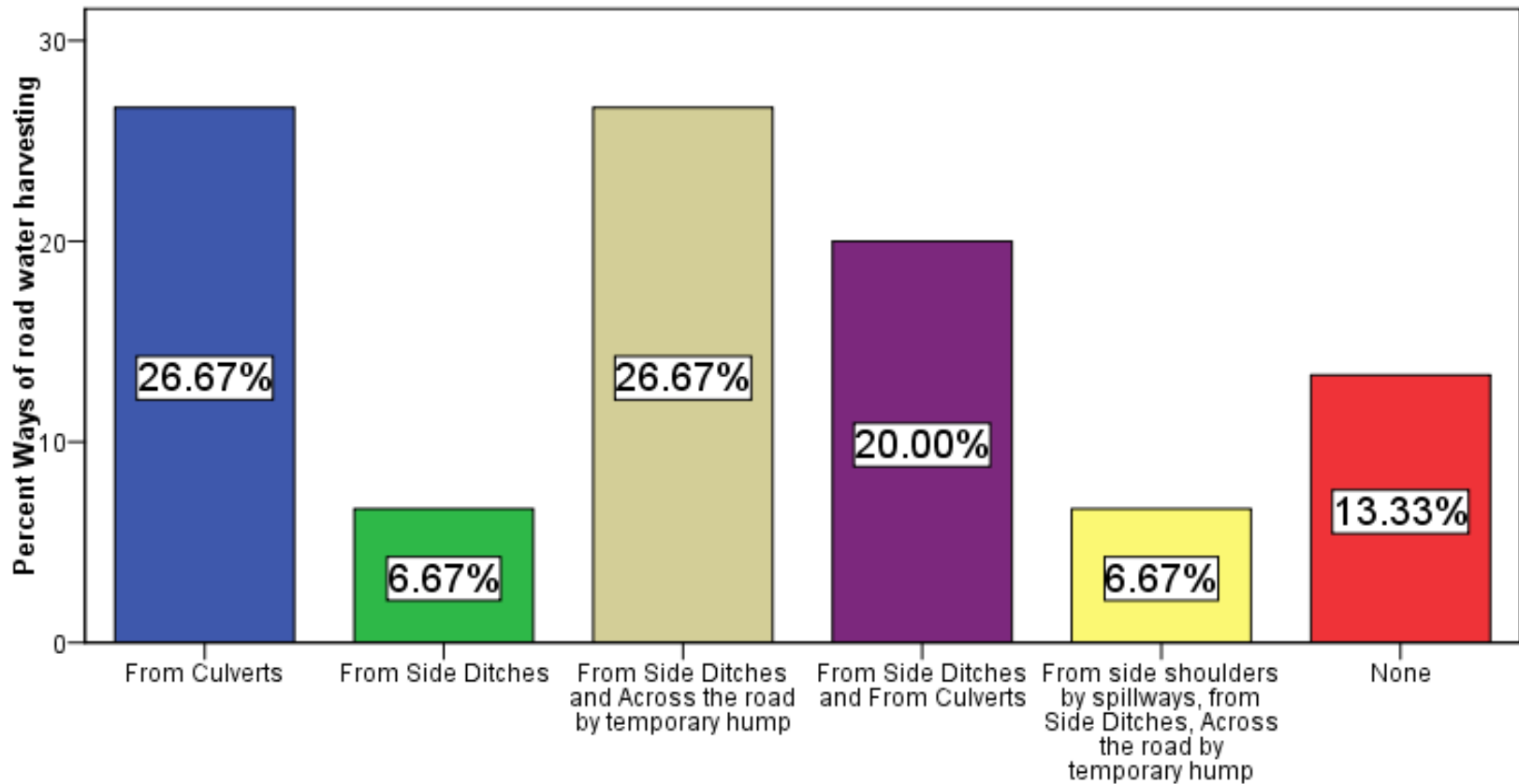
Water floods running from/on roads right experience



- There are ignore for water rights during roads upgrading
- No Idea

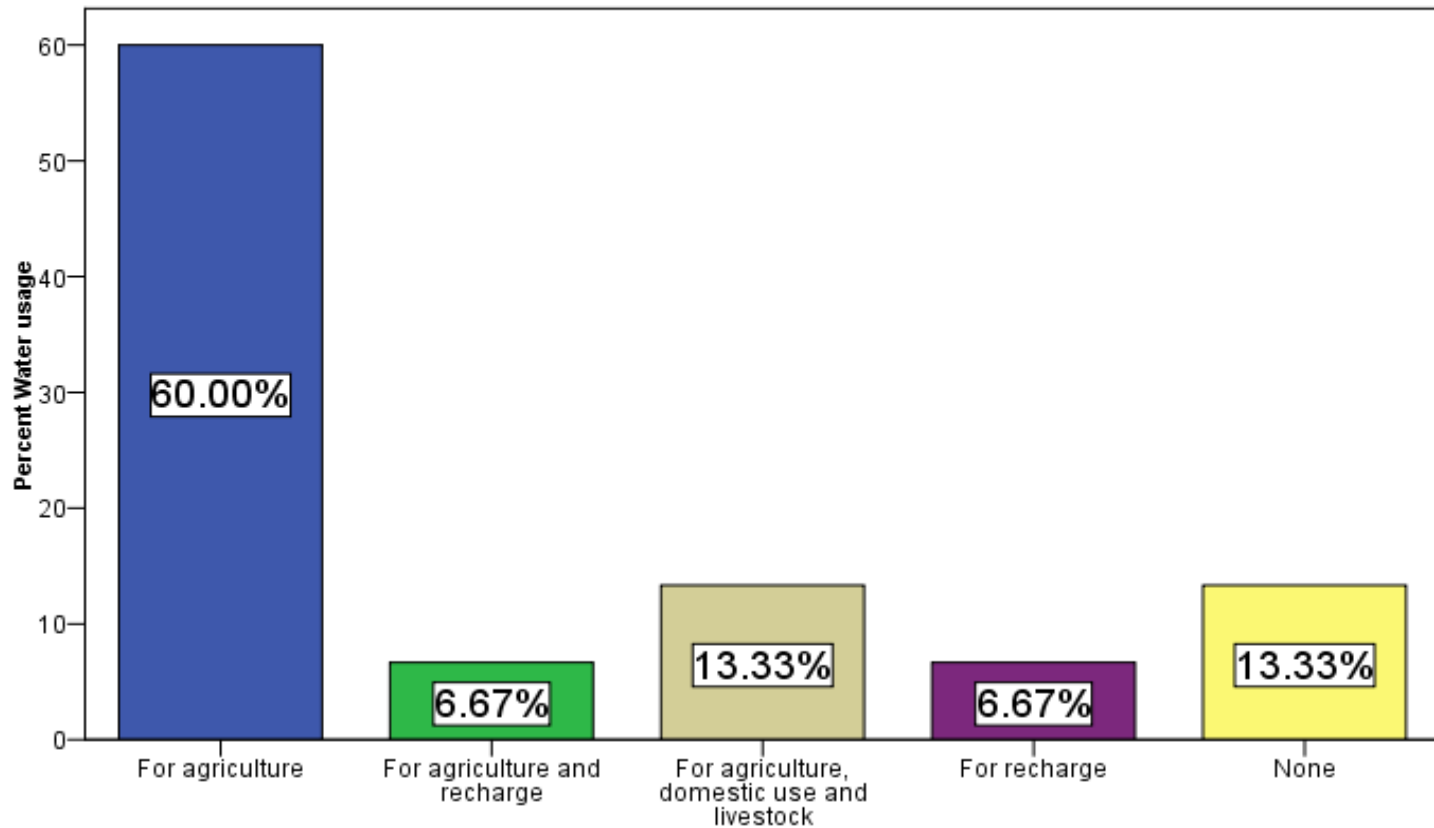
3.Stakeholders Data Collection and Analysis Cont.

Ways of road water harvesting



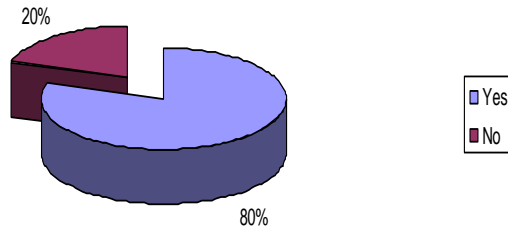
3.Stakeholders Data Collection and Analysis Cont.

Water usage

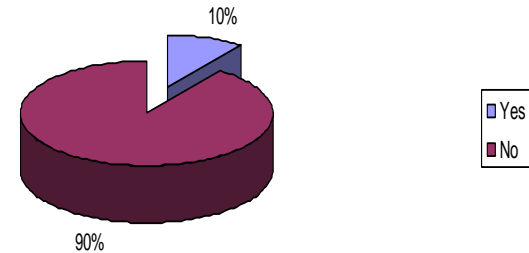


4. Road Engineers data Result and Analysis

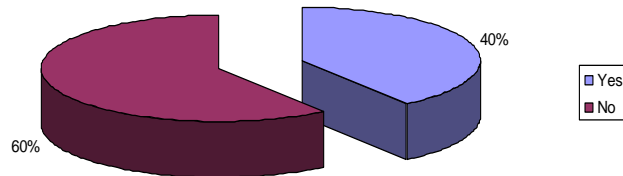
Possibility of using roads construction for ground water recharge



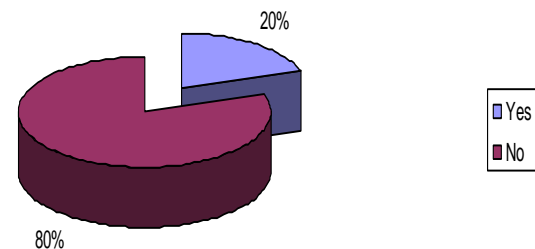
Consideration of water harvesting or irrigation or groundwater recharge from the culvert outlet



Engineers experience about the effect of roads on water harvesting from roads



Consideration of water harvesting or irrigation or groundwater recharge from road side drainage structures



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4. Road Engineers data Result and Analysis Cont.

Summary of Eng. experiences Road Water Structures

Current culvert design understanding

Location of culverts in road projects

The culverts type selection in road projects

The size of culverts design in road projects

Culvert Inlets Design

Culvert Outlets Design

Culvert Outlet Spill-Way Design

Ditches design

The dimension and shape of side ditches in road projects

The longitudinal slope of ditches

The exit of side ditches

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4. Road Engineers data Result and Analysis Cont.

Summary of Eng. experiences Road Water Structures

Ditches design

The dimension and shape of side ditches in road projects

The longitudinal slope of ditches

The exit of side ditches

Choose the type of the ditches (Riprap – Concrete – Earthen):

Calculation of scour depth in spillways

Using curbs at road sides, and the way to defined the outlet

Irish Crossing structure design

5. ESIA of water on road

5. Rainwater Impact to Road

Water erosion and gullies

In Culvert Outlet



Soil erosion in the earth slopes



At Side Drain



Water ponding

In Culvert Inlet



5. ESIA of water on road Cont.

Environmental and Social Impact Assessment (ESIA)

Impact subjects	Predicted Impact	Mitigation
Site hydrology and Surface water quality	Erosion of lands below the road bed receiving concentrated outflow from covered or open drains	<ul style="list-style-type: none"> - 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 RWH 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 to prevent from polluting water bodies or reducing the capacity of hydraulic structures like culvert - Conserve the soil from erosion at the culverts outlets and at the streams water ways with land owners coordination.
	Soil erosion and terraces and flooding	<ul style="list-style-type: none"> - Road rainwater structures (culvert , spillways, ditches, slope orientation ,construct harvesting ponds, maintain the water rights and widening & 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 RWH by cleaning the blocked drainage ditches and side spillways - Widening and stabilizing of embankments - Improvements of culverts outlets, and side drainage - 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 subjected to frequent flooding.

5. ESIA of water on road Cont.

Environmental and Social Impact Assessment (ESIA)

Impact subjects	Predicted Impact	Mitigation
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	Dislocation and compulsory resettlement of people living on the right-of-way. (Near cities and in rich farming regions, many people can be affected.)	Locally unprecedented mechanisms and procedures may be required to arrive at equitable and adequate compensation, and a companion effort to develop the capacity may be required
	Adequate compensation	Land and property acquisition
	Enactment and enforcement of laws	
	Regular meetings with project affected people sign agreement for the land acquisitions approve it at the court	Amicable settlements
water and soil pollution	Induced development: roadside commercial, industrial, residential and 'urban sprawl'	Involve land-use planning agencies at all levels in project design and EISA and plan for controlled development.
	Soil and water contamination by oil, grease, fuel and asphalt plants	Collect and recycle lubricants
erosion	Roadside litter	Provide for disposal facilities. Encourage anti-littering laws and regulations
	Landslides slumps, slips and other mass movements in road cuts	Align route to avoid inherently unstable areas. Stabilize road cuts with structures (concrete walls, dry wall masonry, gabions,etc.).
slopes and terraces	damage of terraces by erosion	Regulated through the maintenance concessions
	instability of slopes and road width	Regular maintenance

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Research Output

**a. specific
Technical
aspects from
the pilot
study road
section to be
considered
during design
and
maintenance**

- 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 culverts 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.

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Research Output Cont.

b- More general technical aspects could be as follows

- 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 culverts outlets.
- gates can be installed at culverts inlet to control water flow.
- The social benefits by harvest more water for different use, increase the farmer's income by planting cash trees 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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Conclusion



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Awareness program should be conducted because the water harvesting concept and practice from roads is not recognized by most of the road engineers

١- يجب عمل برنامج توعية عن مفهوم حصاد المياه من الطرق لأن معظم المهندسين غير مدركين لأهميته او لا يعرفون عن هذا الموضوع ولا يعطونه اي اهتمام اثناء التصميم والتنفيذ

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Several water harvesting techniques are noticed in the pilot road section in the form of initiatives by farmers through directing water to their farms for irrigation.

2- لوحظ وجود اليات (طرق) متعددة لحصاد المياه في مقطع الطريق المدروس بها يقوم المزارعين بتوجيه المياه الى مزارعهم

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The almond trees in the pilot road section need to be wide spread

3-التوسع في زراعة اشجار اللوز

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The uses of RRWH from road surface and nearby areas have to be treated according to water right.

4- استخدام حصاد المياه من الطريق او من المناطق المجاورة يجب ان يكون طبقاً لحقوق المياه

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Road protection works in this pilot section were unique and serviceable such as side shoulder, curbs and spillways which will reflect benefits for both road and rainwater harvesting .

5- اعمال الحماية للطريق في هذا المقطع المدروس مثل الأكتاف الجانبية – الحواجز والحماية الحجرية – قنوات تصريف المياه وغيرها كانت فريدة من نوعها وخدمة

وهذا يعكس الاستفادة منها في حماية الطريق و حصاد مياه الأمطار

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There are different views and ideas amongst the engineers in the design of road drainage structures such as culverts, side ditches and Irish crossing, while, hydrologic and hydraulic data should be applied safely and economically and to be appropriate for RWH from road surface and nearby areas. At the same time, should be compared with the ready made typical forms

6- بحسب الاستبيان هناك وجهات نظر وطرق مختلفة بين مهندسين الطرق فيما يتعلق بتصميم منشآت تصريف المياه من الطرق مثل العبارات - قنوات التصريف الجانبية - وكذلك الجسور السطحية و ينصح باستخدام المعلومات الهيدرولوجية والهيدروليكية عند تصميمها من اجل تحقيق الاقتصاد والأمان وتكون مناسبة في حالة حصاد المياه ومقارنتها بالنماذج الجاهزة المستخدمة في الوزارة

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The WH traditional structures along roads should be rehabilitated ,maintained and utilized

7- المنشآت التقليدية لحصاد المياه يجب اعادة تأهيلها وصيانتها والاستفادة منها

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Applying RRWH will protect the road sections from erosion and damage

8- تطبيق مفهوم حصاد مياه الأمطار من الطرق سوف يحمي مقاطع الطرق من الأضرار والتعرية والانجراف

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The RRWH will increase the availability and utilization of water in the areas nearby road.

9- حصاد مياه الأمطار من الطرق سوف يزيد كمية المياه
وينتفع به في المناطق المجاورة للطريق

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The RRWH techniques and structures will minimize the erosion of landscape especially in mountainous areas as well as in road embankments

10- حصاد مياه الأمطار من الطرق وكذلك منشأتها سوف تقلل من التآكل والأنجراف وخاصة في المناطق الجبلية ومناطق ردميات الطرق.

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RRWH will help planting the area which would improve the stabilization of the road slopes and maintain esthetic value of landscape nearby road

11- حصاد مياه الأمطار من الطرق سوف يساعد في زراعة المناطق التي تؤدي إلى تحسين وتثبيت المنحدرات وتحافظ على القيمة الجمالية للمناظر الطبيعية للمناطق المجاورة للطريق

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Recommendation

During design and construction of roads, surface water resources such as springs should be protected.

1- يجب حماية مصادر المياه السطحية مثل الينابيع وعيون المياه خلال مرحلة التصميم والتنفيذ

Road drainage structure should be located in a proper place to avoid farmers conflicts and serve water rights

2- منشآت تصريف مياه الأمطار يجب ان توضع في اماكن مناسبة حتى نتحاشى المشاكل بين المواطنين وكذلك المحافظة على حقوق المياه

In the areas of RRWH, A vector ecology should be assessed and take steps to avoid creating habitats

3- في اماكن حصاد مياه الأمطار يجب متابعة واتخاذ اجراءات عملية من اجل تجنب عدم تشكل ظروف ملائمة لتموء ناقلات الأمراض (المالاريا) فتصبح مصدر للأوبئة

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Recommendation

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 , MPWH ,MoA and Local Councils

4- يجب تجنب تلوث التربة والمياه من الزيوت - الشحوم - ووقود السيارات على امتداد الطريق واقامة مواقع للتغيير الزيوت والضغط عليهم لتجميع الزيوت واعادة استخدامها بدلا من التخلص منها على الطريق وهذه مسؤولية كلا من هيئة حماية البيئة - وزارة الأشغال العامة والطرق - وزارة الزراعة وكذلك المجالس المحلية

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Recommendation

RRHW should be applied to prevent damage of terraces during the heavy runoff

5- تطبيق نظام حصاد مياه الأمطار من الطرق سوف يمنع تضرر المنحدرات من الأمطار الغزيرة

More attention should be considered in roads investment with water harvesting, watershed management, agriculture, poverty alleviation and infrastructure development agencies

- الاستثمارات في مجال الطرق يجب ان تعطي اهتمام كبير لكلا من حصاد المياه من الطرق - ادارة المستجمعان المائية- الزراعة - التقليل من الفقير

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Recommendation

Awareness campaign and capacity building for road engineers in integrating road design with RRWH.

7- القيام بحملة توعية وبناء قدرات لمهندسي الطرق فيما يتعلق بحصاد مياه الامطار من الطرق

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.

8- مفهوم حصاد المياه من الطرق وتطبيقاته يجب ان يتضمن في خطط صانعي القرار والجهات ذات العلاقة بالتعاون مع مهندسي الطرق -متخصصين المستجمعات المائية - المهندسين الزراعيين وكذلك متخصصي حماية التربة والبيئة

Recommendation

More attention should be considered 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 water harvesting structures (WHS) from different roads.

9- اهتمام اكثر يجب ان يعطى لأعمال حماية الطريق خلال مراحل التصميم - التنفيذ وكذلك الصيانة مع الأخذ في الاعتبار احتمال حصاد المياه من الطريق بمساعدة السكان المجاورين وكذلك السجلات الأولية لحصاد المياه من طرق مختلفة

Farmer's initiatives should be encouraged and improved by technical and institutional support by conducting training, capacity building and awareness workshops.

10- يجب تشجيع المزارعين عن طريق الدعم الفني والمؤسسي - بناء قدراتهم وكذلك عمل برنامج توعية

Recommendation

Road maintenance activities should apply a pilot participation project with shared fund with beneficiaries through conducting 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.

11- يجب تدريب المستفيدين من حصاد المياه من الطرق على كيفية المشاركة في اعمال الصيانة الروتينية للعبارات وكذلك المصارف الجانبية وغيرها حتى يتم الاستفادة من منشآت حصاد المياه

Disseminate rainwater harvesting from roads concept to wider engineers cluster

12- يجب نشر مفهوم حصاد مياه الأمطار من الطرق بشكل واسع بين جماعة المهندسين

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شكرا لحسن استماعكم

