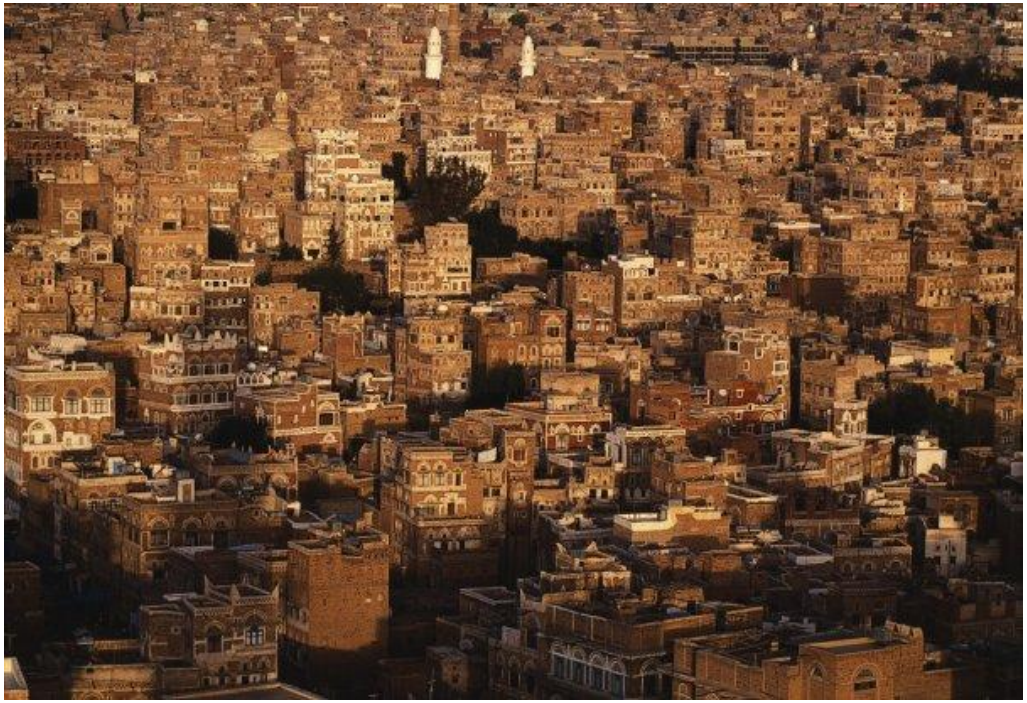
بسم الله الرحمن الرحيم

INTEGRATED WATER RESOURCES MANAGEMENT
MASTER OF SCIENCE

The Potential Of Rooftop Rainwater Harvesting For Sana'a, Yemen

Master Thesis Defense

By : Musa'ed M. Aklan



Supervisors :

Dr. Abbas AL-Omari, Prof

Dr. Lars Ribbe, Prof

Dr. Taha Taher, Prof

January, 2011

www.iwrm-master.info

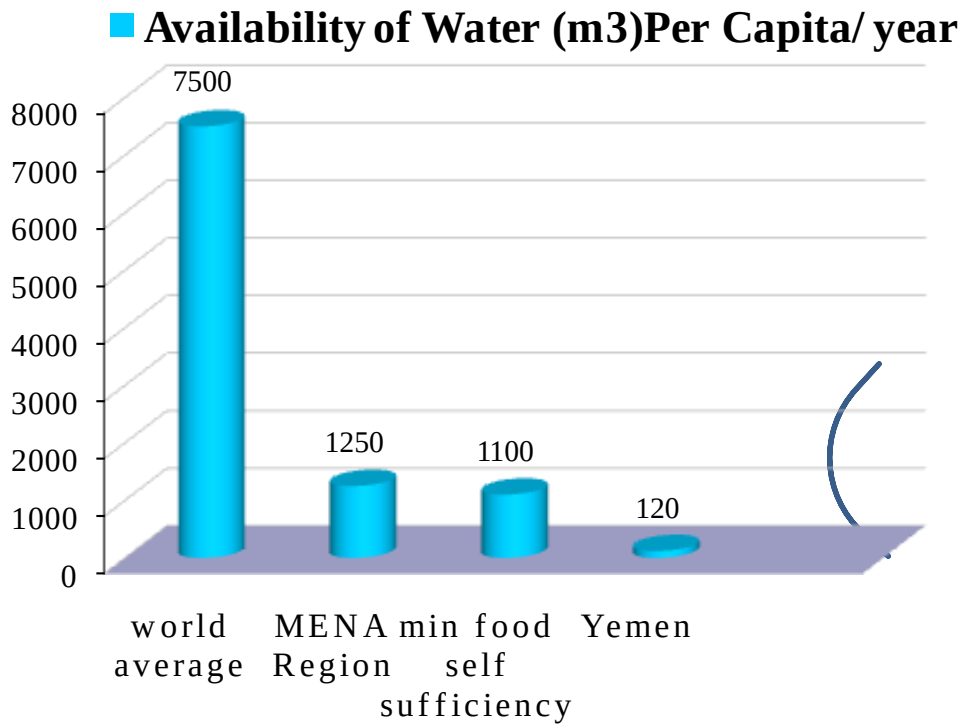
Fachhochschule Köln
Cologne University of Applied Sciences

Outline of the presentation

- Introduction
  - Problem statement
  - Importance of the study
  - Open Questions
  - Objectives of the Study
- Methodology and results
- Conclusions and recommendations

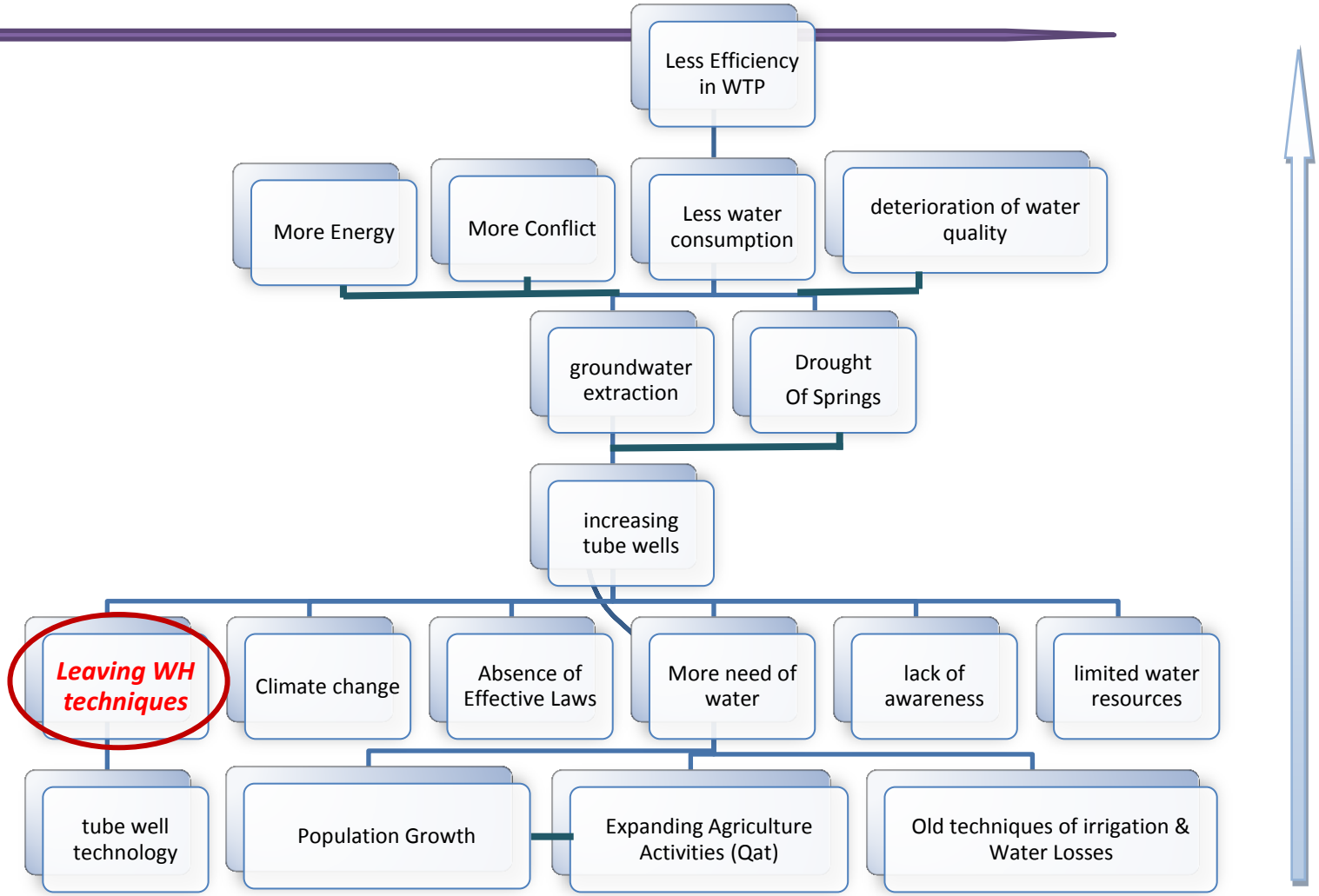
Introduction

Problem statement



Source: Hellegers, et al., 2008

Problem tree for Sana'a basin



Problem statement "figures and numbers"

- Deficit 219 MCM/year
- Water table 7m/year ↓
- Nr. of wells 13256 wells
- Dried wells 1615 wells

→ **Severe depletion**

Sana'a is the first capital all over the world is running out of water

Importance of the study

- The first RTRWH study in urban areas
- A need for studies exploring new sources of water other than groundwater
- Only 55% of the city is covered by network

Open questions

- How much of rainwater can be harvested from the rooftops of Sana'a ? Is it Feasible?

  Acceptable?

  Usable?; and

  Applicable?

- What are the types, sizes and sites of the systems? It is costs?
- To what extent RTRWH could contribute to groundwater saving?

Objectives of the study

- To estimate the amount of water that could be captured from roofs
- To identify for what purposes this water could be used
- To identify potential sites, techniques, and sizes for tanks
- To identify other possibilities of RWH in Sana'a Basin other than RTRW

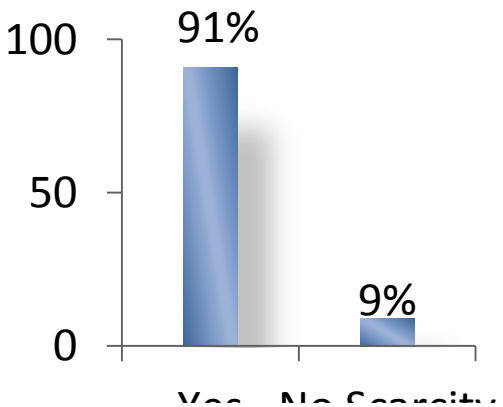
Methodology and **R**esults

Social survey…methodology

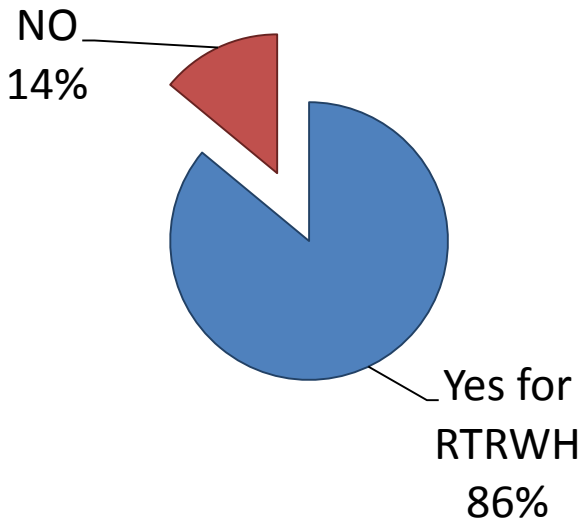
- Key informant interviews
- Interviews
  - Households
  - Existing RTRWH
  - Public building

Social survey…results

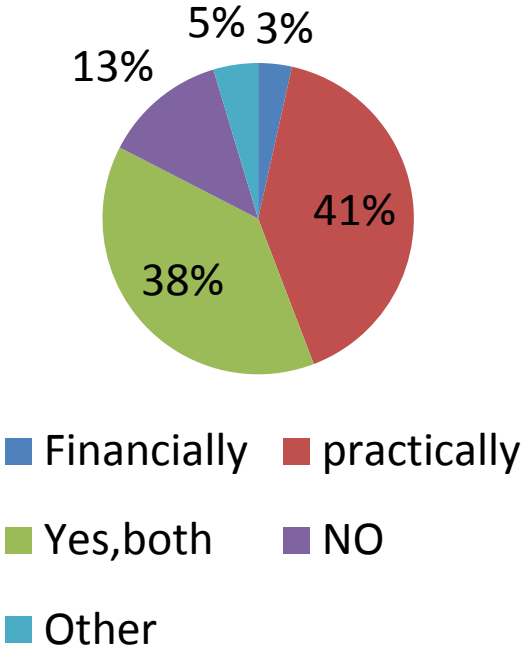
Awareness



Acceptance



Willingness



Rainwater Sampling…Methodology

- Six samples
  - 4 from gutters
  - 2 from tanks

Rainwater quality…results

Parameter	*Unit*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Mean Value*	*Samples above*	*NWRA*	*WHO*
pH		6.83	7	7.92	7.43	7.83	7.94	7.49	0	6.5 - 9	6.5 - 8.5
Turbidity		NA	NA	NA	NA	2.34	6.4	4.37	1	5	5
Electrical Conductivity 【EC】	µS/cm	106	105.4	135.8	374	115.3	205	173.58	0	2500	
Total Dissolves Solids 【TDS】	mg/L	69	69	88	243	75	133	112.83	0	1500	1000
Total Hardness 【TH as $CaCO_3$】	mg/L	43	45	30	148	44	75	64.17	0	500	500
Total Alkalinity 【TA as CaCO3】	mg/L	34	36	35	53	39	58	42.50	0		
Bicarbonate 【HCO_3】	mg/L	41	44	43	65	47	71	51.83	0	500	
Carbonate 【CO_3^-】	mg/L	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0		
Chloride 【Cl】	mg/L	1	1	6	46	7	11	12.00	0	600	250
Sulphate 【SO_4】	mg/L	19	13	16	33	15	40	22.67	0	400	400
Fluoride 【F】	mg/L	<0.01	<0.01	<0.01	0.14	<0.01	0.43	0.29	0	1.5	1.5
Calcium 【Ca】	mg/L	9	11	8	49	16	20	18.83	0	200	
Magnesium 【Mg】	mg/L	5	4	2	6	1	6	4.00	0	150	
Sodium 【Na】	mg/L	4	4	12	9.9	6.4	17	8.88	0	400	200
Potassium 【K】	mg/L	5.3	5	9.3	8.5	4.9	6.1	6.52	0	12	
Nitrate as NO_3^-	mg/L	<1	<1	1.32	11.88	15	16	11.05	0	50	50
Iron 【Fe】	mg/L	0.07	0.09	0.06	0.3	0.084	0.068	0.11	0	1	0.3
Total Colliforms	col./100mL	NA	NA	NIL	NIL	21	3	12.00	2	0	10 *
Fecal Coliforms	col./100mL	NA	NA	NIL	NIL	17	1	9.00	2	0	0

* Here the guideline value of Fecal Coliform is only for an individual water supply source. For the municipal water supply system, the value should be zero.

Total coliform, Fecal coliform

Total coliform…concentration and treatments required

Range of TC	Degree of Contamination	Number of tested samples	Treatment Procedure
0-3	0	3	No treatment required
3- 50	1	1	Chlorination only
51- 5000	2	0	Flocculation, Sedimentation then Chlorination
>50000	3	0	Very high contamination, need special treatment

Source: (Al-Khatib,et al., 2004)

Fecal contamination..typical classification according to level of risk

	Number of tested samples	Degree of Risk
0	2	In conformity with WHO guidelines
1-10	1	Low Risk
11-100	1	Intermediate risk
101-1000	0	High risk
> 1000	0	Very high risk

Source: WHO, (1997)

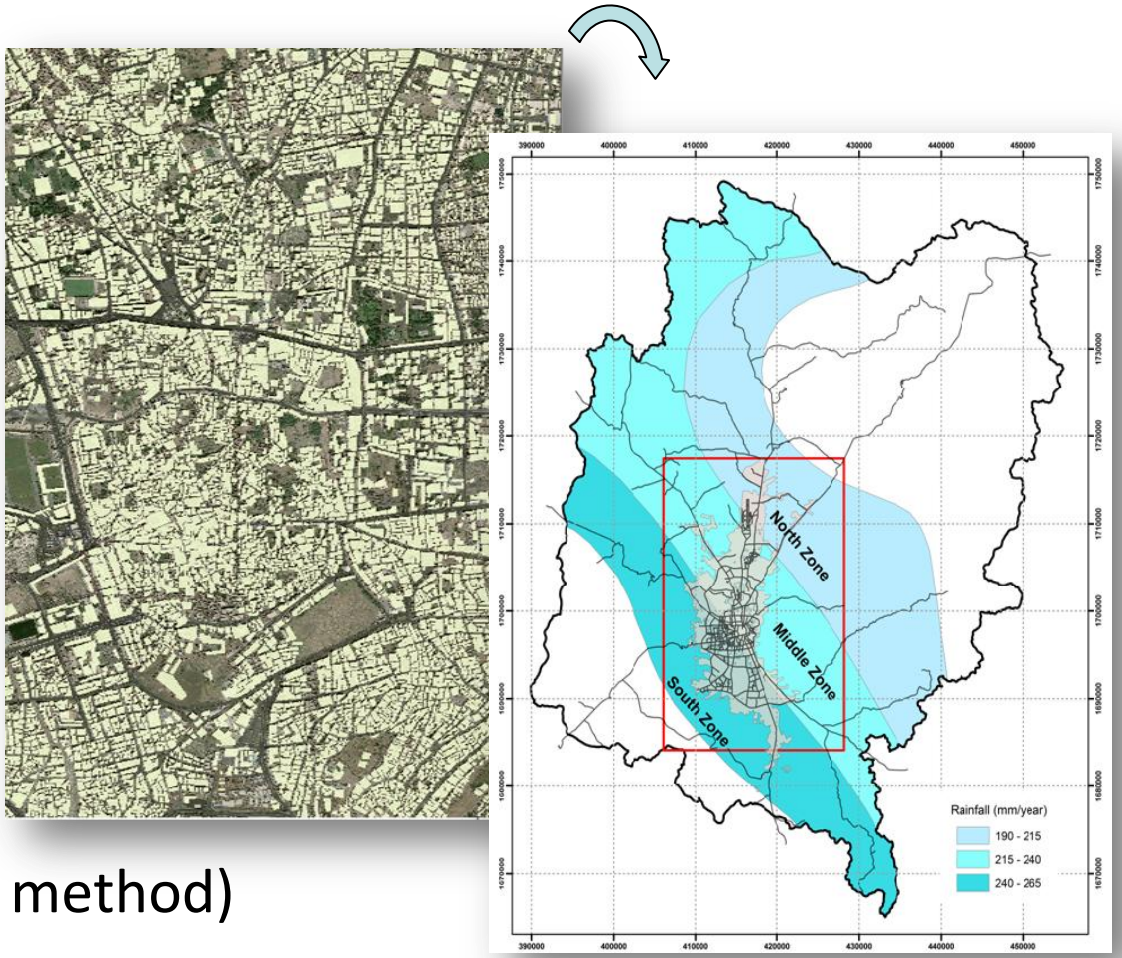
Constraints of Sampling

Why only six samples?

Why not from tanks?

Potential harvested quantity…methodology

- Digitizing
  - Satellite image
  - Envi
  - AutoCAD
  - isohyets map
  - ArcGIS
- Zoning
- Roof areas
- Water quantity (rational method)



Potential harvested quantity…results

Zone Name	Annual Rainfall mm/year	Average Rainfall mm/year	Rooftops Area (km2)	Harvested water (MCM/year)
South zone	190 - 215	202.5	0.423	0.069
Middle zone	215 – 240	227.5	15.642	2.840
North zone	240 – 265	252.5	17.247	3.487
Total			33.311	6.395

Potential harvested quantity…results

- Water demand
  - Population = 2.28 million
  - Per capita consumption = 30-50 liters/day
  - Demand = 33.3 MCM/year
  - Public network water losses = 34%
  - Supplying 6.4 MCM requires 2.2 MCM as losses

8.6 MCM =26% of the demand

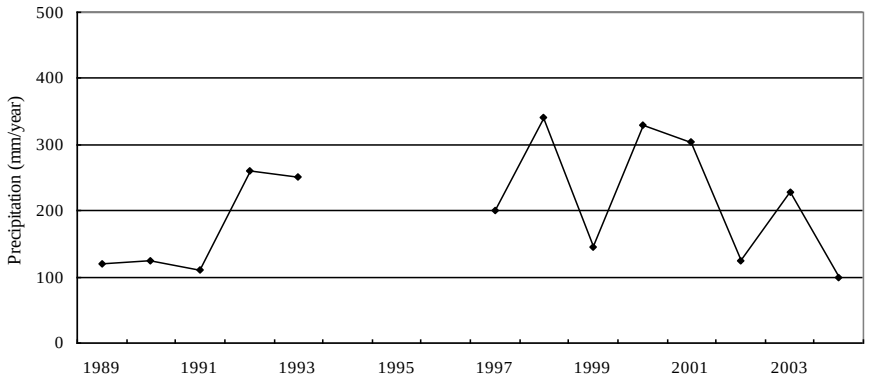
Pumping, distributing, maintaining, and operating costs

Potential harvested quantity…results

- Any drop counts
- Flood mitigation

Data collection.. constraints

- Daily Rainfall data for 16 stations
  - Gabs and missing data
- Accumulation of data over several days recorded as a daily rainfall.
- confusion between no data days and zero rainfall.
- Repeated data
- Zoning the city according to the rainfall density, required isohyets map .



Annual Precipitation (NWRA-A)

Potential Sites, Techniques and Sizes of the Tanks

Main Copm

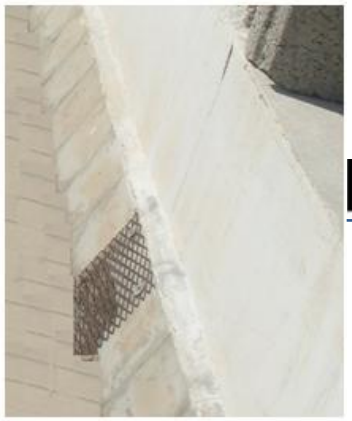
- Roof Tops
- Gutters
- Tanks

Devices for better quality

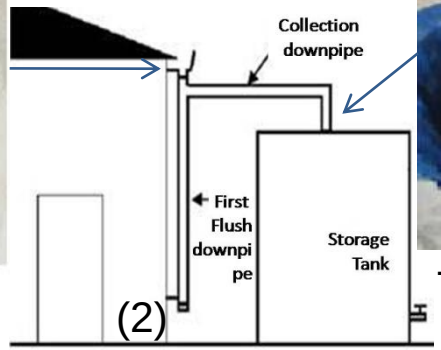
- Filtration screen (1)
- First flush device (2)
- Filtering before drinking(3)

Required practices

- Hygienic practices
- Frequently cleaning



(1)



(2)

Top tank filter (optional)

(3)

The matrix of selection process of tanks

No	Area properties	Examples	Tank type				
			Brick cement	Ferrocement	Block	Concrete	Shared
1	❑ Crowded built area	Old Sana'a	√√			√	√√
2	❑ Non-crowded area ❑ V<30m³		√√				
	❑ Non-crowded area ❑ V>30m³	Public buildings		√√		√	
3	❑ Required building above the tank ❑ V<20m³				√√	√	
	❑ Required building above the tank ❑ V>20m³					√√	

√√ Strongly recommended option √ Second option **V** Required capacity

Water harvesting system

- What do we need?
  - Tow systems for RW and other sources means, more
    - Area and budget are required
    - Efforts for cleaning and maintenance
- Rain water quality might not be worse than other alternatives

Tank size and control

Tank size

- There are several computer-based programs for calculating tank size that connected to more than one source (RainCycle)

(Roebuck and Ashley, 2006)

Tank control

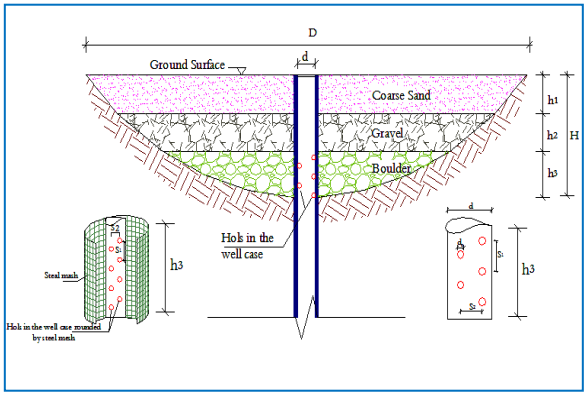
- Besides float valve, control valve is required
- Overflow pipe

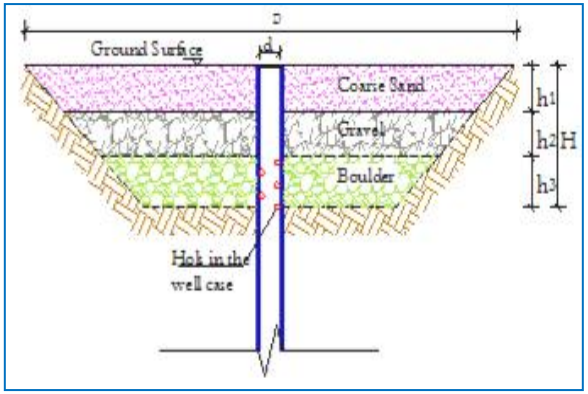
Other possibilities of rainwater harvesting

- Dried-up wells
- Cesspits
- Dug wells at households
- Ponds
- Check dams

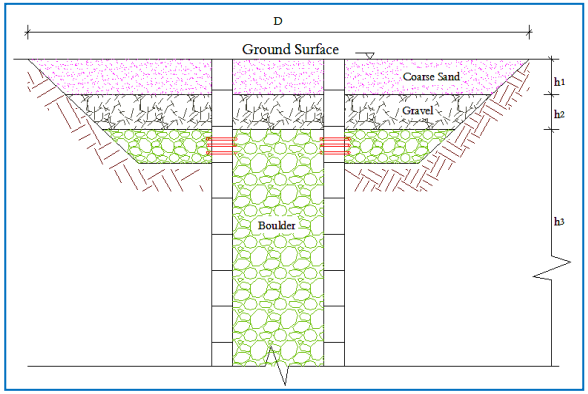
Dried-up wells

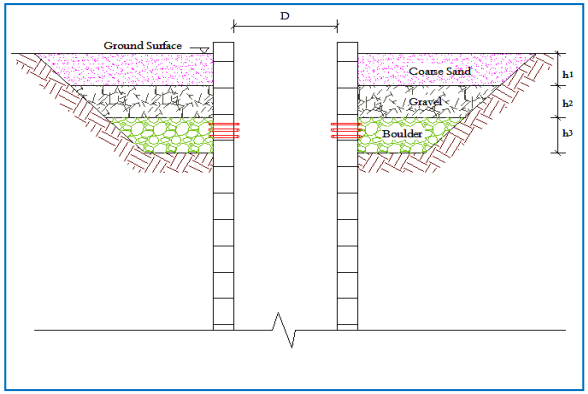
bore wells



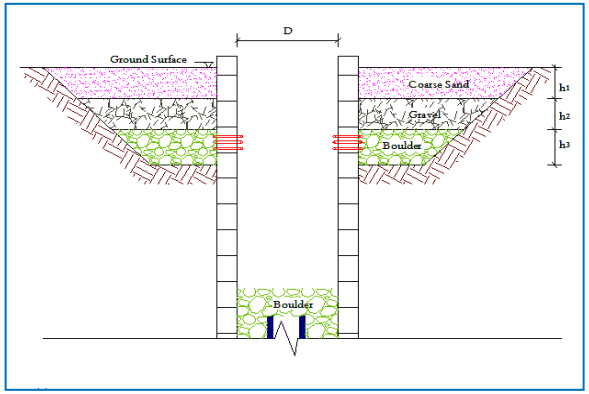


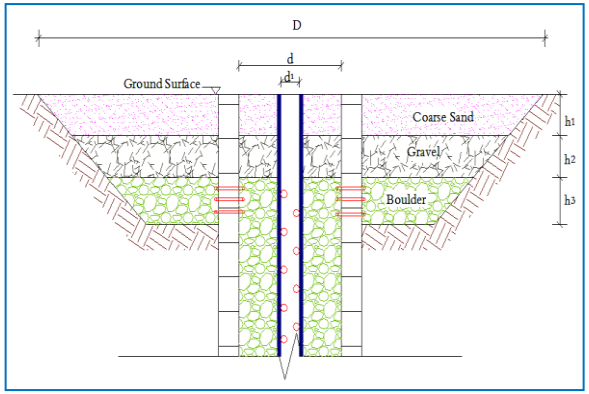
Dug wells





Dug/bore wells





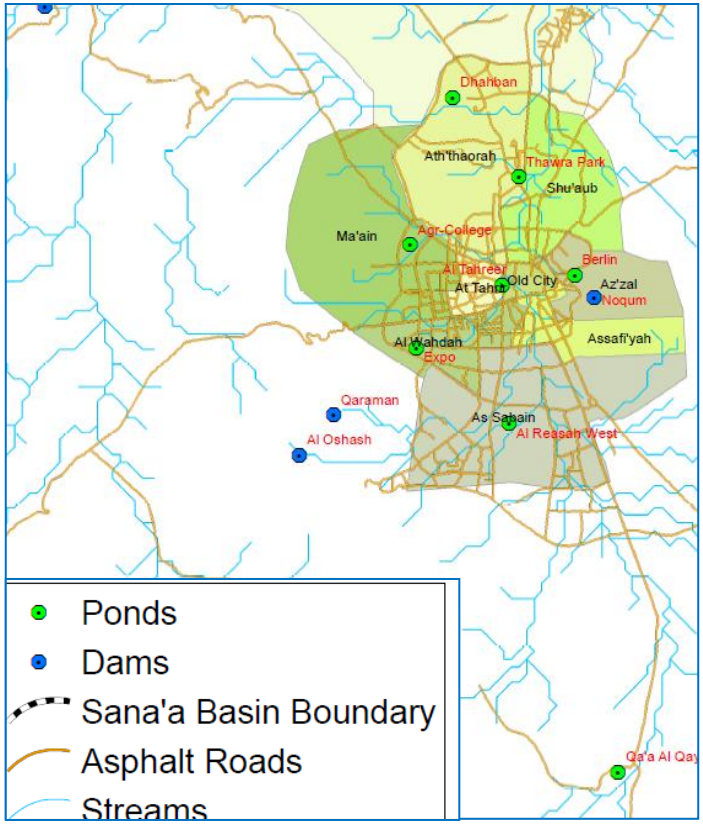
Cesspits & dug wells

- 40% of the city is covered by swage system the rest are using cesspits
- Suggested filters can be used for cesspits
- Many dug wells in the city are still exist

Ponds

- Ponds
- Al-Sailah Pavement

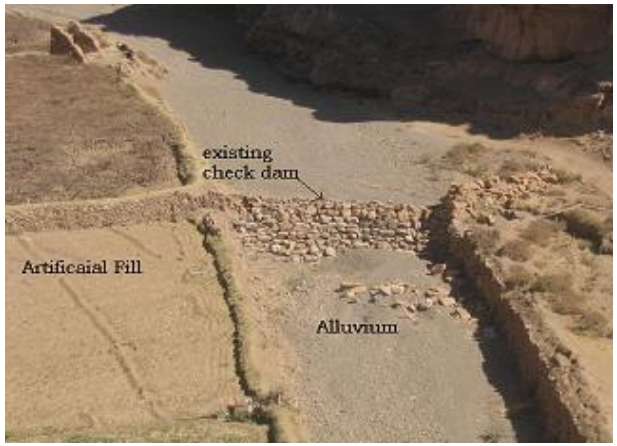
Proposed Ponds and Dams



Source: (Hydrosult, 2010)

Check dams…successful stories

- Benefits of check dams are already felt by communities
  - Bahman check dams and Beryan gravity dam
- Such check dams are advisable to be in the southern part of the basin to increase groundwater recharges and reduce the floods



Conclusion and Recommendations

Conclusion

- RTRWH is feasible and applicable
- RTRWH contribute in a good portion of ground water saving
  - 26% of the whole domestic uses
- Harvested rainwater can be used for all uses (filtering before drinking)
- Harvested rainwater seems to be more reliable than water from other unknown and infrequently tested sources

Recommendations

- More attention to rainwater harvesting should be paid in water management policies and strategies
- Further quality studies
- The start should be at government and public buildings
- Laws and regulations
- House water systems should be conditioned for RTRWH

Recommendations

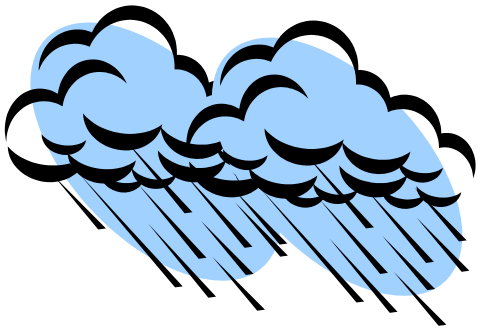
- Cooperation between government, private sector, and urban households is required
- Besides brick cement and ferrocement tanks, Ghala basket, cement jars and concrete ring tanks are also other cheap techniques practiced in Kenya and required further applicability studies

Fachhochschule Köln
Cologne University of Applied Sciences

UNIVERSITY OF JORDAN

ITT

WERSC



Thank You