Water problems in Ta'iz, Yemen

Water use in a rural area

Jasper Bisterbosch
s0103691

6 June 2008
Version 1

Preface

First of all I would like to thank Jan Hoogendoorn who works for Vitens and Mr. Hoekstra who works for the University of Twente for their support during preparing this essay.

During my stay at Vitens in Yemen it was an adventure for me to discover the culture of Yemen. Sometimes it was difficult to get used to some working attitudes, but the people are very friendly.

The problems during this study, which occurred to me, were lack of data available and the willingness to share data. This has been frustrating sometimes, especially when I needed some specific information.

Another remark about information gathering is that a lot of reports about the water situation in Yemen are written by the United Nations Development Program and the Worldbank. Local people didn't understand these reports. When something is asked about the reports they don't have a clue what it is all about.

But I have overcome all those difficulties; sometimes this took a lot of patience. I am glad that I can present the following report on the water usage for qat production and possible solutions or steering tools to manage this problem of allocation of water.

Table of Contents

1 Summary

Introduction

All over the world we struggle with water problems, often there is either too much water or too little of it. In Yemen there is too little water available and the worst depletion in the world is taking place here. This is caused by the production of qat and the high population growth. The purpose of this investigation is to determine how much water a hectare of qat production uses and if it is possible to divert water from the rural area to the urban area.

Determine area for research

The Harbeer area has been chosen because it produces a lot of qat and is close to Ta'iz. The determination of the size of the sub-areas has done by using Google earth, because those maps are more reliable than other maps available.

Pre study though questionnaire

By administering the questionnaire, it became obvious that the farmers have got different values and are very poorly educated. Most of them are not able to read or write and these farmers don't have an administration. These circumstances made it difficult to analyze the answers of the farmers on the questionnaire. Some important remarks of the farmers; they all saw the depletion as a problem and they told that higher prices of diesel, necessary to pump the water, would affect them mostly. But they would pass on the higher costs of farming to the consumers, so there is no effect on the water usage.

Water balance

From the water balance can be concluded that in the Harbeer area there is a water usage of 18 times the net precipitation a year. The over exploration of ground water causes a ground water declining of 10 meters a year. This can't go on forever and will give big problems in the future.

Analysis of water use for crops

Qat has the highest water requirement of all crops in Yemen and in the Harbeer area it is the dominant crop. On top of this the farmers use a lot of inefficient irrigation methods. A lot of water could be saved by drip irrigation instead of flooding irrigation.

Economic analysis

Qat is the crop which gives the highest return, in financial terms, for a cubic meter of water and is the most profitable crop for the farmers. This is the reason why it is produced so much.

Potential methods to reallocate water from agricultural to domestic purpose

In Yemen the people need to become aware of their water problem. The law needs to be enforced and the farmers need to be disarmed. If that doesn't happen a law is useless, because nobody will obey to the law. It is difficult to enforce the law when farmers take up arms and don't accept police on their territory.

When the law can be enforced, it is possible to create the boundary conditions for a water market. If the law cannot be enforced the farmers will put two pipes into the ground instead of one, so the depletion of the ground water will only go faster. This is the reason why this water market approach is not advised in the current situation.

Conclusion

The enforcement of law need to be improved, otherwise a law is worthless. To achieve this, the farmers need to be disarmed, so the police and army get some influence. The public awareness of the problem needs to be increased, so the farmers change their attitude to the usage of water.

The farmers could change irrigation methods, for example to drip irrigation instead of flooding irrigation. The government should see qat-farmers as farmers which they don't do at the moment, and start a promotion campaign among all farmers for drip irrigation.

A water market is not advised because there is no closed system. A closed system is a system where a maximum amount of water can be used; the usage of water is equal to the net precipitation. The depletion and exhausting of the groundwater will only go faster if a water market is introduced. A water market could be taken into account as a possible option, but is not advised.

2 Introduction

All over the world is there a problem of over exploration, this implies that there is used more water than there is refilled (Knapp, Weinberg, Howitt & Posnikoff, 2003). In Yemen the problem is very worse; it has the fastest depletion in the world (Negenman). The problem of the fast depletion cannot be solved very easy, because there is a high population growth. So there is a need for more food and drinking water in the future. This will lead to a higher use of water.

Yemen relies on ground water and the Yemeni people are now over-pumping the groundwater. It is hard to convince people that they should use less water, because they think water is a gift of the gods and the farmers do not see the depletion as a problem.

The water management from 1960 to 1990 could be characterized as uncontrollable groundwater use and development in the private and government sectors as the result of new technology. The lack of coordination between the different water related agencies and authorities causes the continued uncontrollable increase in groundwater usage.

The government has tried to stop this uncontrollable usage of groundwater by introducing the National Water Resources Authority (NWRA). The tasks of the NWRA are to control the water resources management and to monitor the usage of water.

The control of water usage is necessary to fore come conflicts in the future. The risks of a conflict can originate from the fact that there is more water used than there is refilled and eventually will lead to exhaustion of the water (Gleick, 1993). The declining of the groundwater level will increase the costs of pumping the water out of the ground (Riaz, 2002).

Most of the water at this moment is used in the agricultural sector for the production of qat. This is a kind of drug where the leaves have to be chewed. This drug is used all over Yemen, by almost everybody. This delivers a lot of problems. More information about qat can be found in appendix 1.

The scope of this investigation is to determine how much water the production of a hectare of qat uses and if it is possible to divert water from the rural area to the urban area.

In the first chapter of this report the research area will be determined. This research area has to have a lot of qat production, because qat is the topic of this research. Hereafter the used questionnaire will be discussed. Then there will be an analysis of the water usage of crops followed by an economic analysis of the crops. Hereafter the potential methods for reallocation of water from agricultural to urban purpose will be discussed. This will be followed by the conclusions of the report.

The conclusions of the report will contain advice with respect to the possibility to reduce the water use and the possibility of a water market.

3 Determine area for research

The area that will be invested needs to have got some production of qat and needs to be near Ta'iz. The location near Ta'iz is important so it can be visited. With those things in mind, there was a search for the research area.

Because of these requirements the region of Harbeer near Taiz has been chosen. The decision came after talking with the former head of NWRA[1], he said that in the Harbeer area qat is the main crop.

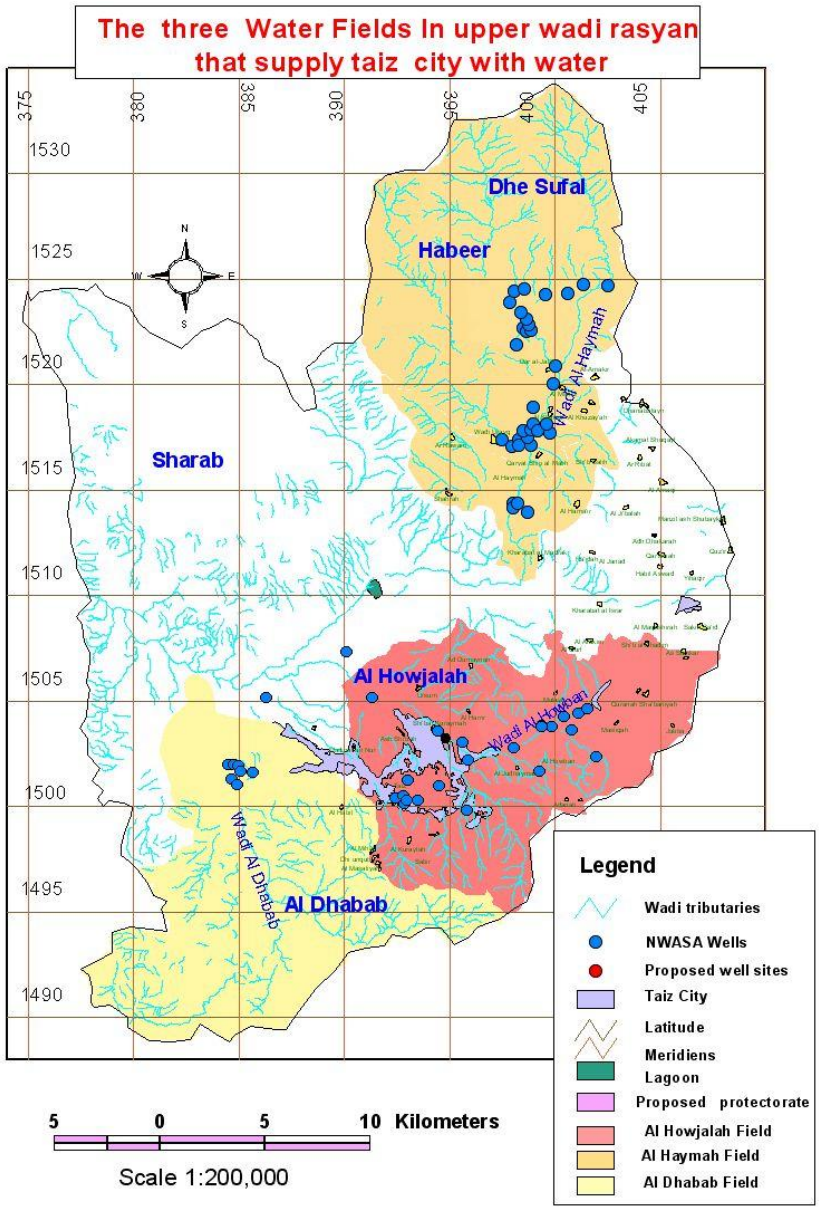

Figure 1: Administrative map of Taiz.
Source: NWRA(1998)

The figure above shows the department of Taiz, the Harbeer area is north of the city.

[1] National Water Resources Authority

After choosing this region the size of the sub area's will be determined. This has been done using Google Earth.

The following pictures are made using Google Earth.

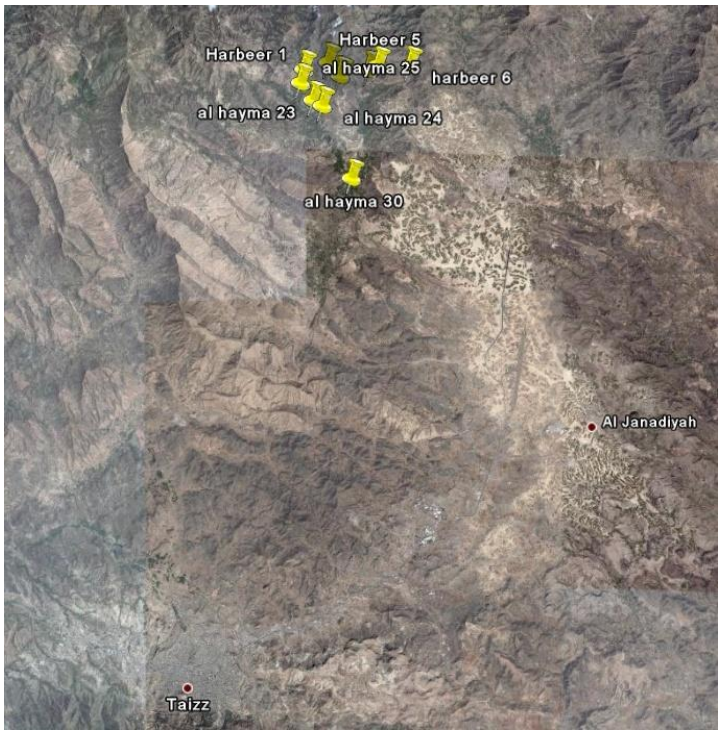

Figure2: Harbeer wells and Taizz

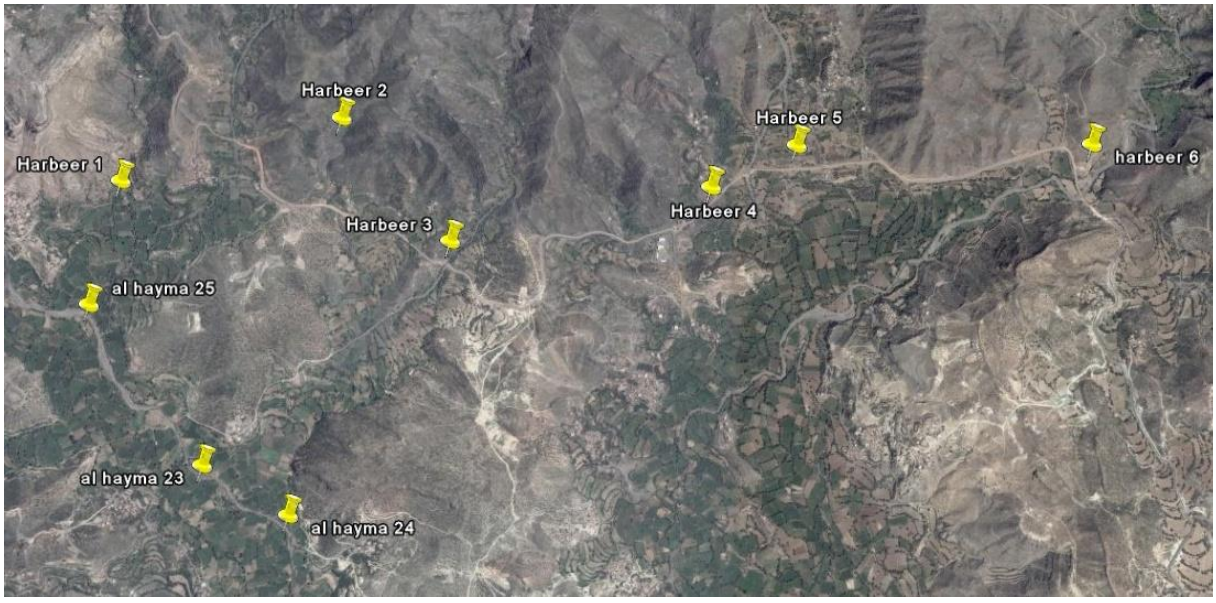

Figure 3: Location of Harbeer wells

In the pictures above the wells of the Harbeer area marked in Google Earth. After marking the wells the distance between two wells could be determined. After the distance it determined, the catchment area of a well can be determined. This will be done with the following formula: distance^2 * pi. After the size of the area is determined, this data can be filled in at the water balance.

The catchment area of Harbeer 1 is 0,22 km^2 , Harbeer 2 is 0,37 km^2 and Harbeer 6 is 1,32 km^2. The size of the catchment area has been determined by looking how far it is away from the other wells of the water company. The assumption is that the pump has an action radius of the distance between the 2 pumps divided by two. When the action radius has been determined, the size of the catchment area is $A = \pi r^2$ with r is the action radius and A is the size of the catchment area.

The problem is that this assumption has got some uncertainties with it, because the size of the catchment area is not exactly known. It is possible that the area is larger or smaller than the determined size because the pump has got a bigger or smaller capacity than is thought. Also other circumstances can have got influence on catchment area of the pump.

4 Pre study through questionnaire

By means of a questionnaire in the Harbeer area is investigated which information was available at the farmers. The main topics were questions about the costs and use of water. There also had to be some control questions in the questionnaire to check whether the information that was given by the farmers was correct or wasn't.

A test version of the questionnaire was made in English and was tested in practice with the farmers. The questionnaire in English with help of an interpreter didn't work in practice because it took a long time to get the information in the questionnaire if it had to be translated in the field circumstances. In this test came out that the questionnaire should be in Arabic and filled in by the farmers themselves.

The second time the questionnaire was translated into Arabic, but the farmers couldn't understand it because they had difficulties with reading. The result of this questionnaire was rubbish because they didn't understand the questions and answered the questions with complete nonsense. They couldn't read or write, but tried to write something down. This wasn't Arabic according to the secretary.

After this the farmers at the field sites were visited with help an Arabic who also speaks English. This man filled in the answers of the farmers in Arabic and translated these answers also into English. In this way he could check or the answers of the farmers were feasible and he could ask questions to me if some things were not clear to the people involved. This way of taking questionnaires worked out well. In appendix 2 the guidelines of the questionnaire involved are described.

The area of investigation was the Harbeer Area. This area has been visited several times. The visits were made together with Mr. Badri, the head of production. Four working days have been spent in the Harbeer Area. In this time 5 farmers were interviewed. To get an impression of the Harbeer area and the circumstances of the conditions of the interviews, a few pictures have been made. Those pictures are in appendix 3.

4.1 Analysis of the questionnaire

For the information that has been gathered by using the questionnaire should be taken into account that some data might be wrong, for instance the data of how much money the farmers receive for their crops. They were not willing to give it, because they thought it is for the taxation. The other problem is that the famers don't have an administration. They don't know how much has been spent on the water, so everything is estimated. Even the size of the farm is not known by them, only that the land is from the big tree to the other big tree. This makes it difficult to use the data from the questionnaire.

The answers that don't contain any numbers are useful. A few things became clear; all the farmers see the declining of the groundwater level as a problem. They see their revenue declining because of the groundwater declining. None of the farmers sees themselves as responsible, but the farmers close to them and the government are responsible in their eyes.

Meanwhile the farmers do not agree with limitations on the use of water, although they see the lack of control on water level as a problem. But they are prepared to take arms to get the water if

limitations on the use of water are set. They have already fought in Harbeer area for control on the water.

Almost all the farmers said a rise in diesel price would affect them mostly and they would use less water. But they would pass on the price of diesel to the consumers. So the mean question is; what is the net effect of this measure.

5 Water balance

5.1 Climate data

The water balance is made on rainfall and climate data that are received from NWRA. The data near the Ta'iz airport can be used, because the Ta'iz airport is close to the Harbeer area.

Table 1: Climate data of the Ta'iz airport

Location	**Ta'iz Airport**			
	temp ^{o}C	humid %	wind (km/day)	sun (hr/day
January	17,8	66	95	8,4
February	18,8	63	138	9,3
March	21,1	58	156	7,8
April	21,7	60	86	9,1
May	23,5	60	268	7,6
June	24,6	55	363	7,9
July	24,6	58	397	7,8
August	24,2	58	216	6,7
September	22,8	56	302	8,5
October	21,2	55	225	9,5
November	18,9	55	242	10
December	17,1	65	173	9,1

Source: NWRA(1998)

The rainfall data that is used are from the Ta'iz station because it only 25 kilometers from the Harbeer Area.

Table 2: rainfall in Ta'iz

	Average rain fall		
	rain	eff.rain	evaporation
jan	7,20	2,37	4,83
feb	13,79	4,49	9,30
march	31,19	9,84	21,35
april	67,77	19,95	47,82
may	86,24	24,47	61,77
jun	70,17	20,56	49,61
jul	77,37	22,35	55,02
sep	77,37	22,35	55,02
aug	98,96	27,36	71,60
okt	64,77	19,18	45,59
nov	19,79	6,37	13,42
dec	7,20	2,37	4,83
Total	621,82	181,66	440,18

Source: NWRA (1998)

The rainfall and effective rainfall were given, this contains that the evaporation can be calculated with the following formula: evaporation = rainfall – effective rainfall.

5.2 Water level pumping station

In the Harbeer area are the wells of the local water company, from these wells the water level of the last year is known. Hereby the depths of the water level of the following pumps stations in 2007 in meter. The water level was measured at the end of each month.

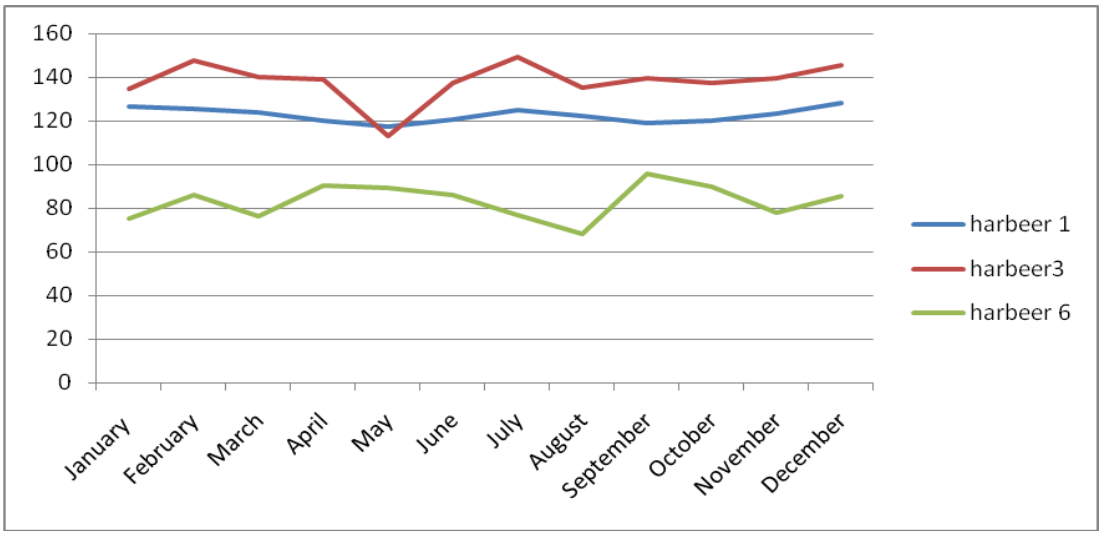

Figure 4: The depth of the water level of pump stations in Harbeer

Above is the groundwater level for each pump station. The average groundwater declining is 10 meter a year. The groundwater fluctuations are caused by not pumping for some time, so the water can recharge in the well. The water level in Harbeer 1, didn't change so much because the farmers have been shooting at each wells so they couldn't pump any water out of the ground because of the damaged pumps in the area of Harbeer 1. The pictures of the Harbeer pumps can be found in appendix 3.

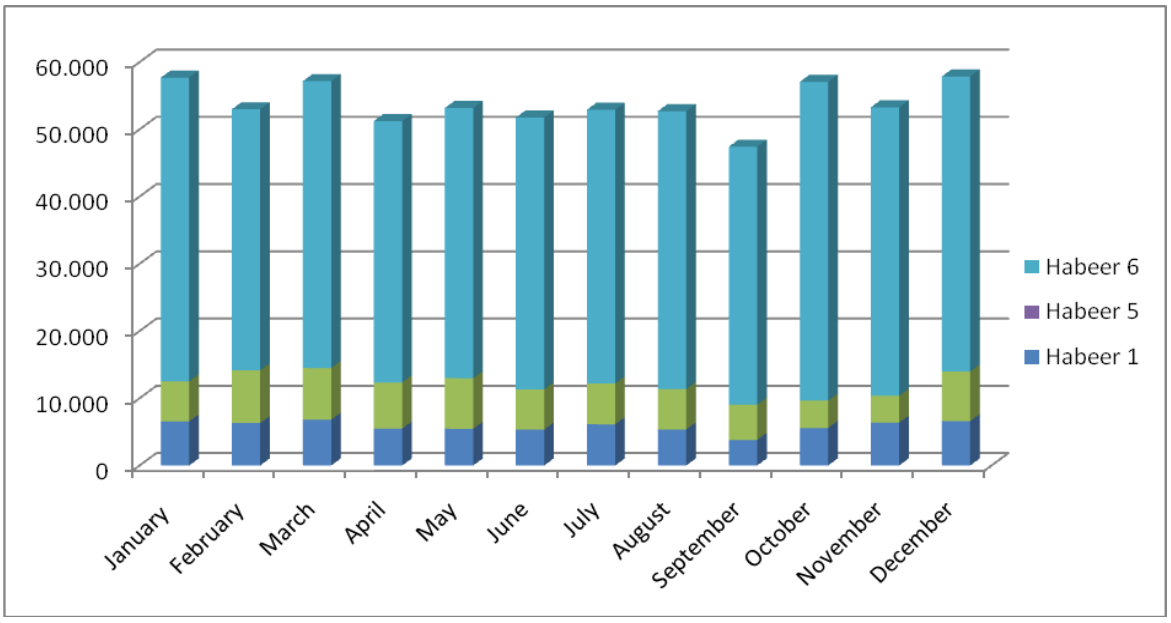

Figure 5: Exploitation of ground water for each pumping station

5.3 Formula of the water balance

The formula of the water balance is:
Precipitation + inflow of water + Δstorage = Evaporation + Use for irrigation + Other use + outflow of water

The precipitation data are from the NWRA. The inflow and outflow of groundwater are not known in this area, so these parameters have been set equal to each other.

The delta storage will be determined by the groundwater level changes. If the groundwater level changes and the porosity of the ground is known, the delta storage could be calculated.

The use of water for irrigation and other usage of water will be determined throughout data that is known by the water company. This will be not completely reliable data and hereby this should be taken into account.

By doing this, the formula of the water balance is:

Precipitation * area + Δstorage = evaporation * area + Use by water company + Use for irrigation

The data for the precipitation and evaporation are from the NWRA.

The water use for the city and industry has been given by TWSLC, the water use for the agricultural has been determined by the following formula:

Water use for agricultural = (precipitation – evaporation) * Area + groundwater use – withdrawal for city and industry.

Groundwater use = groundwater declining * Porosity * area

The porosity for the ground has been an assumption that this is 30%, the porosity is around this value (Verruijt, 2001). This is the reason why this value has been chosen.

The results of the water balance will be shown on the next pages.

5.4 Overview of water balance

Table 3: An overview of the water balance

	size Area (km^2)	Porosity	Declining of groundwater level (m/ year)	
Harbeer 1	0,22	0,3	1,62	
Harbeer 3	0,36	0,3	10,47	
Harbeer6	1,33	0,3	10,46	
	Agricultural water usage (m^3/ year)	Water usage TWLSC (m^3/year)	% used by farmers	% of water use in relation to the net precipitation
Harbeer 1	77.110	69.779	52%	368%
Harbeer 3	1.121.501	74.662	94%	1829%
Harbeer6	3.914.338	500.830	89%	1827%

5.4.1 Water Balance Harbeer 1

Table 4: An overview of the water balance of Harbeer 1

Water balance Harbeer 1			**Month**										
		Source	1	2	3	4	5	6	7	8	9	10	11	12
Precipitation	m^3	NWRA	1583	3035	6861	14910	18974	15438	17021	17021	21771	14250	4354	1583
Evaporation	m^3	NWRA	1062	2047	4697	10520	13589	10914	12104	12104	15752	10030	2952	1062
Water use in m^3														
	Agricultural		2.873	3.588	4.274	7.800	8.835	8.095	7.699	8.474	11.136	7.542	3.950	2.843
	City/ Industry	TWSLC	6.559	6.309	6.800	5.500	5.459	5.338	6.128	5.353	3.794	5.588	6.362	6.589
Use of groundwater	m^3		8910	8910	8910	8910	8910	8910	8910	8910	8910	8910	8910	8910
size of the area (km^2)			0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22
Precipitation	mm/month	NWRA	7,20	13,79	31,19	67,77	86,24	70,17	77,37	77,37	98,96	64,77	19,79	7,20
Evaporation	mm/month	NWRA	4,83	9,31	21,35	47,82	61,77	49,61	55,02	55,02	71,60	45,59	13,42	4,83
Average change in groundwater level in meters			0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14

Porosity 30%

The formula of the water balance can be found on page 15 of the report.

5.4.2 Water balance harbeer 3

Table 5: An overview of the water balance of harbeer 3.

Water balance Harbeer 3			**Month**										
		Source	1	2	3	4	5	6	7	8	9	10	11	12
Precipitation	m^3	NWRA	2591	4966	11228	24398	31048	25262	27853	27853	35626	23318	7125	2591
Evaporation	m^3	NWRA	1737	3350	7686	17214	22237	17860	19806	19806	25776	16412	4831	1737
Water use in m^3														
	Agricultural		89.104	88.002	90.071	94.555	95.513	95.648	96.205	96.284	98.840	97.074	92.511	87.695
	City/ Industry	TWSLC	5.980	7.844	7.700	6.858	7.528	5.984	6.071	5.992	5.241	4.062	4.013	7.389
Use of groundwater	m^3		94230	94230	94230	94230	94230	94230	94230	94230	94230	94230	94230	94230
size of the area (km^2)			0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36
Precipitation	mm/month	NWRA	7,20	13,79	31,19	67,77	86,24	70,17	77,37	77,37	98,96	64,77	19,79	7,20
Evaporation	mm/month	NWRA	4,83	9,31	21,35	47,82	61,77	49,61	55,02	55,02	71,60	45,59	13,42	4,83
Average change in groundwater level in meters			0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87

Porosity 30%

The formula of the water balance can be found on page 15 of the report.

5.4.3 Water balance harbeer 6

Table 6: An overview of the water balance of Harbeer 6

Water balance Harbeer 6			**Month**											
		Source	1	2	3	4	5	6	7	8	9	10	11	12
Precipitation	m^3	NWRA	9573	18346	41479	90136	114704	93328	102900	102900	131618	86147	26322	9573
Evaporation	m^3	NWRA	6419	12377	28397	63597	82154	65981	73173	73173	95226	60635	17847	6419
Water use in m^3														
	Agricultural		305.789	314.933	318.207	335.453	340.155	334.701	336.812	336.162	345.807	325.888	313.370	307.059
	City/ Industry	TWSLC	45.160	38.830	42.670	38.880	40.190	40.440	40.710	41.360	38.380	47.420	42.900	43.890
Use of groundwater	m^3		347795	347795	347795	347795	347795	347795	347795	347795	347795	347795	347795	347795
size of the area (km^2)			1,33	1,33	1,33	1,33	1,33	1,33	1,33	1,33	1,33	1,33	1,33	1,33
Precipitation	mm/month	NWRA	7,20	13,79	31,19	67,77	86,24	70,17	77,37	77,37	98,96	64,77	19,79	7,20
Evaporation	mm/month	NWRA	4,83	9,31	21,35	47,82	61,77	49,61	55,02	55,02	71,60	45,59	13,42	4,83
Average change in groundwater level in meters			0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,87

Porosity 30%

The formula of the water balance can be found on page 15 of the report.

5.5 Conclusion

The over exploration of the groundwater is 18 times the net precipitation. This over exploration is responsible for a drop of 10 meters a year of the groundwater level in the Harbeer 3 and Harbeer 6 area. It is necessary to prevent the over exploration of the groundwater to fore come drought. If that happens than no crops can grow over there, for this reason the over exploration of the groundwater needs to be stopped.

The exploration of the groundwater through the farmers has increased in the last years. The farmers have made more wells to extract the groundwater (NWRA,1998). A part of the solution will be making the farmers more conscientious of the problem of the declining level of groundwater. So the farmers would use less water, because they see the risk of exhaustion of water in the future.

6 Analyses of water use for crops

The use of water by the different types of crops can be determined by a literature investigation or using Cropwat. The literature is used instead of the questionnaire. The results of the questionnaire are not used fully for the determination of the water use because the farmers don't have an administration and have absolutely no clue about how much water they use for the crops. Therefore the data from literature have been used.

In the thesis of Mr. Al Hamdi, he invested the water requirement of the crops. The water requirement of the crops is given in the following table :

Table 7: irrigation water requirement

Crop	Irrigation water requirement	
	(m^3/ha. season)	(mm/season)
Sorghum	7410	741
Wheat	6220	622
Barley	6220	622
Maize	7530	753
Tomatoes	10000	1000
Potatoes	9420	942
Alfalfa	16780	1678
Grapes	14000	1400
Qat	12050	1205

Source: Al Hamdi(2000)

In the analysis with Cropwat, the first step is to fill in the climate data. The second step is to select the type of crop that will be selected. The result is an overview which indicates how much water is required for the crops. Hereby should be taken into account that there can be a difference because the famers use very inefficient irrigation methods, like flooding irrigation. If the irrigation methods are improved a lot of water could be saved, nowadays a lot of water evaporates. By doing the crop analysis this should be taken into account.

The data of Al Hamdi have been validated within Cropwat, hereby there has been a difference between crops throughout the seasons. In the winter the crops uses less water than in the summer. This can be explained by the temperature. How hotter it is outside, the more water is required for the crops. But the data of the water requirement are correct, the average from Cropwat and the thesis of Mr. Al Hamdi are almost the same. So those can be used as the minimum amount of water that is necessary.

The water requirement is almost three times as high as the water supply. The main reason for this problem is the lack of good irrigation system. In the rural area there has been made use of flooding irrigation instead of a better type like drip-irrigation. The result of this is that more than 2/3 of the water evaporates; only 1/3 of the water will be used efficiently. This amount of water efficiency has been found out when the data of the water balance has been compared to the irrigation water requirement.

6.1 Water requirement for crops in the Harbeer area

The water requirement for crops in the area has been calculated with the following formula:

Water use / Average crop requirement = possible hectare for crops

Hectare used for crops/ possible hectare for crops = efficiency

Hectare used for crops = 90% * area size

90% of the area is used for agricultural purpose, this size is determined with Google earth. Most of the farming land is used for the producing of qat, this is around 80 % of the farming land, on the other 20% maize or wheat is produced. This is an estimation of the field investigation in the area.

Average crop requirement = 80%* crop requirement for qat + 10* crop requirement for wheat+ 10% *crop requirement for maize

Average crop requirement = 80% * 12050m^3/ha+ 10%* 6220m^3/ha+ 10%*7530m^3/ha= 11015m^3/ ha
This amount of water described the effective (net) use of water. Depending on the irrigation technique more or much more water is necessary.

Water requirement for crops in the area = Average crop water requirement * crops on area

Table 8: Overview of agricultural use of water in the Harbeer area

Area	Area size (ha)	Crops on area (ha)	Average crop water requirement (m^3/ha/ year)	Water requirement for crops in the area (m^3/ year)	Agricultural water use (m^3/ year)
Harbeer 1	22	19,8	11.015	218.097	77.110
Harbeer 3	36	32,4	11.015	356.886	1.121.501
Harbeer 6	133	119,7	11.015	1.318.496	3.914.338

The calculations for the Harbeer 3 and Harbeer 6 area are reliable. The calculation of the Harbeer 1 area is not usefull, because the farmers have been shooting at each other wells, so their wells didn't work. This is the reason why there is used so less water in the Harbeer 1 area.

The agricultural use of water is 3 times the required water use for the area, this is caused by the irrigation method which is used. Flooding irrigation is used in the Harbeer area at the moment. To reduce water drip irrigation should be used. Polak (1997) has described that drip irrigation could spare out 40- 60% of water usage. This would mean that only 120% to 180% of the water requirement for crops in the area will be used. This can be explained by the fact that there are losses due to the transportation of water and drip irrigation uses more water than the water requirement for crops in the area. By applying flood irrigation even more water will be used.

In the Harbeer area the farmers produce mostly qat. Because of this the water requirement for qat is the highest from all crops. A change of crops to maize or wheat would be better because it requires only half the water what qat requires. A change of crops would reduce the water requirement.

6.2 Conclusion

Qat has the highest use of water by hectare and because of inefficient irrigation methods, 2/3 of the water evaporates. To reduce water there could be a change of crops or irrigation methods.

A following investigation should be about how it can be made possible to chance the types of crops and how it is possible to change the irrigation methods.

7 Economic analysis

The economic analysis of the value of qat is problematic. A questionnaire does not work because the farmers are not willing to give the information about financial aspects and don't have a registration of how much water they use. This is the reason why a literature investigation has been chosen, because the data is more reliable. In the thesis of Mr. Al Hamdi there has been used some pilot farms, this were farms where everything has been monitored from by Mr. Al Hamdi himself.

7.1 Prices of water and prices of qat

Al Hamdi (2000) showed that qat farmers made a profit 0.5 – 0.8 US $ per m^3 of water in the Sana'a area in 1996. This is around 65 - 104 riyals for a m^3 of water. The cost are calculated in US $, because this is a stable coin compared to the Yemeni riyal. The exchange rate of the riyal was 160 riyal for a US dollar. At this moment the rate of the riyal is 200 riyal for a US dollar.

For the water the consumers have a progressive tariff in 2008, so it is promoted to use less water. The basis of the tariffs is monthly time intervals; the tariffs are shown in the following table.

Table 9: prices of water for consumers for a month

Category	price of water per m^3 in riyal	Price of water per m^3 in US dollar
0- 5 m^3	30	0.15
5-10 m^3	40	0.20
10-20 m^3	75	0.38
20-30 m^3	130	0.65
>30 m^3	192	0.96

Source: TWLSC(2008)

This table shows that the consumers have to pay for their water. This is the price of the water that has been delivered. By this price should be taken into account that 30% of the water what has been produced by the water company is lost due to leaks or has been stolen. The main importance for this research is to know the price of the winning of water, because if this price is higher than the price of the water for the farmers it can be bought from them. This implies that they don't use the water on their land any more.

There is another possibility to import some products which contains a lot of water, hereby qat could be imported from Somalia or Ethiopia. By doing this, there will be a virtual water trade (Hoekstra & Hung, 2005). The problem with a virtual water trade is the possibility to import qat, because it has to be consumed within 24 hours after it has been picked. Otherwise the quality will become less and the qat will lose a lot of value due to the quality loss.

7.2 Conclusion

Qat is the crop which delivers the highest return of water; this is one of the main reasons why it is produced so much. Qat is also one of the crops that uses most of the water, so if water needs to be saved another crop must be produced instead of qat. Herefore can be looked at other crops with a high return which uses less water. Only if the profits are almost the same the farmers are willing to change qat for another crop.

8 Potential methods to reallocate water from agricultural to domestic purpose

A large proportion of the water is used in the rural area, while a lot of people are suffering from a shortage of water. The main problem is that the agricultural sector uses too much water. It is responsible for 68 % of the groundwater use in the Taiz area. The agricultural sector is still growing and demanding more water (NWRA). Because of the growth of the agricultural sector and the population the water problems will increase.

A solution for this problem is using less water in the agricultural sector and diverting water from the rural area to the urban area, so the urban area has got more water to divide.

In the next subparagraph the steering tools will be explained. Hereby the advantage and disadvantage of those steering tools will be explained and the possibility of implementing those tools in Yemen for the water for the city.

8.1 Possible steering tools

8.1.1 Water market

The theory of the water market is that when water has a higher value elsewhere; it will flow to a place with the highest value. In this theory also the transportation cost of water and other factors have to be taken in account (Griffin & Hsu, 1993). The possibility of a water market will be discussed in the next sub paragraphs.

8.1.2 Scientific vision of the water market

A free water market would have some benefits but also some disadvantages. In this paragraph the advantages and disadvantages will be estimated. After that a conclusion will be drawn.

The advantage of a water market is that there will be an efficient use of water resources. The farmers will use the water more efficient, because they can sell the rest of the water. There will be an extra income source for the farmers and often a transfer of only 10% of the water from the rural area to the urban area is necessary to fore fill their demands of water (Negenman).

The disadvantage of a water market in Yemen is the risk of a faster depletion. The farmers might put two pipes into the ground instead of one. Then the farmers start pumping a lot of water, because they can sell the water to the city. This will lead to an even faster depletion, with the result that there is no water left in a number of years.

Following the water law it is not allowed to drill a new private well, but it happens. A main problem is how to enforce the law. Maybe the law should be followed, instead of introducing a new system.

The other major disadvantage is the question of how to implement this system if there is no control on the system. This is required to succeed this system, otherwise you get faster depletion.

8.1.2.1 Conclusion

A boundary condition for a water market is a closed system. A closed system implies that there is a maximum amount of water available for using. For the implementation of this, a law should be changed and the law forces needs to be improved. In the current situation no famer is following the

law. Without a closed system, the farmers will drill more water out of the ground for extra money and the groundwater level will deplete even faster. This will only increase the problem.

Only if there is a closed system a water market is possible, because the water can be traded to a place where it has more value and the depletion will be less than in the current situation.

8.1.3 Bold vision of a water market

In the current situation in Ta'iz there is a large problem. Nobody wants to be aware of the risk of the current depletion, the farmers only think about today. They don't care about what happens with the groundwater level in the future. This determines whether or not their kids have got water when they are adults. This behavior will lead to a problem within a few years.

With those things in mind, it is clear that in a number of years there will not be any water left, also not for the water company. The question is whether or not the water company should buy water from the farmers. By doing this the city has got enough water, but the depletion will go faster and there will be sooner no water available for the people.

In this scenario the intention is only to get enough water to the city. In this scenario the farmers will receive for their water as much money as their crops would deliver. The water will go with the place with the highest value if it is economically transferable (Knapp, Weinberg, Howitt & Posnikoff ,2001).

By this theory the price should be above the added value of water by producing crops in the agricultural sector and the production cost of the water. If this amount is offered to the farmers, they are probably willing to share the water. An m^3 of water of irrigation water gives a return of 0,50 up to 0,80 US dollar for each m^3 of water.

Table 10: Cost of production a m^3 of water for Harbeer wells

Cost of producing a m^3 of water for Harbeer wells				
	In Yemini Riyal		In US $	
	2006	2007	2006	2007
Personal cost	YER 18	YER 21	$0,10	$0,11
Maintance	YER 13	YER 16	$0,07	$0,08
Diesel (Quantity *35 Riyal)	YER 66	YER 97	$0,35	$0,50
Total	**YER 98**	**YER 134**	**$0,51**	**$0,68**

Source: TWLSC (2008)

In 2006 the exchange rate was 190 riyal for a US$, in 2007 the exchange rate was 195 riyal for a US$. After the prices has been calculated to US$, there can be seen that most of the money is for diesel. The maintenance and personal costs are low compared to the cost of diesel. With the assumption that the diesel and maintenance cost would be the same amount for the farmers, the conclusion would be that the price that should be offered should more than 0,68 US$ for a m^3 in 2007. Hereby should be taken into account that 30% of the water from the water company is lost due to leaks or is stolen. So the price that needs to be offered for a m^3 of water in the city is 0,68 US$ * 1/0.7=0.97US$.

This price is higher than the cost of producing, but more water would be generated by the farmers and there become more water available for the city. There is also a problem that the production cost of the water from the Harbeer fields is higher than the price for which it can be sold to the citizens.

8.1.3.1 Conclusion

When enough money is offered to the farmers, they are probably willing to share the water. A major risk of this method is that the depletion will go faster and the area will be sooner without any water. An advance of this method is that there will be more water available for the city when this market approach has been implemented.

8.1.4 Business protocol on sustainability reporting of water-intensive goods

There could be a protocol on how many water can be used as described in Verkerk (2007), if there is power over the suppliers. In this approach the people or action groups should be aware of the environment. In developing nations it affects mainly the multinational companies (Hall, 2000). In Yemen the farmers are the main problem in the process of water consumption and the people are not aware of the problem. So this option is not possible in Yemen.

8.1.5 Water rights

Water rights will lead to a more efficient use of water. A condition for water rights is that it will be registered. (Bauer, 1997; Rosegrant & Schelyer, 1995) Farmers will get more irrigation systems because the can sell to the water rights to others downstream. Often a small proportion of the water used in the agricultural sector is enough to meet the growing urban and industrial demands for water. (Rosegrant & Binswanger, 1994) For this system there needs to be a monitoring of how much water has been used, this is not the case so this option is not possible.

8.1.6 Taxes for equipment of groundwater use

By putting a tax on fuel and equipment used for pumping groundwater pumping of water will become more expensive. (Riaz, 2002) The disadvantage of this is that small and poor farmers will be affected mostly because the extra price for pumping water will be passed into the price of the water.

8.1.7 Law forces

In the Yemen water law, there is written something about the winning of water and wells. The important articles for the winning of water are:

- The use of drinking water and household water are favored with absolute priority according to article 20.
- It is also not permitted to dig a well or other water installations without a permit of the NWRA (National Water Resources Authority) according to article 35.
- People of the NWRA have got juridical protection during controls and inspections according to article 63.

The Yemeni water law is good, but there is no control on its enforcement. The result of this is that nobody takes the law seriously. There could be an improvement by enforcing the water law; then the water law has a purpose.

8.1.8 Making people aware of the water problem

In Yemen the farmers see the depletion as a problem, but don't act on it. The farmers think that water is cheap and use inefficient irrigation for that reason. The urban area uses also water

inefficiently. By creating more efficiency it is possible to use more water in an effective way with less water available.

For example the farmers who use flooding irrigation could replace it by drip irrigation. Nowadays most of the water that is used for irrigation will evaporate before it reaches the crop.

In the urban area a lot of tankers are spilling the water out of their water tanks. This causes a lot of water on the streets, when a part of the city gets water. A lot of water is going over the streets. By distributing the water more efficiently, there could be spared a lot of water and maybe solve a bit of the problem.

8.1.9 Let religious leaders speak out against qat use

In Saudi Arabia and other Muslim countries, qat has been declared haram by the religious establishment. In Yemen, qat has never been prohibited on religious ground apart from a short period in the sixteenth century. (Ward)

A spoke out of religious leaders against qat would lead to a lower use of qat. A lower use of qat would lead to less qat fields, which would lead to a lower use of water in the agricultural sector because qat is the crop with the highest demand for water. So there is more water available for the urban area.

The question is whether or not the religious leaders are willing to do this or to burn their fingers on this, because almost everybody is addicted to qat. This includes religious leaders like imams and a lot of the people who are going to the mosque every day.

8.1.10 Import of qat

By importing qat less Yemeni water has to be spent on growing qat. The principle of importing food, so less water has to be spent on water locally is called “Virtual water import”. (Hoekstra & Chapagain, 2005; Hoekstra & Hung, 2004) Hereby there should be taken into account that qat should be fresh or consummated within 24 hours after it has been picked. Otherwise the quality of the qat is not very good anymore and drops a lot in value.

The import of qat would be possible from Somalia or Ethiopia; it is just a short flight but an investigation should be done, whether or not it is logistical and economical possible to import qat.

8.1.11 Promote different irrigation methods

By using different irrigation methods, there could be saved a lot of water. In the current situation they use flooding irrigation; this is an inefficient way of irrigation, only 1/3 of the water is used effectively. By changing to drip irrigation the farmers could save 40-60% of the water compared to flooding irrigation. (Polak et al. ,1997) The disadvantage of this method is that if it is used there could also be produced more qat and this is the reason why it isn’t promoted by the government to qat farmers.

The government is officially against qat and this is the reason why the government doesn’t see the qat farmers as famers. To reduce the water use in the rural area a promotion campaign for drip irrigation could be started to use less water. This is not the final solution but only a method to reduce the water usage in the area, so there is water available for a longer period. More information about irrigation methods can be found in appendix 4.

8.2 Conclusion

The main problem in Yemen is that the people are not completely aware of the problem and there is a lack of control on measures that had been taken to fore come illegal wells. These are the main issues to solve. Hereby there could be thought on disarming the farmers for increasing the possibility to control the farmers and on education of water use, so the farmer uses less water and has a bigger harvest. The irrigation method in Yemen is very inefficient; this is flooding irrigation, so a lot of water evaporates without being used for the irrigation. If this can be changed to drip-irrigation, then less water would be used for crop irrigation.

A water market is only possible with boundary conditions, otherwise the declining of the groundwater level would only go faster; the farmers will put two pipes into the ground instead of one, because they can sell the water and use the water. Because it is not possible to implement these boundary conditions a water market is not advised. To force the boundary conditions for a water market it is necessary to have got some enforcement. Because the law could not be enforced, the option of a water market is not advised.

The second problem is that the government has some rules, but does not enforce them. If something needs to be done, the government should enforce the law they make instead of making new laws. If the rules are followed, there could be an implementation of water right system. By using this system there will be more efficiency in the agricultural sector, because the farmers will try to use less water. (Rosegrant & Binswanger, 1994)

9 Conclusion

The possibility of the relocation of water is difficult to achieve, because the law is not enforced in Yemen. The problem in Yemen is to maintain a law. If that does not happen a law is useless. For the maintenance of the law there need to be a drop in the number of weapons in the rural area, so the police or army have the ability to control the farmers.

The other thing that needs to happen is to get a public awareness of the depletion problem. The farmers need to use less water to reduce their water use. If they don't change their use, it will lead to a problem in the future. There will be no water available for the agriculture.

The water use by the farmers needs to become more efficient. (Gleick, 1993) This can be done by introducing more efficient irrigation methods. Drip irrigation can reduce 40-60% of the agricultural water use compared to flooding irrigation. The problem is how to get the farmers to implement this irrigation system. The farmers needs to be sure that this system works and is worth it value, for this reason a promotion campaign should be started. This campaign should be started for all type of farmers, including qat farmers. At the moment the government doesn't see qat farmers as farmers because the government is against qat use.

The water problems in the city can be solved by a water transfer from the rural area to the urban area. (Knapp et al., 2002) For the implementation of water rights there need to be a law to enforce this. If there is no law the depletion of the field will only go faster, because the farmers can sell water and keep flooding their land. They will use twice the amount of water, so a closed system is necessary to reduce the depletion and let some water over for the next generation. (Negenman) In the current situation a water market would not be possible because there is no closed system and almost every law isn't enforced.

It is possible to create a water market without a closed system, but then should be taken into account that the depletion will go faster. They have a shortage at the moment, so they can solve it by buying water. But it will lead to a faster exhaustion of the available water. This is the reason why this option is not advised, but should be taken into account as a possible option.

The things that need to change for a possible water market are the possibility to enforce the law and a closed water system. After this has been changed, it might be possible to have a water market. For a long term solution, the irrigation method needs to be changed to save a lot of water and the people need to become aware of the water problem. A promotion campaign should be started to let all farmers including qat- farmers change their irrigation method.

10 Reference

Al Hamdi, M.I.(2000). Competition for scare groundwater in the Sana'a Plain, Yemen

Ayars, J.E. Phene, C.J. Hutmacher, R.B. Davis, K.r., Schoneman, R.A., Vail, S.S. & Mead, R.M. (1999) Subsurface drip irrigation of row crops: a review of 15 years of research at the Water Management Research Laboratory [Electronic version] *Agricultural water management*, 42, 1-27

Bauer, C.J. (1997). Bringing water markets down to earth: The political economy of water in Chili, 1976-1995 [Electronic version] *World development*, vol 25, no5 , 639-656

Gleick, P.H. (1993). Water and Conflict: Fresh Water Resources and International Security [Electronic Version] *International security*, vol 18, no 1, 79-112

Griffin, R.C. & Hsu, S. (1993). The potential for water market efficiency when instream flows have value [Electronic version]. *American Agricultural economics Association*, 75, 292-303

Hall, J. (2000). Environmental supply chain dynamics [Electronic version]. *Journal of cleaner production*, 8, 455-47`1

Hoekstra, A.Y. & Chapagain, A.K. (2007). Water footprints of nations: water use by people as a function of their consumption pattern [Electronic version] *Water Resource management*, 21, 35-48

Hoekstra, A.Y. & Hung, P.Q. (2005). Globalisation of water resources: international virtual water flows in relation to crop trade [Electronic version] *Global Environmental Change*, 15, 45-56

Knapp, R.C. Weinberg, M. Howitt, R.& Posnikoff, J.F. (2003). Water transfers, agriculutre and groundwater management: a dynamic analysis [Electronic version]. *Journal of environment management*, 67, 291-301

National Water Resources Authority, water resources action plan for the Ta'iz region

Negenman, T. Evolution of water resources management in Yemen. [Electronic version] *NITG TNO*

NWRA (1998) Agricultural water demand in Taiz region (Upper Wadi Rasyan) [Electronic version]

Polak, P. Nanes, B. & Adhikari, D. (1997). A low cost drip irrigation system for small farmers in developing countries [Electronic version] *Journal of the American water resources association*, 33, 119-124

Riaz,K. (2002) Tackling the issue of rural-urban water transfers in the Taiz region, Yemen [Electronic version]. *National resources forum*,26, 89-100

Rosegrant, M.W. & Binswanger, H.P. (1994) Markets in tradable water rights: Potential efficiency gains in developing country water resource allocation [Electronic version]. *World development*, vol 22, no 11, 1613-1625

Rosegrant, M.W. Schelyer, R.G. & Yadav, S.N. (1995). Waterpolicy for efficient agriculture diversion: market-based approach [Electronic version]. *Food policy*, Vol 20, No 3, 203-223

TWSLC (2008) Personal information from Samir

Verkerk, M.P. (2007) Global water governance. Conceptual design of global institutional arrangement, University of Twente

Verruijt, A. (2001) Grondmechanica, Tudelft

Varisco, D.M. (1986) On the meaning of chewing: the significant of Qat (Catha Edulis) in the Yemen Arabic Replublic [Electronic version]. *International journal of middle east studies*, vol 19, No 1 , 1-13

Ward, C. CDR; building block qat [Electronic version]