Application of Decision Support Tools for Water Resources Management in Coastal Arid Areas (Case study: Aden, Yemen)

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Abstract

Aden is the economical governorate of YEMEN, situated at latitude 12.47 north and at longitude 44.57 east. It is a coastal area located at the Gulf of Aden near the southern entrance to the Red Sea with area of 750 km2, population of about 600,000 and growth rate of 3.8%. As many regions in Yemen, Aden is facing formidable freshwater management challenges and thus allocation of limited water resources, environmental quality and policies for sustainable water use are issues of increasing concern. This research, therefore, aimed to visualize this problem in order to determine current and future vulnerability to climate change-induced water scarcity for its population and to evaluate appropriate adaptation strategies to address these vulnerabilities and build resilience against increasing water scarcity.

This research, which was conducted for the study area, is new in the sense that it involved the use of new methodologies and analytical tools, as well as the mobilization of resources that have not yet been applied to climate change issues. After data collection on water resources, water use, and vulnerability the first tool used is the Rapid Rural Appraisal (RRA) method for participatory assessments among stakeholders. The second tool is The Water Evaluation and Planning System (WEAP) model to evaluate water needs and scarcity among all use sectors under a range of potential climate change scenarios and adaptation strategies. The third used tool is the Multi-Criteria Analyses (MCA-WEAP) Model to determine overall preferences among alternative strategies and measures. MCA-WEAP provides techniques for comparing and ranking different outcomes, even though a variety of indictors is used. The simulation period in this study was twenty years (2006-2026) and the adapted strategies and measures were, Wastewater recharging and reuse, Desalinated water use, Rehabilitation of traditional irrigation channels, Conveying irrigation water through plastic pipes, Introducing drip irrigation technique and Reduction of leakage in water supply networks. The MCA-WEAP result of analysis showed the priorities are, conveying irrigation water through plastic pipes, introducing drip irrigation technique, wastewater reuse in irrigation, Wastewater recharging, Desalinated water use, Reduction of leakage in water supply networks and finally Rehabilitation of traditional irrigation

channels. However, as the WEAP model shows, to reach to approximately sustainable use of water in the study area the strategies, introducing drip irrigation, wastewater reuse in irrigation or wastewater recharging, desalinated water use and reduction of leakage in supply networks needs to be mutually implemented, in case enough financial resources are available.

Keywords: Climate change, Water scarcity, Strategies, Measures, Decision support tools

Objectives of this study

The main objective of this study is to evaluate current and future vulnerability of water resources to climate change in Aden Governorate through comprehensive set of adaptation strategies to address water scarcity and to integrate the findings of these analyses into policy discussions and legislative action.

Approach, methodology and tools

The assessments, which were conducted for the study area, are new in the sense that they involve the use of new methodologies and analytical tools, as well as the mobilization of resources that have not yet been applied to climate change issues. These are summarized as follows:

- Collection of all available and relevant data on poverty and social indicators, water use and surface and ground water availability from reports, maps and other bibliographic resources (see the references).
- Rapid rural appraisal methods were used for participatory assessments among stakeholders to discuss their concerns regarding issues of water scarcity and possible adaptation strategies and measures.
- Water balance modeling tools were used to evaluate water needs and scarcity among all water use sectors under a range of potential climate change strategies or measures (scenarios). These analyses were carried out using the WEAP model.
- Multi-criteria analyses (MCA) were also used to evaluate these adaptation strategies and measures. MCA is a structured approach to determine overall preferences among alternative options, where these options accomplish several objectives. MCA provides techniques for comparing and ranking different outcomes, even though a variety of indictors are used.

The study area location and population

Geographically Aden governorate is situated at latitude 12.47 north and at longitude 44.57 east (Figure 1). It is a city located on the Gulf of Aden near the southern entrance to the Red Sea. The area of Aden Governorate amounts approximately to 750 km^2. According to 2004 Census, the population of the

Aden Governorate is 598,419 from which 53.2% male and the rest is female. This population composes about 3% of total Yemeni population and with a growth rate of 3.8%.

Climate:

As Aden located in the southern plain its rainfall is low and with annual value of 30mm and sometimes reach around 50mm. This can be attributed to many factors, the main one of which is that the direction of the humid wind movement runs parallel with the coast without penetrating into the internal parts; therefore, the impact would be very small and hence the rainfall are of no economic significance whatsoever.

In general the weather in Aden is rather hot and humid where the mean temperature is around 27-30C^0 and the relative humidity ranges between 60% in the night to 80% in the early morning.

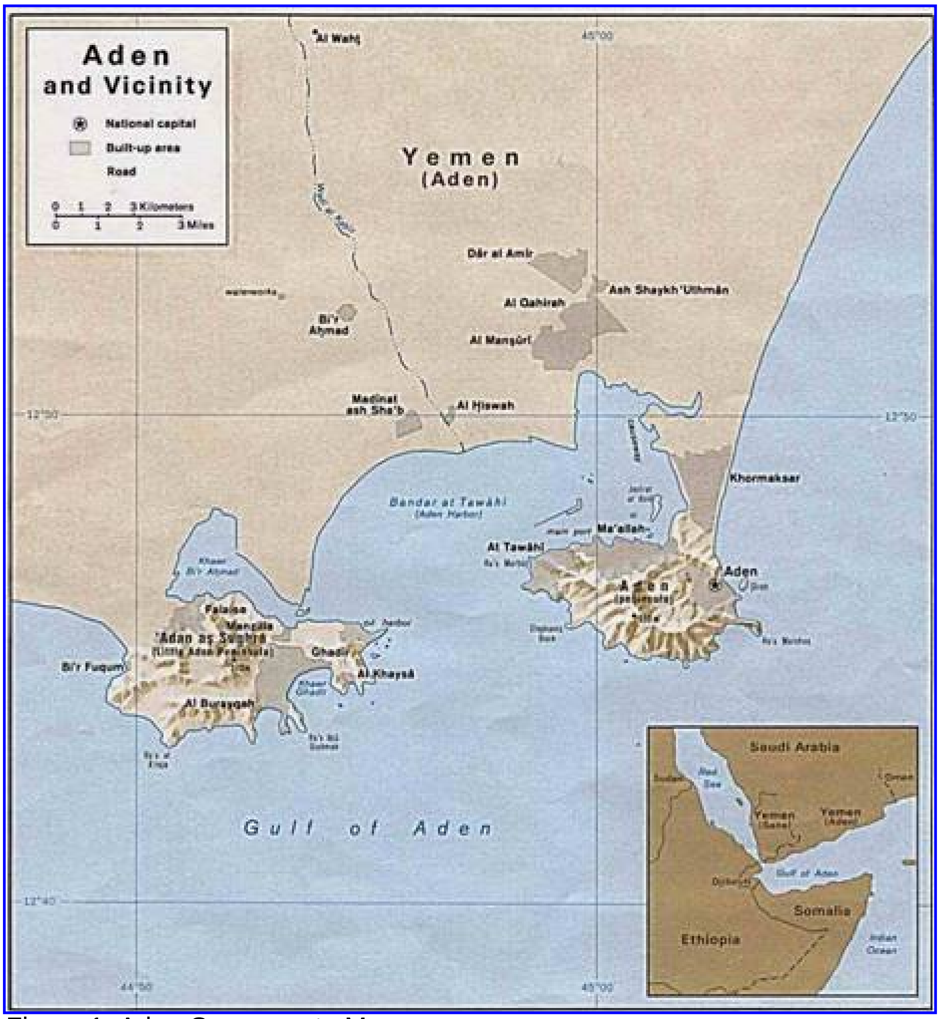

Figure 1: Aden Governorate Map

Water resources and availability for Aden

1. Ground water

Currently Aden Governorate water supply depends largely on underground sources (Tuban & Bana Delta Basins, Figures 2 & 3 which are located in other governorates, Lahej & Abyan). The production wellfields and quantity of drinking water produced in year 2006 for Aden and for local use in Lahij and Abyan is shown in Table 1 (LCs 2006 records).

For ground water irrigation private wells are used, where the estimated abstracted water for irrigation from Abayn Delta is about 94.4 MCM/y and form Tuban Delta is about 127.3 MCM/y (Saif, 1995; NWRA 2000; Komex 2002). This summarized in Table 2.

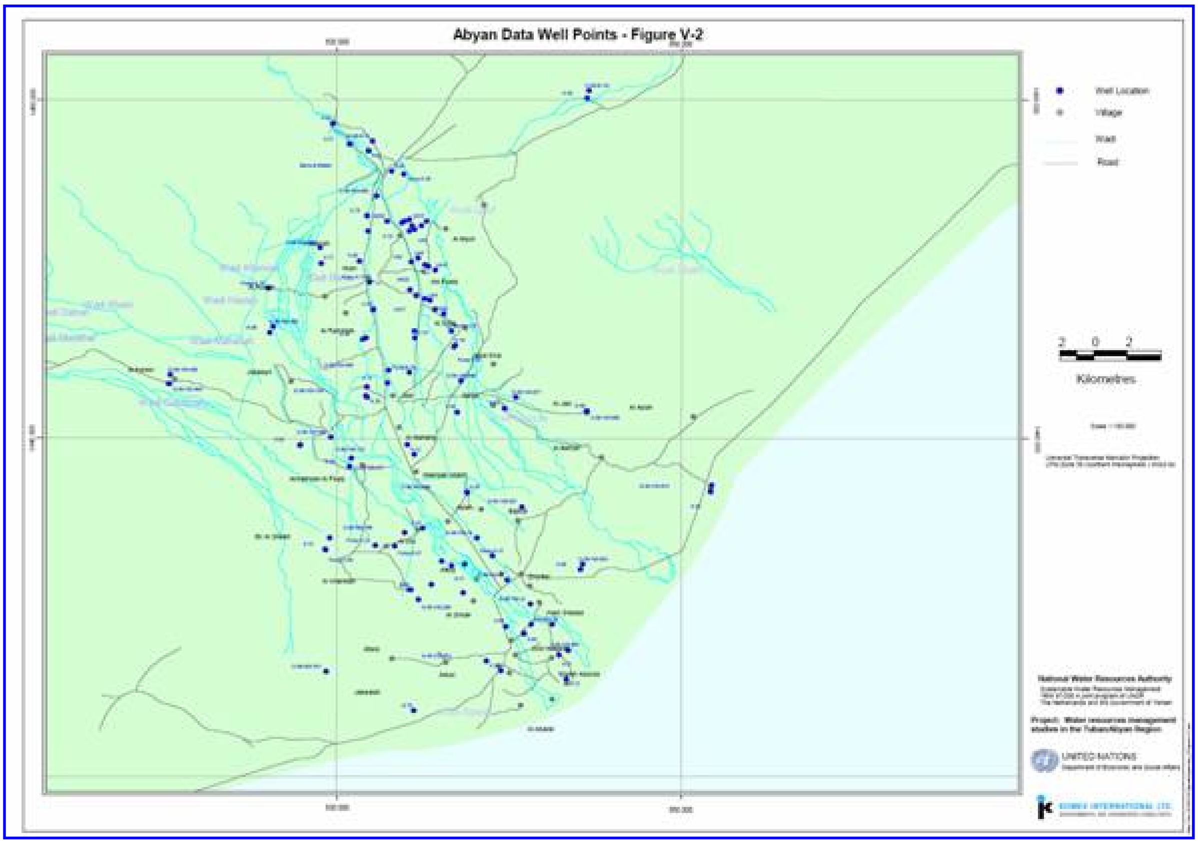

Figure 2: Abayn Delta well location (source, Komex 2002)

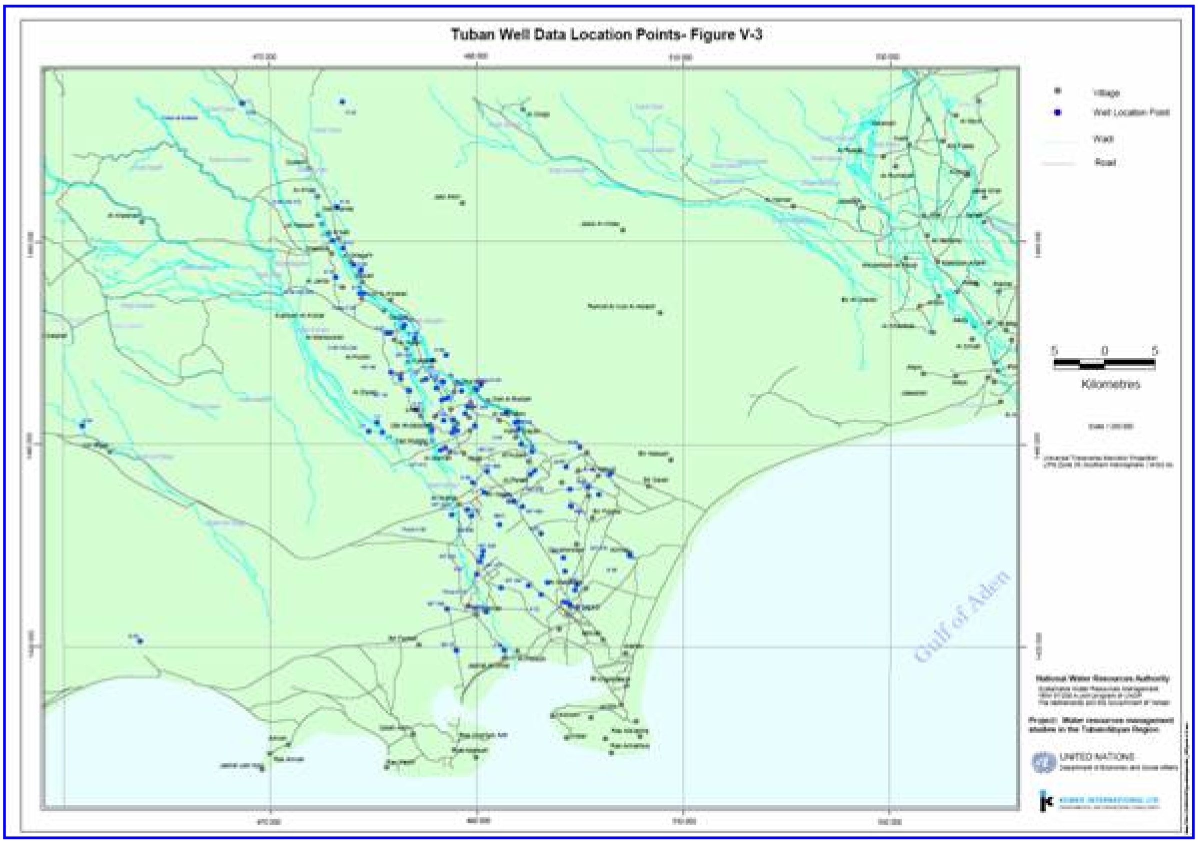

Figure 3: Tuban Delta well location (source, Komex 2002)

Table 1: Summary of wellfilds actual drinking water production for Aden and for local use during the year 2006 (source: Aden LC records)

Wellfield	Number of wells	Total Production (MCM/y)	Quantity for Aden (MCM/y)	Quantity for Aden (m3/d)	Quantity for local use (MCM/y)	Quantity for local* use (m3/d)
Bir Nasser (Lahej)	34	13.195	13.195	36151.5	0	0
Bir Ahmed (Aden)	26	11.933	11.933	32693.04	0	0
Tuban (Lahej)	4	2.168	0.574	1572.66	1.594	4366.97
Rowa (Abyan)	19	12.384	8.407	23033.23	3.976	10894.41
Total	83	39.68	34.110	93451.54	5.570	15261.38

*For the local water supply network in Lahej and Abyan Governorates.

2. Surface water and recharge

There is no direct surface water in Aden Governorate as it receives its water requirements from ground water abstracted from Tuban and Abyan Deltas. Surface water, which is really in the form of flush floods, is essential for

Delta Abyan and Tuban for irrigation needs and for recharging their aquifers. These are the Wadis that originate from the rainfall on the Southern Escarpment of Yemen which extends between Taiz and Ibb Governorates. The main wadis are: Wadi Tuban and Wadi Bana and some other minor wadis in each delta (Table 2). Wadi flows, use and recharge into the Abyan and Tuban were reported by many scattered studies (WRAY, 1994, Ghafourian, 1993; and Negenman, 1995, Atkins, 1984, Sogreah, 1981, Saif, 1998, Komex, 2002). Theses data were analyzed associated with abstracted ground water for domestic and agriculture use and then summarized in Table 2.

Model building using The Water Evaluation and Planning System (WEAP)

For evaluating current and future water needs, and scarcity among all water use sectors under a range of adaptation strategies (scenarios), The Water Evaluation and Planning System (WEAP) is used. WEAP is among a new generation of water management DSS tools developed with the objective and guiding principle to provide, for planning purposes, the balanced integration of both the engineered and natural components of a watershed, as water managers are increasingly called upon to do. WEAP provides database and scenario-driven forecasting, policy analysis, and resource management capabilities. A WEAP application for the Aden was developed and calibrated for the followings objectives:

- Evaluate current vulnerability of water resources to climate change in the basin
- Evaluate future water vulnerability via development of scenarios and analysis of future water balances
- Identify a preliminary set of adaptation strategies that address water scarcity in the case study area

Aden Model Layout and setup

Although this study is for Aden Governorate, Aden is located at the gulf of Aden downstream of Abyan and Tuban deltas and hence Aden water resources are obtained from these two deltas. Thus, the model divides the basin into two major sub-basins: the Delta Bana (Abyan) and the Delta Tuban (Lahij). In each delta there are two sources for water, surface water and ground water. In Abyan delta surface flow is expressed in terms of Delta Bana Wadis (ephemeral wadis) which convey flush flood during rainy season (seif and Kharief) down the delta from catchments located in other governorates. Ground water is expressed in terms of Abyan aquifer. Delta Bana Wadi supply Abyan Agriculture catchment's area with about 60% of its irrigation demand while the rest is supplied from Abyan aquifer which also supplies Abayn city with its total water demand in addition to Aden City with 25% of its domestic water demand (Table 2).

In the same manner, Tuban delta has surface water expressed in terms of Delta Tuban wadis (ephemeral wadis) and a ground water source expressed by Delta Tuban aquifer. Delta tuban Wadis supplies Tuban Agriculture catchment with about 30% of irrigation demand while the rest is supplied from Delta Tuban Aquifer which also supplies Lahij city with its total water demand in addition to Aden city with 75% of its domestic water demand (Table 2). Abyan and Tuban governorates have no sewerage systems or wastewater treatment plants now where they discharge wastewater with no treatment through cesspits to the aquifers. However, it is reported by an official in Abyan Local Corporation for Water and Sanitation (ABLCWS) that a sanitation system design was completed by a German consultant firm (KFW). This will be implemented at the beginning of 2008 and will be in operation by 2009. The same is applied for Lahij governorate but the study was done by a Dutch consultant firm (ARCADIS).

Aden city has a sewerage system and a treatment plants but it is now discharging the effluent to the sea. Aden also has a hydropower plant located in Alhiswa which also produces desalinated water; the total capacity of which is 8 MCM/year. All these parameters are input in the Aden WEAP Model, some of which are playing role in the base year and the others will play role in the suggested scenarios discussed after. The general Aden WEAP Model layout is shown in Figure 4.

Model calibration process

For domestic water use the demand and the delivered supply are accurately known and hence they will match at the base year 2006. For agriculture demand it is not accurately known as the GIS landuse maps define the area of mixed crops but not for each crop type, and hence it is difficult to assign an accurate Crop Coefficient (kc) value in Rainfall Runoff (FAO) model for the mixed crops. Instead, the kc value was used as a calibration factor to adjust the agriculture demand to approach the observed delivered irrigation water either from wadis or from ground water aquifers. The WEAP application calibration results for irrigation in Abyan and Lahij governorates are shown in Table 3.

Aden Model result

The result of the model in terms of unmet water demand of all sites for the reference year is shown in Figure 5 and summarized in Table 4. As it can be seen these demands will be only met up to year 2014 for Lahij governorate via Aden agriculture and up to 2019 for Abyan Governorate via Aden city. This severely reflected in irrigation demand especially in Tuban delta where Tuban wadis deliver its maximum share 56.3MCM/y i.e. the maximum average flow available in the wadi and the rest is met from Lahij Aquifer until it is depleted in August 2015 followed by Abyan aquifer in November 2020 (Figure 6).

Table 2: Summary of the observed data interpolated to the base year 2006

Delta (aquifer)	Surface water (average), Mm^3/yr					Ground water abstraction, Mm^3/yr								Recharge, Mm^3/year						Total Recharge Mm^3/year
				Recharge						Water supply, Mm^3/year										
											Share Mm^3/year			Water supply losses			Wastewater infiltration			
	Wadis	flow	Irrigation[$]	Wadi infiltration	Return from irrigation	Wellfield	Total	Irrigation[*]	Recharge *(return flow)*[**]	Total	Aden	Abyan	Lahej	Aden	Abyan	Lahej	Aden	Abyan	Lahej	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
Abyan	Bana	154	142.11	26.1	49	Rowa	106.824	94.44	18.9	12.384	8.407	3.976	0	34.2 %	33.1 %	33.8 %	Treated and Discharged to the sea	Treated and Discharged to the sea	Discharged through soakpits (assumed 80%)	
	Hassan	30																		
Tuban	Tuban	123	61.335	61.85	7.74	Bir Nasser	154.866	127.57	31.9	13.195	13.195	0	0							
	Abrayn	4				Bir Ahmed				11.933	11.933	0	0							
	Bilah	3				Tuban				2.168	0.574	0	1.594							
Total		**314**	**282.6**				**261.69**		**50.8**	**39.68**	**34.109**	**3.976**	**1.594**	**11.67**	**1.32**	**0.536**	**0**	**0**	**1.275**	**256.401**
									Net Consumption		**22.44**	**2.66**	**1.06**							
Source		**Komex 2002**								**Aden Local Corporation Records (2006)**				**NWSA**			**Komex 2002**			
		Approximate net storage, Mm^3 at year 2001												**Aden**	**Abyan**	**Lahej**	**Aden**	**Abyan**	**Lahej**	census2004
		Abyan aquifer	**Tuban Aquifer**						**Cultivated area, ha**	**Rainfall**				207	19908	11269	589419	433819	722649	population
		550	750							**Surface water (floods, springs, dams)**				144	17414	11683	3.88	2.4	2.6	Growth rate %
Source		**Komex 2002**								**Ground water**				1155	10889	6345	610764	73640	138579	Beneficiaries (Water)
Recharge percentage of total (%)	**Karif Jul-Oct.**	34								**Others (tankers, etc.)**				34	29	298	619951	-	-	Beneficiaries (sanitation)
	Saif Mar-May	66							**Total cultivated area, ha**					1540	48240	29595				
Source		**Atkins 1984**							**Available Cultivable area**					**2834**	**60757**	**26390**				

[$] estimated as 90% of flow and the remaining 10% is evaporated as runoff proceeds along wadis, [*] Interpolated that there is 2% annual increase in ground water abstraction for irrigation

[**]calculated that 20% & 25% (for Abyan and Tuban respectively) of the abstracted ground water for irrigation returns to the aquifer as recharge, (Komex, 2002)

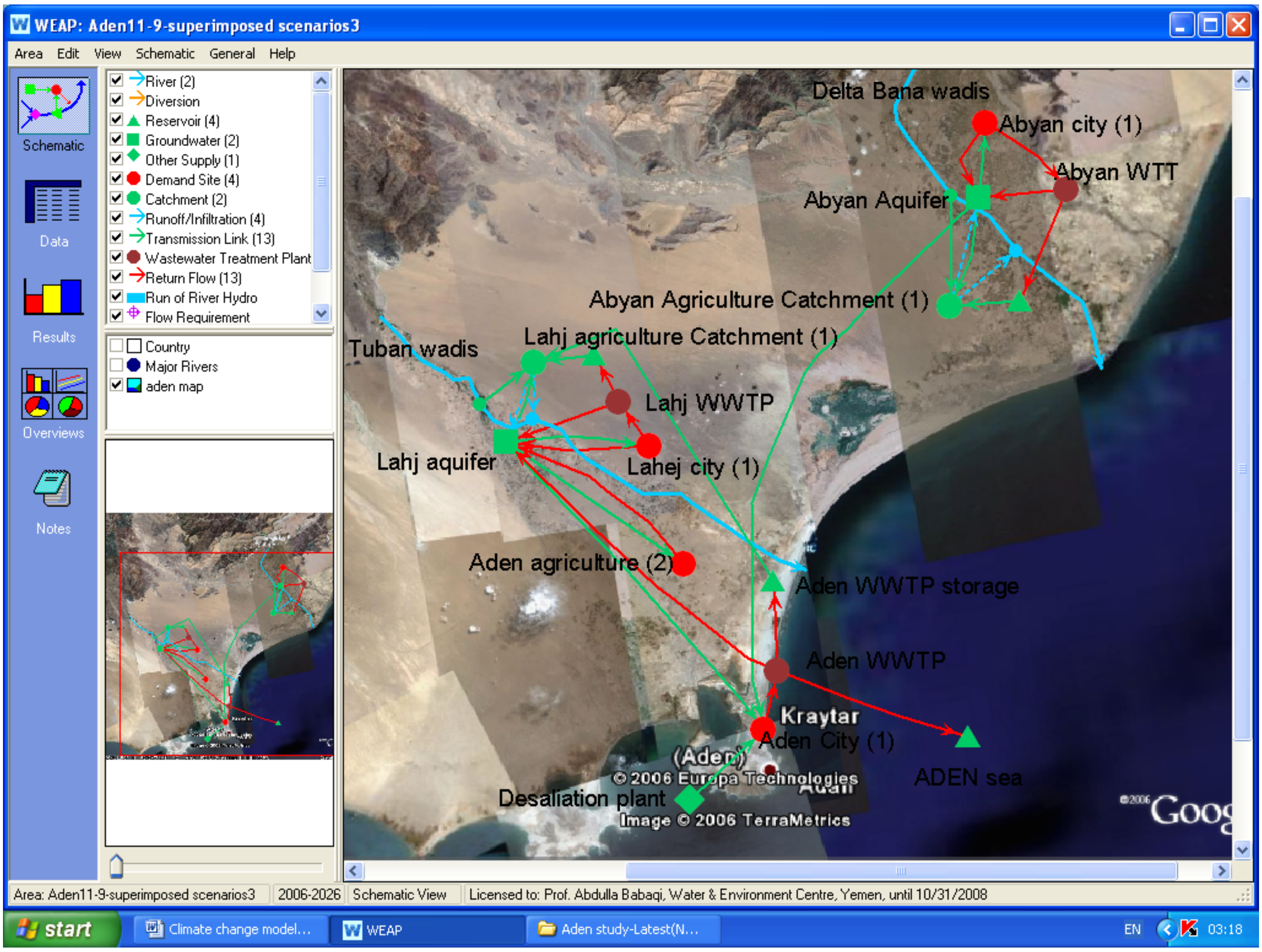

Figure 4: Aden WEAP model layout

Table 3: Calibration result for irrigation

Governerate	Observed values (base year 2006) Table 21			Predicted values (base year 2006) WEAP Model			Error	
	Surface water (Wadis flow)		Ground water	Surface water (Wadis flow)		Ground water		
	Total Head flow MCM/y	Diverted for irrigation MCM/y	Abstracted for irrigation MCM/y	Total* Head flow MCM/y	Diverted# for irrigation MCM/y	Abstracted$ for irrigation MCM/y	Max %	Min. %
Abyan	184	142.11	94.44	188.3	134	93.3	-5.7	-1.2
Lahij	130	61.34	127.57	132.7	56.3	127	-8.2	-0.45

*See WEAP application inflow to Area; #See WEAP application stream flow; $See WEAP application groundwater inflow and out flows

Table 4: Unmet Demand (in Million Cubic Meters) Scenario: Reference Status: all months, annual total

Demand Cites	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Sum
Abyan Agriculture Catchment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13.7	15.9	48.3	52.3	16.2	55.6	40.2	**242.1**
Abyan city	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.1	2.9	8.9	9.8	3.1	10.7	7.4	**45.0**
Aden City	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.7	8.6	25.1	29.1	9.7	32.0	24.5	**135.6**
Aden agriculture	0	0	0	0	0	0	0	0	0	2.2	3.6	5.4	1.4	4.2	4.6	1.9	5.9	5.4	2.0	6.1	4.7	**47.3**
Lahej city	0	0	0	0	0	0	0	0	0	9.5	16.4	24.3	6.4	22.5	23.3	8.8	28.9	26.2	11.5	31.9	24.9	**234.5**
Lahj agriculture Catchment	0	0	0	0	0	0	0	0	0	38.8	64.7	102.9	22.0	92.9	95.1	29.1	114.7	102.7	38.0	122.1	90.8	**913.7**
Sum	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**50.6**	**84.6**	**132.6**	**29.7**	**119.5**	**145.4**	**67.1**	**231.7**	**225.6**	**80.5**	**258.5**	**192.4**	**1618.2**

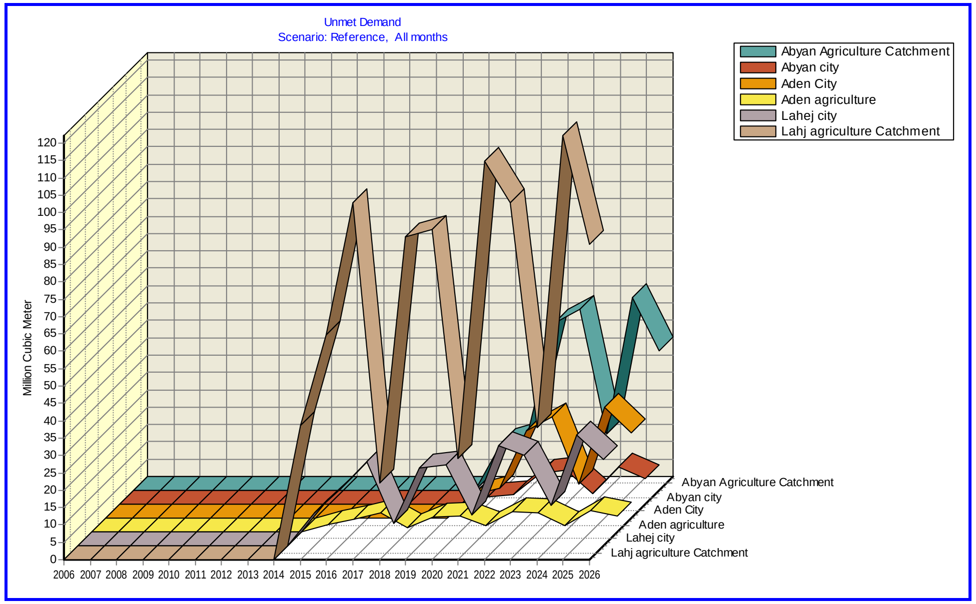

Figure 5: Unmet water demand for the reference year

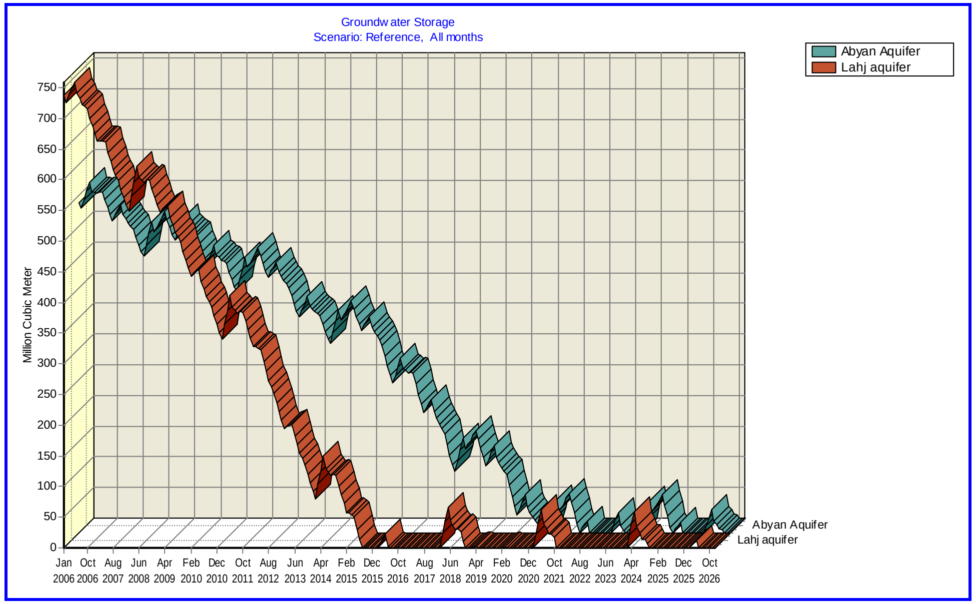

Figure 6: Water storage decline in Abyan and Tuban aquifers (reference year)

It is found (NWSA 2006) that in a six years period the drop in water level at upper Tuban wells reached to 23 meters and in those close to the coast it reached 1 meter with salt intrusion. Water storage in Abyan aquifer also declines with time but less than that in Lahij. It is because Lahij aquifer is under more stress than Abyan where the abstracted groundwater for irrigation is about 2/3 what is obtained from Tuban wadis, while it is the reverse for Abyan.

Adopted strategies and measures

In the WEAP application future water vulnerability in the case study area was evaluated for 20 years (up to year 2026) incorporating adaptation strategies in terms of scenarios. The suggested strategies and measures are:

1. Supporting Aden City with desalinated water from Alhiswa Hydropower plant.
2. Enhancing irrigation technique via,
    a. Introducing drip irrigation
    b. Conveying irrigation water through closed conduits (plastic pipes)
    c. Rehabilitation of traditional irrigation channels
3. Wastewater recharging (injection) from Aden Wastewater Treatment Plant
4. Wastewater reuse for irrigation from Aden Wastewater Treatment Plant
5. Wastewater recharging (injection) from Abyan & Lahij Wastewater Treatment Plants
6. Wastewater reuse for irrigation from Abyan & Lahij Wastewater Treatment Plants
7. Reduction of leakage from drinking water supply networks (Aden, Abayn & Lahij)

There are also two additional scenarios, OSU core climate and UKHI dry weather; they are used in order to see the effect of climate change on the case study area relative to the reference scenario.

- *OSU core climate*
  In this scenario it is assumed that there is increase in rainfall with about +1.5%.
- *UKHI dry weather*
  In this scenario it is assumed that there is decrease in rainfall with about -1.5%.

The WEAP application results for the adapted scenarios in terms of unmet demand are summarized in Table 5. Table 5 shows for all the demand cites, and for each scenario the following:

- Up to which year the demand will be met, and for how many years relative to the reference scenario?
- How much is this unmet demand, and how much water saved relative to reference scenario?

The scenarios also arranged, after the reference scenario, in a descending manner according to water saving and to number of years of meeting the demand. However, for scenarios Nos. 11 and 12 (Table 5), they are only used to see the effect of climate change relative to the reference scenario.

Analysis of results

As seen in Table 5 the best scenario is enhancing irrigation techniques using drip irrigation in terms of water saving and noumber of years of meeting demand. If this scenario is adopted some water will be regained, about 25% and hence this will completely meet the demand in Abayn up to 2026 and will shift the unmet demand three years later i.e. up to 2017 in Lahij. This will certainly improves the situations in Abayn and Tuban aquifers (Figure 7). However, the cost of implementing such a system is high (about 800-1000$/hectare) and hence most of the farmers can not afford it unless it is subsidized by related government bodies or any other NGOs.

Mutual effect of scenarios and result

In this model all these scenarios were superimposed in order to have their cumulative effect. As a result is Figure 8 which shows how ground water storage is improved, and thus to reduce ground water declining in the study area all theses scenarios needed to be implemented as no single scenario can solve the problem. In addition, there are other measures can be adopted such as growing crops which consume less water. However, as the financial resources in Yemen are limited it is difficult to implement all these scenarios together. Therefore, it is needed to select a scenario which has more enhancing effect on the limited water resources and more cost affective than the others.

Strategies prioritization based on stakeholder criteria weighting

From the previous result it can be seen that the first strategy (Table 5, No. 2) is more logic to adopt, but the second strategy i.e. wastewater aquifer recharging needs substantial financing for implementation the necessary recharging infrastructure, to treat wastewater to a degree that it can be injected to the aquifer without polluting the ground water; in addition its effect is not tangible on short term basis. The third strategy also needs substantial financing for building the irrigation infrastructure, conducting training and health awareness campaigns and for treating the wastewater to a degree that it can be used safely in irrigation. Therefore, two criteria for evaluating the strategies are not enough. Based on this more evaluating criteria were needed to be introduced to answer these questions:

1. Can the stakeholders afford the technology of the new strategy or measure?
2. Can the stakeholders implement and maintain it?
3. How much water the study area can gain from implementing a strategy?
4. How long the strategy technology may last and to which extent can it preserve the existing way of living?

Table 5: WEAP application results-Aden Case: Scenarios' results compared to reference scenario

Demand cites :		• **Abyan Agriculture** • **Abyan City** • **Aden City**		• **Lahij Agriculture** • **Lahij City** • **Aden Agriculture**				
Serial No.	Scenario	Demand meeting final year	Demand meeting duration	Demand meeting final year	Demand meeting duration	Total Unmet demand	Water saving or deficit Total *+ saving* *- deficit*	Water saving or deficit Annual average *+ saving* *- deficit*
		Year	(Years)	Year	(Years)	(MCM)	(MCM)	(MCM/y)
1	Reference	2019	0	2014	0	1618.2	0	0
2	Using drip irrigation	2026	7	2017	3	562.1	1056.1	52.8
3	Wastewater recharging (Aden WWTP)	2022	3	2019	5	693.8	924.4	46.22
4	Wastewater reuse (Aden WWTP)	2021	2	2019	5	792.2	826	44.45
5	Conveying irrigation water through closed conduits	2025	6	2016	2	827.6	790.6	39.53
6	Rehabilitation of traditional irrigation channels	2022	3	2015	1	1072.5	545.7	27.285
7	Leakage reduction from drinking water networks	2021	2	2014	0	1281.5	336.7	16.835
8	Desalination water use	2021	2	2014	0	1462.4	155.8	7.79
9	Wastewater recharging (Abayn & Lahij WWTPS)	2019	0	2014	0	1736.9	-118.7	-5.935
10	Wastewater reuse (Abyan & Lahij WWTPS)	2019	0	2014	0	1747.5	-129.3	-6.465
11	OSU core climate	2020	1	2014	0	1462.8	155.4	7.77
12	UKHI dry weather	2018	-1	2014	0	2008.7	-390.5	-19.5

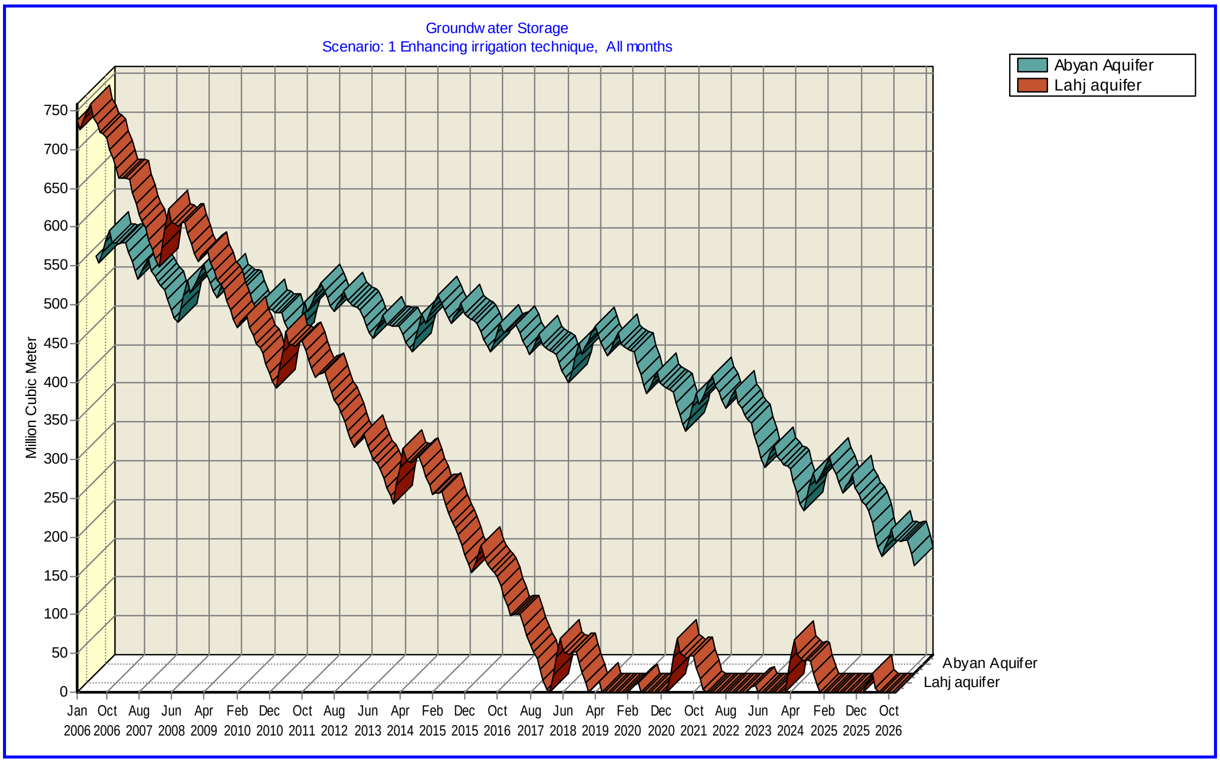

Figure 7: Ground water storage improvement during drip irrigation scenario

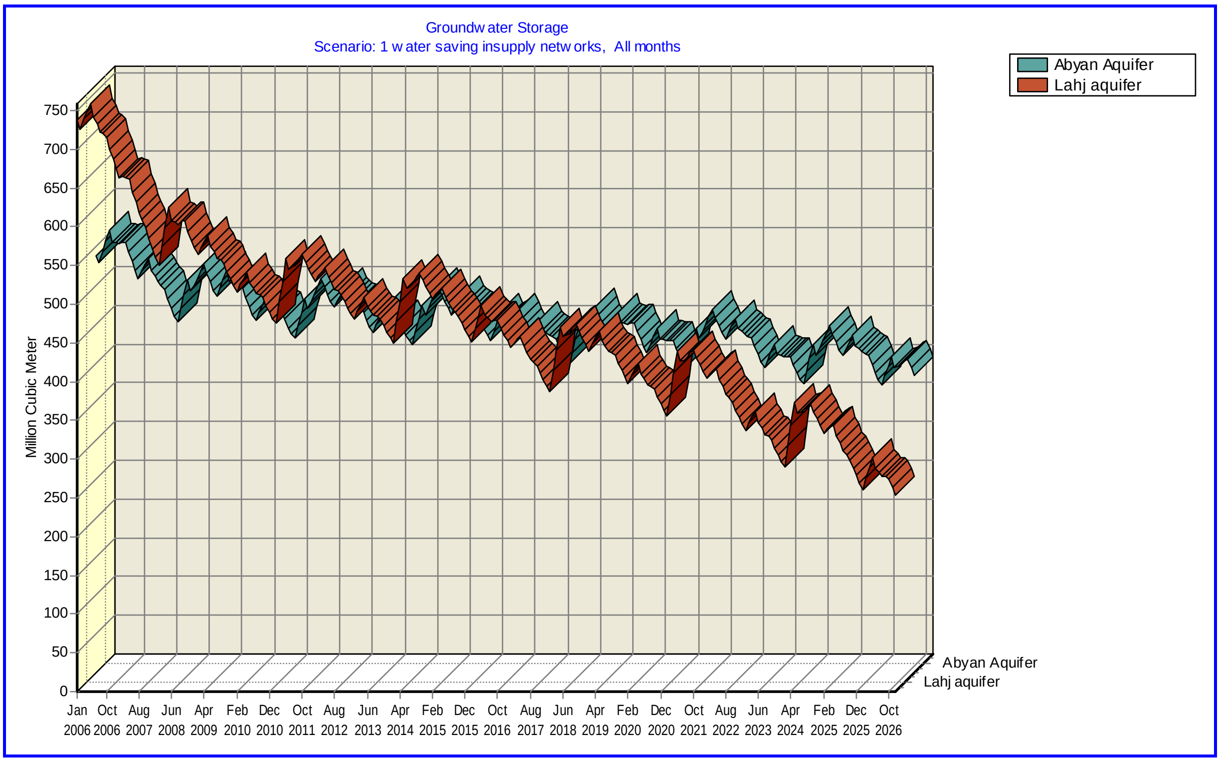

Figure 8: Mutual effect of all scenarios on ground water storage.

To get some answers to theses questions the following criteria were introduced to evaluate each adapted strategy:

a. Capital cost (implementation cost)
   It includes cost of infrastructure implementation (building, instruments, rehabilitation, further treatment, conducting training or awareness campaigns etc.)
b. Maintenance cost
   Cost to maintain infrastructure in a good condition to insure sustainability
c. Quantity of water saving
   The quantity of water can be offered by an adapted strategy
d. Sustainability
   With a proper maintenance, the infrastructure life time of an adapted strategy.
e. Knowledge to implement and maintain
   Eligibility of a stakeholder to implement and maintain a strategy
f. Preservation of local practice and lifestyle
   To which extent an adapted strategy, compared to another, can insure that a stakeholder will continue his existing way of living without shifting to another job.

To obtain the other criteria values, meetings with 21 stakeholders were conducted. These stakeholders involve farmers, domestic users and decision makers from Abyan, Lahij and Aden governorates. The result of stakeholder consultations regarding the suggested strategies and evaluation criteria were analyzed and then input into the MCA-WEAP (Model 4) for determining preferences and prioritization for adaptation strategies.

Module 4: Evaluation Criteria

Criteria scores (central estimates)

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Criteria short name>>>	Capital cost	Maintenance cost	Water saving	Sustainability	Preserve local practice and life style	Knowledge to implement & maintain
Type of measurement unit>>>	Quantitative; low score best	Quantitative; low score best	Quantitative; high score best	Quantitative; high score best	Qualitative (1-100); high score best	Qualitative (1-100); high score best
Units >>>	Thousands US Dollars	Thousands US Dollars	Million m3/year	years	score of 1 to 100	score of 1 to 100
Desalination water use	12000	600	7.79	50	11	0
Wastewater injection	20000	1000	46.22	50	42	0
Rehabilitation of traditional irrigation structures (channels)	15400	1540	27.285	2	21	100
Introducing drip irrigation method	17600	880	53.8	10	53	50
convey irrigation water through closed conduits	13200	660	39.53	10	42	100
Wastewater reuse	23000	1150	44.45	40	37	70
leakage reduction in drinking networks	15000	750	16.835	40	11	0

Module 6: Ranking of Adaptation Initiatives by central scores

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Final ranking (by central sc[illegible])

Initiative \ Score	Total central score
Convey irrigation water through closed conduits	70
Introducing drip irrigation method	62
Wastewater reuse	62
Wastewater injection	61
Desalination water use	58
Leakage reduction in drinking networks	51
Rehabilitation of traditional irrigation structures (channels)	48

Discussion of the Results

- *Conveying irrigation water through closed conduits*
  It can be seen from Module 6 that the prioritized strategy is usually plastic pipes or fabric pipes, though in the latter some of the irrigation water is evaporated from fabric skin. This practice has already been practiced by some farmers and it is, comparatively, easy to afford, implement and maintained.

- *Using drip irrigation*
  This strategy is the best in terms of water saving and sustaining the farmers existing life style but more expensive compared with first one and needs some training for implementing and maintaining it. If this strategy is subsidized it will be then the best and can be afforded by a wide sector of farmers which are mostly poor.

- *Wastewater reuse*
  This potential strategy will save a lot of wastewater from Aden waste treatment plants which is nowadays discharged to sea and can be diverted for the agriculture in Aden and Lahij governorates. The problem is that its quality is not adequate for use in irrigation unless it is improved to be used safely in irrigation. Thus this strategy need substantial investment which is mostly in he hand of the government.

It is worth mentioning here that wastewater reuse from Abyan and Lahij were not put for evaluation in MCA-WEAP as the WEAP results show that there is no improvement to the existing situation occurs when this scenario is adopted but even worsening it. The reason is that, with evaporation losses, the diverted treated wastewater for irrigation is less than the untreated wastewater which is used to be directly discharged to the aquifer through cesspits before implementation sewerage system. However, the treated wastewater from Abayn and Lahij treatment plants must be reused in irrigation in order to keep some balance in the aquifers otherwise the situation will become severe if it is discharged to the sea.

- *Wastewater injection*

  This scenario is approximately in the same level of wastewater reuse scenario (see Model 6) and it can be used instead but it effects is not tangible on short time basis as wastewater reuse scenario.

It can be concluded then that though wastewater recharging and reuse scenarios are also another alternatives in alleviating fresh water resources, the costs of implementation and maintenance are high and hence it needs the government intervention. In addition, if the cost of implementation, operation and maintenance are added to cost of water the farmer may not afford it.

Conclusions and Recommendations

- Many coastal arid areas regions such as Gulf Area and Aden are facing formidable freshwater management challenges. Allocation of limited water resources, environmental quality and policies for sustainable water use are issues of increasing concern.
- Conventional supply-oriented simulation models are not always adequate as they ignore stakeholders concerns regarding issues of water scarcity and socio-economic preferences and prioritization for adaptation strategies.
- Water scarcity in coastal arid areas, such as Aden, can be then tackled by introducing adequate strategies, measures and polices for sustainable use through application of integrated approach Decision Support Tools (DST).
- For Aden case, and by using DST, many strategies were found effective for sustainable use of fresh water resources such as wastewater recharging, wastewater reuse and enhanced irrigation methods (conveying irrigation water through closed conduits and using drip irrigation).
- Drip water irrigation method was found to be the best of all the adapted strategies but for implementation it needs to be subsidized by the government as most of the farmers are poor.
- Wastewater reuse and recharging were found to be very efficient (Table 3) but less applicable as they need the government intervention in terms

of investment for improving wastewater infrastructure and quality and legislations for adequate use in irrigation or in groundwater recharging.

- The most affordable option is conveying irrigation water through cheap closed conduits instead of open canals to prevent evaporation.
- The WEAP model for the study area (Aden) shows that an approximately sustainable use of water can be attained only if the following strategies are mutually implement which are, *introducing drip irrigation, wastewater reuse in irrigation or wastewater recharging, desalinated water use and reduction of leakage in supply networks*.
- The WEAP & MCA-WEAP models are proved to be a good evaluation and decision makers tools for water resources evaluation related to climate change and for adapted strategies evaluation and prioritization and therefore it is recommended to be adopted by the relevant authorities in Yemen and in the Gulf Area in the planning process of water resources development and use.

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