Integrating water balance and cost-effectiveness analysis for water management: An application in Jordan and Lebanon

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February 7th, 2008

Abstract

This paper is part of the European MEDITATE project (MEditerranean Development of Innovative Technologies for integrAted waTer managEment). A cost-effectiveness analysis is carried out in two water catchments: Chekka Bay (CB) in Lebanon and Amman Zarqa Basin (AZB) in Jordan. The purpose is to report on the integrated use of hydrogeological models and cost-effectiveness analysis in order to design water management measures in two strategic groundwater management. Water demand and supply are assessed over the period 2005-2030. In CB, the water deficit is estimated to 127 MCM/year in 2030, whereas in AZB it should reach 268 MCM/year. For the purpose of the study, these values are set as the objective to overcome by 2030 for the programs of measures of CB and AZB. Planned water policy measures are identified and analysed related to their local impacts and perspectives. Where necessary complementary and alternative measures are proposed and compared in order to fulfil the water deficits at the lowest costs. Least-cost combinations of measures are proposed at the catchment scale. However, uncertainties on measures costs and water quantities constitute serious limitations to the method. Besides, the method ignores the complexity of water transfers from one catchment to another and disregards the water efficiency use between water catchments. Knowing this, decision makers should consider CEA cautiously and are invited to integrate complementary criterias in their decision processes.

Keywords: Cost-effectiveness analysis; water management measures; water scarcity in Jordan and Lebanon; Water scenarios.

1 Introduction

The present work is part of EU project MEDITATE (MEditerranean Development of Innovative Technologies for integrAted waTer management of the 6^{th} Framework program) which aimed at developing a Water Management Support System (WMSS) at the scale of water catchment and integrating alternative water resources such as fresh water from karstic submarine springs or wastewater treatment and reuse. Water scarcity mitigation is an important challenge in many arid and semi-arid regions in Mediterranean and Middle East countries. For the countries considered here, Lebanon and Jordan, the population growth is highly increasing and greatly contributes to damage the water balance. Water resource availability is therefore becoming an increasingly limiting factor for economic development, compelling water scarce societies to improve the economic efficiency of water use. Water authorities are then induced to take measures to improve water management under a sustainability constraint. There is a relatively recent changing perception on the necessity of combining the water supply and demand-side measures. This approach aims at comparing both kinds of measures and their relevant combinations in order to identify the least-cost ones that enable to satisfy the water objectives, expressed in terms of physical units. Economic evaluation of water management policies and programs is now scheduled in most of government water policies, for example through the European Union Water Framework Directive [WATECO, 2003, Massarutto and Paccagnan, 2007] or the United States Environment Protection Agency [EPA, 2000].
The present paper considers a holistic approach of cost-effective water quantity management at the water catchment scale regarding both demand and supply-side measures. Similar approaches of water management have been investigated from a single effectiveness perspective such as in Loukas (2007) and Wheida (2007). The authors modelled surface water and groundwater resources, water demand for each economic sector, water balance and demand and supply side measures to achieve the objective of sustainable management of water resources. However, they did not consider economic aspects of management programs of measures.
The primary purpose of this paper is to examine the usefulness of the cost-effectiveness analysis as an *ex ante* evaluation method for the water catchment resource management and Water Management Support System (WMSS). A secondary purpose is to discuss the results of the CEA applied

in two different contexts of water planning practices and to compare them in terms of decision support for a sustainable 'water management.

2 Case studies description

2.1 Case study 1: Chekka Bay area

The Chekka Bay (CB) area in North Lebanon regroups three water catchments (Abou Ali, El Asfour and El Jaouz Rivers) with a total surface area of 1,200 km^2 (Figure 1). Administratively, the CB area includes five administrative municipalities named *cazas* hereafter. The area includes also the entire Chekka aquifer catchment that discharges at Chekka Submarine Karstic Springs (SKS). The SKS are considered to be the most productive freshwater submarine springs in the Mediterranean Sea with a few springs that permanently discharge during the dry season [Kareh, 1967, Kareh, 1968, El-Hajj *et al.*, 2006].
Due to lack of geological knowledge and river monitoring, water resources estimate is a real challenge in the case study area [Al-Omari and Lanini, 2007], especially for groundwater resources quantification. Even if the case study seems quite well endowed with water resources, the percentage available for water supply could be about 25% of the annual renewable water. This makes theoretical available water for extraction of 200 MCM of which 130 MCM/year are from groundwater resource. The CB is characterized by a high popula-

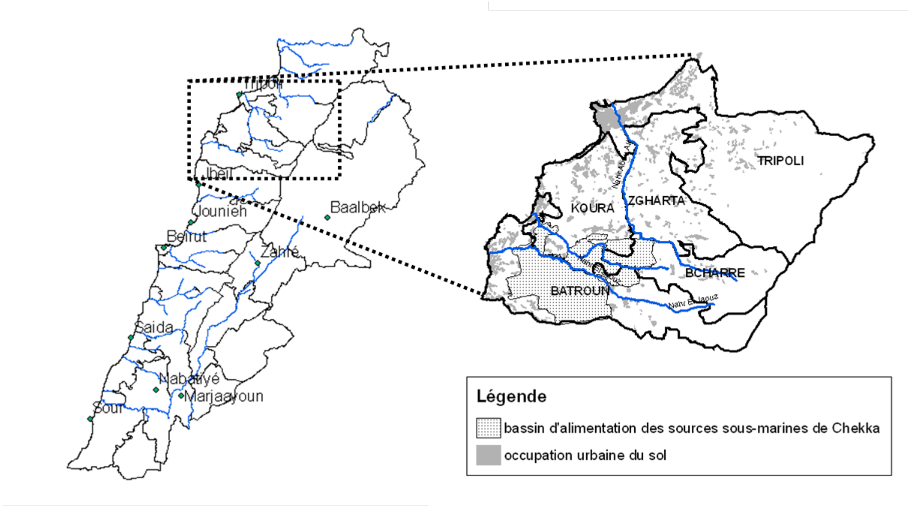

Figure 1: Chekka Bay location

tion density rate of 761 inhab./km^2. This is twice the national average rate. The total population within the area is estimated to around 925,000 inhabitants in 2005 according to the statistics of the Ministry of Social Affairs.

Tripoli is the most populated town with about 400,000 inhabitants. The domestic water demand is estimated to 98 MCM per year (43% of the total water demand). The study area is also an important industrial basin especially around Tripoli and in the coastal zone of Chekka Bay. Large-scale industries consist mainly of cement production which contributes to high water consumption totalling about 22 MCM per year (10% of total water demand). The tourism sector is less important: the water demand does not exceed 0.2 MCM per year. Agriculture remains the highest water consumer in the studied area. During the last decades, irrigated perimeters were developed by the Ministry of Energy and Water. However, they are characterized by high water inefficiency rates due to the extensive use of open flooding techniques. In addition, private and scattered irrigated areas exist in the whole catchment using mainly groundwater. The total agricultural water demand is estimated to 106 MCM per year, representing 47% of the total water demand. Finally, the total water demand approaches 226 MCM in the year 2005.

Future water demand in each sector is forecasted according to the baseline scenario for the period 2005-2030 (The baseline scenario was defined considering regional and national sectorial strategic plans and expected development of water uses). Within this scenario, the total water demand is likely to increase by 44% to reach 327 MCM in 2030 (Figure 2). The increase of 101 MCM is mainly due to the increase of domestic water demand as illustrated in the Figure 2 below and despite the forecasted improvement of water use in agriculture. Assuming that the water supply will not increase during the period 2005-2030, the water demand-supply deficit is estimated to reach 127 MCM in 2030.

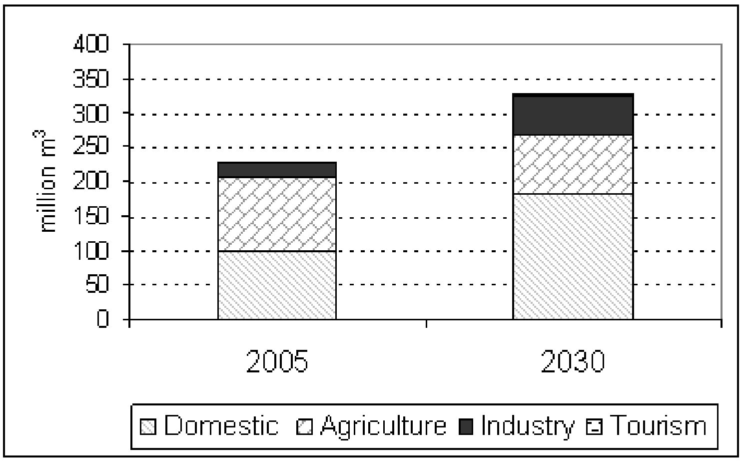

Figure 2: Present and future water demand estimations in Chekka Bay area

2.2 Case study 2: Amman Zarqa Basin

Located in the northern part of Jordan within the Syrian border, the Amman Zarqa Basin (AZB) covers a total area of 4,094 km^2 of which 3,739 km^2 in Jordan (4% of the entire country's area). The Jordan part of AZB, focused in this study, is shared among 6 administrative governorates (Figure 3) and includes big urban agglomerations such as great Amman city, Zarqa, Mafraq, Jarech and Russaifeh. This makes AZB the most populated basin in Jordan. The population was estimated about 3.2 millions in 2005, representing about 58% of the total Jordan's population. According to the Department of Statistics, the average and annual population growth is estimated to 2.8 for the period 1998-2005.
The AZB includes the Zarqa River which is the second largest tributary to Jordan River, and the wadi Dhuleil. The total surface water in AZB amounts 70 MCM/year. Almost all the available surface water resources in the basin have been harvested, mainly for irrigation purposes. In terms of hydrogeology, the AZB aquifers system is considered one of the most important groundwater basin in Jordan with respect to its total renewable groundwater safe yield estimated to 88 MCM per year [MWI, 2004]. However the current groundwater abstraction exceeds the safe yield by about 60%. The current treated wastewater is around 50 MCM per year which is totally used for restricted irrigation purpose. It is assumed that the potential of wastewater reuse will be increased by 5 MCM every five years and will replace the potable water used in agriculture. The total water supply is estimated to be around 300 MCM per year in 2030. In terms of water demand, agri-

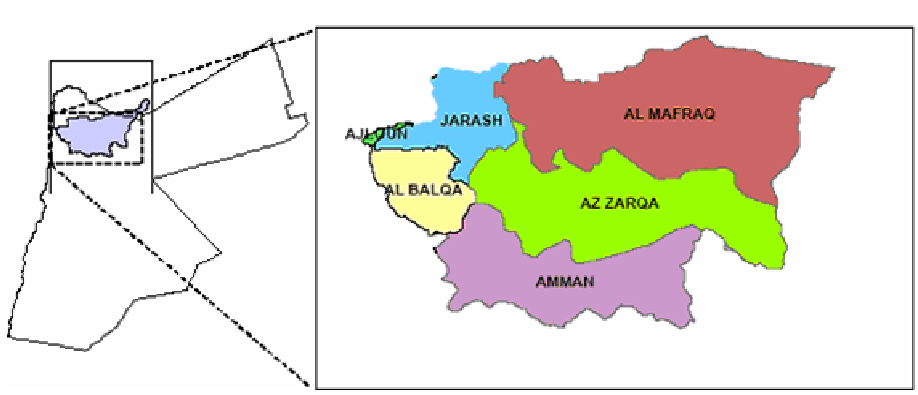

Figure 3: Localisation and administrative subdivisions of Amman Zarqa Basin

cultural sector is by far the most dominant water sector in AZB. Based on the Ministry of Water and Irrigation (MWI) estimations [MWI, 2004], the agricultural water demand represents about 228 MCM in year 2005 (59% of total water demand). Considering the average 110 litres per capita per day

of water consumption, the domestic water demand is estimated to 150 MCM in 2005 (39%). The total industrial water demand amounts 7.5 MCM, representing around 2% of total water demand. The tourism sector absorbs about 0.5% of the total present water demand (2 MCM/year). According to the MWI, the Unaccounted For Water (UFW, that is domestic and industrial water losses) is estimated to be less than 61 MCM per year. The total water demand in AZB is then approximated to be 387 MCM for the year 2005.
The water demand projections are based on the ones made by the MWI under the National Water Master Plan [MWI, 2004]. These projections were displayed at the AZB level for the period 2005-2020. The 2030 estimation was obtained by extrapolation. The overall results of the baseline scenario projection reveal that the total water demand will increase by 21% in 2030 to reach approximately 568 MCM/year (Figure 4). Thus, the total water deficit in the basin will be appreciatively about 258 MCM in 2030.

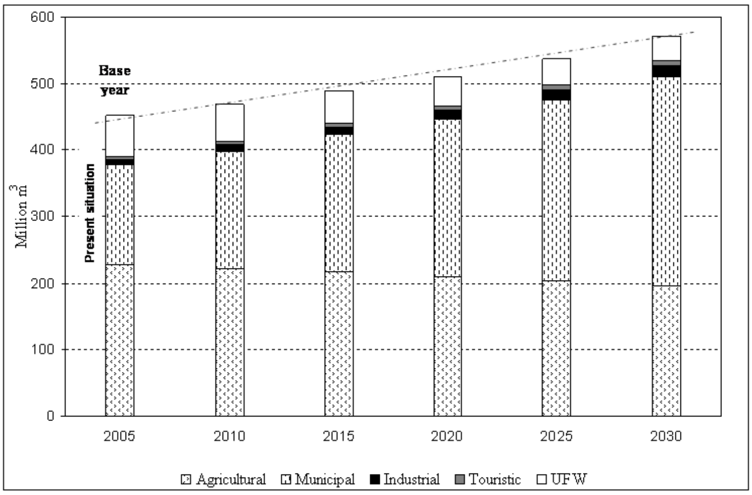

Figure 4: Present and future water demand in AZB up to 2030 (MCM/year)

3 Identification of the water management measures

In order to resolve the future water deficit at the case study scale, a selection of water management measures were identified through a consultation of water decision makers and the review of national water plans. These measures cover all water sectors and consider both the demand-side measures (i.e. water resource conservation) and the supply-side measures (i.e. increasing water resources). The costs and the water saving or production of each measure were estimated on the basis of available data. In the following, details of selected measures and their associated assumptions are summarised.

3.1 Selected measures in CB case study

In Lebanon, the Northern Water Authority is responsible for local water management and the Ministry of Energy and Water (MEW) is in charge of the national water planning policy. In response to the foreseen increasing water demand, the MEW designed a 10-years plan (2000-2009), which allocates 67% of the total budget to the procurement of additional exploitable water resources through dams and hill lakes construction [MoE, 2001]. In the frame of this study, additional water management measures are considered. These measures are briefly described in Figure 5:

Alternative measures	**Code**	**Measures assumptions**	**Water output (MCM/year)**
Demand side measures			
Development of sanitary water saving	SWS	30 m^3 of water saved per year per household. 50% of households adopt the measure.	4.25
Adjustment of water pricing policy	WPP	The price is set to allow a 10% water saving.	18.17
Improvement of water efficiency along distribution networks	EDN	Rehabilitating the old current pipes and transmission pipes, extension of the drinkable water public network to 80% of the 2030 population, restoration and extension of house connections. Water losses reduced to 30%.	42.5
Improvement of irrigation systems	IIS	Water efficiency is elevated to 85% within 50% of the total irrigated surface.	7.4
Development of domestic rainfall storage capacity	DRS	Small water tank of 3.5 m^3 per household. 20% of households adopt the measure.	1.34
Supply side measures			
Construction of dam for surface water storage	DWS	Construction of 3 dams in CB area totalizing a 59 MCM water capacity.	59
Wastewater treatment and reuse Option 1	WWR1	Option 1 considers wastewater reuse from the current 3 WW plants in the area.	17
Wastewater treatment and reuse Option 2	WWR2	Option 2 considers the collection of all wastewaters, the construction of new WW plants and the treatment and reuse of all wastewaters.	69.8
Chekka SKS exploitation Option 1	SKS1	Submarine spring exploitation on the basis of 1 m^3/s during winter and 150 l/s during summer, with small water treatment.	18.4
Chekka SKS exploitation Option 2	SKS2	Submarine spring exploitation combined with desalination plant of 20,000 m^3/day. Freshwater and seawater are mixed in order to improve desalination yield.	21.6
Sea water desalination of sea water Option 1	SWD1	Reserve Osmosis desalination plant of 50,000 m3/day capacity.	18.25
Sea water desalination of sea water Option 2	SWD2	Two Reserve Osmosis desalination plants totalizing a 100,000 m3/day capacity.	36.5
Construction of hill lakes for surface water storage	HLWS	Construction of 3 hill lakes in CB area totalizing a 3 MCM water capacity.	3

Figure 5: Selected water management measures for Chekka Bay area

3.2 Selected measures for AZB case study

In Jordan, the MWI is responsible at national level for the overall management of the water resources. The MWI handled the water issue with the Water Sector Investment Program 1997-2011 and the National Water Master Plan in 2004. In order to bridge the water deficit in the AZB (especially for great Amman area), the MWI suggested a number of management measures including both water demand and supply alternatives. Respect to the above programs, the already planned measures considered for the study are summarised in Figure 6. For some measures only part of the total water produced or saved is dedicated to AZB. These are given in the last column of Figure 6. It should be noticed that the suggested alternative measures for AZB include large projects, and smaller ones, all of widely differing characteristics and objectives, with a different degrees of definition and status. Amongst them, some are fully defined - down to final design including tender documents - and some remain with preliminarily design and feasibility study to be executed. Figure 6 also includes some measures which are in fact on-going programs (AWD, WWTP and ZMD) and other which are basically components of larger integrated programs (WSS and GWP) or large water supply projects (Disi and RSDSC).

Alternative measures	**Code**	**Measures assumptions**	**AZB water output (MCM/year)**
Demand side measures			
Al Wahdah Dam construction	AWD	Water surface storage by the construction of a major Dam to regulate Yarmouk river: estimated storage capacity is of 110 MCM of which almost half for AZB supply.	50
As Samra wastewater treatment plant	WWTP	Upgrading of the plant and re-use of additional treated wastewater for agricultural and industrial uses.	70
Zara Main Desalination project	ZMD	Desalination of brackish springs' water: the total desalinated water is estimated about 40 MCM/year of which a part supplies AZB for domestic water.	21.2
Disi aquifer conveyer project	Disi	Abstraction of groundwater from Disi aquifer and transfer to AZB for domestic water use for AZB.	110
Desalination of sea water: RSDSC project	RSDSC	Create a source of desalinated sea water and transfer via a canal from the Red Sea to the Dead Sea (RSDSC) to supply AZB for the domestic and industrial uses.	400
Supply side measures			
Rehabilitation of water supply system of Amman area	WSS	Water savings in municipal water supply by reducing the Unaccounted for Water by 50%	30
Groundwater policy measure	GWP	Water savings by reducing agricultural groundwater abstraction (enforce groundwater control) equivalent to the over-exploitation volume in the AZB aquifers.	60

Figure 6: Selected water management measures for AZB case study

4 Results and discussion

The measures of both case studies are evaluated according to the Total Annualized Economic Cost ($TAEC$) method as defined in Equation 1.

$$TAEC = \frac{rI_0(1+r)^T}{(1+r)^T - 1} + AOC \quad (1)$$

where I_0 is the total capital cost and
AOC is the Annual Operational Cost.

The cost-effectiveness ratio is the average per unit cost of water (C/E_a), that is the $TAEC$ divided by the annual expected amount of water (W) produced or saved by the measure (Equation 2).

$$C/E_a = \frac{TAEC}{W} \quad (2)$$

The final CEA's results differ significantly according to the discount rate and the time horizon used in the calculation of ratios [Zanou, 2006]. For the already planned measures, costs were estimated on the basis of initial feasibility studies (Jordan case) or expected project funding by development banks (Lebanon case). For all other measures, costs were estimated according to local experts' knowledge or on the basis of cost data of similar measures. In both cases, a common discount rate of 4% was taken according to European Commission and World Bank recommendations for social projects. In the same logic, single lifetime cycles were defined for similar measures found in the local literature.

4.1 CB case study results

A set of 13 measures are evaluated. The results as well as measures ranking according to the value of $C/E_a$are presented in Figure 7. Under the assumptions considered, the dam construction appears to be the third most cost-effective measure (0.211 €/m^3) and the first of supply side measures ranked before wastewater reuse and desalination. Dam construction alone, as defined in the government water policy, is not sufficient to fulfil the water gap by 2030. However, it can not be avoided since the two first ranked measures (SWS and WPP) only represent 18% of the water deficit. Inversely, wastewater reuse measure appears as a competitive measure whereas it is not planned by the government. For the less cost-effective measures, desalination seems to be better than hill lakes storage, also planned by the government.
From the ranking of Figure 7, demand and supply-side measures must be

Measures	Code	Water output (MCM/year)	TAEC (M€)	C/E_a (€/m^3)	Rank
Development of sanitary water saving	SWS	4.25	0.55	0.127	1
Adjustment of water pricing policy	WPP	18.17	3.15	0.180	2
Construction of dam for surface water storage	DWS	59.00	12.50	0.211	3
Wastewater treatment and reuse Option 1	WWR1	17.00	8.30	0.489	4
Wastewater treatment and reuse Option 2	WWR2	69.80	34.10	0.489	4
Improvement of water efficiency along distribution networks	EDN	42.50	28.01	0.660	5
Chekka SKS exploitation Option 1	SKS1	18.40	14.72	0.800	6
Chekka SKS exploitation Option 2	SKS2	21.60	17.28	0.800	6
Sea water desalination of sea water Option 1	SWD1	18.25	18.25	1.000	7
Sea water desalination of sea water Option 2	SWD2	36.50	36.50	1.000	7
Construction of hill lakes for surface water storage	HLWS	3.00	3.50	1.181	8
Improvement of irrigation systems	IIS	7.40	10.10	1.365	9
Development of domestic rainfall storage capacity	DRS	1.34	5.36	4.010	10

Figure 7: Cost-effectiveness ranking of the selected measures in CB area case study

combined to achieve the objective of 127 MCM per year. Two combinations of measures are investigated. Combination A piles up all the measures according to their rank. Two options are considered: $A1$ (with option 1 of measures WWR, SKS and SWD) and $A2$ (with option 2 of measures WWR, SKS and SWD). Combination B assumes the dams' construction is not technically feasible (i.e. high water losses due to geological fractured karst) and wastewater reuse is abandoned since effluents are to be throw offshore. Two options are again considered: $B1$ (CS1 and DSW1) and $B2$ (CS2 and DSW2). The results of combinations A and B are illustrated in Figure 8 and Figure 9 under the form of cumulative costs and water produced/saved. The 2030 water gap is represented by the horizontal line. Figure 8 reveals

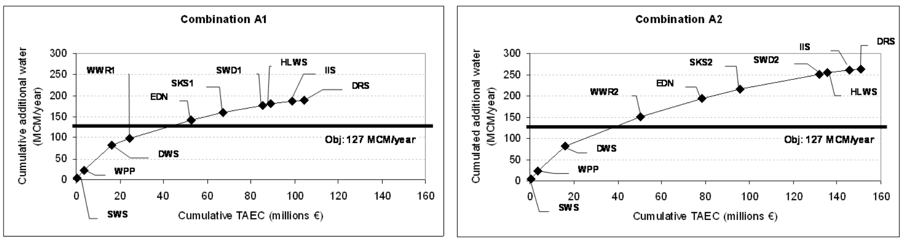

Figure 8: Cumulative costs and effectiveness for combinations $A1$ and $A2$

that development of dams' construction and wastewater reuse should be necessary measures in order to achieve the objective by 2030. Extending the capacity of wastewater reuse, as illustrated in combination $A2$, seems the most cost-effective solution to achieve the objective ($C/E_a = 0.303$ vs. 0.341 €/m^3). The objective should then be reached at a lower cumulative cost (< 40 millions €). If this combination $A2$ is not feasible by 2030 for any reasons like political, financial or other, then the improvement of water distribution network becomes the most interesting measure (combination

$A1$). Within combination $B1$, all the measures are not sufficient to reach the

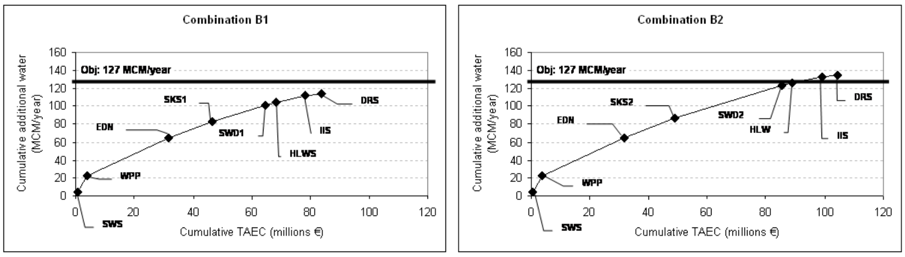

Figure 9: Cumulative costs and effectiveness for combinations $B1$ and $B2$

objective as illustrated in Figure 8. In this case, additional water production from desalination of submarine springs (SKS2) and sea water (SWD2) becomes necessary (combination $B2$). The total cost of this combination approaches 90 millions euros of which 60% are due to desalination measures (Figure 8B). This implies that the objective should be achieved for a total cost that is more than twice (2.3) the cost of combination $A2$.

4.2 AZB case study results

In the context of the AZB, 7 measures were investigated for the economic evaluation. This was undertaken on the basis of individual feasibility studies carried out during the past years in the frame of the Jordan water planning [MWI, 1997]. For all measures, the economic costs and outputs were updated with a relatively acceptable approximation. The same assumptions than for the CB study are considered (4% discount rate). The following economic calculations are based on total water produced or saved and total costs of measures. Figure 10 summarises the calculation of the C/E_a ratio and the associated ranking. The results of the analysis clearly re-

Water measures	Code	AZB water output (MCM/ year)	TAEC (M€)	C/E_a (€/m^3)	Rank
Al Wahdah dam construction	AWD	50	5.57	0.051	1
Groundwater policy measure	GWP	60	4.15	0.069	2
As Samra plant (WWTP)	WWTP	70	15.72	0.225	3
Desalination of Zara Main springs	ZMD	21.2	9.96	0.249	4
Amman network rehabilitation	WSS	30	8.28	0.276	5
Desalination of sea water (RSDSC project)	RSDSC	400	169.22	0.423	6
Disi aquifer conveyer	Disi	100	46.15	0.462	7

Figure 10: Average cost per unit of water (C/E_a)

veal that the supply-side measure, Al Whahda dam project is the most cost-effective measure with an average cost per unit of water estimated to around 0.051 €/m^3. Then comes the first demand-side measures, groundwater policy, which has a slightly lower unit C/E_a ratio of 0.069 €/m^3. It is followed by non-conventional water supply measures of wastewater reuse

(WWTP) and spring water desalination (ZMD) with respectively 0.225 and 0.249 €/m^3. The analysis shows that large water supply measures such as Disi and the RSDSC projects are less cost-effective in comparison with smaller water supply or demand-side measures.

With respect to the objective achievement by 2030, the analysis indicates that 5 out of the 7 selected measures are necessary. Figure 11 shows the cumulative $TAEC$ and the cumulative water output delivered to AZB. Thus, the potentially most cost-effective combination of measures should at list includes: Al-wehdah dam (AWD), groundwater policy measure (GWP), Zara Main springs water desalination (ZMD), As Samra wastewater plants (WWTP) and rehabilitation of water supply system (WSS). The total potential of water of these measures amounts to 240 MCM/year. With respect to the considered assumptions, it appears that the larger projects of Disi and RSDSC are less necessary to achieve the objective before 2030.

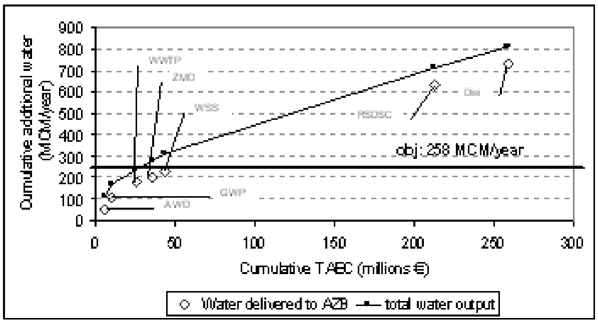

Figure 11: Cumulative costs and effectiveness of selected measures based on C/E_a

5 Conclusion

The CEA was carried out through the two case studies to evaluate water management measures at the scale of water catchments. At this scale, the objective was to resolve the future water deficits, estimated to be around 127 MCM and 258 MCM in 2030 for Chekka Bay area and Amman Zarqa Basin respectively.

From the results of the water balance analysis carried on in CB and according to the assumptions made, it seems that the current Lebanese water strategy focusing mainly on dams and hill lakes construction should not be sufficient to bridge the water deficit by 2030. Moreover, according to the economic evaluation, dams' construction does not appear as the most cost-effective solution. Under the assumption where dams are technically infeasible, CEA shows that desalination of SKS water or sea water could contribute greatly to achieve the objective without high costs.

In the context of AZB, the analysis reveals that not all measures may be necessary to achieve the 2030 water balance objective at the catchment level. The two large scaled projects (Disi and RSDSC) appear to be the less cost-effective measures. In addition, the potential water production of these projects seems disproportionate compared to the future water demand with respect to the baseline scenario.

Finally, the CEA application shows several obvious limitations. First, if CEA points the least-cost combination of measures to fulfil the water deficit, uncertainties on costs and water yields constitute serious limits to the relevance of the results. These uncertainties may significantly bias the ranking of the measures and consequently the associated optimal combinations. For instance, the decrease of Al Wahdah water's production in half will double the marginal unit cost. Sensitivity analysis has been realised regarding to discount rate. Contrasted scenarios can also be tasted taking into account uncertainties on both costs and water. Second, measures were selected avoiding any interdependencies that could have affected the possibility to sum the costs and outputs. Besides, water transfers from one basin to another are disregarded in this study. This is of particular concern for large scaled measures such as the RSDSC for which water will serve area outside the AZB. The CEA does not allow evaluating the effectiveness with multiples objectives.

Knowing these limitations, CEA should not be used alone as a decision tool. CEA allows comparing and ranking measures from a pure economic point of view independently of other criteria such as social or political acceptability. This is particularly highlighted in the Lebanon case study where non conventional water (wastewater reuse and desalination) is considered as a economically viable alternatives despite the fact they are not included in the current water strategy. In addition, CEA does not say anything of the the net value of a measure or a combination of measures. This has to be estimated through costs-benefits analysis. With substantial limitations of the CEA, the analysis remains an interesting support in providing information to decision makers who are in concern of integrated water management at the catchment scale.

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