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Enhancing Water Resource Management in Arid Areas, Disi Basin - Jordan

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Abstract: Water shortage is a main issue in Jordan as the annual share per capita is less than 145 cubic meters that categorizes Jordan as one of the top five poorest countries in the world in respect to fresh water resources. Limited financial and natural resources and water shortage play significant constraint to development; concurrently the population growth is 2.3%, in addition to large number of refugees from neighboring countries since 1948. Integrated Water Resources Management (IWRM) including implementation of decision support tools is necessary to balance the present demand and future generations. Decision support system software based on Multi-Criteria Analysis (MCA) used to analyze multiple variables associated with agricultural crops. The MCA utilized Analytical Hierarchy Process (AHP) which resulted in the prioritization of sustainable water policies for management in the Disi Basin (the biggest non renewable ground water basin in Jordan). The inputs to the MCA were generated through applying of Modflow (groundwater), Penman Montieth models and the estimated water productivity of agricultural and industrial sectors. The use of MCA led to develop good management practices of water resources and also recommended how to enhance a long-term sustainability in Disi Basin, while allowing for water utilization and economic growth. It can be concluded that the MCA tool and AHP are potentially positive tools contributing to the process of decision-making for selection and ranking of alternatives and policies, therefore helping in solving problems and sustaining the management of the precious water resources.

Key words: Disi Basin · Multi-criteria analysis · Sustainable water management

INTRODUCTION

Jordan lies in a transitional zone between the Mediterranean climate in the west and the arid climate to the east and south. Hydrologically the country subdivided to 12 basins (Fig. 1) [1]. The most important non-renewable groundwater resources are the Disi and Shedia sandstone fossil aquifers in southeastern Jordan. 70 million m^3 of fresh water is extracted annually from Disi for agricultural purposes as well as for domestic purposes for the city of Aqaba [2]. The sustainable yield over 100 years of all non-renewable ground water resources in the country has been estimated 90 to 140 million m^3 per year [3]. Estimates of groundwater storage in this basin are about 6 billion m^3 [4].

The groundwater of the Rum group (Disi aquifer) is of good quality, suitable for potable use with a range of salinity of 200-300 mg/l in the unconfined section increasing slightly in the confined section to 250-350 mg/l. The overlying Khreim group, of marine origin, contains groundwater of significantly greater salinity ranging from 1000 to 10000 mg/l.

It now seems accepted that the Disi aquifer is of fossil origin, with negligible amounts of recharge. The [13] Howard Humphreys model indicated sustainable abstraction of up to 65 MCM/yr but it was recommended that no more than 45 MCM/yr should be extracted. Further modelling in 1986, which took account of abstractions in Saudi Arabia and the natural extension of the aquifer into that country, indicated that the aquifer could be exploited at 110 MCM/yr. HSI in [5], in their study of the Disi aquifer of Jordan and Saudi Arabia, considered that the Disi aquifer in Jordan could be developed at 125 MCM/yr. Haiste-SWK & WAJ in 1994, after further exploratory drilling and preliminary modelling, suggested that there are adequate resources in Jordanian territory to satisfy short-term demand (30 years) of 70-80 MCM/yr with very high degree of confidence, additional to the current production of 75 MCM/yr. With less degree of confidence, the same quantities could be abstracted for 100 years.

Current Uses of the Disi Aquifer: The current production from the aquifer is about 70 MCM/yr. About 55 MCM/yr is used for irrigation purposes in

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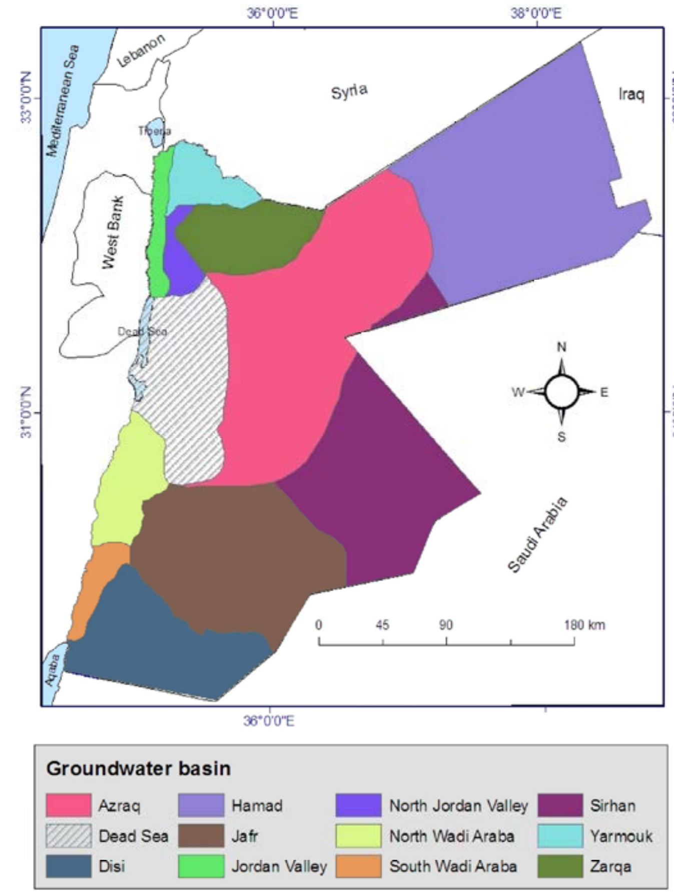

Fig. 1: Groundwater basins.

Disi and Mudawwara area. There are four main farming corporations are currently active; RUM, WAFA, ARABCO and GRAMACO. The Rum farms is located in the Disi area and has about 50% of the total abstraction for agricultural purposes. The other farms are around Mudawwara. Out of the total abstraction rates about 20 MCM/yr is used for Aqaba water supply. In addition, the local village supply of Disi, Toueiseh and Qa Ghal is estimated at about 2 MCM/yr [6].

MATERIALS AND METHODS

Multi-Criteria Analysis and Water Management: Application of multi-criteria analysis (MCA) allows for the evaluation of the optimal utilization of available water mainly depends on forecasting models to obtain predictions of important variables. These variables include water salinity; water productivity and crop water requirements variables. These forecasts form the input to the model subsystem to derive policies for water resources used by different sectors. The model for decision making used is the Analytical Hierarchy Process (AHP) in the MCA "expert system" software Expert Choice [7]. The expert system has a major advantage ease of use by non-specialist users and has been applied successfully in many aspects of water resource management [8].

A MCA is the general forum within which several sub-MCA can be combined to incorporate all necessary interacting components which play a role in the decision making process [9].

Estimation of Potential Evapotranspiration (ETP): The meteorological data for concerned area during the period 1980-2010 will be utilized as input to EVAPOT program. EVAPOT uses Penman-Montieth equation to calculate the reference evapotranspiration:

$$Rn = \frac{\Delta(Rn - G) + \rho.Cp(ea - ed)/ra}{\Delta + \gamma(1 - ra/rc)} \quad (1)$$

The EVAPOT program follows the updated methodology of FAO [10] to compute the reference evapotranspiration with the Penman Monteith method. The following data will be used as input to EVAPOT:

maximum and minimum air temperature, relative humidity, wind speed and sunshine duration or solar radiation.

The crop coefficients will be determined using the KCISA program, which is based on the procedure described by FAO 56 [10].

The above mentioned calculations will be utilized to calculate water productivity for major crops cultivated in the concerned area according to the following methodology:

The values for the net economic return from each crop will be calculated using equations described by McLennan, [11].

The gross margin of profit is calculated as:

$$GM = TR - VC$$

where;
GM = Gross margin (JD/dunum),
TR = Total return (J.D./dunum),
VC = Variable cost

$$N.R. = \frac{G.M.}{W.C.} \quad (2)$$

Net return (JD/m^3) per each unit of water consumed:
where;
NR = Net return (JD/m^3),
GM = Gross margin (JD/dunum),
WC = water consumed (m^3/ dunum).

Analytical Hierarchy Process for Achieving the Best Crop Growing in the Disi Area: The problem was broken into different levels to construct a hierarchy tree. The hierarchy tree composed of three levels. The first level defined the 'goal' to be achieved which is to choose the best crop growing in the Disi area.

The second level outlines the main objectives, based upon them we can synthesized our judgments to achieve our goal. These are profitability, water consumption, salinity tolerant and marketing. The third level lists the alternatives, which consist from the main crops grown in Disi area; these are Tomato, Potato, Onion, Sweet melon, Watermelon, Eggplant, Cauliflower, beans green, Bell pepper, Grapes, Barely and Sudan grass.

Based on the goal (level 1), the objective priorities were defined. Different approaches followed to achieve the priorities for the alternatives (level 3) with respect to the objectives indicated in level 2.

Profitability and water consumption were calculated according to the known scientific methodology, salinity tolerant estimated based on FAO and yield marketing priorities set up based on the information available in the Ministry of Agriculture, yearly report, [6] and DOS Annual Report, [12].

Analytical Hierarchy Process for Achieving the Best Industry: The process for the industrial sector hierarchy tree was similar to the agricultural sector, but the objectives and alternatives were specific to industry. The hierarchy tree is composed of three levels. The first level defined the 'goal' to be achieved which is to choose the best industry. The second level outlines the main objectives; these are profitability, water consumption and marketing. The third level lists the alternatives, which consist from the main industrial sectors; high economic return manufacturing industries (Manufacture of apparel, publishing, manufacturing of electronic), services (education, health and Recreational and cultural activities) and construction.

Different approaches followed to achieve the priorities for the alternatives (level 3) with respect to the objectives indicated in level 2.

General MCA Diagram: Analytical Hierarchy Process to Achieve Sustainable Water Resources Management in Disi Basin: The outputs of the two above mentioned sub-MCA diagrams; sub-MCA diagram of Water Productivity for Agricultural sector and sub-MCA diagram for Industrial sector are used to construct the main MCA diagram for sustainable water resources management in Disi Basin. To construct the main MCA diagram, a brainstorming session including experts held in Al-Balqa Applied University. Most of the participants are experts in water issues with high knowledge in Disi Basin problems and some of them have a good experience in the MCA and construction of analytic hierarchy process (AHP). The group defined the components of a four levels hierarchy tree including relevant variables to achieve sustainable water resources management. The first level defines the goal to be achieved, which is sustainable management of water resources in Disi Basin. The second level, the objectives, are therefore correspondingly 1) to operate within the baseline abstraction, 2) No water abstraction above 45 MCM per year and 3) No water abstraction above 100 MCM per year. The third level allows the user to weight the following combinations of water allocation alternatives; a) Allocation to one sector: domestic, b) Allocation to two sectors: domestic and industrial c.) Allocation to three sectors: domestic, industrial and agricultural.

The fourth level consists of a set of policies to achieve groundwater resources sustainability: Limit groundwater uses to Disi area, limit groundwater uses to Disi and Aqaba city and limit groundwater uses to Disi, Aqaba and Amman.

RESULTS AND DISCUSSION

Evapotranspiration: Penman Montieth Model: The values calculated for potential evapotranspiration by Penman Monteith model using EVAPOT program for the years (1980-2010). As shown graphically in figure 2, the maximum and minimum potential evapotranspiration occurs during July and December respectively. The values of potential Et will be utilized in calculation of actual evapotranspiration Etc for the major crops grown in Disi area.

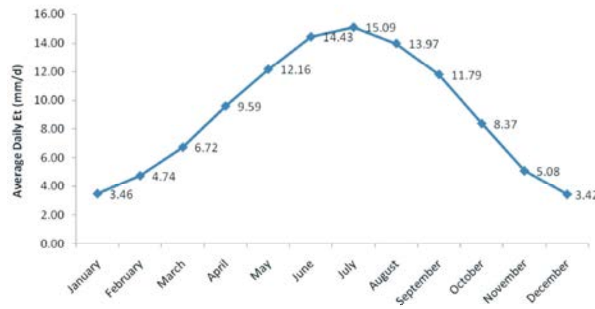

Fig. 2: Average potential evapotranspiration for Disi area by Penman Monteith Model using EVAPOT program for the period 1980-2010.

Multi-Criteria Analysis

Agricultural Sector: Table 1 summarized the results of the agricultural sector for 4 scenarios that will determining the selection of the "crop, based on the following priorities: Scenario 1. Water consumption (55%), Scenario 2. Water productivity (17.3%), Scenario 3, Salinity Tolerance (6.2%) and Scenario 4. Marketing (21.5%).

To construct the main MCA diagram, we have to prioritize our objectives and give weights for each objective, as mentioned in the methodology a brainstorming session including experts held in Al-Balqa Applied University. Most of the participants are experts in water issues with high knowledge in Disi Basin problems and some of them have a good experience in the MCA and construction of analytic hierarchy process (AHP), the results demonstrated that water consumption (55%) got the highest-ranking and followed by marketing (21.5%), water productivity (17.3%) and salinity tolerance (6.2%).

The highest-ranking crop in "water consumption" category was beans green 55% and grapes ranked the lowest 1%. The highest-ranking crop in the "water productivity" scenario was beans green 40.4%,

Table 1: Priorities of alternatives (major crops in Disi area) based on multi-criteria analysis under different scenario

Water consumption (55%)	Water productivity (17.3%)	Salinity tolerant (6.2%)	Marketing (21.5%)	Overall
Beans green (20.1%)	Beans green(40.4%)	Barley(38.4%)	Beans green(42%)	Beans green(19.1%)
Cauliflower(19.7%)	Grapes(16.7%)	Sudan grass(16.2%)	Tomato(34.9%)	Cauliflower(14.9%)
Eggplant(12.3%)	Onion(13.4%)	Grapes(13.2%)	Potato(18%)	Onion(11%)
Onion(12.1%)	Water melon (6.1%)	Cauliflower(7.4%)	Bell pepper(11.4%)	Eggplant(9.7%)
Potato(8.2%)	Sudan grass(5%)	Bell pepper(5.3%)	Onion(6.7%)	Tomato(9.3%)
Bell pepper(7.9%)	Bell pepper(3%)	Tomato(4.2%)	Eggplant(5.3%)	Potato(8.9%)
Sweet melon(5.3%)	Tomato(2.9%)	Eggplant(4.1%)	Grapes(4.3%)	Bell pepper(7.7%)
Water melon(5.2%)	Potato(2.9%)	Sweet melon(3%)	Cauliflower(3.9%)	Water melon(4.8%)
Tomato(4.9%)	Sweet melon(2.9%)	Potato(2.3%)	Sweet melon(3.6%)	Sweet melon(4.6%)
Barley(2.1%)	Cauliflower(2.9%)	Onion(2.2%)	Water melon(3.6%)	Barley(3.7%)
Sudan grass(1.4%)	Barley(2.9%)	Water melon(2.1%)	Barley(2.6%)	Grapes(3.5%)
Grapes (1%)	Eggplant(1.9%)	beans green(1.5%)	Sudan grass(2.6%)	Sudan grass(2.6%)

Table 2: Priorities of alternatives (major industries in Aqaba city) based on multi-criteria analysis under different scenarios

Scenario1Profitability has Priority (50%)	Scenario2Water consumption has Priority (20%)	Scenario3Marketing has Priority (30%)	Over all
M. Apparel 25.7%	M. Electronic27.3%	Education26%	M.Apparel21%
Publishing19%	Publishing21.2%	Health17.1%	M. Electronic20.37%
M. Electronic18.7%	M.Apparel20.2%	M.Apparel16.8%	Education17.63%
Education 15.5%	Education11.4%	M. Electronic15.1%	Publishing16.77%
Health 8.8%	Recreational8.6%	Publishing10.1%	Health10.70%
Recreational 6.8%	Health6.2%	Construction9.4%	Recreational6.97%
Construction 5.5%	Construction5.1%	Recreational5.5%	Construction6.67%

Table 3: Priorities of alternatives and policies with respect to identified objectives (under different scenarios)

MCA with respect to main goal: to achieve sustainable management of water resources in the Disi basin"		
Objective 1To operate within the baseline abstraction 70 MCM/year(23.1%)	Objective 2No water abstraction above 45 MCM/year(70.9%)	Objective 3No water abstraction above 100 MCM / year (6%)
Policy 1Limit groundwater uses within Disi area34.3%	Policy 2Limit groundwater uses to Disi and Aqaba city70%	Policy 3Limit groundwater uses to Disi, Aqaba and Amman10.5%
Objective 1: To operate within the baseline scenario (abstraction 70 MCM/year)		
Alternative 1Allocation to one sector: domestic9.9%	Alternative 2Allocation to two sectors: domestic, industrial36.4%	Alternative 3Allocation to three sectors: domestic, industrial and agricultural.53.7%
Policy 125.2%	Policy 257.8%	Policy 317%
Objective 2: No water abstraction above 45 MCM per year		
Alternative 1 Allocation to one sector: domestic9.9%	Alternative 2 Allocation to two sectors: domestic, industrial36.4%	Alternative 3Allocation to three sectors: domestic, industrial and agricultural.53.7%
Policy 125.2%	Policy 257.8%	Policy 317%
Objective 3: No water abstraction above 100 MCM per year		
Alternative 1Allocation to one sector: domestic9.9%	Alternative 2Allocation to two sectors: domestic, industrial36.4%	Alternative 3Allocation to three sectors: domestic, industrial and agricultural.53.7%
Policy 125.2%	Policy 257.8%	Policy 317%

while eggplant receives low rankings 1.9%. With respect to “salinity tolerance” placed barley in the highest 38.4% and beans green the lowest 1.5%. The final scenario “marketing” placed beans green the highest 42% and Sudan grass the lowest 2.6%. Meanwhile, the results demonstrated that overall bean green got the first priority with respect to the main goal “to choose the best crop”, where the highest weight for bean green was 19.1% and the lowest weight for Sudan grass was 2.6%. The results depicted in Table 2 illustrated that the relative confluence or divergence of desired objectives for each crop, for example the weight of water consumption scenario 55% will anticipates in raising the weights of crops with low water consumption, on contrast the salinity tolerance scenario has no significant effect in raising the weights of crops with high salinity tolerance.

Industrial Sector: Table 2, summarizes the results of the industrial sector using 7 industries. Three scenarios are constructed to determine the selection of the “best” industry, based on the following priorities: Scenario 1: Profitability, Scenario 2: Low Water Consumption and Scenario 3: Marketing. Under the “profitability” scenario, the highest rankings were apparel manufacturing (25.7%) followed by publishing (19%), electronics manufacturing (18.7%), education (15.5%), health sector (8.8%), recreational (6.8%) and the lowest sector was construction (5.5%). The “low water consumption” scenario ranked electronics manufacturing highest with a priority ranking of (27.3%) and the lowest ranking was for construction sector (5.1). The final scenario, “marketing” scored education highest with a priority ranking of (26%) and placed the recreational at the lowest with ranking of (5.5%). While, the results of overall ranking demonstrated that apparel manufacturing comes at the top of priorities (21%) with respect to main goal “to choose the best industry” and construction sector at the end of the priorities (6.67%) with respect to the main goal.

General MCA: AHP for Sustainable Water Resources Management in Disi Basin: Outputs of the two above mentioned Sub-multi-Criteria analysis; Agricultural sector and Industrial sector would be valuable indication to construct the main MCA by the help of Analytical Hierarchy Process AHP. The goal of the general MCA is to achieve sustainable management of water resources in the Disi basin. The General MCA follows from the following second level objectives;

- To operate within the baseline abstraction, 2) No water abstraction above 45 MCM per year and 3) No water abstraction above 100 MCM per year.

The third level allows the user to weight the following combinations of water allocation alternatives;

- Allocation to one sector: domestic. b) Allocation to two sectors: domestic and industrial. c.) Allocation to three sectors: domestic, industrial and agricultural (Table 3). And the forth level help the users and/or decision makers to prioritize the suggested policies including; To limit groundwater uses within Disi area, to limit groundwater uses to Disi and Aqaba city and to limit groundwater to Disi, aqaba and Amman (Tables 3).

With respect to identified main goal" to achieve sustainable management of water resources in the Disi basin" the highest priority objective (70.9%) is objective 2, which would not allowed abstraction of groundwater more than 45MCM per year, this figure of abstraction has been calculated by different models as an indicator for sustain groundwater abstraction followed by objective 1 "to operate within baseline abstraction scenario 70MCM/year (existing condition). The analysis assigned the lowest priority (6%) to objective three, which would not allowed abstraction of groundwater more than 100 MCM per year. In contrast, with respect to main goal, the MAC ranked Policy 2 "Limit groundwater uses to Disi and Aqaba city" in the first order (70%) followed by policy 1"Limit groundwater uses within Disi area" with score (34.3%) and assigned the lowest priority (10.5%) to policy 3 " Limit groundwater uses to Disi , Aqaba and Amman". (Table 3).

MCA conducted to prioritize alternatives and policies with respect to each objective (Table 3). With respect to the first objective "To operate within the baseline abstraction 70 MCM/yea" the AHP assigned the first priority for third alternative" Allocation to three sectors: domestic, industrial and agricultural" and the second policy with score of 53.7% and 57.8% respectively. With regarding to second objective "No water abstraction above 45 MCM/year" the first priority was placed to second alternative" Allocation to two sectors: domestic and industrial" and second policy "Limit groundwater uses to Disi and Aqaba city" with score of 44.3% and 54.3% respectively. Under third alternative "No water abstraction above 100 MCM/year" the first priorities were for alternative 3" Allocation to three sectors: domestic, industrial and agriculture" and policy 2" "Limit groundwater uses to Disi and Aqaba city" with score of 76.1% and 67% respectively.

It is concluded that to achieve sustainable management for groundwater resources in disi basin, under any circumstances the annual total abstraction from the basin should not exceeds 45MCM per year and the recommended policy groundwater uses should remain within the southern part of the kingdom specifically within Disi area and Aqaba city and supplying the surrounding activities only.

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