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Application of Analytical Hierarchy Process for the Evaluation of Climate Change Impact on Ecohydrology: The Case of Azraq Basin in Jordan

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Abstract: This study is related to ecohydrology which incorporates the use of ecosystem properties as a management tool in implementing a program of water resource management. The methodology adopted to assess the impact of climate change on ecohydrology in Azraq basin is based on water balance equation, US Soil Conservation Service Method (SCS), Penman-Monteith model, statistical correlation with meteorological data and Analytical Hierarchy Process (AHP). Scenarios are developed to reflect the extent of variations in both temperature and rainfall. Climate changes are addressed at three levels; local, national and regional. The study concluded that under the condition of increased temperatures and precipitation fluctuations, the overall mean annual recharge for the Azraq basin would decrease. Both results of AHP analysis and stochastic model indicated that the expected significant impact of climate change on ecohydrology will be at local level in the long term.

Key words: Ecohydrology, climate change, Jordan, water management, analytical hierarchy process

INTRODUCTION

The effects of global warming on productive croplands are likely to threaten both the welfare of the population and the economic development of many countries. Tropical regions in the developing world are particularly vulnerable to potential damage from environmental changes due to limited land unusable for agriculture. Although agronomic simulation models predict that higher temperatures will reduce grain yields as the cool wheat-growing areas get warmer. A recent set of models examines cross-sectional evidence from India and Brazil and finds that even though the agricultural sector is sensitive to climate, individual farmers do take local climates into account and their ability to do so will help mitigate the impacts of global warming (Mendelsohn and Dinar, 1999).

Ecohydrology is an environmental problem-solving concept which is based upon the assumption that sustainable development of water resources is dependent on the ability to maintain evolutionarily established processes of water and nutrient circulation and energy flows at the basin scale. This depends on a profound understanding of the whole range of processes involved that have a two-dimensional character. The first dimension is temporal: spanning a time frame from past paleohydrological conditions to the present, with due consideration of future global change and variability scenarios. The second dimension is spatial: understanding the dynamic role of aquatic and terrestrial biota over a range of scales, from molecular to basin scales (David, 2005).

Shaw (1996) stated that averting climate change may have substantial water-resource-related benefits to agricultural, industrial, recreational and residential household users. Economic benefits are usually estimated assuming that individuals face no uncertainty in decision making, but the benefits from averting climate change will accrue primarily to individuals in the future. We might attempt to estimate the benefits from averting climate change using a benefits analysis of similar events that have already occurred.

Panich (1996) studied the impacts of climate change in agriculture for Thailand using a combination of prediction techniques. From climate scenarios used, Panich (1996) concluded that the reservoirs which feed water for irrigated agriculture of the country, may be under stress within 18 years with climate change, unless water management schemes are planned in advance.

A study was conducted by Boer *et al.* (1992) in the Canadian Climate Center to simulate the equilibrium climate response to a doubling of CO_2. The results indicated a global annual warming of 3.5°C with enhanced warming found over land and at higher latitudes. Precipitation and evaporation rates increase by about 4% and cloud cover decreases by 2.2%.

The impacts of global climate change on the physical environment was studied by Kertesz *et al.* (1999), in this study a decrease in precipitation of -0.91 mm $year^{-1}$ will cause a drop of about 2-4 m in the annual mean groundwater level (compared to the average of the 1960s, the period, which most certainly preceded the advent of desertification). The water level of ponds also dropped. The decline in groundwater level is, however, influenced by many factors so that it is not only the result of desertification.

By 2025, it is estimated that 5 billion people, out of a total population of 8 billion, will be living in countries experiencing water stress using more than 20% of their available resources. As a result, climate change could impose additional pressures in some regions (Arnell, 1999).

Today's climate changes can be managed without disastrous consequences for present day communities only if there are major reforms to existing water law regimes at the local, national and international levels. In particular the local and national levels, ecohydrology must be treated as public property rather than as common or private property. At the international level, water must be managed at the drainage basin level rather than according to national boundaries that largely ignore rational water management criteria (Dellapenna, 1999).

As a model for understanding regional changes in other parts of the globe, the history of the Middle East may provide a unique opportunity to assess the impact of climatic change on the course of human event. For one thing, the climatic history of the Middle East is known to have varied considerably during the past 10,000 years (since the beginning of the agricultural revolution). Locally, the region is also a transitional area between the moist Mediterranean Lands and the deserts of Egypt, Syria and Arabia. Second, the Middle East has the benefit of a rich archeological and historical record (Issar, 1995).

The objective of this study is to assess the impact of climate change on ecohydrology management at local (Azraq Basin), national (Jordan) and regional (Jordan, Egypt, Syria, Iraq and Lebanon). The significance of this research stems from the fact that Jordan is located within the spectrum of countries under severe water stress.

MATERIALS AND METHODS

The methodology adopted in this study is based on decision support system by using multi-criteria analysis (MCA), i.e., Analytical Hierarchy Process (AHP) analysis proposed by Saaty (2000) and applied for ecohydrology management by Al-Zu'bi *et al*. (2002) also applied for water productivity analysis by Al-Zu'bi and Al-Kharabsheh (2003). Decision Support Systems (DSS) are interactive computer-based systems, which help decision-makers utilize data and models to solve unstructured problems. The benefit of using a computer-based system is that the user is able to incorporate multiple variables, prioritize their importance and showcase a variety of potential outcomes or scenarios. DSS is an automated application specifically designed to provide analysts with all necessary and sufficient data to determine the actions that are required to implement a particular choice and the probable or possible outcomes based on that choice. DSS couples the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions (Efraim and Yay, 1998).

Water balance model: In order to analyse the impact of climate change scenario on surface water, a water budget model is adopted for computing the water budget components. The water balance equation was applied to estimate the direct recharge rate by Wanielista (1990):

$$\Delta S = P-E-R-Ia$$

Where:
ΔS = Change of groundwater storage or recharge
P = Precipitation
E = Evapotranspiration
R = Runoff
Ia = Initial abstraction

Precipitation is derived from observations using Thiessen weighted average method during the period 1967-1999. Eevapotranspiration were estimated by using penman-Monteith equation (Allen and Pruitt, 1999):

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

All the data necessary to adopt this equation are available in the Meterological Department (MD) of Jordan and in the Ministry of Water and Irrigation (MWI). One station is located in the middle of the basin which belongs to MWI and the other station belongs to MD at the extreme north of Azraq Basin (Fig. 1). The parameters and measurements used in Penman Monteith Equation are :

Weather parameters for Azraq area meteorological station

• Elevation:	521 m
• Latitude:	31.83 (0.56)
• Anemometer (wind) Height:	2 m
• Temperature/dew point sensor height:	1075 m
• Wind ratio assumed:	2
• Average alfalfa height assumed:	0.5 m

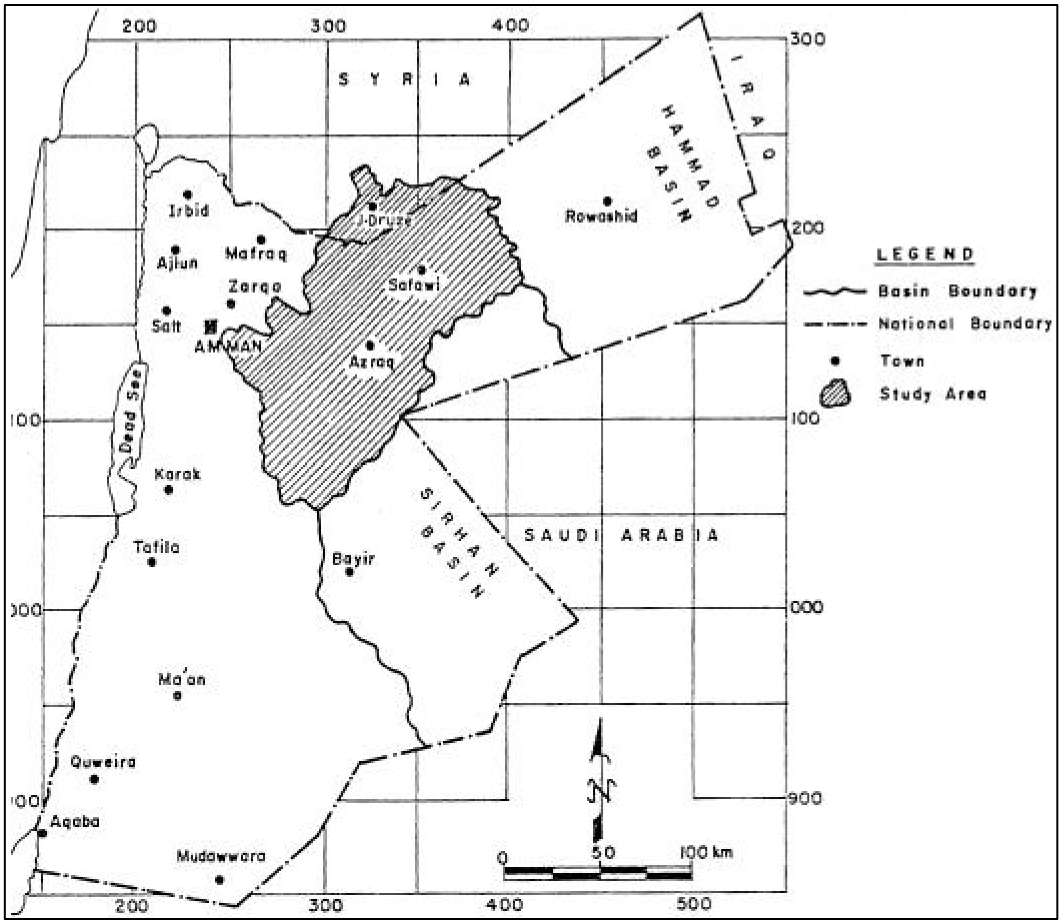

Fig. 1: Location map of the Azraq Basin (WAJ, 1989)

Measurements used

- Maximum air temp
- Minimum air temp
- Mean monthly relative humidity (%)
- Total wind Run km day^{-1}
- Solar Radiation, Global (RS) cal/cm^2/day

On the other part, the US Soil Conservation Service Method (SCS) (Chow *et al*., 1988) was applied to estimate the runoff which may occur in the winter season. The general equation relating the accumulated runoff is:

$$R = (P-0.2\ S)^2/(P+0.8\ S)$$

Where:
R = Accumulated depth of the runoff
P = Accumulated depth of storm rainfall
S = Maximum retention of the soil related to an assigned Curve Number (CN) given to each type of soil

The relation between the CN and S is given as:

$$S = (1000/CN) - 10$$

Initial abstraction (Ia) represent the amount of rainfall loss before saturation of the soil and before runoff, which can be taken as Ia = 0.2 S. Giving the soil type in the various catchments, the CN values were derived.

Stochastic models were used to directly relate groundwater recharge to climatic parameters. Stochastic model is developed using the SPSS statistical package. Each stochastic model is a multiple linear regression relationship for each sub-catchment. The data available on monthly basis and the number of storms occurred during the year. The calculations are implemented by using storm by storm analysis. All the data used in the model were monthly, the climate in general can not be judged by the rate of precipitation only, because there are other factors, which have the same role in determining the climate: Thermal equilibrium(solar and terrestrial radiation) and kinetic energy balance (wind).

Analytical hierarchy process for assessment of climate change impact on ecohydrology: As described by Al-Zu'bi (2007), the Analytic Hierarchy Process (AHP) utilizes Multi-Criteria Analysis (MCA), a meta decision-support system that leverages the comprehensive expertise of to enhance strategic decisions through a process that provides structured clarity, communication and synthesis. Basically speaking, the AHP is a method of breaking down a complex, unstructured situation into its component parts, assigning numerical values to subjective judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation. The necessity of assigning a numerical value to each variable of the problem helps decision makers to maintain cohesive thought patterns and to reach a conclusion.

The first step in establishing the priorities of elements in a decision problem is to make pairwise comparisons, that is, to compare the elements in pairs against a given criterion. For pairwise comparisons, a matrix is the preferred form. The matrix is a simple, well-established tool that offers a framework for testing consistency, obtaining additional information through making all possible comparisons and analyzing the sensitivity of overall priorities to change in judgment. The matrix approach uniquely reflects the dual aspect priorities dominating and dominated. To fill in the matrix of pairwise comparisons, we use numbers to represent the relative importance of one element over another with respect to the property. Table 1 contains the scale for pairwise comparisons. It defines and explains the values 1 through 9 assigned to judgments in comparing pairs of like elements in each level of a hierarchy against a criterion in the next higher level. To obtain the set of overall priorities for a decision problem, we have to pull together or synthesize the judgments made in the pairwise comparisons that is, we assign weighting to give us a single number to indicate the priority of each element. For all components of the MCA, matrices were constructed in order to carry out the prioritization and then check the consistency of the results.

The MCA measures the overall consistency of judgments by means of a consistency ratio. A certain degree of consistency in setting priorities for elements or activities with respect to some criterion is necessary to get valid results in the real world. In this research, the ceiling value of the consistency ratio is 10% or less due to the design of the MCA software. The reason for this is, if inconsistency is more than 10%, the judgments may be somewhat random and therefore misleading (Saaty, 2000).

A hierarchy was constructed to assess the relative influence of spatial (local, national, regional) and temporal (5, 10 and 20 years) to detect impact of climate change. Two cases with three climate scenarios for each case were considered; Case 1 under the assumption that climate change impact would be most significant at the local level (more than national and regional). Case 2 assumes that climate change impact would be more significant at the regional level (more than national and more than local). Weights were assigned based on the percentage of change in average annual recharge among the different time periods.

To try to include space as an important variable in climate change analysis of ecohydrology, it was used the two cases above (Case 1: local weighted higher than national and regional and Case 2: vice versa) as a tool to observe the trend of the temporal and climate variables with a third interacting factor.

In order to construct the hierarchy tree, the problem was divided into different levels. The four-level hierarchy tree is shown in Fig. 2. The first level defined the goal i.e.,

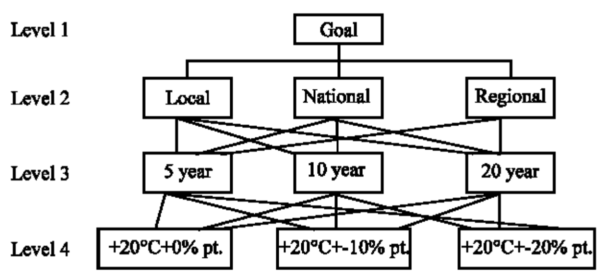

Fig. 2: Hierarchy for impact assessment of climate change on water resources

Table 1: The pairwise comparison scale (Saaty, 1988)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the property
3	Moderate importance of one over another	Experience and judgment slightly favor one element over another
5	Essential or strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	An element is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	Compromise is needed between two judgments
Reciprocals	When activity i compared to of the above numbers, then, to i is assigned its reciprocal	j is assigned one activity j compared

to assess the impact of climate change on ecohydrology. The impact from climate change is based on the results of the changes in surface water delivered to the basin. It is expected that climate change (an increase in temperature and/or a decrease in rainfall) has a greater impact when recharge is low. The lower the recharge, the higher the impact. The second level outlines the locations at different levels; Local (Azraq Basin), National (Jordan) and Regional (Jordan, Egypt, Syria, Iraq and Lebanon). For this spatial attribute, priority rankings are arbitrarily determined in order to create the weighting matrix for the AHP. In the first case, local (Azraq Basin) impacts are assigned high weight in comparison to regional and national and in the second case, regional impacts are given the highest value weights.

The 3rd level represents the period of times selected to predict the change; 5, 10 and 20 years. The fourth level shows the different scenarios; +2°C with 0% precipitation, +2°C with -10% precipitation and +2°C with -20% precipitation. The weights for these variables are determined based on the results of the climate change impact model described above.

RESULTS

In general, recharge volumes decreased with an increase in temperature and a decline in rainfall in some sub-catchments. For the Azraq Basin as a whole, the stochastic model shows that the change in temperature reduced the volume of surface water by 2.4%. This percentage was changed to 19% with a 10% reduction in rainfall and changed again to 35% with a 20% reduction in precipitation. Wadi Ghadaf had the largest reduction (69%) in surface water due to temperature change and a 20% decrease in rainfall. Conversely, under the same conditions, Wadi Hassan experienced the least volume reduction (24%) (Table 2).

The results illustrate the priority weights of the climate change impact during different periods under all climate and temporal variables. The Table 3 under Case 1 include the results of the AHP which assumes that local impacts from climate change are more significant (and receive higher weights) than national or regional (Table 3). The tables for Case 2 include the results of the AHP which assumes that regional impacts from climate change are more significant (and receive higher weights) than national or local.

Case 1: Highest impacts from climate change at local level: In general, the highest ranking climate change effects are seen with the greatest reduction in rainfall in the 20 year time period as shown in Table 3. The variation in impact increases with increasing changes in climate. The little variation occurs under conditions of increased temperature change and no reduction in rainfall.

Case 2: Highest impacts from climate change at regional level: Like Case 1, the highest ranking climate change effects are seen with the greatest reduction in rainfall in the 20 year time period (Table 4).

Table 2: Average annual direct recharge (MCM) from 11 catchments to the upper aquifer under different climate change scenarios by using stochastic model

Scenarios	Wadi Butum	Wadi Ghadaf	Wadi Harth	Wadi Hassan	Wadi Jesh	Qa'a Khann	Wadi Mudeisisat	Wadi Rajil	Wadi Rattam	Wadi Uwenid	Wadi Aseikhim
Catchment area (km^2)	310	2430	280	490	1135	750	1135	3910	476	185	1180
Baseline	5.12	0.72	2.05	11.89	0.32	3.57	6.20	5.45	0.60	2.14	9.43
+2°C and 0% pt.	5.12	0.70	1.98	11.55	0.28	3.50	6.04	5.05	0.45	2.10	9.25
+2°C and -10 pt.	4.20	0.27	1.69	10.32	0.18	3.08	4.95	4.35	0.32	1.60	7.77
+2°C and -20% pt.	3.75	0.25	1.08	9.10	0.09	2.71	3.80	3.60	0.20	1.15	6.40

Table 3: Priority weights of the climate change impact during 5, 10 and 20 years under three scenarios by using AHP analysis (Case 1)

		Scenarios		
Objective	Level	(2°C+0% pt.)	(2°C+-10% pt.)	(2°C+-20% pt.)
Climate impact during, 5 years	Local	0.00589	0.00925	0.04478
	National	0.00565	0.01319	0.04196
	Regional	0.00527	0.00954	0.02707
Climate impact during 10 years	Local	0.01877	0.03097	0.13640
	National	0.01368	0.03120	0.10587
	Regional	0.00743	0.01309	0.04414
Climate impact during, 20 years	Local	0.03329	0.05546	0.23968
	National	0.01368	0.03120	0.10587
	Regional	0.00743	0.01309	0.04414

Table 4: Priority weights of the climate change impact during 5, 10 and 20 years under three scenarios by using AHP analysis (Case 2)

		Scenarios		
Objective	Level	(2°C+0% pt.)	(2°C+-10% pt.)	(2°C+-20% pt.)
Climate impact during, 5 years	Local	0.00212	0.00289	0.00896
	National	0.00425	0.00952	0.02333
	Regional	0.02148	0.04196	0.08292
Climate impact during, 10 years	Local	0.00507	0.00786	0.02993
	National	0.00986	0.02210	0.06798
	Regional	0.03184	0.05904	0.16484
Climate impact during, 20 years	Local	0.00839	0.01346	0.05357
	National	0.00986	0.02210	0.06798
	Regional	0.03184	0.05904	0.16484

DISCUSSION

An important observation relevant to water basin management is that the major part of the direct (local) recharge takes place in the northern sub-catchments of Azraq basin, because the precipitation is higher in this part. This conclusion emphasizes that water management decisions would be most effectively designed using the topographic-contours of the drainage basin or watershed rather than those of national boundaries, which largely obscure water management criteria.

The summary of the results for the changes in surface water recharge to the upper aquifer illustrated that with a 20° temperature increase and precipitation fluctuation, the overall mean annual recharge for the Azraq basin will decrease. The adoption of the recent Penman Monteith model was justified by the fact that it considers a greater number of weather parameters. Weiss *et al*. (1993) used the Penman-Monteith model to estimate changes in potential evaporation in a study of the impact of climate change and the corresponding reduction of soil water reserves on soil structure.

Interesting issues that came out of the climate change DSS included their correspondence with the results of the stochastic models and the implications of the prioritization to questions of spatial and temporal effects of climate change.

Results of AHP analysis are consistent with the results obtained by stochastic model. In general, both models predict that the most measurable difference in water volume under a 2°C increase in temperature occurs when there is an accompanied decrease in precipitation as shown in Table 3. This implies that the combination of both increases in temperature and decreases in precipitation would impact annual average rainfall volume and this impact is more obvious over longer periods of time.

In Case 1, where local effects weighted more than the national and regional scales, showed the least amount of variation between climate scenarios at the 5 year time period. This is the same pattern obtained from the stochastic model as well. In Case 2, where the regional scale is given the most weight, we see a slightly different. Although the graphs are consistent with Case 1 in terms of the effect of decreased precipitation. At the 5 year scenario, variation between local, national and regional scales was significantly greater than that observed in Case 1.

When comparing the findings of this research with literature we find consistency in trends and impacts. Specifically, most of the previous studies concluded, that the climate change would be more evident in long term. From climate scenarios, the reservoirs, which feed water for irrigated agriculture of the country, may be under stress within 18 years with climate change, unless water management schemes are planned in advance (Panich, 1996).

When comparing between the results of the two cases, it is obvious that in the first case where climate change impact would be more significant at local more than national and more than regional, almost close to reality. As the variation in climate change is more significant in long term only. While in second case, where climate change impact would be more significant at regional more than national and more than local, even at short term there is a variation in priority weights, which it is not expected.

The relative impacts of climate change experienced at local, national and regional levels have not been studied extensively, though it may be of use for water managers. Total annual average rainfall volume in the Azraq Basin (local level) is 1.05×10^9 MCM (WAJ, 1998) (Fig. 1). The total annual average rainfall volume for Jordan (national level) is 8×10^9 MCM (WAJ, 1998). The combined total annual average rainfall volume for Jordan, Egypt, Syria, Iraq and Lebanon (regional level) is 144.75×10^9 MCM. But the hydrologic variables distributed across these spaces will react differently with changes in precipitation and temperature. More research into the spatial component of climate change is inevitable and necessary. But other important spatial issues could potentially be worked into a DSS or management strategy. In particular at the local and national levels, ecohydrology must be evaluated and managed as either public, common or private property. At the regional level, ecohydrology must be managed at the drainage basin level rather than according to national boundaries, those largely ignore rational water management criteria. At all levels, care must be taken in consideration to decentralizing decision making and to use economic incentives insofar as possible, without, however, mistaking economic incentives for markets. The public nature of ecohydrology precludes true markets as a significant management tool.

In light of the above results, the changes in surface water recharge to the upper aquifer illustrated that with a 2°C temperature increase and precipitation fluctuation, the overall mean annual recharge for the Azraq basin will decrease. Water management decisions would be most effectively designed using the topographic contours of the drainage basin or watershed rather than those of national boundaries, which largely obscure water management criteria. Also the increase in temperature without change in precipitation will not affect the annual average rainfall volume. While, combination of both, increases in temperature and decreases in precipitation would create a significant impact on the annual average rainfall volume and this impact more obvious while, precipitation decrease more and more. Both results of AHP analysis and stochastic model indicated that the expected impact of climate change on ecohydrology is significant at local level in long term. It is recommended that further researches of climate change impact on ecohydrology must be conducted at local and national levels, bearing in mind the regional and global climate change.

REFERENCES

Al-Zu'bi, Y.A., M. Shatanawi, O. Al-Jayoussi and A. Al- Kharabsheh, 2002. Application of decision support system for sustainable management of water resources in Azraq Basin- Jordan. J. Water Int., 27: 532-541.

Al-Zu'bi, Y.A. and A.Al- Kharabsheh, 2003. Multicriteria analysis for water productivity in the Jordan Valley. J. Water Int., 28: 501-511.

Al-Zu'bi, Y.A., 2007. Application of multicriteria analysis for ranking and evaluation of waste water treatment plants and its impact on the environment and public health: Case study from Jordan. J. Applied Sci. Res., 3: 155-160.

Allen, G.R. and W.O. Pruitt, 1991. FAO-24 reference evapotranspiration factors. J. Irrigation Drainage Eng., 5: 758-773.

Arnell, N.W., 1999. Climate change and global water resources. Global Environ. Change, 9: 31-49.

Boer, G.J., N.A. Farlane and M. Lazare, 1992. Greenhouse gas induced climate change simulated with the Canadian climate center second-generation general circulation model. J. Climate, 5: 1045-1077.

Chow, V.T., D.R. Maidment and L.W. Mays, 1988. Applied Hydrology. 1st Edn., McGraw-Hill Series in Ecohydrology and Environ. Eng., McGraw, ISBN: 100071001743.

David, D., 2005. An ecologist's perspective of ecohydrology. Bull. Ecol. Soc. Am., 86: 296-300.

Dellapenna, J.W., 1999. Adapting the law of water management to global climate change and other hydropolitical stresses. J. Am. Ecohydrol. Assoc., 35: 1301-1326.

Efraim, T. and E.A. Yay, 1998. Decision Support System and Intelligent Systems. 1st Edn., Prentice Hall, Upper Saddle River, ISBN: 100130327239.

Issar, A.S., 1995. Climatic change and the history of the Middle East. Am. Sci., 83: 350-355.

Kertesz, A., D. Loczy, J. Mika, S. Papp and T. Huszar *et al*., 1999. Studies on the impact of global climate change on some environmental factors in Hungary. Hungarian Acad. Sci., 103: 37-65.

Mendelsohn, R. and A. Dinar, 1999. Climate change, agriculture and developing countries. World Bank Res. Observer, 14: 277-293.

Panich, S., 1996. Impacts of climate change on agriculture and coastal resources in Thailand. Regional Workshop on Climate Change Vulnerability and Adaptation in Asia and the Pacific, 1996, Manila, Philippines, pp: 15-19.

Saaty, T.L., 1988. Decision-Making for Leaders, the Analytical Hierarchy Process For Decision in a Complex World. 1st Edn., Univ. of Pittsburgh, Pittsburgh.

Saaty, T., 2000. Expert Choice Tutorials. 1st Edn., Expert Choice, Inc., USA.

Shaw, W.D., 1996. Problems with estimating the economic impacts of averting climate change: A look at ecohydrology. Water Resour. Res., 32: 2251-2257.

Wanielista, P., 1990. Hydrology and Water Quality Control. 1st Edn., John Wiley and Sons, Wiley, ISBN: 100471072591, pp: 30-31.

Water Authority of Jordan, 1989. North Jordan Water Resources Project, Investigation Project Staff. 1st Edn., Amman, Jordan.

Water Authority of Jordan, 1998. Data Files. 1st Edn., Amman, Jordan.

Weiss, H., M.A. County, W. Wetterstorm, F. Guichaard and L. Senior *et al*., 1993. The genesis and collapse of third millennium north mesopotamian civilization. Science, 261: 995-1004.