Optimum Water Resources Management (OWRM) in the Middle-East & Nile

Najah M. L. Al-Maimuri, Arkan Radi Ali
Civil Dept. Babil Tech. Institute, Babil, Iraq.

Keywords: optimum water resources management (OWRM), water demand (WD), groundwater (GW), kirkuk irrigation canal (KIC)

Abstract

An optimization water resources management study is developed in the Middle-East region and Al Nile Valley. It is based on assessment of hydrologic element of a specified area within the region, development of groundwater model, conjunctive use study, and rebalancing of the resulting water resources. Al Adhaim basin of 4110.28 km^2 which is located in northern-south of Iraq is chosen as sample of study for the availability of data. It is found that the optimization technique and rebalancing of the hydrologic elements in the considered area saves 282.8 million m^3 per year of surface releases, reduces operation time of Kirkuk Irrigation Canal (KIC) to 6 months per year, and treats the problems of water table rise due to the excessive surface water releases.

1 Introduction

Soeng (2004) signifies water crisis that exists is set to worsen despite continuing debate over the very existence of such a crisis. For many years over the past decades, 6,000 people and mainly children under five have died every day. Descriptions more severe than 'a crisis' have been associated with events in which 3,000 people have lost their lives in a single day under thirsty.

River water disputes becomes a global phenomenon, the Colorado, Ganges-Brahmaputra, the Syr Darya-Ana Darya (in Kazakhstan), and the Nile, are examples. Middle East is one of the regions where water scarcity is most apparent. Water scarcity is an important consideration in the peace process for Islamic Republic, if it is not addressed, it could become a wider problem affecting the Islamic Republic of Iran, Iraq, Israel, Jordan, Lebanon, Syria, and Turkey. To resolve water issues, it must be the considered as an economic resource. These issues need to be addressed using an appropriate water optimization modeling technique to assist in the economic management of water in the middle-east region which. Currently, this region of 284 million people (5 percent of the world's population) has access to 1 percent of the world's fresh water Franklin and Hossein (2001).Franklin et al.(2002) adopt a cost-benefit analysis of water management infrastructure; this is illustrated by an analysis of the need for desalination in Israel and the cost - benefits of adding a conveyance line. The use of such models can facilitate cooperation in water, yielding gains that can be considerably greater than the value of the disputed water itself. They find that the value of the water in dispute in the region is very small and the possible gains from cooperation are relatively large. Analysis of the scarcity value of water is a crucial feature. They use a cost-benefit objective function.

$$Max\ Z = \sum_i \sum_d \left(\frac{B_{id} * (QD_{id} + QFRY_{id})^{ALPHA_{id}+1}}{ALPHA_{id} + 1} \right) - \sum_i \sum_S (QS_{iS} * CS_{iS}) - \sum_i \sum_j \left(QTR_{ij} * CTR_{ij}\right)$$
$$- \sum_i \sum_j \left(QRY_{ij} * CR_{ij}\right) - \sum_i \sum_j \left(QTRY_{ij} * CTRY_{ij}\right) - \sum_i \sum_S \left(CE_{id} * (QD_{id} + QFFRY_{ij}\right)$$

Where:Z net benefit in from water in millions of dollars; QS_{is} quantity supplied by sources in district i, in 10^6 m^3; QD_{id} quantity demanded by sector d in district i, in 10^6 m^3; QTRij quantity of fresh water transported from district i to j, in in 10^6 m^3; QTRYij quantity of recycled water transported from district i to j, in in 10^6 m^3; QRYid quantity of water recycled from use d in district i, in in 10^6 m^3; QFRYid quantity of recycled water supplied to use d in district i, in in 10^6 m^3; PR_{id} percent of water recycled from sector d in district i, in in 10^6 m^3.

Ballestero (2004) developed an inter-region bargaining model to achieve equilibrium in quantity and price.

Jin et al (2007) developed a dynamic model for equitable distribution of water in water-shortage areas to optimally satisfy the requirements of each locality, given limited supplies, and to maximize the total economic benefit of the entire area. The Heihe River Basin in northwest China was chosen as the area for the pilot study. This research focus to optimum policy investment for local water resources in any area within thr Middle East Region and North Africa since the whole region is characterized with same fresh water resources crisis, conflicts, and scarcity.

2.1 Research Significance

Although, Middle-East is characterized with the diversity of natural water resources; rainfall, surface water, and groundwater, the problem of surface water scarcity is still unsolved. Most of the regions in the Middle East experience the shortage in surface water; therefore most lands are left uncultivated and nowadays compose deserts over most the countries within this part of the world. This meteorological phenomenon is occurred because other types of water resources are badly managed or uninvestigated. In this study, the optimum (complemented) management of the available water resources is matured.

2.2 Objective of the study

The objective of this research is to adopt an optimization scenario to rebalance the hydrologic elements in any area in Middle-East

2.3 Geographic Features

Middle-East located between latitudes 10^o- 40^o and longitudes 0^o- 60^o. The area is bounded by the Mediterranean Sea at the north and South Africa and Arabic Sea represent the southern border. Iran is the eastern boundary and the Atlantic Ocean is the western boundary. Fig.(1) indicates the geography of the Middle-East. In general, the Middle-East is characterized with different topographic features but the important matter that desertation problem is dominant phenomenon there. Why?

2.4 Climate

I) Rainfall: Middle-East has extreme seasonal variations in climate of average monthly rainfall, potential evaporation, and average daily maximum and minimum temperatures for various locations. Large rainfall variations occasionally are also occurred. Consecutive years of relatively low annual rainfall have an enormous effect on the region and, in the case of dry periods. Currently, the greatest challenge to manage the region's precious water resources. Rainfall within the region experiences high variation. Rainfall reduces from north to south and from the west toward the east. Average annual rainfall ranging between 1200mm at the north of the region to 50mm at the desert areas.

II) In the Coastal Plain, average daily temperatures are between 16 - 22 °C in winter and 20 - 31 °C in summer. The desert region exhibits a wide range of temperatures. In August average daily maximum temperatures are between 34 -50 °C whereas in winter, the air is very cold and dry with an average daily minimum temperature between 2 - 9 °C.

Fig.(1) Geographic Map of Middle East

2.5 The Importance of Basin Management within the Context of Diversity

OWRM basically should be managed depending on natural hydrological units whether river basin, lake basin, aquifer basin, and precipitation. The geographic situations are also diverse and seldom compatible with administrative units. Some countries are managed as single administrative units although they have international borders since they are shared with one or more water resources such as Syria, Iraq, and Turkish or as Sudan and Egypt whereas others are considered as separated administrative units since they are characterized with private hydrologic units as Lybia and Iran.

2.6 Desertation Problem in the Middle East

Many countries in the Middle East have the three types of water resources as in Iraq, Egypt, and Syria therefore anywhere stakeholder invests comfortably surface water because it is a preferable choice and then the scarcity in water demand is complemented by the available groundwater and rainfall resources. But in others countries where surface water is inexistent stakeholders can't compensate the leakage in growing water demand by rainfall and subsurface water. If these sources are inadequate consequently thousands hectares of land left uncultivated or entirely unpopulated to compose deserts such the desert of Algeria and the western desert of Al Saudi.

3 Suggested OWRM Policy

Since the surface water source is the favorable and critical source in Middle-East, then current study focuses on many assumptions based on maintaining of this critical source consuming. Optimization policy sequentially requires:-

1- Full consuming to the rainfall water source. If it is not adequate then;
2- Full consuming to the groundwater storage provided that it is not depleted. If it is not adequate then;
3- Integrated consumption of the available surface water source to satisfy the scarcity of local water demand.

4 Main Headlines of OWRM Study

The main headlines issue in studying the OWRM requires the following hydrologic elements:

1- Assessment of meteorological elements.
2- Assessment of local surface water sources.
3- Assessment of local water requirements; including water demand (WD) for agriculture and urban areas.
4- Assessment of groundwater source; including geologic stratification study and mathematical modeling for both the confined and unconfined aquifers.

5 Geography Definitions & Topography of the Study Area

Al Hawija Basin of 4110.28km^2 has been selected as an example of the management study. This area is located at the northern West of Iraq as pointed Fig.(1)and bounded by typical hydraulic boundaries. The sink line of Bteawa Mountain and Kurkuk Irrigation Canal represent the northern west boundary whereas Himreen Mountain series bounds the study area from the south. Al Khassa Valley and Lesser Zab River are the western and eastern boundaries respectively. Such boundaries are typical for mathematical modeling process. The area is situated between Longitudes (43^0 30′ - 44^0 18′) and Latitudes of (34^0 54′ -35^0 36′) and characterized with a rugged land with maximum height of 245m a.m.s.l at the north and 132 m.a.s.l at the south. Fig.(2) shows the most important features of the area.

In general the basin compramizes many natural valleys to collect the incoming water during rainy storms; such Oil, khassa, and Reyaid Valleys. The foregoing streams are very active in collecting surface water from middle of the basin to convey it to Zgaton Valley in the south.

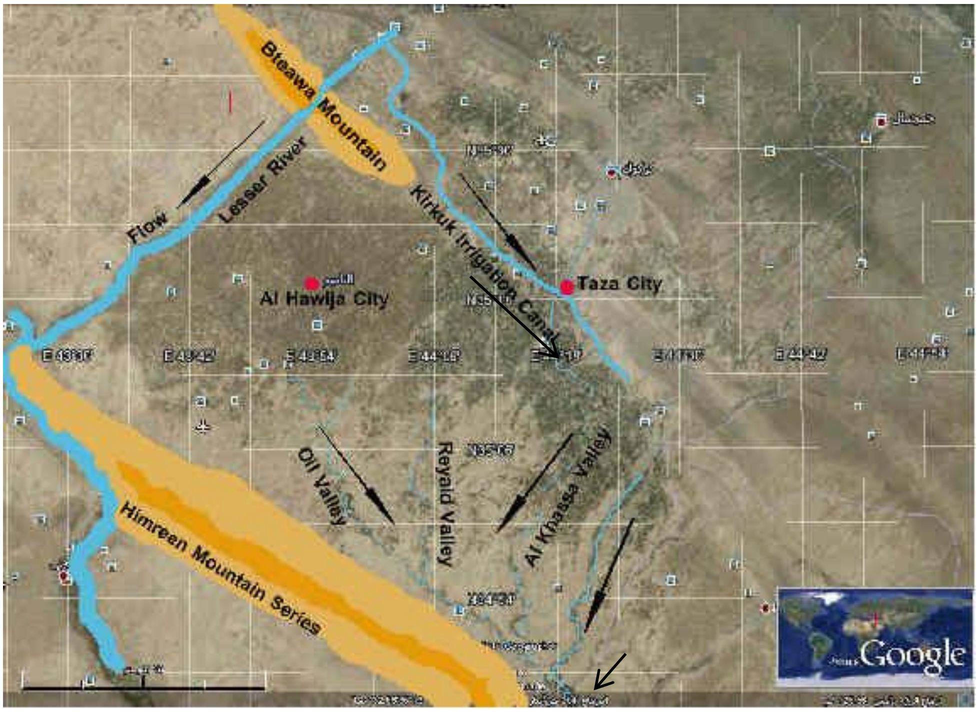

Fig.(2) Location, Geography, and Hydraulic Boundaries of the Study Area

5.1 Meteorology

A) Rainfall: in general, the average rainfall of the last twenty years in the study area is shown in table [1]. Whereas, the rainfall in m^3/day per 1 km^2 is presented in row (3), Table [2].

Table [1] Average Rainfall of Last Twenty Years

Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.
Ave. Rainfall in (mm)	91.4	61.89	55.4	37.7	15.6	15.7	59.8	65.6	0	0	0	0

(Iraqi Metrological Organization, 2011

B) Temperature: the study area is characterized with a temperature of (22^{o}C$^{)}$. Anyway, the weather in the Middle East is cold-rainy in winter hot-dry in summer).

5.2 Surface Hydrology

The topography and slopes of Al Hawija Basin lets the farmer to use the available releases of KIC for their irrigation activities since the water of Lesser Zab River is unattainable for them. Anyway, some water of KIC is needed at the tail of the canal to feed Al Adhaim dam and the net available releases is included in Table (3) and the average releases in m^3/day per 1km^2 are shown in row (1), Table (2).

Table (3) Net Available Surface Releases of KIC Available for Use in Al Hawija Basin

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Releases, m^3/s,	56.05	41.99	41.62	28.46	11.86	33.58	44.75	44.65	60.39	72.39	76.05	58.52

Iraqi State Commission for Dams and Reservoirs, 2012

Table(2) Hydrologic Elements of Al Hawija

Row No.	Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.
1	Ave. Available Releases of KIC in m^3/day per $1km^2$	1178	883	875	598	249	706	941	939	1270	1522	1599	1230
2	WD, m^3/day per $1km^2$	1176	1140	1086	1171	1818	2954	3238	2266	3096	3836	3213	2058
3	Rainfall in (m^3/day per $1km^2$)	2948	2063	1343	1216	557	506	1993	2116	0	0	0	0
4	Safe Withdrawal Rate in (m^3/day per $1km^2$)	133	0	0	0	355	1033	1270	695	1255	1466	1221	787
5	Row(2)-Row(3)	-1772	-923	-257	-45	1261	2448	1245	150	3096	3836	3213	2058
6	WD Scarcity Row(5) – Row (4)	-1905	-923	-257	-45	906	1415	-25	-545	1841	2370	1992	1271
7	WD Status	satisfied	satisfied	satisfied	satisfied			satisfied	satisfied				
8	Adjusted Releases of KIC in m^3/day per $1km^2$	0	0	0	0	906	1415	0	0	1841	2370	1992	1271
9	Adjusted Safe Withdrawal Pumping Rate in (m^3/day per $1km^2$)	0	0	0	0	355	1033	1245	150	1255	1466	1221	787

5.3 Total Water Demand (WD)

In general the estimation of water demand depends mainly on the weather condition which includes temperature, number of hourly sun shine, humidity, wind speed, elevation above sea level, longitude, laltitude …etc and plant type, which reflects plant requirement for water. The amount of the evapotranspiration outlines by Blaney- Criddle method Israelsen & Hansen, (1962) which reflects the effects of all these parameters is used:

Breifly, the WD in mm is estimated depending on the above parameters and indicated in Table (4), whereas the total WD of the basin in m^3/day per $1km^2$ is estimated and listed in row(2), Table(2)

Table (4) Water Requirements of Al Hawija Basin

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
WD,mm	36.455	34.194	33.662	36.308	50.899	91.585	97.142	70.234	92.878	118.921	99.618	61.738

5.4 Sub-Surface Hydrology

1) *Hydrogeological Consideration*

Briefly, outcrops of several geologic formations are found in the region with different ages that range between the Middle and Upper Miocene. The older formations usually appear along the eroded anticlines and quaternary deposits cover most of the study area, and consist of old and young deposits with different morphologic features. In general older deposits constitute:-

1) Old Alluvium Deposits which belongs to the upper Pleistocene age.
2) Flood Plain Deposits of the Lesser-Zab.
3) Terraces Deposits are mainly spread near the flow of rivers such as the Lesser Zab, and Tigris Rivers.

4) Deluvio Fluvial Deposits created from mountain slopes during rainfall floods erosion of the upper part of the soil

Younger Alluvium Deposits are made up of thin layers of Quaternary deposits which constitute:-

1) Shallow Depression Deposits are common deposits because of the morphologic features in the study area.

2) Slope Sediments are generally consist of fine gravel and aggregates of clastic and old rocks fragments

3) Gypseous Soil Deposits.

4) Polygenetic Cover of Desert Plain Deposits. More information and figures are found in Kassab and Jassim. (1980) and Najah M. L. (2005).

2) Simulation Technique and Mathematical Modeling

This process is usually started with preparation and assessment of necessary information such as natural and artificial recharges estimation, mesh design of the considered area domain, stratification of sub layers and hydrogeologic properties (aquifer properties).

For more information about mathematical modeling, Prickett and Lonngquist (1971), Al Assaf (1976), Najah (2005) and Najah (2008) report a brief study of simulation techniques; calibration, verification and limitations. Several programs have been written for aquifer simulation by a mathematical model, using a finite difference approach. The program of Prickett and Lonngquist (1971)has been modified and used for its flexibility and modification. The derivation of finite difference equation is based on the mass conservation principle and Darcy's Law. A detailed derivation of the finite differences equations and convergence test for errors study are found in Prickett and Lonngquist (1971).

3) Discretization of the Domain

The first step in modeling job is to discretize the system by superimposing a mesh of finite difference grid over a geographical map of the area. The size and the number of nodes to be chosen depend on the requested accuracy. The total dimensions of the grids are defined by NC (the number of columns), and NR (the number of rows) of the model. (NC = 26) and (NR = 30) are the selected number of columns and rows respectively. The total number of grids inside the modeled area equals 370. Such discretization of the domain gives a scale equals (1node space =3.333km). Fig. (3) shows the discretization of the domain.

4) Natural Water Level

Hydrogeologic data is collected using the natural water levels of the existing Lesser river, Kirkuk Irrigation canal, Al Khassa streams and the 85 pumping wells which are found in study area. The natural water levels are represented in Fig.(4)

5) Safe Yield Abstraction

Birkholz et al (2003) defined that *Sustainable Yield as the a mount of groundwater can be withdrawn from an aquifer based on continual pumping at rated pump capacity without causing a progressive decline of the water level at least 7.5m below the static water level within an existing water well that is completed in consolidated geologic formation*. Excessive drawdown leads to harmful water table levels drop in wells or to dry up them entirely. The impacts of over abstraction can also lead to a harmful social, economic and environmental consequences such as: critical changes in patterns of groundwater flow to and from adjacent aquifer system; declines in streams base flow; increased in pumping costs and energy; air entrapment into aquifers and reduction in porosity causing land subsidence …etc. A drawdown of 30% of the average thickness of the unconfined aquifer is used as an allowable limit in the optimization model. It is to be noticed that such a drawdown will occur in a producing well site. Beyond the site of the well the drawdown is undoubtedly less. Fortunately, the thickness of the unconfined aquifer overall the considered area exceeds this value. Accordingly, the safe yield of the unconfined aquifer is obtained after the model operation for five years. Table (2) includes the monthly safe yield of Al Hawija basin.

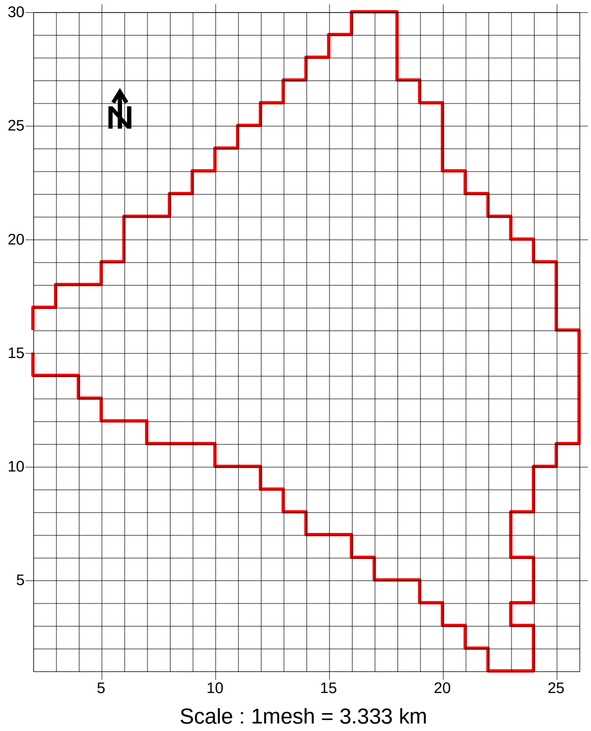

Fig.(3) Mesh Design of Al Hawija Basin

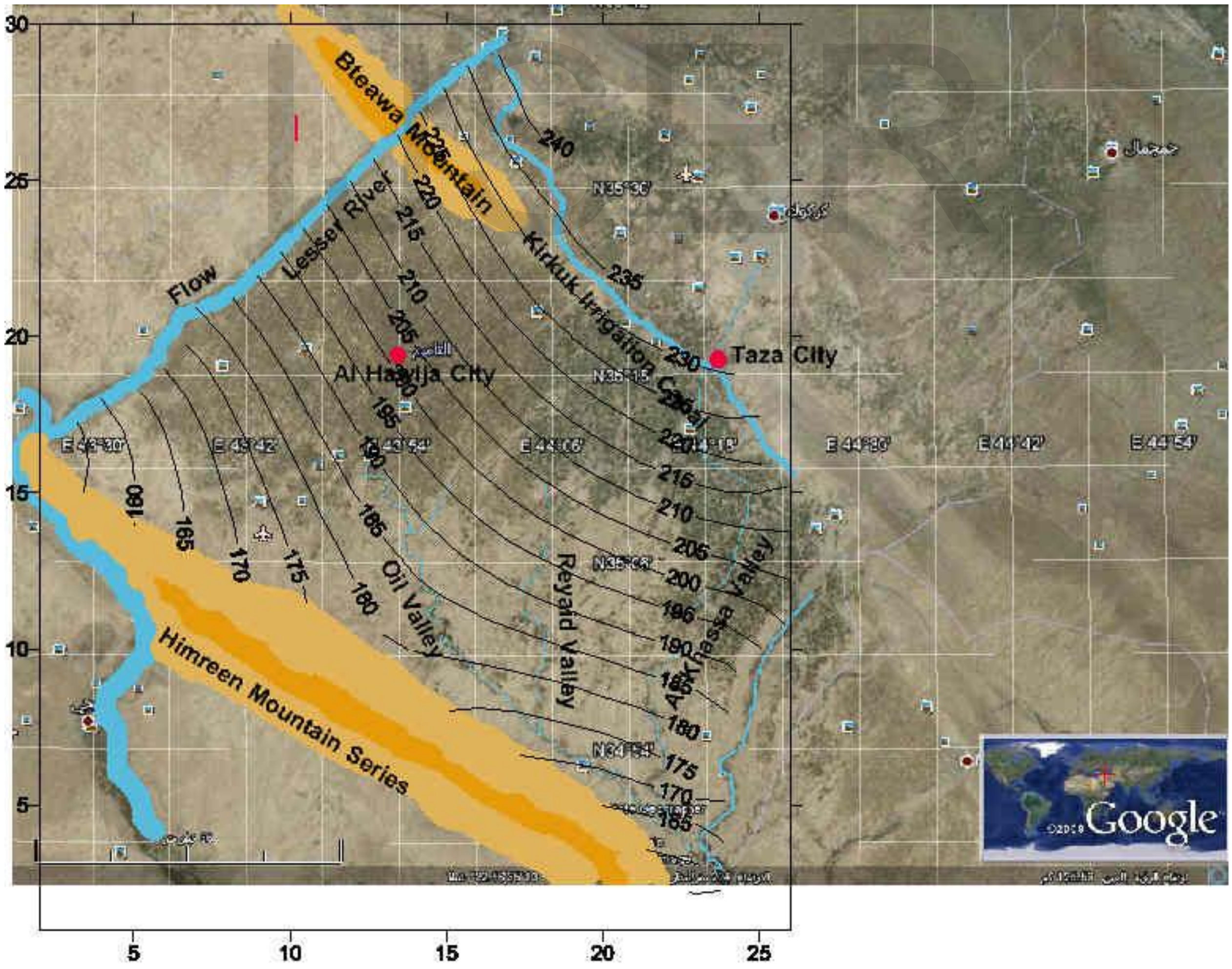

Fig. (4) Natural Groundwater Levels of Al Hawija Basin

5.5 Potential Abstraction of Al Hawija Basin

The water demands (WD) of Table (4) are introduced in the current groundwater model as input data to evaluate the potential yield of the aquifer. It is suggested to construct an abstruction well in each mesh overall the area. The potential (safe) yield is obtained provided that the maximum permissible drawdowns are not exceeded overall the modeled area. The output average safe withdrawal rate allocated for $1km^2$ of the model is listed in row(4) of Table (2).

6 Optimization Criteria & Reblancing of Hydrologic System

The optimization policy of water resources managements in the middle east requires to save and economize the surface water as much as possible for its rarity and scarcity, therefore the annuall rainfall should exploitated firstly and GW safe yield secondly to satisfied the WD as shown in row(5)&row(6) repectively, if it is emerged not enough then it is complemted by using the avialable surface water releases as indicated in row(8). Table (2) row(7) shows that the WD is satisfied by the rainfall and groundwater exploitation in Oct., Nov., Dec., Jan., Apr., and May. The hydrologic elements of Table (2) and Fig.(4) reveals that the WD is satisfied by the rainfall in the beginning of the water year specifically in Oct., Nov., Dec., and Jan. and any excessive complementary water from KIC and groundwater exploitation are not necessary. This is adjusted in rows (8) & (9) of Table(2) and shown graphically in Fig.(5). Fig.(6) shows the hydrologic elements in a histogram presentation.

Comment: Sometime, the WD may be satisfied by the rainfall and part of the aquifer safe yield as happenend in April and May Table(2), therefore the total safe yield of Table(2) row(4) should be adjusted and reduced

by the amounts of 25 and 545m^3/day in April and May. This is done in row(9).

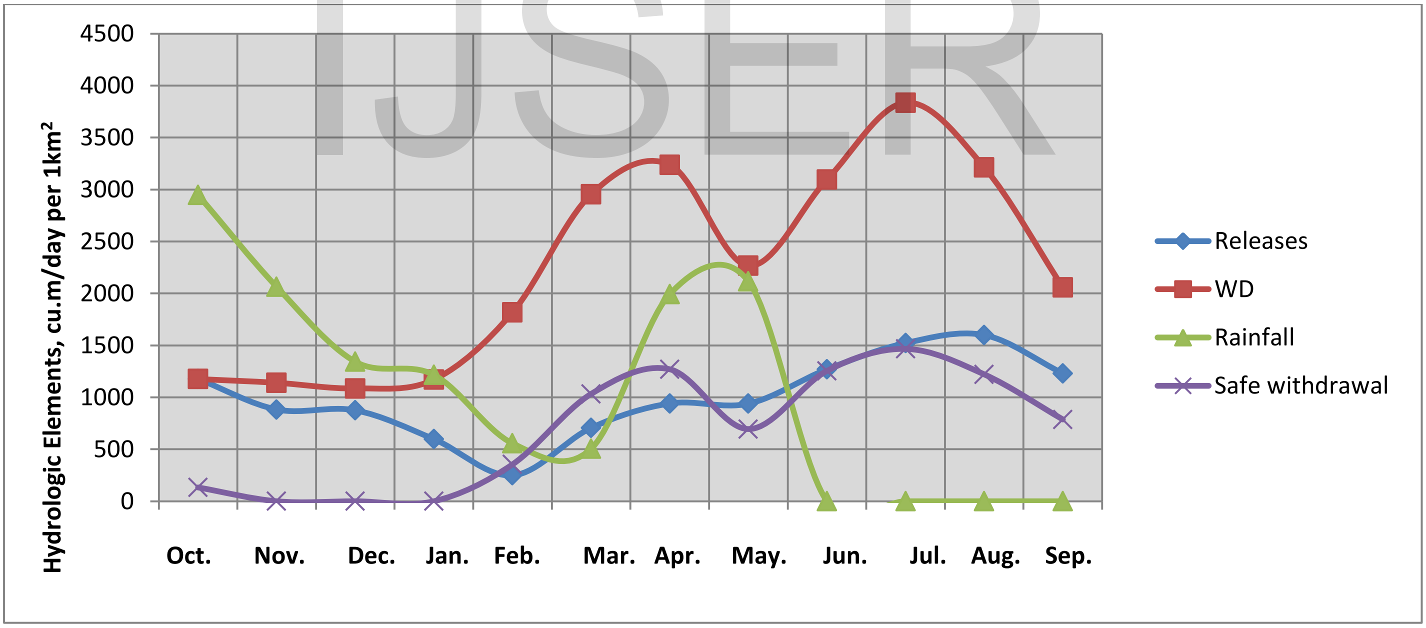

Fig.(5) Available Hydrologic Elements

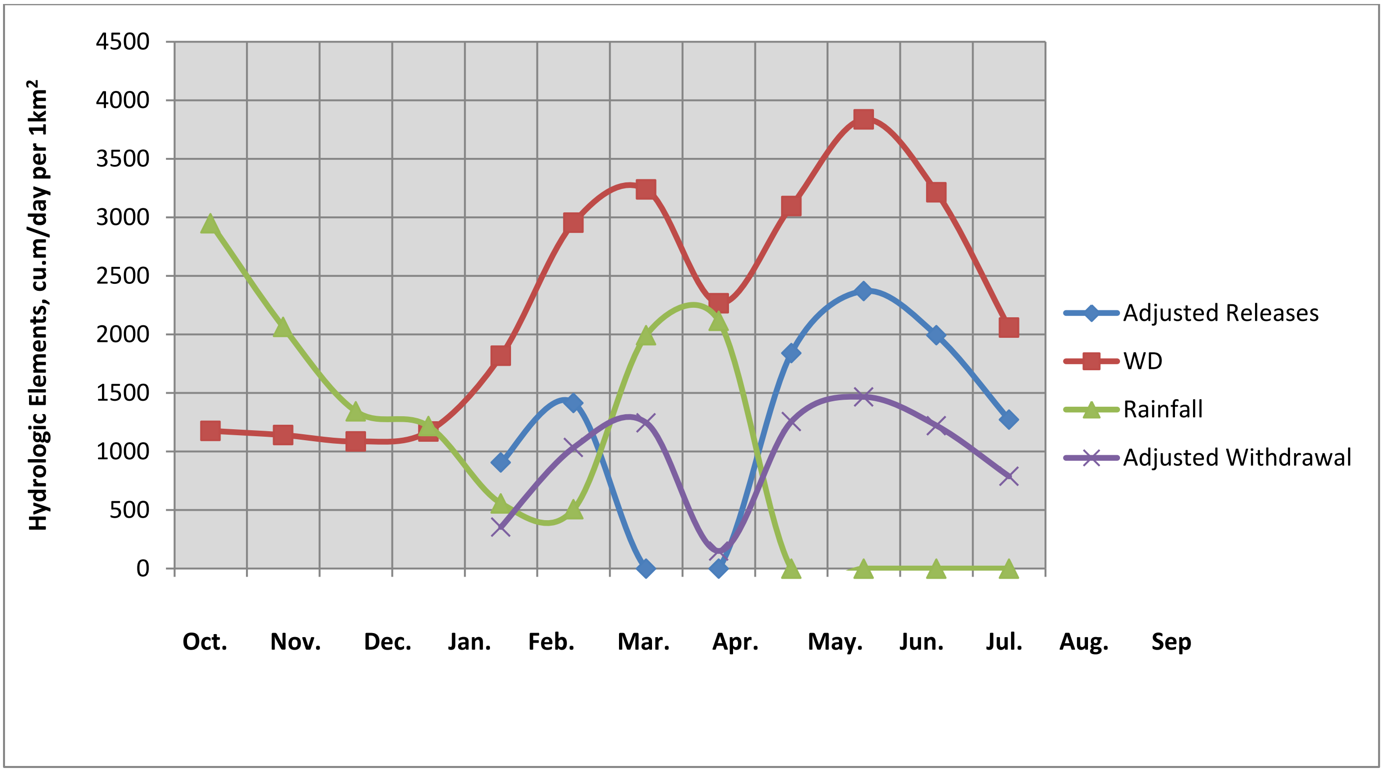

Fig.(5) Adjusted Hydrologic Elements

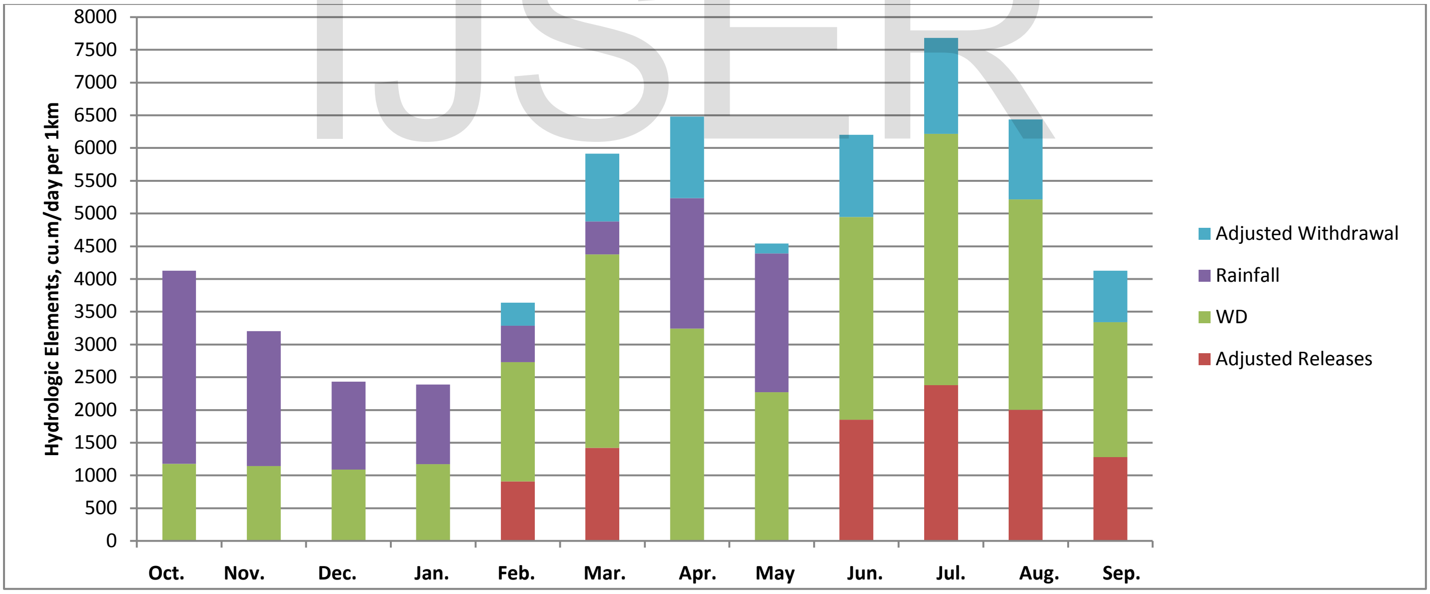

Fig.(6) Adjusted Hydrologic Elements

7 Analytical Discussion

Row(1) of Table (2) represents the monthly current releases of KIC to the basin which are set arbitrary causing a watertable rise, soil logging and swamps at most of the basin. Indeed , surface releases of row(1) are not enough to satisfy the WD row(2) along the year, furthermore WD can not be satisfied by using a GW exploitation and rainfall row(3). In general, the adjusted (corrected) releaseas of row(8) which indeed represent the complementary water to satisfy the WD; these quantities can not be covered by current releases of KIC row(1). Thus the hydrologic elements should be rebalanced. This can be achieved by the followings:

1- During Oct., Nov., Dec., and Jan., KIC releases and GW exploitation should be breaked off since the WD can be satisfied by the rainfall source (see Table(2) row(8&9).
2- During Apr. and May, KIC releases should be breaked off since the WD is satisfied by full rainfall and part of GW exploitation.
3- The residual WD of row(8) [for Feb., Mar., Jun., Jul. Aug., and Sep.]should be satisfied by the saved storage water of breaking off months.
4- Fig.(6) shows that the summation of the used availble water resources is equall to the total WD except for the first four months since the rainfall is uncontollable.

8 Surface water analysis & Evaluation

Briefly, KIC releases are decided in row(1), Table (2); the total volume of surface water releases is estimated and listed in Table (5) as senario No.(1) which is equal to 1506.90674332 millions m^3 per year. Whereas, the total volume of the adjusted surface water releases of row(8), Table (2) is listed in Table (5) as senario No.2 and equals 1224.1030382 millions m^3 per year. The difference of 282.80370512 Million m^3 per year represents the saved surface water if senario No.2 is used

Table (5) Senarios of Surface Water Releases in millios m^3

Months	Senario No.1	Senario No. 2
Oct	150.09920504	0
Nov	108.8813172	0
Dec	111.491345	0
Jan	76.19637064	0
Feb	28.65687216	104.26958304
Mar	89.95758808	180.2974322
Apr	116.0332044	0
May	119.64614052	0
Jun	156.601668	227.0107644
Jul	193.93123096	301.9822716
Aug	203.74246932	253.81801056
Sep	151.669332	156.7249764
Sum	1506.90674332	1224.1030382

Saved Surface Water = 282.80370512 Million m^3 per Year

9 Benefits

The optimization policy of senario No.2 is characterized with followings:
1- Saving 282.80370512 Million m^3 per year which is nowadays releasing causing water logging and swamps.
2- Breaking off KIC operation for six month per year as shown in row(8), Table (2).
3- Breaking off GW exploitation for four months as represented in row(9), Table(2).

11 Conclusions

1- The current optimization study saves about 282.8 millions m^3 per year.
2- Satisfying the WD of the study area.
3- Breaking off six months of KIC operation.
4- Breaking off four months of GW exploitation.
5- Lowering of GW levels within the study area.

12 Recommendation:

It is recommended to make a conjuctive use modeling to rebalance the hydrologic elements of any area within the middle east according to the suggested policy in this research.

References

1- Prickett, T. A., and. Lonngquist, C. G., "*Selected Digital Computer Techniques for Groundwater Resource Evaluation"* (Illinois State Water Survey Bulletin 55.) 62 pp. ,1971
2- AL Assaf, S. A.,*" Application of Computer Technique to Groundwater Flow". Problems*. Dpt. of Geology, Univ. College London, 1976.
3- Birkholz, (2003), "Natural Resources and environmental Protection Act", Committee on Resource and Environmental Affairs.
4- Najah M.L. "The Effect of Al Jadrei Lake on The Ground Flow Pattern", Al Taqani Journal. Vol.21, No.4, 2008
5- Kassab, I. I. M., and Jassim, S. Z., "The Regional Geology of Iraq", General Directorate for Geological Survey and Mineral, Baghdad, Iraq, 1980.
6- Najah M. L., " Optimum management of Surface and Subsurface of Al Ahdiam Basin" Phd. Research, Baghdad Unv. 2005.
7- Franklin M Fisher and Hossein Askari., "Optimal Water Management in the Middle East and Other Regions" Finance & Developmet, A quarterly magazine of the IMF, 2001
8- Franklin M. Fisher, Shaul Arlosoroff, Zvi Eckstein, Munther Haddadin, Salem G. Hamati, Annette Huber-Lee, Ammar Jarrar, Anan Jayyousi, Uri Shamir, and Hans Wesseling, 2002, "Optimal water management and conflict resolution:The Middle East Water Project" Water Resources Research vol. 38, No. 11, 1243, doi:10.1029/2001WR000943, 2002
9- Jin F. Wang, Guo D. Cheng, Yi G. Gao, Ai H. Long, Zhong M. Xu, Xin Li, Hongyan Chen, Tom Barker,"Optimal Water Resource Allocation in Arid and Semi-Arid Areas", Springer Science + Business Media B.V. 2007
10- Ballestero E, " Inter-basin water transfer public agreements: a decision approach to quantity and price". Water Resour Manage 18:75–88, 2004
11- Seong M. H., "Water Resources in the Middle East: Conflict and Management" International Symposium of KAMES, 2004