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The Potentials of GIS in Water Management and Conflict Resolution

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Abstract

The Middle East is heading towards a severe water crisis that will have impacts on the geopolitical map of the region. The populations and living standards of most countries in the Middle East are steadily increasing, and correspondingly are their water demands. Yet, the water resources available for most of these countries, are more or less, remaining the same if not being reduced due to abusive utilization of resources and pollution. Clearly, the region must work towards schemes for shared responsibilities of its water resources and a framework for potential joint management of the scarce water resources. However, an essential prerequisite for such scheme is acces to reliable data.

This paper provides an overview of the potential of using Geographic Information System (GIS) in joint water management. GIS is becoming an important and indispensable tool for environmental and water management. It proposes the establishment of a Water Information Net System (WINET) in the Meddle East, that will include an integrated environmental database with a Geographic Information System (GIS) to allow easy access of information, data retrieval, data dissemination, data analysis, environmental modeling and hydrological and hydrogeological modeling. Such a system would certainly enhance the prospects of joint management and establish confidence and trust among the regional parties.

Introduction:

The Middle East, predominantly an arid to semi-arid region, is located at a crossroads of climatic and botanical zones. Although diverse environments exist within the region including alpine, tropical, coastal and desert, the countries in the region generally share common water resources problems, and seek similar solutions.

Integrated joint water resources management for the Middle East has been gaining momentum in the last years but received a set back as a result of the stalling in the peace process.. Being a truly interdisciplinary concept aiming to consider quality and quantity problems of both surface and groundwater, integrated joint water resources management requires the sustained cooperation of experts having different academic and technical backgrounds in the region.

Hydrological and hydrogeological studies are carried out at different scales and require data, which are consistent and up-to-date. The amount of data involved in hydrological and hydrogeological studies require a system which store large quantities of data and which can process the data for hydrological and hydrogeological applications. The increasing complexity of hydrogeological modeling requires flexible manipulation of data input and considerable visualization functionality for model output. Also, there is an increasing need for up to date information, on time dependent variables, like groundwater levels, groundwater quality and abstraction rate.

GIS is an essential tool that can address the above mentioned requirements. The system is considered to be a tool for collection, storage, query, analysis, modeling and display of multi-disciplinary data from various sources including remote sensing imaging, digital maps, field sampling and survey information. There are broad categories of data for input to the system : (1) alphanumeric; (2) pictorial or graphic; (3) remotely sensed data in digital form. Table 1 represents the defferent elements of an integrated Geoggraphic Infornation system..

The entry of alphanumeric data is straight forward because they are available in computer readable form. The input of pictorial or graphic data, such as maps and photographs, requires the use of a digitizer which converts the features into strings of coordinate values. A usual approach is to represent polygonal boundaries as lines and to represent lines as a sequence of very short, straight line segments which can represented by an ordered sequence of points defining the segments (Marble and Peuquet, 1983, in Lo C. P., 1986).

Remotely sensed data generated by multispectral scanners or high resolution video cameras from space platforms, are in raster format. However, these spectral data have to be restored enhanced, filtered or geometrically transformed by the techniques of image processing before they can be incorporated into geographic information system.

While three dimensional GIS such as Digital Elevation Models (DEMs) is essential for representing surfaces such as landscape morphology, much can be accomplished with a two dimensional GIS, particularly in the area of surface hydrology. Since surface hydrologic processes are related to groundwater processes, two dimensional GIS significantly contribute to groundwater studies as well.

The two dimensional GIS uses vector data consisting of points, lines and polygons and their associated attribute, and the three-dimensional is use raster data in which all information is represented as values in a grid. The vector data structure permits representation of locations with a great deal of precision, however its analytic capabilities are somewhat limited by the complexity of programming required to handle large numbers of x, y coordinates. The precision of raster data is limited by size of the grid cell, however the structure permits easier analysis primarily because of implicit row and column indexing of locations. Therefore, raster GIS permits complex analysis that are difficult to accomplish with vector data, and is particularly useful for hydrologic modeling.

Table 1: The Geographic Information System elements.

MANAGEMENT SYSTEM
ORGANIZATION STAFF PROCEDURES

DATA PROCESSING SUBSYSTEM		**DATA ANALYSIS SUBSYSTEM**			**INFORMATION USE SUBSYSTEM**
DATA ACQU-ISITION	DATA INPUT	DATA STORAGE	RETRIEVAL AND ANALYSIS	INFORMATION OUTPUT	USERS
PRIMARY DATA	CONVERSION TO MACHINE RECORD	BASIC DESEGREGATE DATA	RETRIEVAL	REPORT GENERATION	RESEARCHERS
SECONDARY DATA	GEOCODING	AREAL UNIT SUMMARIES	STATISTICAL	MAPPING	PLANNERS
SURVEY DATA	IMAGE PROCESSING			GRAPHIC DISPLAY	
IMAGE DATA	ENTITY TRANSFORMATION AND FORMATTING	TIME PERIOD SUMMARIES	MODELLING	DERIVATIVE MACHINE RECORDS	MANAGERS

(Source: Tomlinson, 1972 in Lo C.P., 1986)

The multi-disciplinary aspect of GIS permits integration of data that represent a variety of environmental factors which influence hydrologic processes. Data about various properties of soils, geology, terrain morphology, rainfall, hydrology, vegetation cover available in digital map format can be tied together with remote sensing imagery and information collected in field through their location. Depending on the precision and accuracy of data it is possible to perform analysis at a variety of scales to provide schematic low resolution views of processes, or more detailed views of particular areas of interest. The low resolution studies can be verified through more data collection intensive and precise studies and the validity of various models at different scales can be analyzed. Finally, a variety of map and tabular products can be developed for analysis, engineering and planning purposes.

Table 2 represents the needed digital hydrological and hydrogeological geographic database for integrated water management:

The Use of GIS in Joint Water Management:

The water crisis in the Middle East is not simply due to insufficient supply, but of an uneven and inequities distribution which is aggravated by inappropriate consumption practices. The heart of the water crisis in the Middle East is in the inequities of water's allocation and usage among the Middle East countries and nations which threatens the stability of this region. For example, Palestinians are allowed to utilize about 19 % of their water resources as a result of Israel's practices (figure 1). Most of the water resources are shared between more than one riparian. However, the current utilization of water resources in the region did not come as a result of negotiations, but in most cases was imposed by force. Joint management of shared rivers and aquifers in the region is still far from becoming a reality.

Table 1: The needed digital hydrological and hydrogeological geographic database for integrated water management.

Subject	**Object type** **P= Point, L= Line,** **A= Area, R= Raster**	**Scale**
Precipitation	P, L	
Potential Evapotranspiration	P, L	
Land use	A, L	1:20,000
Land cover	A, L	1:20,000
Population distribution	A	
Urban areas	A, L	1:20,000
Industry	A, P	
Soil type	A	1:250,000
Temperature	P, L	
Topography	3D Line	1:20,000
Digital Elevation Model (DEM)	R	50 m pixel size
Slope Model	R	50 m pixel size
Aspect	R	50 m pixel size
Perspective view	L	Based on 50 m pixel size DEM
Drainage	L	1:20,000
Catchment area	A, L	1:250,000
Wells	P	

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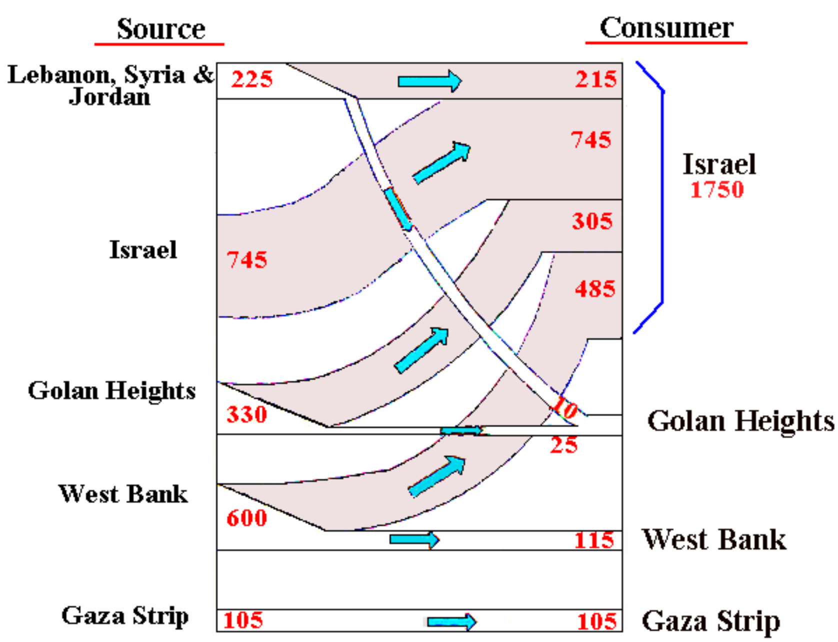
Springs	P	
Groundwater Basins	A, L	1:250,000
Geological features	A, L	1:250,000

It is rather unfortunate that the ongoing Middle East peace process in both its bilateral and multilateral tracks has so far failed to address the heart of the water disputes in the region. While some progress was achieved between Israel and Jordan, little progress has been accomplished between Israelis and Palestinians with regard to water. According to Oslo B agreement, the Israeli government recognized the Palestinian water rights, but these will be determined through final status negotiations. The gap between the positions of the two parties regarding the issue of water rights was so wide during the last rounds of negotiations that almost caused a collapse of the interim phase agreement. The compromise that was finally reached will only load the agenda of final status negotiations. The bilateral talks between Israel on one hand and Lebanon and Syria on the other are dragging behind which led the latter two countries to boycott the multilateral talks. Thus, the multilateral talks have not promoted genuine regional cooperation as they were intended to and thus, have been confined to some modest activities.

Figure 1: *Sources and Consumers of Water Resources in the Occupied Arab Territories and Israel*

Source: Modified after USIS



Regional cooperation to protect the water resources in the Middle East is a responsibility shared by a number of countries, regardless of their political differences. Throughout the Middle East, the natural facts of water supply and the socio-political facts of water control, consumption and demand interact to form a complex hydroploitical situation. The allocation of the region's three major river basins , the Nile, the Euphrates-Tigris and the Jordan, are sources of tension and potential sources of conflict. The need to preserve a region's water resources and the recognition of this need have already created s successful framework for regional water resources cooperation in the Middle East.

Since all of the rivers within the region cross international borders and many of the ground water aquifers are shared, an essential step for initiating joint water management structure is the issue of water allocation. Central to the riparian dispute between Israel and Palestine is the Jordan drainage basin, which constitutes the region's chief water resource. The headwaters of the River Jordan, located in northern Israel, the occupied Golan Heights and southern Lebanon (including Israel's self-proclaimed "security zone"), feed Lake Tiberias; Syrian and Jordanian waters (most importantly the Yarmouk River), meanwhile, and West Bank and Israeli springs feed the Jordan River below Lake Tiberias. As a whole, these elements constitute the Jordan international drainage basin, a naturally-defined area that cannot be artificially sub-sectioned. A second area of dispute is the control of aquifers which flow west from the heights of the West Bank towards the Mediterranean. Underground water resources are the most important in this second area of dispute: surface waters contribute only 30% of total supply in Israel and Palestine.

Following the 1967 occupation, Israel applied stringent policies that prevented Palestinians from fully exploiting the West Bank's groundwater. These included the expropriation of wells belonging to absentee owners, denial of granting permissions for new wells, and imposing rigorous water quotas.

Ground water in Gaza, which is estimated to have a potential of 65 mcm per annum is the only source for fresh water. At present, more than 100 mcm are pumped from these shallow aquifers which resulted in the gradual invasion of seawater into Gaza aquifers.

The current situation is unsustainable. A resolution of the water allocation between Israelis and Palestinian is needed. This issue almost caused a collapse in the negotiations on the interim agreement. The Palestinian water rights can be summarized in the following:

- Absolute sovereignty over all the Eastern Aquifer Systems since the recharge and storage this aquifer are entirely in the West Bank making it not a shared water resource;

- Equitable water rights in the western and northeastern aquifer systems. Although these aquifer are recharged almost entirely from the West Bank , Israel is utilizing more than 85 % of the waters in these aquifers as shown in the following figure:

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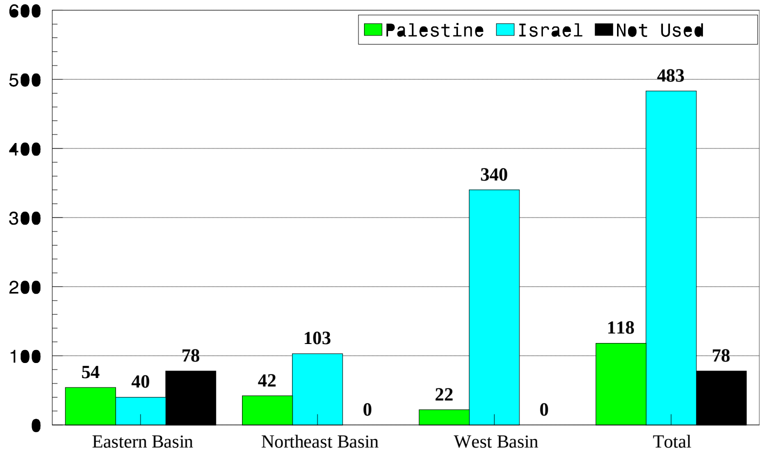

Extraction of Water from Groundwater Basins in the West Bank

- Equitable water rights in the Jordan River System since Palestine is downstream riparian in this international basin.
- Storage and fishing rights in the Lake Tiberias since this natural reservoir is an integral part of the Jordan River System, in which Palestine is a legally a riparian nation with the privilege to equitably utilize all of its available

The resolution of the Palestinian-Israeli allocation and water rights disputes will necessarily be governed by the principles of international law. Two legal aspects of the conflict concern us here. Firstly, Palestinians and Israelis must reach a consensus on sovereignty over water resources in the West Bank and Gaza. And secondly, Palestinians and Israelis must reach agreement on rightful allocation of shared water resources to each party.

The Helsinki Rules (1966) provide the most comprehensive codification of international water law, listing a total of 11 relevant factors to be considered in the resolution of riparian conflicts. Relevant factors which are to be considered include, but are not limited to:

(a) The geography of the basin, including in particular the extent of the drainage area in the territory of each basin State;
(b) The hydrology of the basin, including in particular the contribution of water by each basin State;
(c) The climate affecting the basin;
(d) The past utilization of the waters of the basin, including in particular existing utilization;
(e) The economic and social needs of each basin State;
(f) The population dependent on the waters of the basin in each basin State;

(g) The comparative costs of alternative means of satisfying the economic and social needs of each basin State;
(h) The availability of other resources;
(i) The avoidance of unnecessary waste in the utilization of waters of the basin;
(j) The practicability of compensation to one or more of the co-basin States as a means of adjusting conflicts among uses; and
(k) The degree to which the needs of a basin State may be satisfied, without causing substantial injury to a co-basin State.

GIS will be an extremely powerful tool for getting the parties to agree on water allocations based on catchment area, storage, modeling, ..etc.
GIS will also help determining the apportionment among regional parties to deal with yearly variations in rainfall, recharge, discharge of wells and springs, water consumption, ... etc.
For example, suppose one wants to identify the stream types within a particular catchment area. One quick way to do this is to manually overlay a stream map and a catchment map. This is an easy operation if the streams of only a small catchment area is needed. But what if you need to find out the stream types for all the catchment areas in the West Bank ? And what if some catchment areas contain more than one stream types, permanent or intermittent? and what if some of these streams are extened to Israel. These questions are more difficult to answer, but such an operation is easily performed in a GIS using topological overlay. Topological overlay is one of many spatial operations which can be performed with a GIS to create new spatial relationships. Figure 5 shows the catchment areas of the West Bank with the distribution of different stream types, permanent or intermittent.

According to OSLO B agreement water data will be exchanged between Palestine and Israel, but so far little has been done in this field . We propose that a Water Information Network (WINET) be established and have a web site for all water experts to provide and exchange data. This should not wait and could be initiated immediately by interested academicians and experts.

Design of the Water information Net System (WINET):

In the design of the WINET, an integrated database and Geographic Information System (GIS) software should be used.

1. GIS software:

A GIS based on ARC/Info or PAMAP software can be used to create, protect, analyze and model the different layers. Each layer is a map containing relevant information on one hydrological and hydrogeological issues.

2. Database software:

Data base software such as Oracle or Foxpro software can be used to develop a data base for different hydrological and hydrogeological parameters. The software is used to store, manage, process and interpret different water parameters.

3. Linkage of database to the GIS:

One of the most valuable features of the GIS technology is the possibility to connect its proper internal data to any other external database. The information in the developed database could be located, analyzed and manipulated in an integrated manner to provide real assessment and projections. Such a procedure will facilitate the assessment of environmental impact for any specific plan or project on the natural resources of Palestine, in addition to proposing solutions and measures for hydrological and hydrogeological protection in a particular defined zone or in the whole area in general. Linkage of database with GIS is a powerful tool that could help planners and decision-makers in the Palestinian National Authority in taking decision on water issues.

The linkage occur when one has information in one file, for example wells, and different information in another file. The operation to bring them together is easily achieved by using a key common to both files in this case, the well number. Thus, the record in each file with the same well number is extracted and the two are jointed and stored in another file.

WINET should comprise GIS ARC/Info, compiled with Oracle database as tools to compile the maps and models. Figure 2 outlines the strategy to be used during compilation: primary borehole data, stored in the Oracle data base, is integrated with secondary data such as surface geology, topography and drainage. Integration, interpretation and analysis of deferent interpreted parameters are done in the GIS environment. The final output would be maps, reports and models which can be used for various reasons.

Other Application of Water Information Net System (WINET):

1. Database[1] :

To be able to create Middle East information system. data on location, address, well, well_ID, owner, chemical data, geology, catchment areas, pipe water network, etc. must be compiled. Any such record is a candidates for inclusion into GIS. It is important that the extent of these records is established in the design phase. ARIJ Water Unit has its own water database bank installed on GWW software. The table below shows an example of the wells data base installed on ARIJ GIS computers. Data from GWW and GIS systems can be exchanged easily.

$Record	Well	Well_ID	Well #	Owner	X(UTM)	Y(UTM)
1	2	20	W5022	Sabri Khalaf	734324	3527041
2	3	21	W5023	Moh'd Abu Shushah	732944	3528831
3	1	22	W5024	Sulaiman All Barham	734268	3526842
4	4	23	W5025	Jawad All Masri	735230	3526013
5	5	24	W5026	Joudeh Abdullah	734227	3528003

[1]*Maher et al,1995.*
Source: Maher et al, 1995.

2. Monitoring[1] :

Pollution and monitoring systems of wells, springs and even of the groundwater basins can be done through the GIS. As a simple example, consider the table below:

Well_ID	Well #	X(UTM)	Y(UTM)	Depth to GW Table(m)	SAR
1	W5029	73820	3527447	8.3	9.6
2	W5030	736903	3527714	7.88	5.1
3	W5033	736231	3526188	18.44	8.3

Asking "What is the SAR value in each location ?" is a spatial query. Asking "Which wells have an SAR value of (7.88)?" is a spatial query that can only be answered using latitude and longitude data and other information.

GIS links different data sets. The linkage occurs as mentioned before when one has two different files with common items as the following example illustrates:

Well #	**Ca (PPM)**
W5029	370
W5035	393
W5039	265

Well #	**Depth to Water Table (m)**
W5029	8.3
W5035	19.96
W5039	17.8

Well #	**Ca (PPM)**	**Depth to Water Table (m)**
W5029	370	8.3
W5035	393	19.96
W5039	265	17.8

Some types of information are collected in more detailed or less frequently than other types. For example, depth to water table is measured quite frequently. On the other hand, pollution data are collected at less frequent intervals. If the two types of data are for the same well, then the solution for making the data match the same well is to create two separate files and then match them using the common item, (well #).

Well #	**NO_3 (PPM)**	**Date**
W5029	15	20-3-1995
W5035	52	20-3-1995
W5039	12	21-3-1995

Well #	**Depth to Water Table (m)**	**Date**
W5029	9.60	20-3-1995
W5035	5.60	20-3-1995
W5039	17.8	21-3-1995
W5035	5.50	15-6-1995
W5039	17.6	15-6-1995

Well #	NO3(ppm)	Depth to Water Table (m)	Date
w5029	15	9.60	20-3-1995
w5035	52	5.60	20-3-1995
w5039	12	17.8	21-3-1995
w5029	15	9.75	15-6-1995
w5035	52	5.50	15-6-1995
w5039	12	17.6	15-6-1995

So, with GIS, one can query, monitor and predict the quality of water resources.

3. Drainage pattern delineation, gully and channels development and erosion:

The GIS permits development of a flow accumulation data set which can be used in prediction of flow of water along the landscape and delineation of potential drainage patterns. This is particularly true in areas of high relief such as the West Bank. ARIJ GIS unit is working to build a model for drainage pattern in the West Bank, and for that, a Digital Elevation Model (DEM) containing Z-value with a pixel of 50 was created for the West Bank. This model was constructed using the finite difference techniques of the Topographer Model of the PAMAP GIS software version 4.2. This finite difference techniques is considered to be suitable for using trend data as the input data. The trend data represents the overall shape of the terrain. It is usually contour lines. Figure (3) represent the produced DEM.

A three dimensional perspective view showing the drainage pattern in the West Bank was constructed using the above mentioned DEM figure (4). This view is also constructed using the perspective view model of the Topographer Model of the PAMAP GIS software version 4.2.

It is important to note that drainage pattern data is essential for GIS as well as data about soil, vegetation, geologic and precipitation parameters, potential exists for being able to predict gully and channels formation and make estimate of attendant erosion.

4. Stream flow modeling:

The same flow accumulation data set, if used in conjunction with rainfall, runoff and channel slope, can be potentially useful in modeling stream flow and carrying capacity for separate intervals of time.

5. Locating sediment sinks and potential aquifer recharge area:

The GIS permits discovery of topographic depression on the modulated surface. In conjunction with data on other environmental parameters, this information can be used to discover areas of sediments deposition and aquifer recharge areas.

6. Planning and placement of man-made erosion control structure and reservoir:

Knowledge of flow patterns, natural sediments sinks, and watershed boundaries can be directly helpful in identifying best location for man-made sediment control structures. Although, GIS permits modeling of watershed for potential dams, and through insertion of information on the elevation of spillways into DEMs, it is possible to model the Arial extent and volume of reservoirs created by the dam.

7. Riparian area modeling (Dead Sea area):

Models of sediments yield and stream flow can be useful in determining influx of sediments and pollution into streams from non-point source. GIS programs that delineates steepest overland paths of flow have a potential for modeling pollution from point sources. Areas of potential pounding and deposition of sediment can be identified using the GIS capability to detect surface depressions.

Conclusions:

So far, some potential several uses of GIS in water management have been outlined. Many other applications in the water management are also possible. Various hydrologic models may be explored for potential interfacing with spatial data processing capabilities. Once the design of a particular model that forms part of a tool-set is completed, the model will be tested and verified against actual data collected in field. If successful, it could provide complete sets of methods to field offices for use in watershed planning and management. These methods should facilitate and improve both the utilization of GIS capabilities and informed planning and decision making related to watershed management. The time has come for water experts in the Middle East to utilize GIS in data exchange and water management including addressing the sensitive issue of water allocation.

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