CRP 514: TERM PAPER FINAL REPORT

Correlation of Impacts of Pumping between Agricultural Pumping Wells and Domestic Pumping Wells in Eastern Province, Saudi Arabia, Using GIS

SUBMITTED TO
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MAY ALLAH BE WITH YOU ALL

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Abstract

This study is a demonstration of how GIS can be utilized in groundwater management. Knowing the actual location of wells is a vital requisite to solving groundwater problems, such as contamination and subsidence. Based on its accuracy and precision, GIS was employed in this work for location of agricultural and domestic wells in part of the Eastern Province, Saudi Arabia. To evaluate the impacts of pumping in the wells, hydrogeological models were applied to analyse the well data that were supplied to ArcGIS®9.3. Using the ESRI data set of ArcGIS®9.3 as the data source, Spatial Analyst tool was used to plot the contour lines that represent the magnitude of drawdowns in the wells. Results indicate that if the existing trend of increased pumping continues, especially in agricultural pumping wells, considerable additional impacts will occur. Therefore, effective groundwater management and conservation schemes need to be adopted.

Key Words: GIS, groundwater management, hydrogeological models, pumping well, impacts, Eastern Province, Saudi Arabia.

Chapter One: General Introduction

1.1 Introduction

Insufficient attention has been given to management issues of groundwater in desertic aquifers, especially pumping policies and the proper design of well fields, that is, the spatial distribution among wells and among well fields. In Saudi Arabia, many wells have been drilled in small areas, and in some parts of the Kingdom, groundwater pumping has increased drastically during the last three decades (1980 – 2010). Heavy pumping from large numbers of clustered wells in closely spaced well fields has resulted in unacceptable impacts on water levels and water quality in Saudi Arabia.

The Kingdom of Saudi Arabia, located in south-western Asia, is a vast landmass; it is the world's thirteenth largest country covering approximately 2.25 million km^2. Saudi Arabia occupies about

Figure 1.1: Map of Saudi Arabia showing the major cities and Saudi Arabian borders

80% of the Arabian Peninsula, with a population of almost 22.7 million inhabitants in 2004 (TED, 2004). It is bounded by the Red Sea and the Gulf of Aqaba to the west, Yemen and Oman to the south, Qatar, the United Arab Emirates and the Arabian Gulf (also known as the Persian Gulf) to the east, Kuwait, Iraq and Jordan to the north (Figure 1.1).

Saudi Arabia is a poor country in terms of agricultural potential and water resources, relative to its considerable size; the natural agricultural area is very limited; and indeed, cultivated land accounts for less than 1% of the total area (Alkolibi, 2002). Improvement in the agricultural sector (in both traditional and commercial farms) in Saudi Arabia has not been as successful as was planned, and this may be due to the fact that agriculture in Saudi Arabia experiences significant pressure from various sources. Many of these are related to the climate, such as extreme weather conditions and scarcity of water, which together present the Kingdom's farmers with major challenges.

Water availability is very low. There is very high reliance on groundwater which is in increasing shortage, evidenced by rapidly falling levels. This is a consequence of the discovery, detection and exploitation of the Kingdom's oil resources from 1938 onwards, which resulted in rapid development and population growth. The ensuing increase in government reserves prompted the Ministry of Agriculture and Water (MAW) since the 1980s to heavily subsidize the sector in order to broaden the Kingdom's economic base. Although the people of Saudi Arabia have always depended on both shallow and deep aquifers, an explosion in agriculture since the programme began has generated a huge increase in the demand for water to irrigate crops (TED, 2004). Groundwater is currently being exhausted at alarming rates, partly through ill-advised and inefficient use over the last thirty years. Many current patterns of water withdrawal in Saudi Arabia are almost certainly unsustainable, particularly where pumping from aquifers is at rates far greater than recharge. This massive increase in demand for water, especially for irrigation, is reflected in declining groundwater levels in most areas of the country (MAW, 1984). Consequently, Saudi Arabia is facing a growing crisis related to water availability, allocation and policy.

1.2 Study Aim

The overarching aim of this study is to use GIS as a tool to depict the results of hydrogeological analysis on a real map. This study is also set to establish scientifically reasonable correlations between impacts of pumping from agricultural wells and domestic wells using GIS, as a way of emphasizing the need for proper groundwater management in Saudi Arabia.

1.3 Methodology

- I extracted coordinate locations of pumping wells from a hydrogeologic report and converted the coordinates to Universal Transverse Mercator (UTM).
- Saudi Arabian Base Map was extracted from the World Map Shape File and Ocean Shape File.
- The data supplied into ArcGIS® 9.3 are results of hydrogeological modeling of pumping well data
- The Extension used is Spatial Analyst, and the Data Source is ESRI Data Set
- The tasks performed include Querying, Analysing, Editing and Reporting

- The Layers are agricultural pumping site, domestic pumping site, base map update, contours, Alat Aquifer, Khobar Aquifer, UER Aquifer, Neogene Aquifer, ocean and cities.
- The Layers are represented by symbols, colors, labels, lines and polygons.

1.4 Term Paper Outline

This section provides the outline adopted to actualize the objective of this term paper. Chapter 1 is a general introduction to the main aim of the term paper, starting with the context of water use and agriculture in Saudi Arabia, followed by an explanation of the study aim and the methodology used.

Chapter 2 contains information on the principal aquifers in Saudi Arabia. Specific attention is given to aquifers in the Eastern Province, with the simple descriptions of their hydrogeological properties.

Chapter 3 contains well locations in coordinates (longitude and latitude), and the use of GIS to represent them on a real map. Analysis of well data using hydrogeological modeling is contained in Chapter 4. This is followed by the use of GIS to output the result (drawdowns) on a real map.

Conclusions and recommendations are contained in Chapter 5.

Chapter Two: Aquifers in Saudi Arabia

2.1 The Principal Aquifers

In considering the major groundwater resources of Saudi Arabia from a geologic viewpoint, the crystalline rocks of the Arabian Shield can be omitted (Figure 2.1), since they have low permeability and are only significant in providing extensive, higher areas of surface runoff, or shallow subsurface wadi underflow (Burdon, 1982).

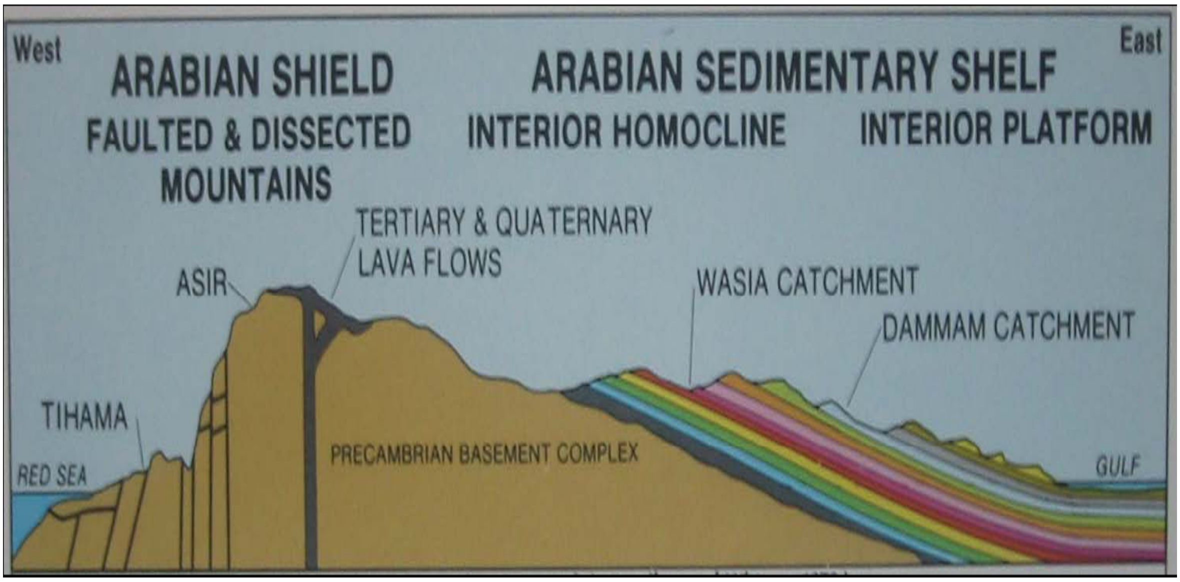

Figure 2.1: Geological cross-section of Saudi Arabia (modified from MAW, 1984)

To the north, east and south of the Arabian Shield, there are very large sedimentary basins with many thick, highly permeable aquifers, which contain the majority of groundwater resources of the Kingdom.

Eastern Province, Hail, Jouf, Qaseem and Riyadh are the regions that produce over 80 percent of all agricultural production in Saudi Arabia. A considerable amount of production is also found in Tabuk region. The major aquifers utilized for agricultural production dip across these regions

(Figure 2.2). These aquifers have been discovered only in the last four to five decades. They are often referred to as non-renewable fossil waters due to their high depths and old age of their water.

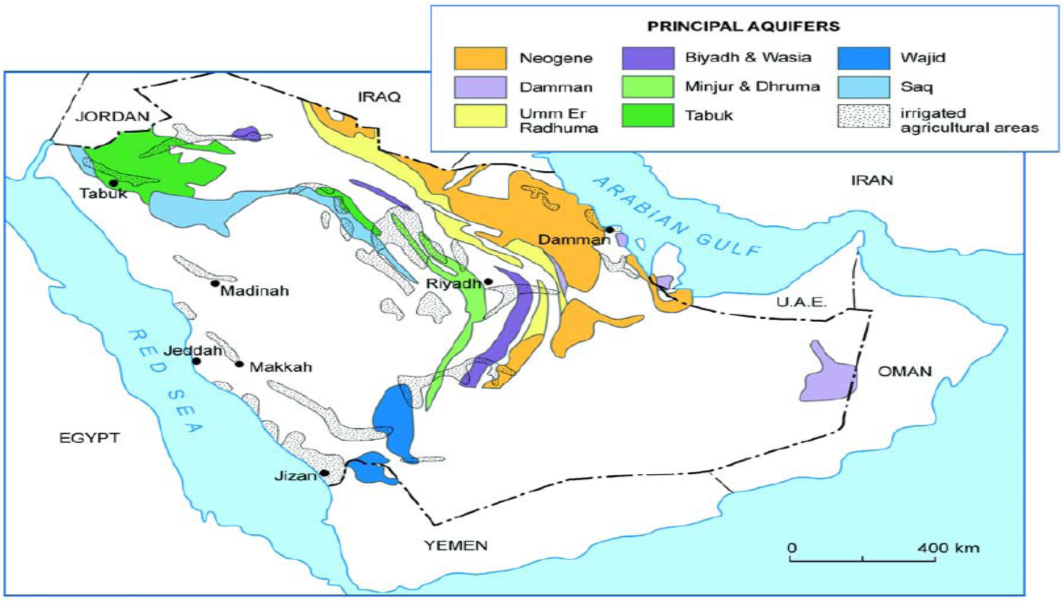

Figure 2.2: Principal aquifers of Saudi Arabia showing relation with main irrigated agriculture area (Foster, 2007)

2.2 Aquifers in Eastern Province

The results of hydrogeological studies by Italconsult (1969), BRGM (1977), GDC (1980), and Rasheeduddin et al. (1989) have indicated the existence of a multiaquifer system in Eastern Province (Table 2.1). The system consists of three main aquifers separated by semi-confining beds. In ascending order, they are: the Umm Er Radhuma (UER) aquifer, the Rus aquitard with Midra and Saila Shales and Alveoline limestone members, the Khobar aquifer, the Alat Marl aquitard, the Alat aquifer and Neogene aquifer. Vertical flow between the aquifers occurs through the leaky intervening aquitards depending on the hydraulic head gradient in each aquifer.

AGE			FORMATION	MEMBER	GENERALIZED LITHOLOGIC DESCRIPTION	Thickness (m)	HYDROGEOLOGIC UNIT
Quaternary			Surficial deposits		Gravel, sand and silt		Variable productivity depending on recharge
Tertiary	Palaeogene	Neogene	Neogene	Hofuf, Dam, Hadrukh	Sandy marl, skeletal limestone, silty clay, sandy limestone	0 - 285	Aquifer
		Eocene	Dammam	Alat	Skeletal, detrital and dolomitic limestones		
					Dolomitic marls with limestone intercalations	0 - 30	Aquitard
				Khobar	Skeletal-detrital limestones, dolomitic limestones with argillaceous limestones near the bottom	0 - 70	Aquifer
				Alveolina Limestone	Limestone interbedded with shales and marls	0 - 20	Aquitard
				Midra and Saila Shales	Blue and dark gray fissile shales with gypsiferous lenses	0 - 10	
			Rus		Chalky limestones, anhydrites marls and shales	10 - 90	
		Palaeocene	Umm Er Radhuma (UER)		Limestones, dolomitic limestones and dolomites	> 100	Aquifer
Cretaceous			Aruma		Limestones, subordinate dolomites and shales	-	Aquifer

Table 2.1: Generalized lithostratigraphic succession of the Eastern Province (modified after Powers et al., 1996)

Chapter Three: Location of Pumping Wells Using GIS

3.1 Coordinate Location of the Wells

In a hydrogeological report prepared by KFUPM (2009), locations of a number of wells were given in coordinates. The wells were categorized into two: (i.) Agricultural Pumping Wells, and (ii.) Domestic Pumping Wells. Tables 3.1a and 3.1b contain the coordinate values that represent where the agricultural pumping wells and domestic pumping wells, respectively, are located.

Longitude (E)	Latitude (N)	Longitude (E)	Latitude (N)	Longitude (E)	Latitude (N)	Longitude (E)	Latitude (N)
48˚ 58'	26˚ 13'	49˚ 58'	26˚ 27'	48˚ 54'	26˚ 45'	49˚ 14'	24˚ 22'
48˚ 52'	26˚ 11'	49˚ 57'	26˚ 27'	49˚ 35'	25˚ 25'	49˚ 16'	24˚ 20'
49˚ 00'	26˚ 09'	49˚ 59'	26˚ 25'	49˚ 37'	25˚ 22'	49˚ 10'	24˚ 17'
48˚ 55'	26˚ 08'	49˚ 55'	26˚ 21'	49˚ 27'	25˚ 22'	49˚ 00'	24˚ 14'
48˚ 50'	26˚ 07'	49˚ 58'	26˚ 20'	49˚ 26'	25˚ 20'	49˚ 06'	24˚ 14'
49˚ 52'	26˚ 36'	48˚ 43'	26˚ 49'	49˚ 32'	25˚ 18'	49˚ 03'	24˚ 13'
49˚ 54'	26˚ 34'	48˚ 48'	26˚ 49'	49˚ 35'	25˚ 17'	48˚ 29'	27˚ 58'
49˚ 56'	26˚ 34'	48˚ 54'	26˚ 49'	49˚ 35'	25˚ 17'	48˚ 33'	27˚ 58'
49˚ 54'	26˚ 33'	48˚ 48'	26˚ 45'	49˚ 19'	24˚ 28'	48˚ 37'	27˚ 58'
49˚ 52'	26˚ 33'	48˚ 52'	26˚ 45'	49˚ 21'	24˚ 25'	48˚ 50'	27˚ 27'
				49˚ 10'	27˚ 04'	49˚ 05'	27˚ 09'

Table 3.1a: Coordinate locations of some agricultural pumping wells in Eastern Province

Longitude (E)	Latitude (N)	Longitude (E)	Latitude (N)
49˚ 36'	26˚ 08'	50˚ 11'	26˚ 14'
49˚ 40'	26˚ 03'	50˚ 09'	26˚ 11'
50˚ 04'	26˚ 39	48˚ 47'	26˚ 55'
50˚ 02'	26˚ 34'	49˚ 35'	25˚ 28'
50˚ 11'	26˚ 23'	49˚ 41'	25˚ 22'
50˚ 03'	26˚ 19'	49˚ 37'	25˚ 17'
50˚ 09'	26˚ 19'	49˚ 29'	25˚ 14'
50˚ 04'	26˚ 18'	49˚ 10'	27˚ 04'
49˚ 58'	26˚ 18'		
50˚ 04'	26˚ 15'		

Table 3.1b: Coordinate locations of some domestic pumping wells in Eastern Province

3.2 Location of Wells on a Real Map Using GIS

In groundwater management, knowing the actual location of wells is vital because it will enhance better monitoring of the wells. And in the event of a problem, such as contamination problem or land subsidence, the knowledge of the actual location of the wells will serve as guidance in determining where the problem emerged before mitigatory measures can be applied. Geographic Information Systems (GIS) is a tool which enables high level of accuracy and precision in the location of an object on a real map.

In this study, GIS method is used to locate the coordinate well locations in Tables 3.1a and 3.1b on a real map. The software used is ArcGIS® 9.3. The data source and the extension used are ESRI data set and Spatial Analyst respectively. Figure 3.1 is a depiction of the actual location of the wells on a real map.

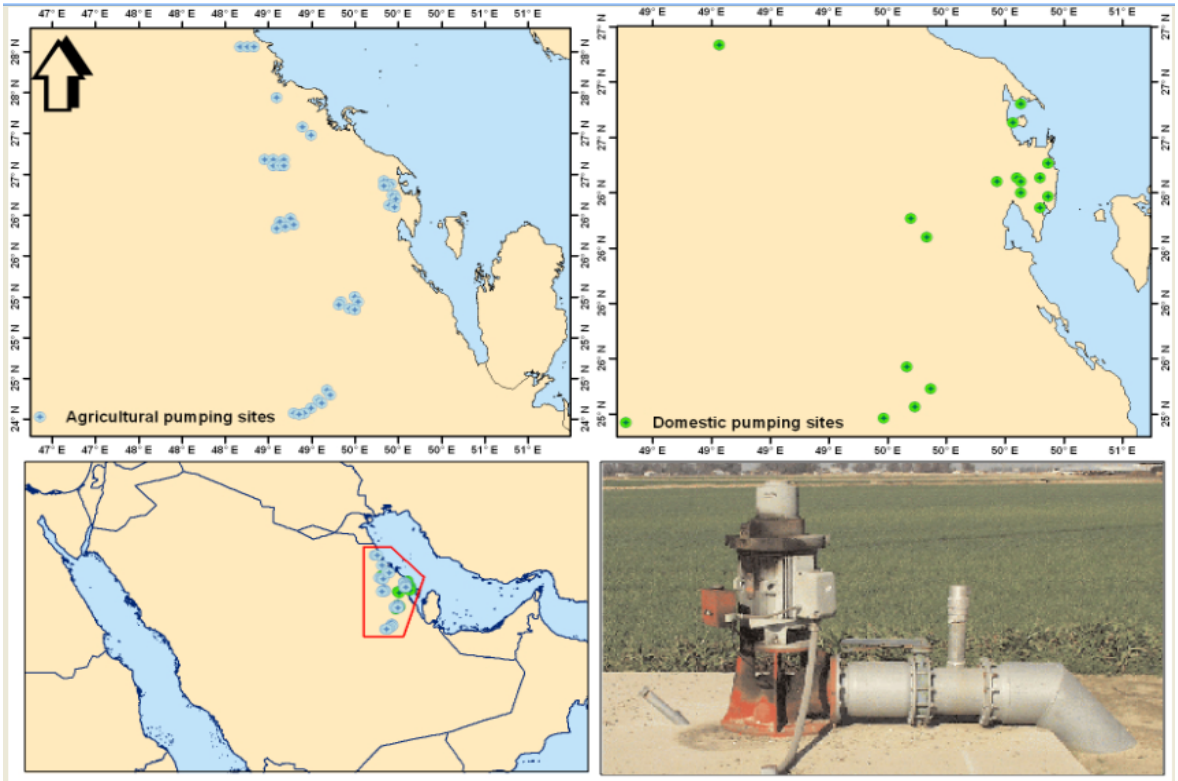

Figure 3.1: Actual locations of the wells enabled by GIS

Chapter Four: Hydrogeological Modeling and Use of GIS to Display Results

4.1 Numerical Modeling

For the visualization of subsurface data of the aquifers in the Eastern Province, numerical modeling approach was used. The software used is RockWorksTM14.

To carry-out this task, two cross-sections were plotted on a real map of the Eastern Province using ArcGIS®9.3. The first cross-section was plotted around the Al Hassa area (A to A'), and the second cross-section was plotted around Dammam area (B to B').

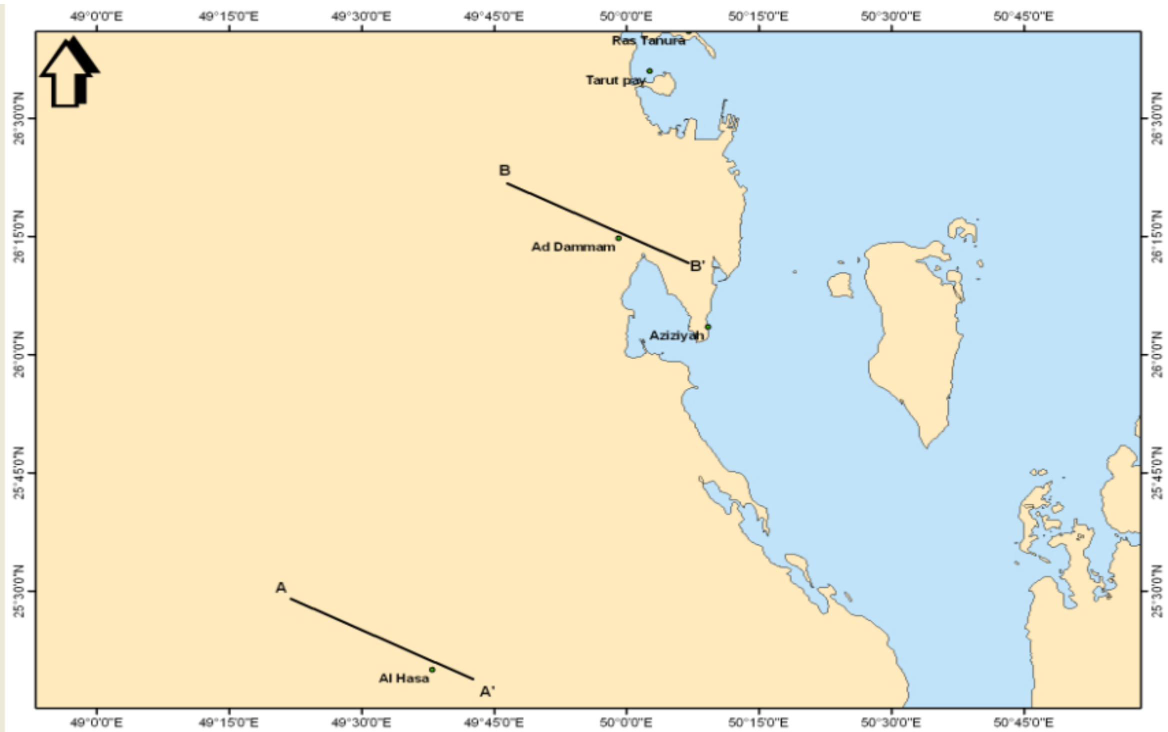

Figure 4.1: Cross-sections used for the numerical modeling

Borehole data manager of the RockworksTM14 was used for entry of well data including stratigraphic contacts, aquifer thicknesses, lithologic patterns and color, while RockWorks Utilities was used for the conversion of longitude and latitude coordinates to UTM.

Figures 4.2a and 4.2b are conceptual views of the aquifer system in the Eastern Province. Umm er Radhuma Formation is the oldest in the sequence while the Quaternary Sand is the youngest. All the Formations in the sequence are water-bearing except the Rus Formation which is categorized as an aquiclude. Among the Members of the Dammam Formation, only two water-bearing Members (Khobar and Alat Aquifers) are present but are both represented as Dammam Aquifer in the conceptual view for convenience. Both the Quaternary Sand Aquifer and Neogene Aquifer occur in Figure 4.2a (Al Hassa area), but are absent in Figure 4.2b (Dammam area).

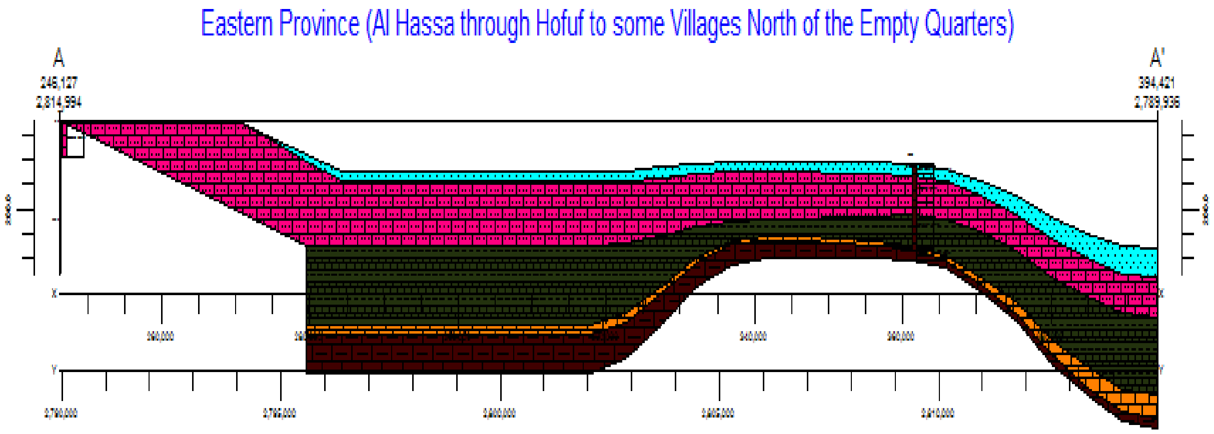

Figure 4.2a: Conceptual view of aquifers in Eastern Province (cross-section A – A')

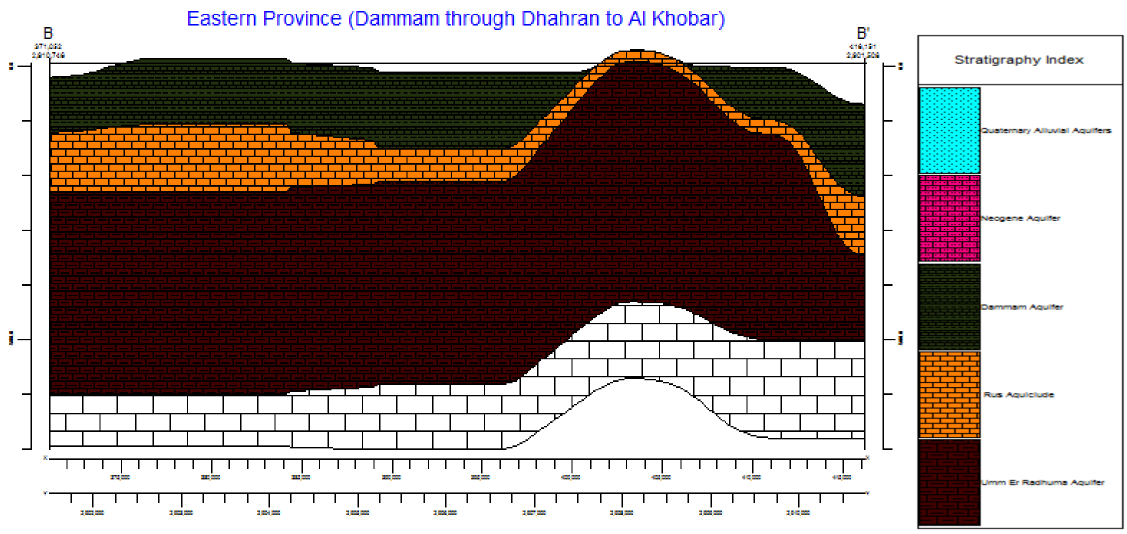

Figure 4.2b: Conceptual view of aquifers in Eastern Province (cross-section B – B')

4.2 Analytical Modeling

T. V. Theis (1935) postulated a theory that let us evaluate the behavior of a well pumping in a confined aquifer under transient condition. He developed models which are presented below:

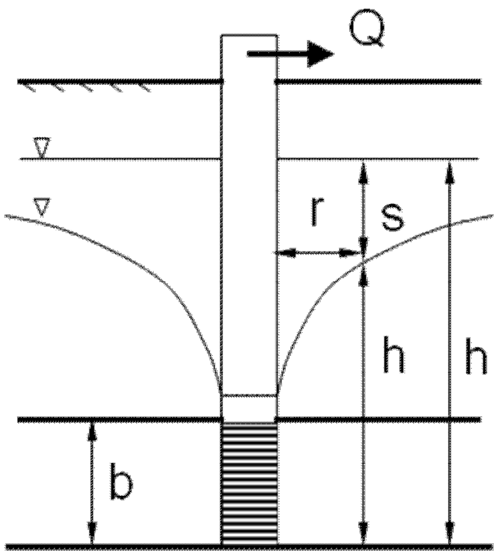

Figure 4.3: Idealization of Theis Models

$$u = \frac{r^2 S}{4Tt} ------------(1)$$

$$s = \frac{Q}{4\pi T} W(u) --------(2)$$

$$s = b - (b^2 - 2s'b)^{1/2} ----(3)$$

Where,

s = Drawdown (m)

S = Storativity of the aquifer

T = Transmissivity of the aquifer (m^2/sec)

Q = pumping rate (m^3/day)

b = Aquifer thickness (m)

r = radial distance (m)

W(u) = Well function

T = time (days)

The aquifer pumping parameters S, r, t and T are used in finding the values of u (u is a small value used in obtaining the value of the well function) in the first equation. After obtaining the values of the well function W(u), we use it in the second equation with Q and T to calculate the values of the drawdown (s).

The results are presented in Tables 4.1a, 4.1b, 4.1c and 4.1d for Neogene, Alat, Khobar and Umm er Radhuma Aquifers respectively.

Pumping Site	Well Location	Year	Q (m^3/day)	r (m)	s (m)
Agriculture	49° 21'E 24° 25'N	1980	220	12	7.5
		1990	1990	35	7.1
		2000	9700	60	4.75
		2010	2100	130	2.3
Domestic	49° 35'E 25° 28'N	1980	35	2	7.9
		1990	160	12	7.6
		2000	250	12	7.6
		2010	1900	25	7.4

Table 4.1a: Drawdown results for Neogene Aquifer

Pumping Site	Well Location	Year	Q (m^3/day)	r (m)	s (m)
Agriculture	49^o 52'E 26^o 36'N	1980	310	12	9.1
		1990	2900	41	7.7
		2000	11200	63	4.9
		2010	27500	142	1.8
Domestic	50^o 04'E 26^o 39'N	1980	30	1	9.85
		1990	230	14	9.3
		2000	680	18	8.65
		2010	2360	21	8.1

Table 4.1b: Drawdown results for Alat Aquifer

Pumping Site	Well Location	Year	Q (m^3/day)	r (m)	s (m)
Agriculture	49^o 56'E 26^o 34'N	1980	280	10	5.8
		1990	1900	28	4.3
		2000	9500	52	2.6
		2010	1800	105	1.7
Domestic	49^o 40'E 26^o 03'N	1980	0	0	6.5
		1990	25	3	6.1
		2000	200	7	5.9
		2010	1300	20	4.85

Table 4.1c: Drawdown results for Khobar Aquifer

Pumping Site	Well Location	Year	Q (m^3/day)	r (m)	s (m)
Agriculture	49° 21'E 24° 25'N	1980	220	12	7.5
		1990	1990	35	7.1
		2000	9700	60	4.75
		2010	2100	130	2.3
Domestic	49° 35'E 25° 28'N	1980	35	2	7.9
		1990	160	12	7.6
		2000	250	12	7.6
		2010	1900	25	7.4

Table 4.1d: Drawdown results for Ummer er Radhuma Aquifer

4.3 Use of GIS to Display Results

The results presented in the tables above are better understood when represented on a map. Again, GIS method was used to actualize this. Using ESRI data set of ArcGIS® 9.3 as the data source, Spatial Analyst tool was used to plot contour lines. The contour lines were used to represent the drawdowns in the wells given different pumping rates for the periods of 1980 to 2010. Figures 4.4a, 4.4b, 4.4c and 4.4d are used to depict the drawdowns in agricultural pumping site and domestic pumping site for Neogene, Alat, Khobar and Ummer er Radhuma Aquifers respectively.

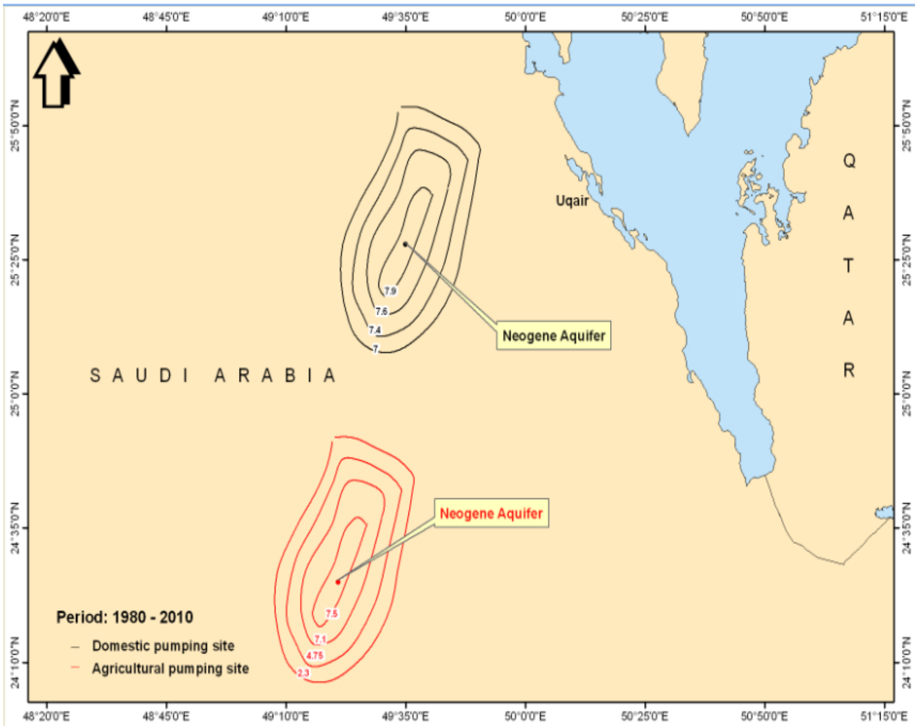

Figure 4.4a: Drawdowns of agricultural (wheat) pumping well and domestic pumping well in Neogene Aquifer

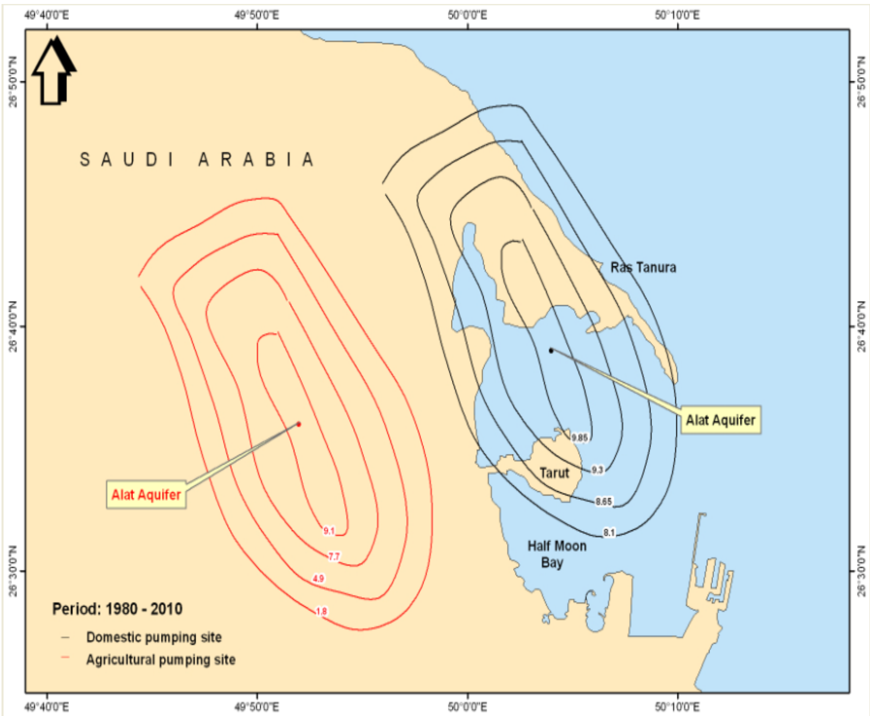

Figure 4.4b: Drawdowns of agricultural (wheat) pumping well and domestic pumping well in Alat Aquifer

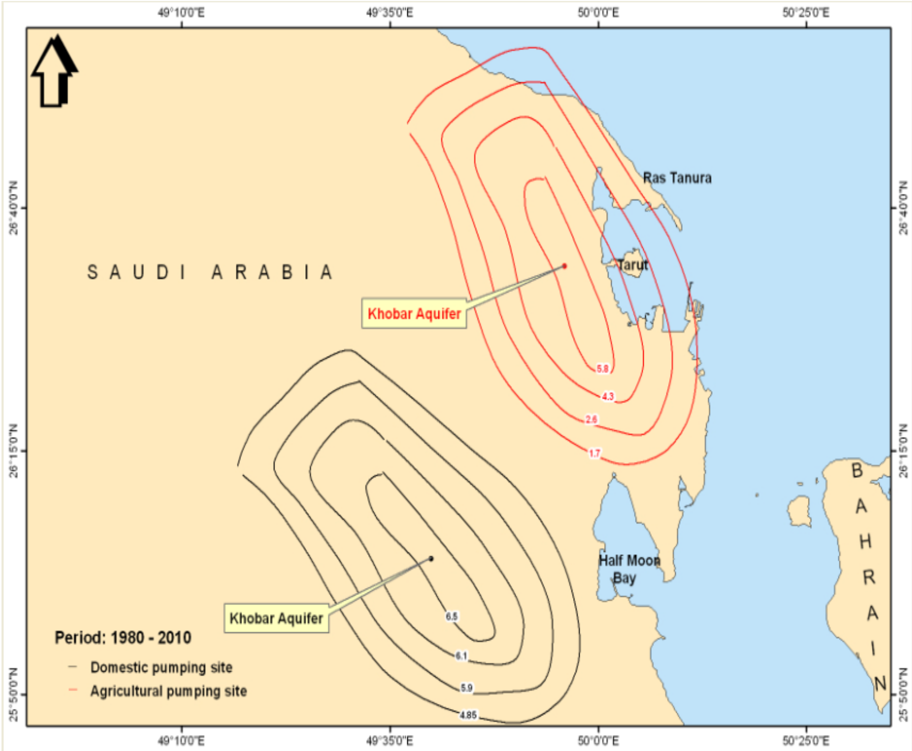

Figure 4.4c: Drawdowns of agricultural (wheat) pumping well and domestic pumping well in Khobar Aquifer

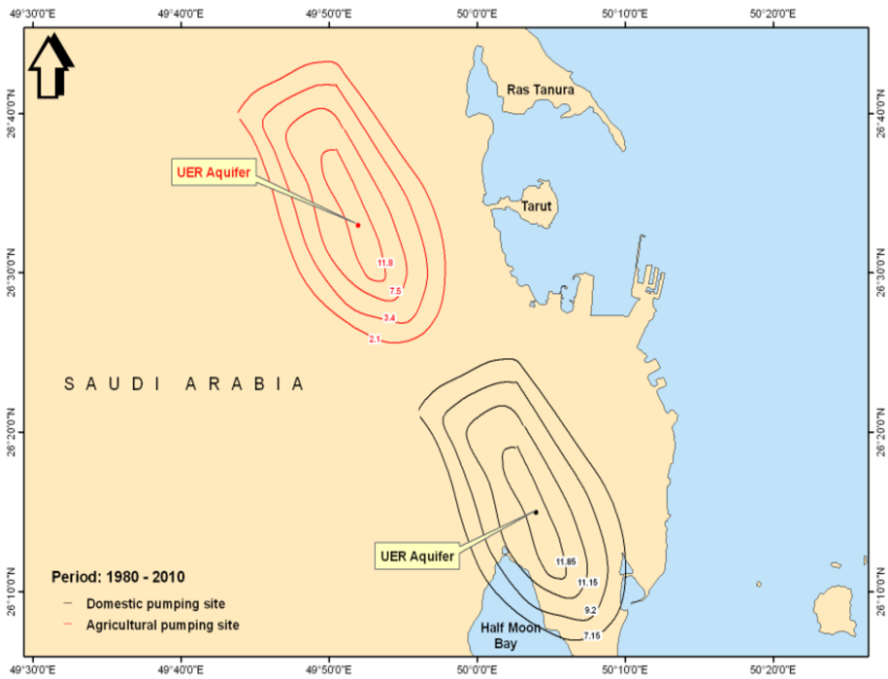

Figure 4.4d: Drawdowns of agricultural (wheat) pumping well and domestic pumping well in Ummer er Radhuma Aquifer

From these results, it is very clear that the drawdown of the agricultural pumping wells for all the four aquifers are more than the drawdown of the domestic wells. This implies that the rate of water abstraction from the agricultural pumping wells for wheat production is far greater than the rate of water abstraction for domestic purposes. Therefore, continuous groundwater abstraction for agricultural production in the aquifers of the Eastern Province will pose a threat to the environment as the environment will be rendered more vulnerable to unwanted impacts such as land subsidence.

Chapter Five: Conclusions and Recommendations

From the foregoing, it can be concluded that:

- GIS ensures precision and accuracy in the location of pumping sites on a real map
- It enables efficiency in the use of well data and enhances clear presentation of results
- Results of this work indicate that if the current trend of pumping is continued, especially in agricultural pumping sites, considerable additional impacts would occur
- Proper groundwater management and conservation scheme need to be adopted

To mitigate the impacts of groundwater abstraction for wheat production, the government of Saudi Arabia needs to take additional measures to:

- reduce the water consumption for wheat production to increase the long-term productivity and quality of the aquifers
- augment groundwater resources from non-conventional resources such as desalination, wastewater reuse
- implement artificial aquifer recharge
- design a training program to educate farmers on efficient use of water
- face-out wheat production and increase investment in crops that have lower water consumption

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