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SPATIAL MODELING FOR GROUNDWATER SALINITY: NEOGENE AQUIFER, AL-HASSA, SAUDI ARABIA

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Water sustainability has the highest priority in all countries, whether developed or developing. Geographic information systems (GIS) technology is gaining importance as a useful tool in sustainable water management and development. Groundwater salinity levels in irrigated areas may vary depending on the quantity and quality of applied irrigation water and on the efficiency of the drainage system. Moreover, groundwater salinity plays a critical role in irrigation systems by influencing whether the environment is suitable for plant production. Therefore, it is essential to monitor temporal and spatial changes in groundwater salinity. In this study, a spatial model for groundwater salinity was created based on chemical parameters including electrical conductivity, sodium absorption ratio, pH and chloride. The method looks at the spatial and temporal relationships between the main salinity classes available in the study area, their typical locations (i.e. areas where the salinity classes are most frequently located), and the alternate salinity classes in those locations in any of the years of the time series. As a case study, the method was applied to multi-year data (1967-2004) in the Al-Hassa irrigation and drainage project (9000 ha) in the southern part of the Eastern region of Saudi Arabia.

INTRODUCTION

In irrigated areas, groundwater salinity levels may vary depending on the amount and quality of irrigation water applied and on the effectiveness of the drainage system. Groundwater salinity plays a vital role in irrigation systems by influencing whether the environment is suitable for plant growth. Hence, it is necessary to monitor changes in groundwater salinity both temporally and spatially (Gundogdu and Aslan, 2008). The quality of groundwater is a function of physical, chemical and biological parameters. Moreover, geology and aquifer materials also determine the chemistry of the groundwater system (Ahmed et al., 2000). In alluvial regions, groundwater with a total dissolved solids (TDS) concentration as high as 46,000 mg/l can be found. Moreover, in desert oasis areas, layering of relatively fresh water (TDS 500–3500 mg/l) above the saline groundwater (TDS 7,000–12,000 mg/l) can occur. Zonation pronounced through vertical distribution of groundwater quality within the same aquifer often occurs (Barica, 1972).

The management of water resources requires the integration of very large volumes of disparate information from numerous sources; the coupling of this information with efficient tools for assessment and evaluation that allow broad, interactive participation in the planning, assessment, and decision making process; and effective methods of communicating results and findings to a broad audience (Fedra, 1995)

Water management is the efficient and effective use of the available water resource by minimizing wastage, promoting recycling, and increasing water quality alongside sustainable economic development. Water management is a crucial issue to the survival of humans and all living things in the present era as water resources become scarcer. The amount of water we need and the availability is out of balance. With proper water management we can minimize the effect of drought and the famine being faced by many developing countries.

In order to manage water better it is crucial to have an inventory of the water available, how it is being managed, the drainage area, and the demand and supply of water. GIS based methods have been very useful in mapping and data analysis, and have greatly aided in the understanding and decision making for a water sustainable development.

Water resource planners need access to reasonably accurate spatial data and time series data in order to assess resources, demands and constraints, evaluate options and formulate alternative strategies.

This study focuses on the Al Hassa oasis, which is situated some 70 km inland of the Gulf coast (Figure 1) between 25º 05ʹ and 25º 40ʹ N Lat and 49º 10ʹ and 49º 55ʹ E Long and it covers an area of approximately 20,000 ha. The area occupied by the oasis is L-shaped and consists of a group of oases surrounded and intersected by redbeds and sabkhas. The oasis is about 130 to 160 m above sea level.

The water of the Al Hassa oasis discharges from a karstified Neogene aquifer. There were 32 main springs in the Al Hassa oasis, situated on a line connecting the three urban centers of Hofuf, Mubarraz, and Mutairifi on the western border of the oasis (Figure 2). The springs used to produce a total discharge of 4.72 m^3/s (until the early 1990s, when natural or pumped discharged stopped). Approximately 4000 hand-dug or drilled wells are dispersed over the entire oasis, producing a total discharge of about 0.68 m3/s (Figure 3).

Presently, pumps are placed in former springs due to substantial drops in piezometric pressure

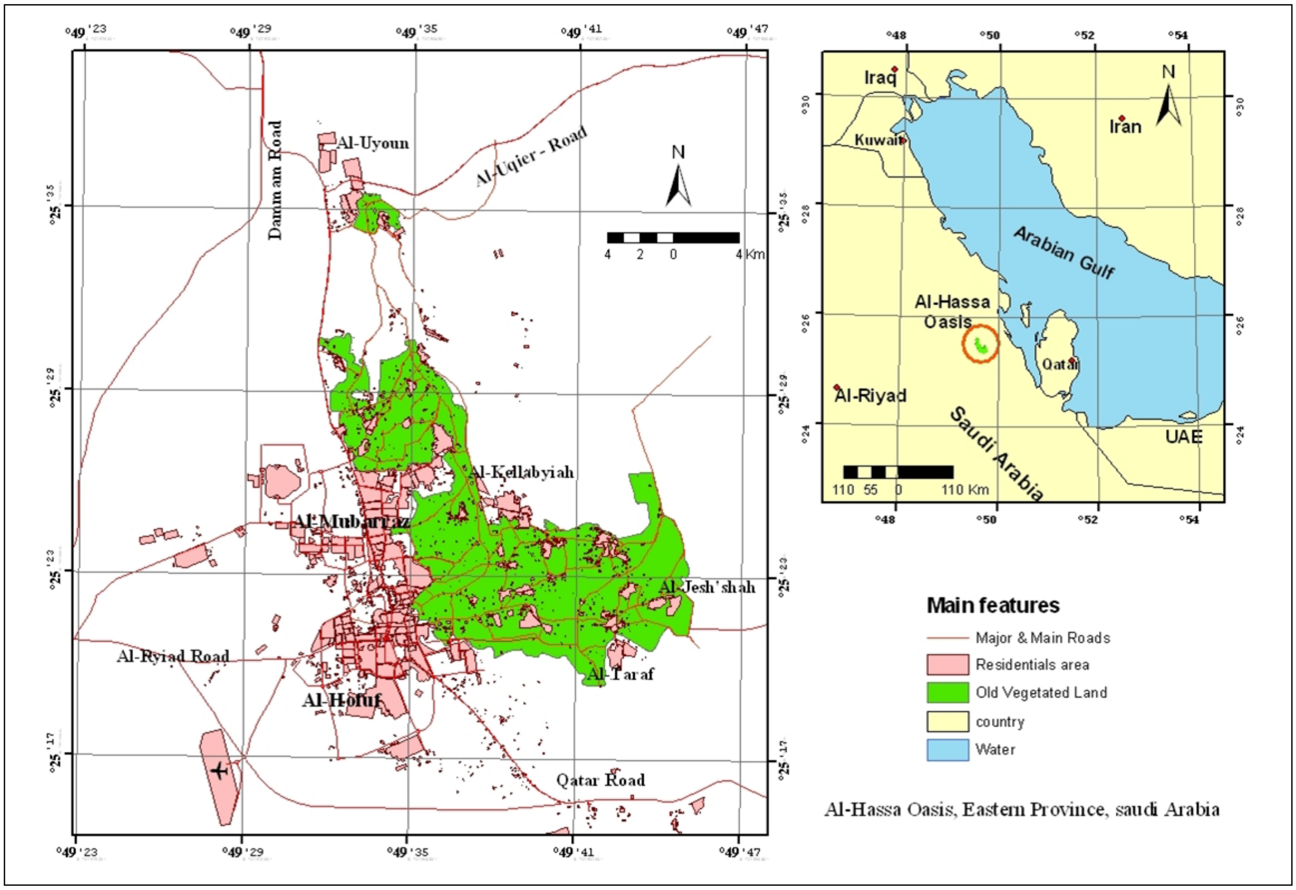

Figure 1 The location of Al-Hassa Oasis.

and water salinization. The main directions for drainage follow the natural slope within the oasis (i.e. to the east in the eastern oasis and to the north in the northern oasis). The drainage network is shown in Figure 4.

The drainage water discharges into two evaporation lakes, which are located north and east of the oasis. Some drainage water is mixed with groundwater and reused for irrigation (Aldakheel, 2001). Because salinity occurs in the long run with accumulation, it is inefficient to analyze groundwater salinity with annual data alone. Therefore, evaluation of GW Salinity with multi-year data is more appropriate.

The aim of this research is to investigate the temporal and spatial change in groundwater salinity of the Neogene aquifer in this area using the spatial modeling techniques of GIS.

PROCEDURES AND METHODS

The data collected for the development of the spatial database for the Al-Hassa oasis was divided into these types: topographic maps, field survey data and attributes, and documented reports.

Each geographic feature shown in the collected maps is distinguished and classified into points (water springs), lines (roads, irrigation and drainage canals), and polygons (residential areas). Data which were collected directly using a GPS instrument in the field, are tabulated and prepared for data entry and processing. Attributes and documented reports of data collected from different authorities are classified, sorted, and prepared in an electronic form.

The data for groundwater wells (Figure 5) for different periods (1967, 1985, 1998, and 2004)

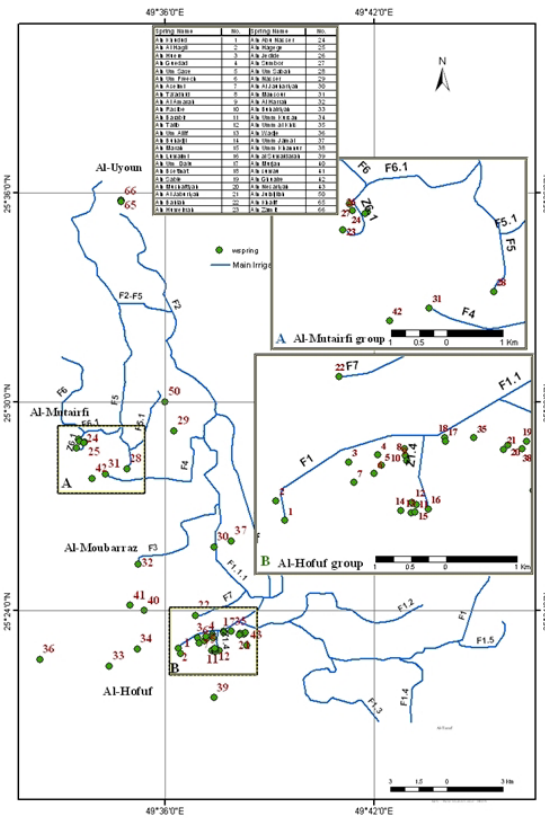

Figure 2 Water springs in the Al-Hassa Oasis.

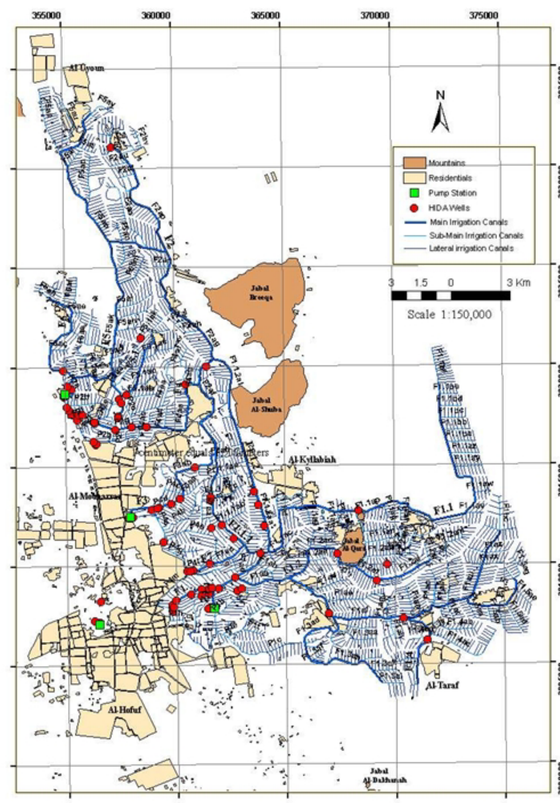

Figure 3. Irrigation system and water wells in the Al-Hassa Oasis

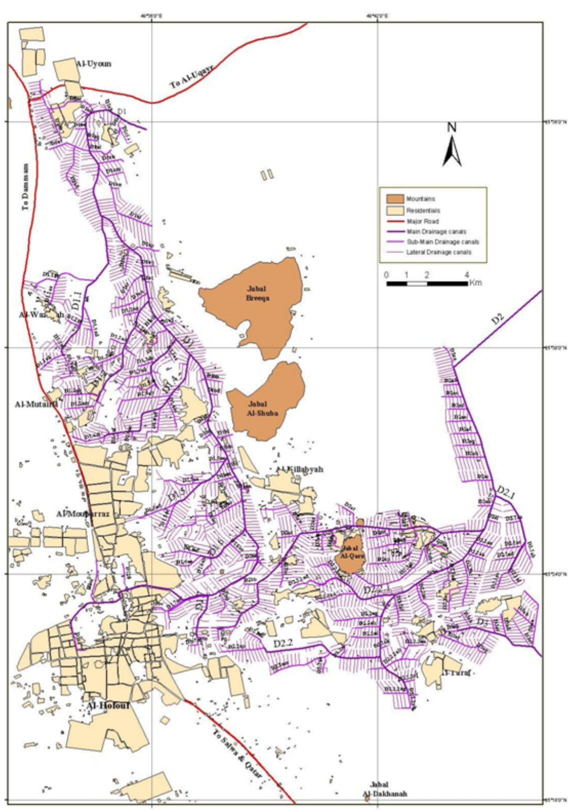

Figure 4. Drainage system & urban areas in the Al-Hassa Oasis.

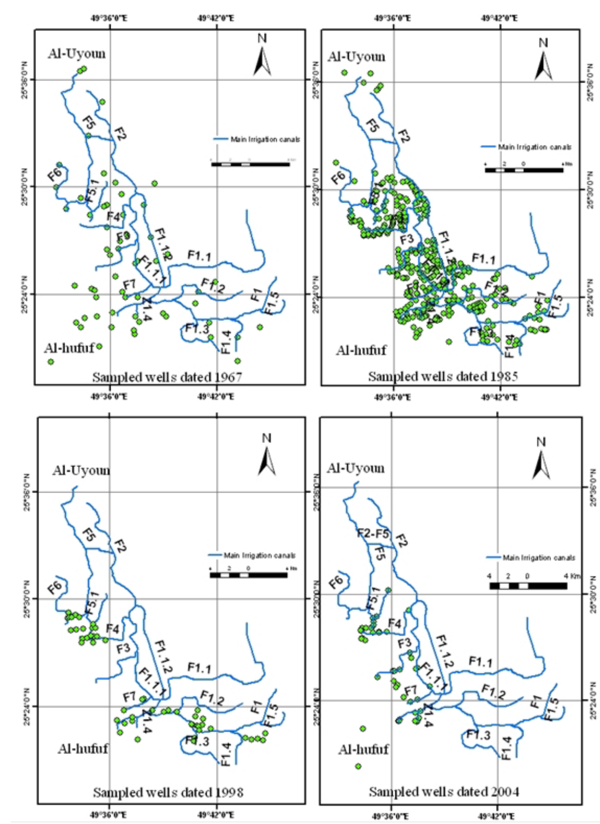

Figure 5. Sampled wells.

were tabulated and transformed to a geodatabase and projected using ArcGIS software in different layers (see Figures 2 to 5). Other attribute data related to geographic features such as name of the canals are entered to the coverage related tables after editing and constructing the topology for all layers using tables management in ArcGIS. A schematic diagram of the procedures is presented in Figure 6.

Map projections are used to represent spherical geographic positions on a flat surface, and ensure that a known relationship exists between locations on the map and their true locations on the surface of the earth. In addition, map projections are usually referenced to the geographic grid system of latitude and longitude in angular units of degrees, minutes and seconds.

The spatial models for the chemical analysis of groundwater were created based on the parameters found in the prepared tables using the Spatial Analyst module in ArcGIS. To predict a value for any unmeasured location, the inverse distance weighted (IDW) method uses the measured values surrounding the prediction location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away.

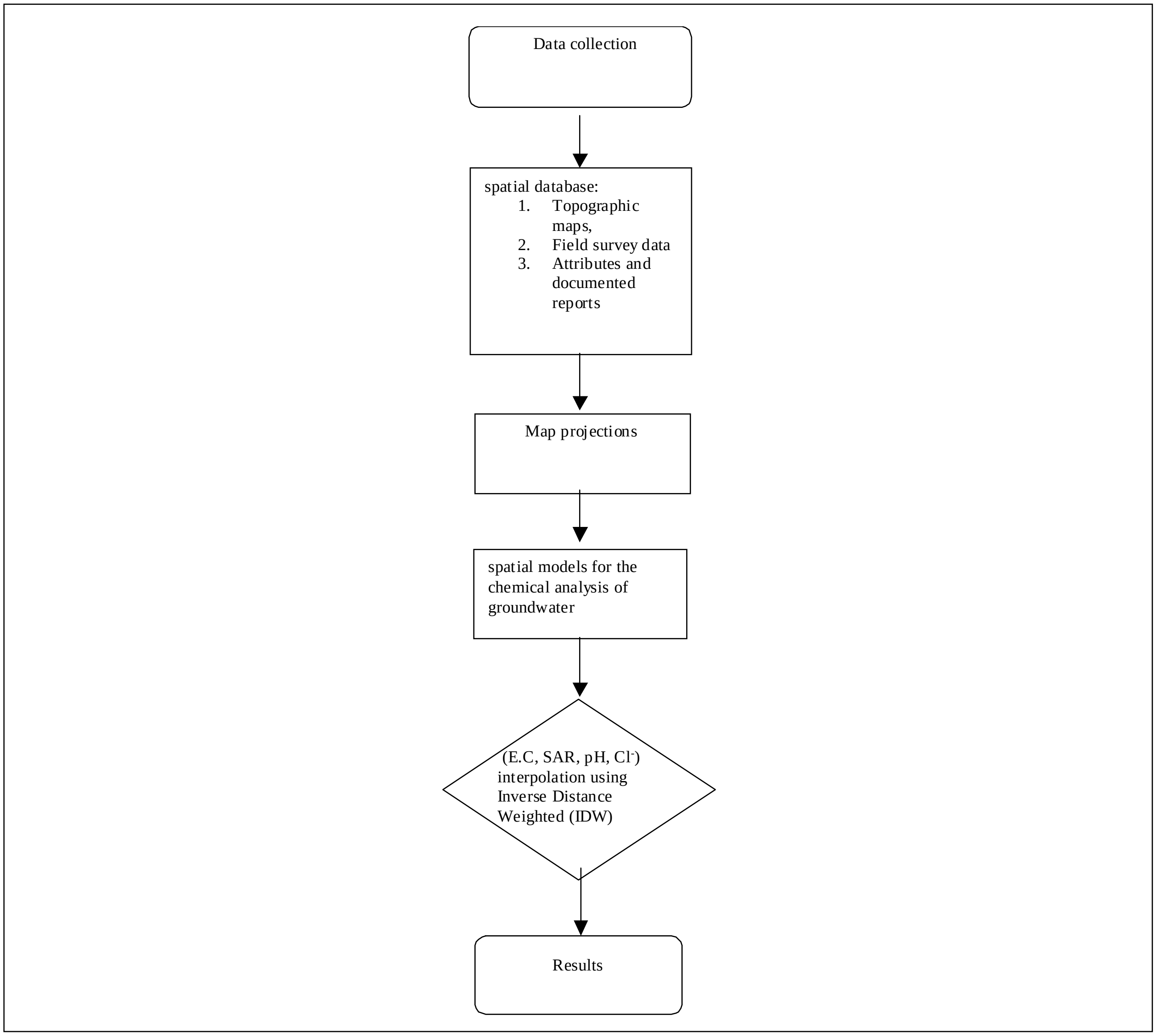

Figure 6. Schematic procedures for spatial modeling.

ArcGIS, programming tools and applications have been developed for the front-end users for searching, downloading, exporting, viewing, analyzing and sharing data. A number of system management tools have also been developed for updating the database. Each parameter (EC, SAR) was interpolated using inverse distance weighting (IDW) with distance equal to 0.0005 DD which represent 50 m.

RESULTS AND DISCUSSION

Figure 7 illustrates the spatial models for salinity of the Neogene aquifer in different years (1967, 1985, 1998 and 2004), while Figure 8 illustrates the spatial models for sodium adsorption ratio (SAR) of the Neogene aquifer for two years (1967 and 1998).

Different water quality maps have been produced using the spatial analyst function of ArcGIS. Several water quality parameters have been selected and their respective maps have been prepared believing that the analytical results would indicate the water quality conditions of the study area.

The resulting maps of EC from spatial modeling of the Neogene water salinity for different years (1967, 1985, 1998, and 2004) are classified into 5 classes, ranging from low to high saline water. EC is a measure of the degree of the mineralization of the water, which is dependent on rock water interaction, and thus the residence time of the water in the rocks.

The salinity maps show that the groundwater salinity increased gradually from 1967-2004 (Figure 7), particularly in the wells towards the east and north of the oasis. EC values ranged from 2.0-2.7 ds/m during 1967 and dominated about 80% of the oasis, while during 2004 about 85% of the oasis wells produced water with EC values ranged from 3.1-4.2 ds/m. The number of working wells has decreased, because some have become unsuitable for irrigation because of poor quality and a drop in groundwater level. This is in agreement with Zubari et al. (1994), where they showed that there were trends in the quality of groundwater in Bahrain with respect to salinity during the period from 1941 through 1992. Their results demonstrated that the groundwater salinity was generally elevated above 2×10^3 mg/l. Specifically, in the period from 1986 to 1992, about 33% of the well water showed a TDS content greater than 4×10^3 mg/l (6.25 ds/m). Moreover, they attributed the change in salinity to the impact of over exploitation on groundwater.

The resulting maps from spatial modeling of the Neogene aquifer SAR show that it has also increased with the time period from 1967 to the recent years due to the deterioration of water quality (Figure 8). During 1967, the SAR of groundwater in the study area did not exceed 10%, However, during 1998 the SAR reached 30% which indicates that groundwater is no longer suitable for irrigation in the area colored in red in Figure 8.

Previous hydrological studies (Al-dakheel and Al-Safarjalani, 2005) show that there was inter-connection between all the water springs of the Al-Hassa oasis. Therefore, withdrawal of water from one of them leads to direct effects on decreasing groundwater level in the neighboring springs, or in the spring water basin. In fact, this was happening in the early 1980s, where there was a dramatic increase in the number of drilled wells tapping the Neogene aquifer and an increase in pumping rate as well. Those two factors led to a large decrease in groundwater level in the entire spring basin and therefore, all springs were dry by the early 1990s. Groundwater depth in the Neogene aquifer was about 0.3 m before 1971 and increased to 2.5 m in 1987. Spring water of the Al-Hassa oasis that was extracted from the Neogene aquifer was categorized as C4-S2 according to the US Soil Salinity Laboratory classifications. This means that the water is highly saline with

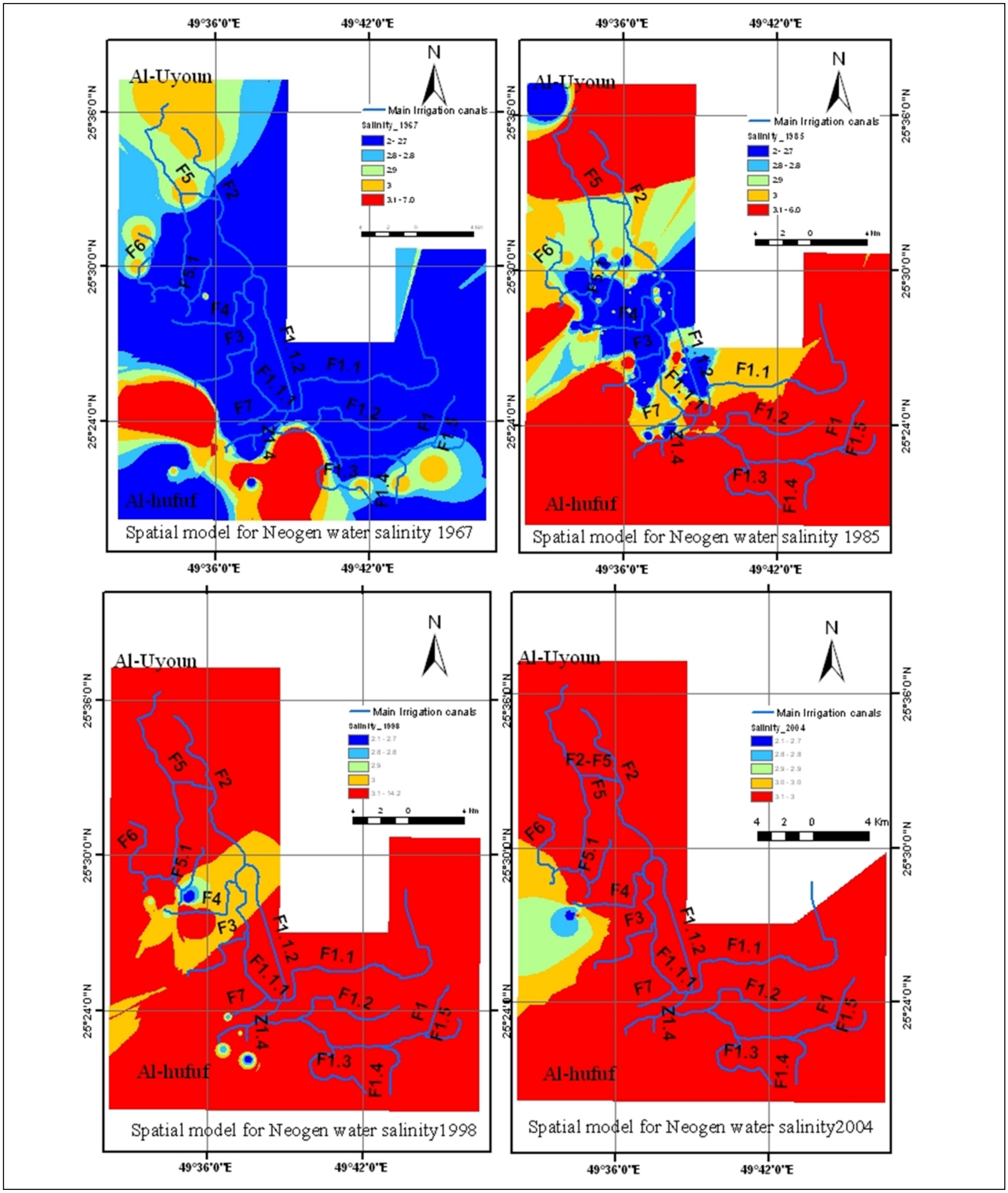

Figure 7. Spatial models of groundwater salinity of the Neogene aquifer.

low alkalinity, hence the total dissolved solids (TDS) ranged from 1520 to 1810 mg/l during the study period (1967- 2004). Al-dakheel and Al-Safarjalani (2005) showed that there was a negative relationship between the decrease in groundwater level and the increase in total dissolved salt concentration.

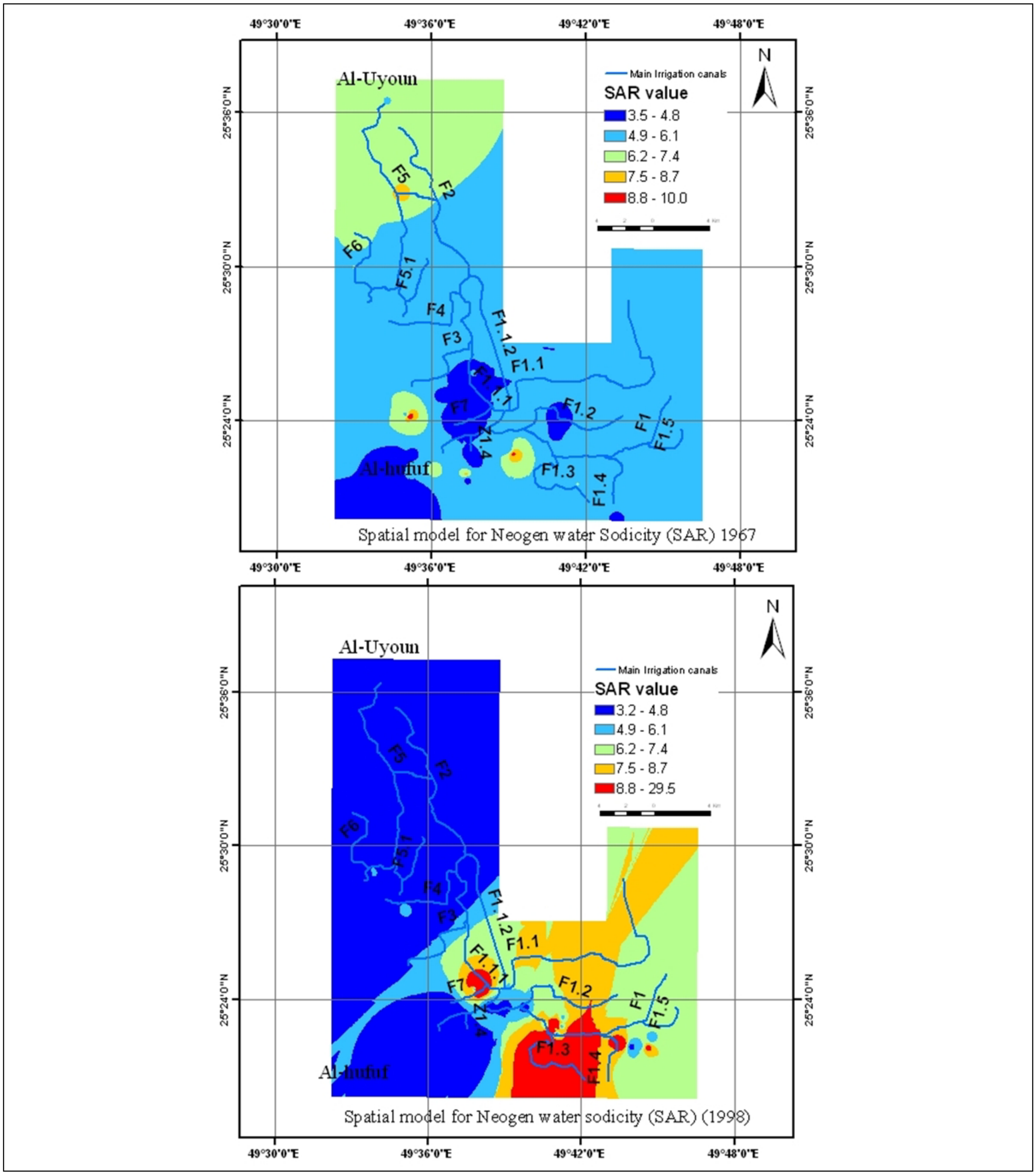

Figure 8. Spatial models for SAR, (1967, 1998), Neogene aquifer.

CONCLUSIONS

The conclusions that can be drawn from this study are:

- Spatial models are important and valuable to predict the groundwater quality in the different sites across the study area and to show the changes of water characteristics for different periods, which gives the decision makers and the planners an overview about the future changes in the water quality of the selected environment. It will also be helpful for the decision maker to take the best decision for the development of the study area. In addition, it will be the main data source for taking a decision about the suitability of a location for digging a new well.

- Considering cost, capacity and portability, GIS is a useful tool for water resources management and sustainability, especially if there is a correct and complete database for water resources, and other features and socioeconomic data in the study area.

- Spatial models are important and valuable to predict the groundwater quality at different sites across the study area and to show the change in water quality over different time periods.

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