Towards sustainable development for groundwater in Al-Hassa and the role of geographic information systems

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Abstract

Water sustainability has the highest priority in all countries, whether developed or developing. Geographic information systems (GIS) technology are gaining importance as useful tools in sustainable water management and development. This paper discusses the use of GIS technology in some areas for sustainable water development and management in Al-Hassa Oasis, KSA, with case examples.

Al-Hassa is one of the largest oases of the world and located in the southern part of the eastern region of Saudi Arabia. The agricultural development in Al-Hassa oasis depends totally on groundwater that occurs in three aquifers. These are from bottom to top, the Um er Radhuma, Khobar-Alat, and Neogene. Recently the policy oriented towards the reuse of drainage water and treated waste water.

Keywords:, GIS, ArcGIS, sustainable development**,** spatial modeling, water quality

Introduction

The solution for providing food security to all people of the world without affecting the agroecological balance lies in the adaptation of new research tools of information technology, particularly GIS and combining them with technology of Remote Sensing. Sustainable water development is one of the prime objectives in all countries in the world, whether developed or developing.

Sustainable development concept has come into common vocabulary since 1990s. Before that it is called conservation or wise use. The sustainable development concept which has been accepted by many politicians and economists is that defined by WCED (world Commission on Environment and Development) in 1987 as: " Development that meet the needs of the present without compromising the ability of future generations to meet their own needs" (Ngo An, 2004)

The efficiency of information technology has increased a lot during the recent 20 years. New tools of collecting, storing, handling, analyzing, and managing the astronomical quantities of information in the form of enhanced images or spatial data have been developed. Geographic Information Systems (GIS), enable planners to conduct more complex and extensive analysis. GIS also facilitate the decision making process at different levels of planning in the various fields of applications especially in natural resources management.

The management of water resources requires the integration of often 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 water resource available 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 it is a resource, which is getting scarcer. The amount of water we need and the availability is unbalanced. With proper water management we could minimize the effect of drought and thus famine being faced by 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, the demand and supply of water. GIS has been very beneficial in mapping and data analysis, and thus greatly aiding in the understanding and decision making in 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.

The study area

Location

Al Hassa oasis is situated some 60 km inland of the Gulf coast (Fig. 1) between 25^{o} 05’ and 25^{o} 40’ N Lat and 49^{o} 10’ and 49^{o} 55’ E Long and 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 red beds and sabkhas. The oasis is about 130 to 160 m above the sea level. East of the oases is the flat Al-Jafura desert floor, which extends with a very low gradient towards the Gulf coast. West of the oases is a flat, hard-rock plateau called the “AsSumman”. Beneath the plateau, west of the oasis, lies the gigantic Al-Ghware oil field, the largest in the world. The hydrogeology of the oasis is strongly influenced by the Ghawar structure laid out by Cretaceous and lower Tertiary tectonics. The north-south-trending anticline west of Al Hassa is 20 to 40 km wide (Hotzl and Zotl, 1978). The lithostratigraphic sequence at Al Hassa is in Al-Syari and Hotzel (1978). South of Al-Hassa is a gravel fan of delta of Wadi As Sah’ha (Pliocene/Pleistocene) down to Ar Ruba’ Al-Khali in the south to near Qatar (Powers et al., 1966).

Al-Hassa Climate

The aridity of climate is characterized by potential evapotranspiration (PE), which far exceeds precipitation in the region. The similarity between the PE and the temperature curves indicates that temperature has a strong influence upon evaporation (Hoyningen-Huene (1979).

Water Resources

The water of Al Hassa oasis discharges from a karistified neogene aquifer belonging to the Ummer-Raduma formation. This stratum occurs at a depth of some 280 m with a thickness of approximately 320 m (Al-Sayari and Zotl, 1978). There are 32 main springs in Al Hassa oasis, situated on a line connecting Hofuf, Mubarraz, and Mutairifi on the western border of the oasis Fig. (2). The springs produce a total discharge of 4.72 m^3 s-1. Approximately 140 less important springs and 560 hand dug or drilled wells are dispersed over the entire oasis, producing a total discharge of approximately 0.68 m^3 s-1(Von, 1979; Al-Hassa Irrigation and Drainage Authority (HIDA), 1981), HIDA wells are shown in Fig. (3).

Presently, pumps were dug in springs due to substantial drops in piezometric pressure 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 water discharges into two evaporation lakes, which are located north and east of the oasis. Some drainage water is mixed with spring water and reused for irrigation.

Procedures and Methods

Data Collection

The data collected for the development of the spatial database for Al-Hassa oasis was divided into four main data types: a-Topographic maps, b-Field survey data and d-Attributes and documented reports.

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

Data Preparation and Implementation

Data Preparation

The data for groundwater wells for different periods (19967, 1985, 1998, and 2004) are tabulated using spreadsheets (example as in Table (1)). After that the tables are transformed to a geodatabase and projected using ArcGIS software in different layers. Some of these layers are listed in Table (2), Figures from (2) to (5). Other attributes 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 table's management in ArcGIS.

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.

Data Implementation and Modeling

The spatial models for the chemical analysis of groundwater and soil were created depending on the parameters found in the prepared tables using Spatial Analyst module in ArcGIS. To predict a value for any unmeasured location, inverse distance weighted (IDW) will use 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.

Each parameter (E.C, SAR, pH, Cl^-) was interpolated using Inverse Distance Weighted (IDW) with distance equal to 0.0005 DD which represent 50 m. Figure (6) illustrate the spatial models for salinity of the Neogene aquifer in different years (1967, 1985, 1998 and 2004). While (7) illustrate the spatial models for sodium adsorption ratio (SAR) of the Neogene aquifer in two years (1967 and 1998).

In order to see the effects of the irrigation water quality on the soil salinization and crop productions in Al-Hassa oasis the following procedures are applied:

- Soil salinity was determined in 1:3 extract using EC meter for about 1000 soil samples across the oasis.
- Kriging methods are used to obtain spatial maps of soil salinity from soil samples, based on a coarse grid over the area of study, Fig. (8).
- Spatial estimation methods are extended for mapping the date palm yield. The resulted yield map is shown in Fig.(9).

Tools and Applications

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.

Results and Discussion

- Water quality

These spatial models will be important and valuable to predict the ground water quality in the different sites across the study area and to showing the changes of water characteristics along the 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 pest 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 (x, y) for digging a new well.

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

- **Total Dissolved Solids (TDS) or Electrical Conductivity (EC) Maps**

The resulted maps from spatial modeling to the Neogene water salinity (EC/ds/m) for different years (1967, 1985, 1998, and 2004) are classified into 5 classes, ranged from low to high saline water. The salinity maps show that the groundwater salinity increased gradually across the time from 1967 up to now, refers to Fig. (6) Especially in the wells towards the east and north of the oasis. The number of the working wells decreased, because some of which became unsuitable for irrigation and for decreasing of groundwater level.

- **Sodium Adsorption Ratio (SAR)**

The resulted maps from spatial modeling to the Neogene sodium ratio (SAR) show that the SAR, also increased with the time period from 1967 to the recent years due to the low of water quality, refers to Fig. (7).

Conclusions

Inter-agency co-operation and relationship is essential to sustainability of any development. The number of errors can be reduced over time if there is feedback from users of the database and integration between all concerned authorities of water resources management. 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 will be important and valuable to predict the ground water quality in the different sites across the study area and to showing the changes of water characteristics along the different periods.

There are closely relationship between the results obtained from water quality maps and the maps of soil salinity and yield. There is a significant effect of the irrigation water quality on the soil salinization and the yield production.

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Table (1) Chemical analysis of sampled wells 1967 (Italconsolt,1967)

ID	X_dd	Y_dd	TDS	Na_K_meq	Mg_meq	Ca_meq	CI_meq	SO_meq	HCO3_meq	SAR
1	49.614444	25.397222	1400	10.52	4.52	7.48	11.70	7.49	3.56	4.3
2	49.611667	25.402222	1405	10.96	4.52	7.73	12.01	7.81	3.69	4.4
3	49.626389	25.397222	1340	10.70	4.52	7.53	11.90	7.56	3.47	4.4
4	49.568889	25.373611	1290	10.09	4.36	7.38	11.05	6.89	3.72	4.2
5	49.576389	25.377778	1225	9.61	3.86	6.94	10.29	6.14	3.20	4.1
6	49.605000	25.503611	1355	12.04	3.86	7.33	12.41	6.14	3.52	5.1
7	49.641944	25.502778	1330	12.04	3.95	7.04	12.83	6.14	2.79	5.1
8	49.631944	25.482778	1410	11.56	4.03	7.78	12.66	7.04	3.67	4.8
9	49.654167	25.437500	1410	12.09	4.11	8.23	13.00	7.56	3.70	4.9
10	49.612500	25.473889	1410	12.04	4.11	7.83	12.86	7.29	3.75	4.9
11	49.545000	25.330556	1280	9.35	4.28	7.09	10.29	6.14	3.28	3.9
12	49.611389	25.493056	1410	11.78	3.86	7.24	12.41	6.14	3.20	5.0
13	49.597222	25.483333	1400	11.35	3.86	7.28	12.41	6.04	3.28	4.8
14	49.581944	25.473611	1390	11.74	3.95	7.19	12.41	6.14	3.20	5.0
15	49.597222	25.441667	1410	12.22	4.03	8.08	12.80	7.58	3.61	5.0
16	49.609722	25.449444	1410	12.22	4.03	8.08	12.80	7.53	3.56	5.0
17	49.616111	25.455000	1410	11.43	3.86	7.28	12.41	6.04	3.36	4.8
18	49.590278	25.351389	1220	8.17	4.11	6.59	10.01	5.00	3.20	3.5
19	49.623611	25.428333	1380	10.70	4.60	7.98	11.87	7.31	3.65	4.3
20	49.643056	25.430556	1390	11.74	4.44	7.58	12.07	7.60	3.59	4.8
21	49.682500	25.402222	1340	10.74	4.28	7.04	11.70	6.97	3.03	4.5
22	49.698611	25.411111	1360	11.91	4.28	7.58	12.21	7.70	3.56	4.9
23	49.693056	25.373611	1350	11.78	4.60	7.38	12.21	7.70	3.41	4.8
24	49.623056	25.362500	1350	9.91	4.19	7.19	10.86	6.76	2.79	4.2
25	49.550278	25.499722	1640	14.78	3.86	7.83	15.37	6.14	2.79	6.1
26	49.623611	25.379167	1560	11.96	5.18	8.18	13.82	8.37	3.41	4.6
27	49.567222	25.407500	1615	13.91	3.95	7.88	14.38	6.14	3.52	5.7
28	49.588056	25.379167	1640	11.91	5.18	8.78	12.83	6.14	4.26	4.5
29	49.594444	25.512500	1440	12.09	4.03	7.88	13.00	7.26	3.72	5.0
30	49.559722	25.479167	1500	11.91	3.86	7.33	12.97	5.41	3.36	5.0
31	49.573333	25.489444	1430	12.04	4.11	7.98	12.86	7.29	3.72	4.9
32	49.638333	25.452778	1430	12.35	4.11	8.13	13.00	7.26	4.20	5.0
33	49.612500	25.473889	1450	12.26	3.95	8.08	13.11	7.41	3.72	5.0
34	49.597222	25.462500	1430	12.96	4.60	8.03	13.23	7.56	3.82	5.2
35	49.600000	25.436667	1470	12.48	4.19	8.33	13.31	7.91	3.62	5.0
36	49.608333	25.442500	1430	12.26	4.11	8.18	13.00	7.41	3.92	4.9
37	49.626389	25.430556	1455	11.61	4.03	7.33	12.83	5.41	3.36	4.9
38	49.719444	25.337500	1560	11.74	5.10	7.63	13.62	7.14	3.41	4.7
39	49.719444	25.359722	1650	14.35	5.59	8.08	17.37	7.14	3.39	5.5
40	49.680000	25.391667	1460	12.00	4.93	8.03	13.25	7.85	3.41	4.7
41	49.583333	25.404722	1640	14.35	4.44	8.63	14.78	9.03	3.70	5.6
42	49.605556	25.416667	1480	11.48	4.52	7.83	12.66	7.66	3.61	4.6
43	49.572778	25.368889	2110	14.04	6.74	11.03	17.20	10.00	4.26	4.7
44	49.572222	25.607500	1690	15.17	4.19	8.53	16.81	7.78	3.47	6.0
45	49.575833	25.609722	1800	16.70	4.52	8.73	18. 27	8.39	3.38	6.5
46	49.552778	25.520278	1735	16.17	4.28	8.08	16.92	6.97	2.54	6.5
47	49.580556	25.547222	2120	20.43	5.18	9.18	20.87	8.95	3.28	7.6
48	49.594444	25.481389	1750	13.83	5.76	9.53	15. 23	9.68	4.10	5.0
49	49.593056	25.579167	2120	19.09	5.26	8.48	21. 29	6.04	2.87	7.3
50	49.740278	25.369444	2050	16.09	7.07	7.73	22.28	5.00	2.95	5.9
51	49.694444	25.359722	1730	16.13	5.67	8.13	19. 23	7.26	3.31	6.1

52	49.652778	25.379167	3110	30.56	10.77	12.18	29.67	17.96	5.08	9.0
53	49.601944	25.369167	2220	18.56	6.33	9.23	22.00	6.04	3.52	6.7
54	49.649444	25.381944	2210	14.83	7.65	11.43	20.59	8.95	2.62	4.8
55	49.627222	25.373889	2090	11.56	6.58	10.13	21.15	6.76	2.79	4.0
56	49.587500	25.397222	1680	15.91	4.28	8.28	17 . 06	7.97	3.29	6.3
57	49.585833	25.403333	4300	39.30	11.84	19.36	39.59	24.65	6.00	10.0
58	49.622222	25.366111	3250	27.26	8.96	16.97	29.89	19.61	3.33	7.6
59	49.602778	25.382778	2000	16.43	6.33	10.18	20.02	9.39	3.69	5.7

Table (2) GIS & geodatabase layers

Layer name	Structure	Type	Description
Springs	Vector	Point	The old water springs in Al-Hassa
Wells_67	Vector	Point	Sampled and tested wells 1967 (ItalConsolt)
Wells_85	Vector	Point	Sampled and tested wells 1985
Wells_98	Vector	Point	Sampled and tested wells 1998
Wells_04	Vector	Point	Sampled and tested wells 2004
M_Irr	Vector	Line	Main irrigation canals (irrigation system of HIDA)
SubM_Irr	Vector	Line	SubMain irrigation canals (irrigation system of HIDA)
L_Irr	Vector	Line	Lateral irrigation canals (irrigation system of HIDA)
M_Dr	Vector	Line	Main drainage canals (irrigation system of HIDA)
subM_dr	Vector	Line	Submain drainage canals (irrigation system of HIDA)
L_Dr	Vector	Line	Lateral drainage canals (irrigation system of HIDA)
Residentials	Vector	Polygons	Urban area (Towns & Village)
EC_Neog67	Raster	Grid	Spatial model foe water salinity Neogene Aq. 1967
EC_Neog85	Raster	Grid	Spatial model foe water salinity Neogene Aq. 1985
EC_Neog98	Raster	Grid	Spatial model foe water salinity Neogene Aq. 1998
EC_Neog04	Raster	Grid	Spatial model foe water salinity Neogene Aq. 2004
SAR_Neog67	Raster	Grid	Sodium adsorption ratio model Neogene Aq. 1967
SAR _Neog98	Raster	Grid	Sodium adsorption ratio model Neogene Aq. 1998
Palm_Yield	Raster	Grid	Spatial model for predicted yield 2000
Soil_EC_U	Raster	Grid	Spatial model for soil salinity untreated areas 2004
Soil_EC_T	Raster	Grid	Spatial model for soil salinity treated areas 2004

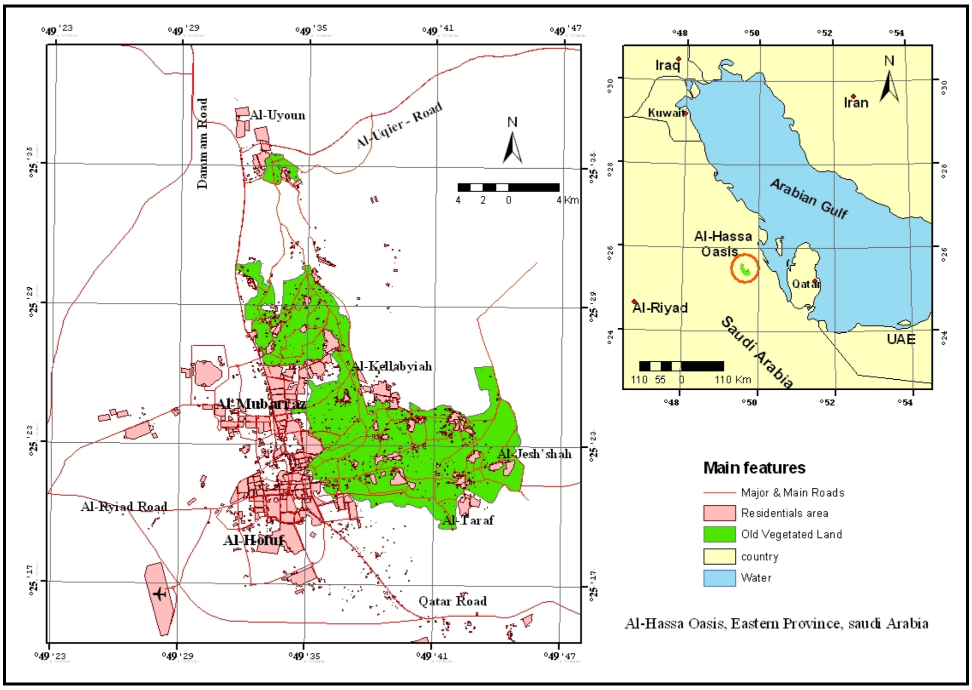

Fig. (1) The location of Al-Hassa Oasis, Eastern Province, KSA

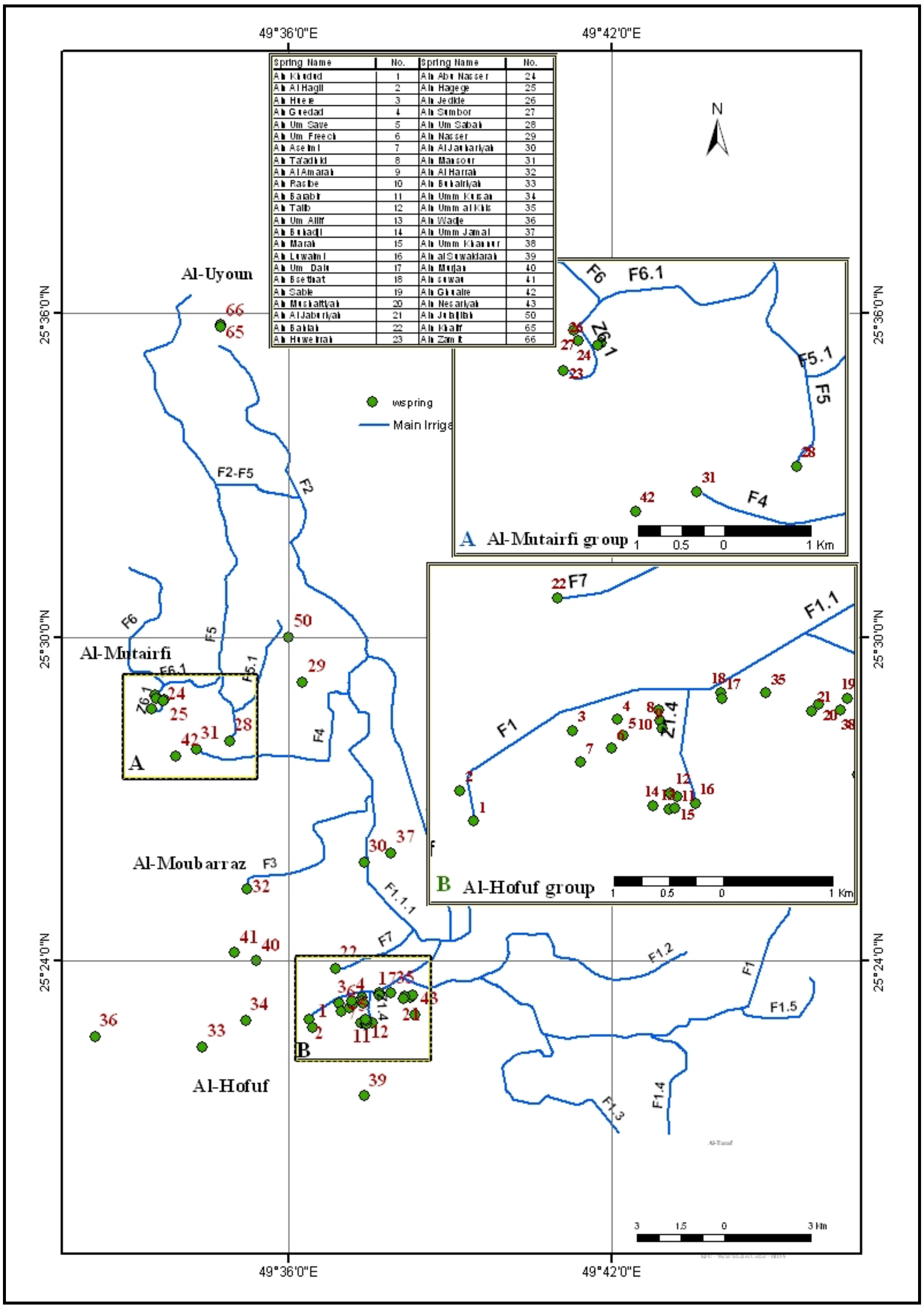

Fig. (2) water springs in Al-Hassa Oasis

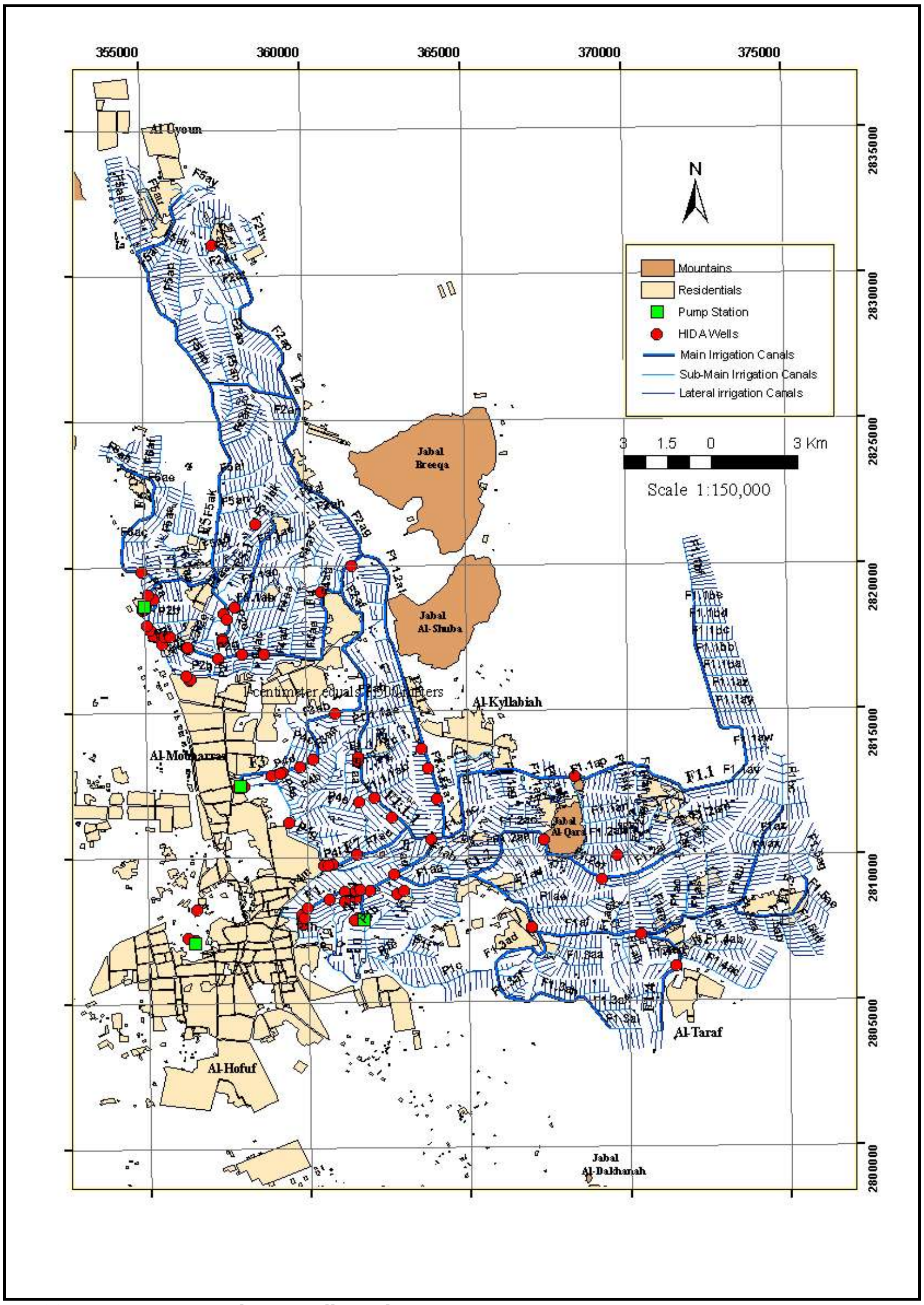

Fig. (3) Irrigation system and water wells in Al-Hassa Oasis

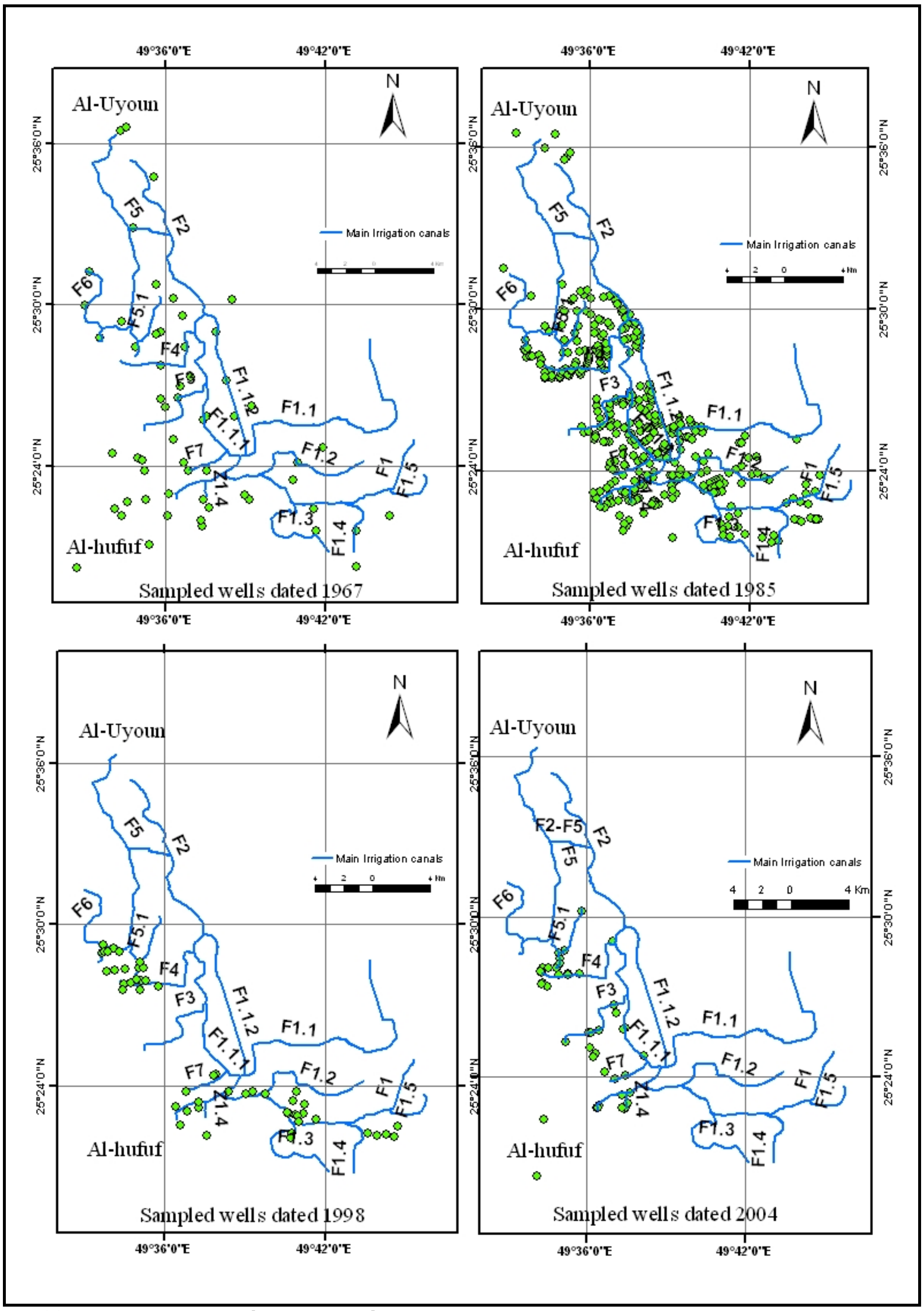

Fig. (4) Drainage system & urban areas in Al-Hassa Oasis

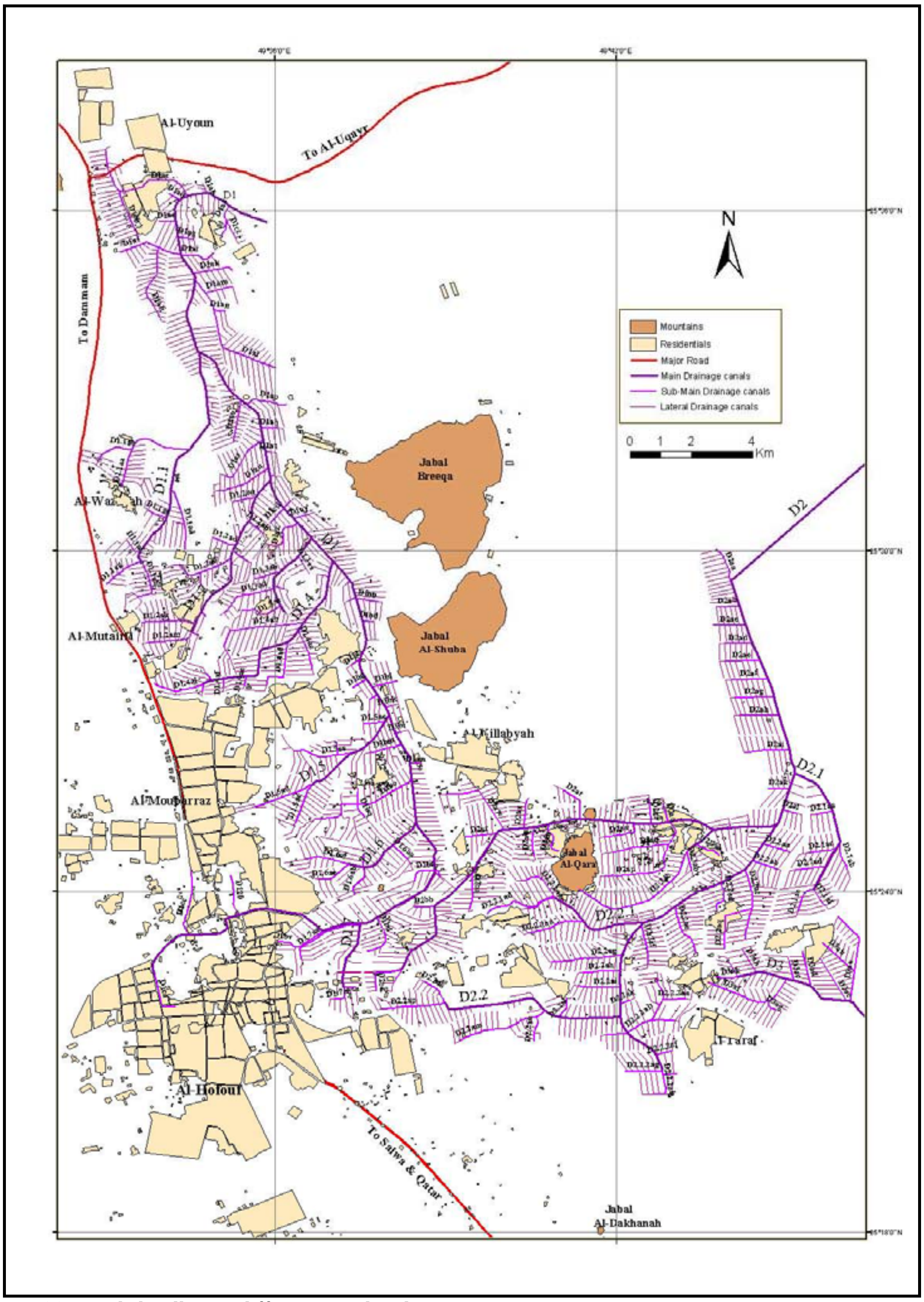

Fig. (5) Sampled wells in a different periods, Al-Hassa Oasis

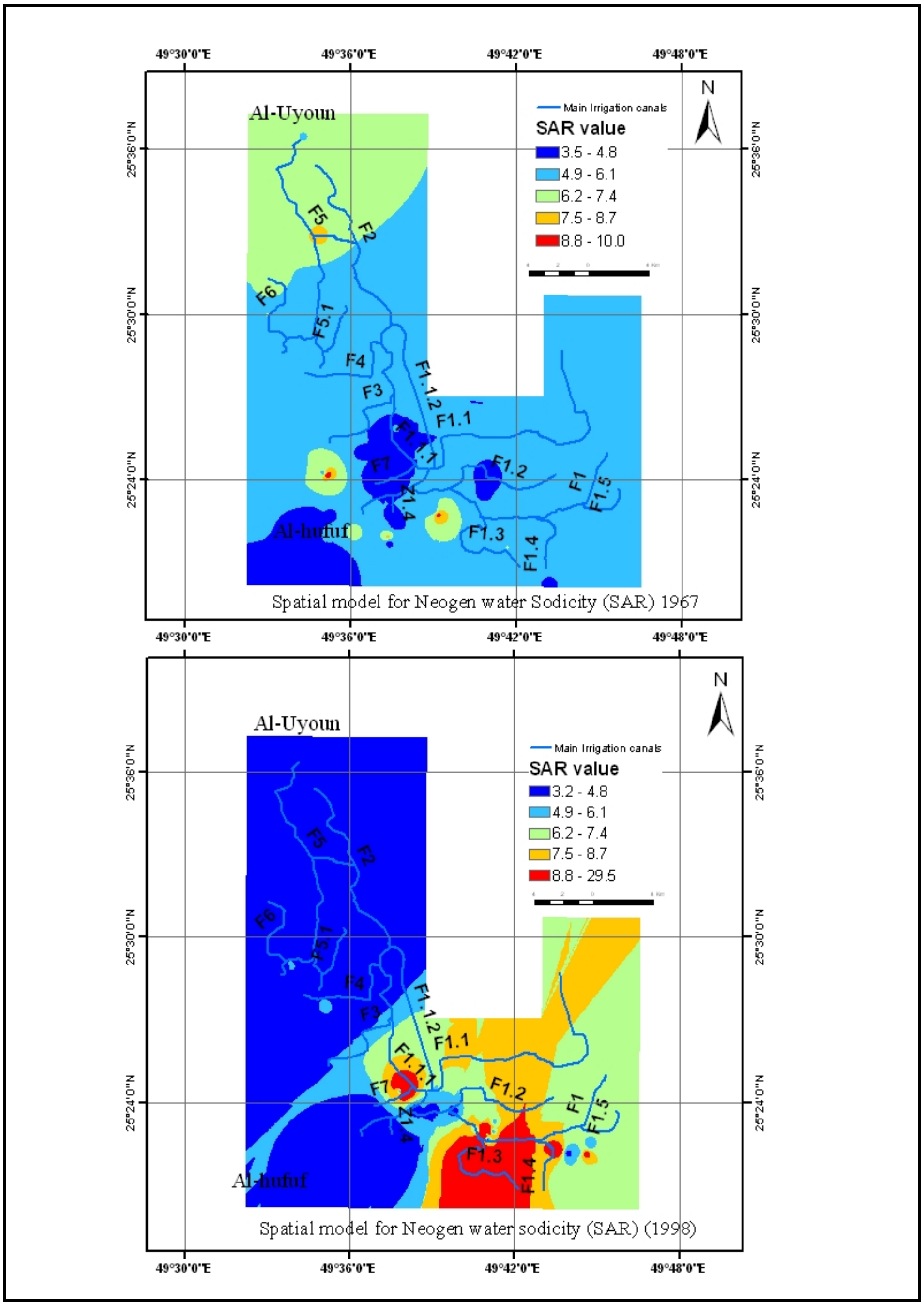

Fig. (6) Spatial models of salinity in a different periods, Neogene aquifer

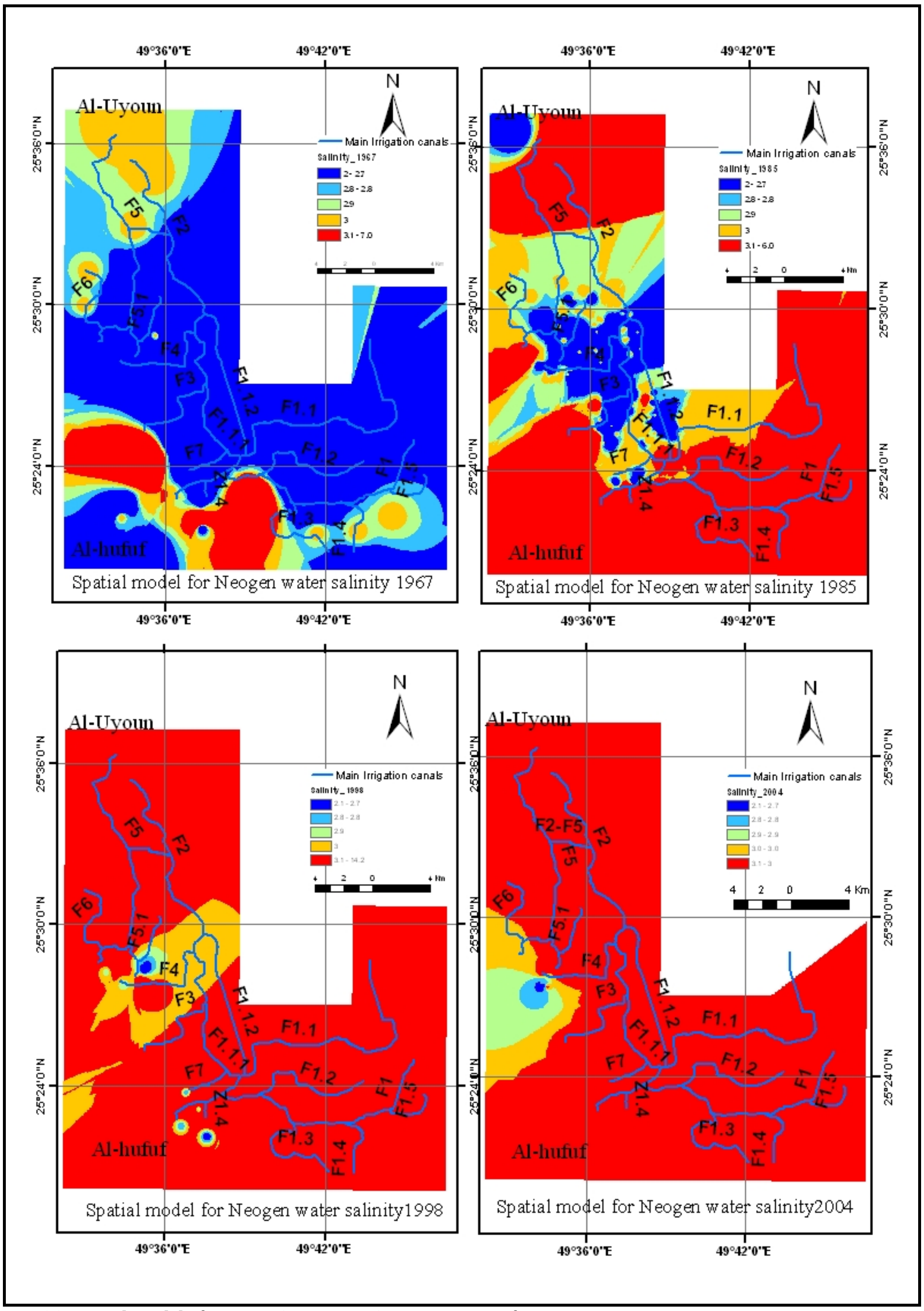

Fig. (7) Spatial models for SAR, (1967, 1998), Neogene aquifer

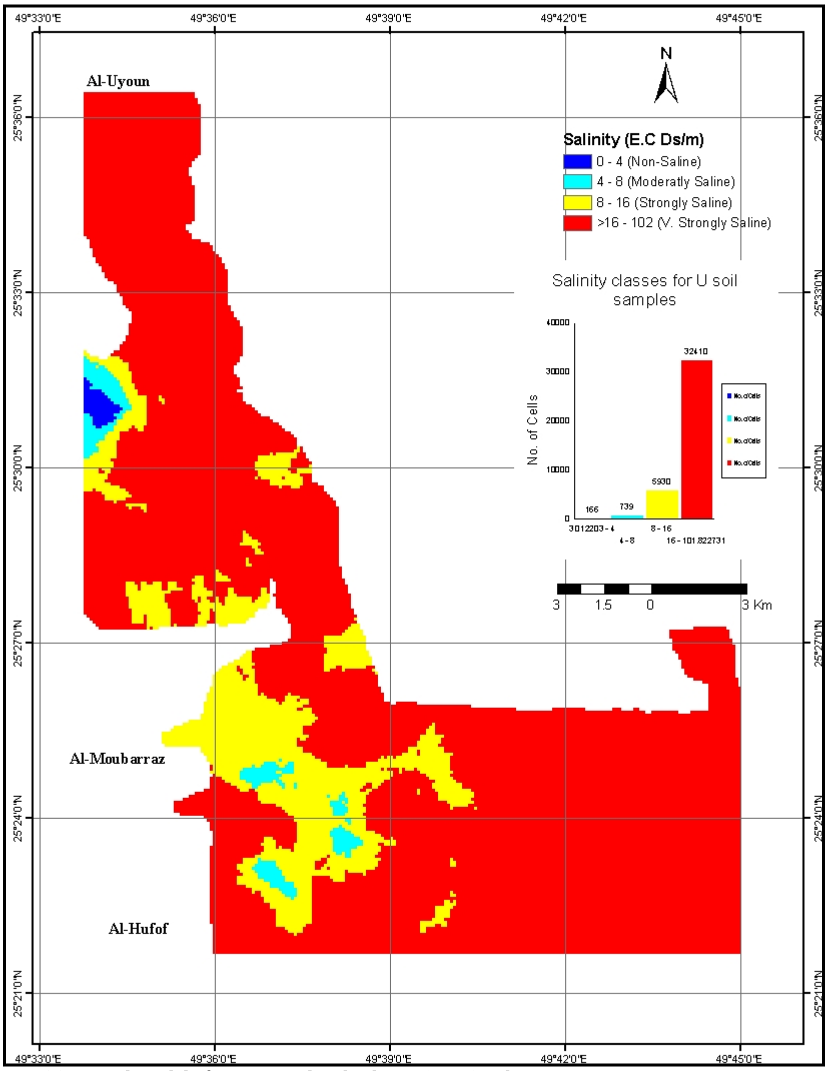

Fig. (8) Spatial models for untreated soil salinity (2004), Al-Hassa

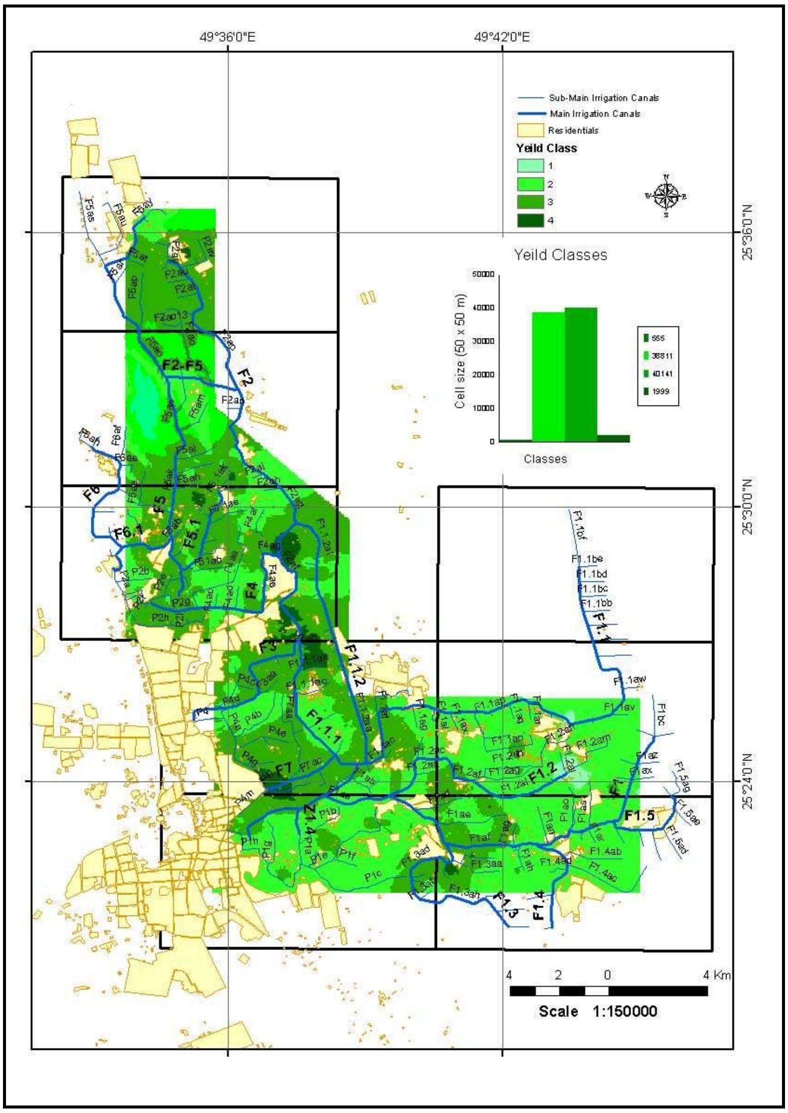

Fig. (9) Spatial models for predected yeild (2002), Al-Hassa

التنمية المستدامة للمصادر المائية بواحة الإحساء ودور نظم المعلومات الجغرافية والنمذجة المكانية في إدارتها

يوسف يعقوب الدخيل ومسعود عبد العاطي مسعود

مركز الدراسات المائية – جامعة الملك فيصل – السعودية

قامت الدولة على مدى أكثر من عدة عقود بالكثير من مشاريع استكشاف وتقييم خزانات المياه الجوفية وأنشأت الكثير من مشاريع الحصاد المطري وتغذية المياه الجوفية ومحطات التحلية للمياه المالحة، ومحطات المعالجة الثلاثية لمياه الصرف الصحي، وهذه الجهود تدخل في متطلب المعرفة التامة لمصادر المياه العذبة والبدائل المتاحة بالدولة، وهو المتطلب الأول لتحقيق التنمية المستدامة لتغطية الطلب الشديد علي المياه العذبة للأجيال الحالية والأجيال القادمة، في ظل الظروف المناخية الحالية من الجفاف وقلة الأمطار وارتفاع درجة الحرارة، وفي ظل الزيادة في معدل السكان. وتمشيا مع هذه السياسة العامة بالانتقال من الطرق العادية لحفظ ومعالجة البيانات إلي الطرق ألآلية، قامت جامعة الملك فيصل ممثلة بمركز الدراسات المائية بإنشاء وحدة الدراسات المكانية المتقدمة ونظم المعلومات، من أجل توفير قاعدة البيانات المكانية ونماذج التنبؤ الرياضية ونظم المعلومات لمعرفة أثر بدائل الإدارة على المخزون المائي (كما وكيفا) وهي المتطلب الهام لتحقيق التنمية المستدامة.لقد تم بناء نظام معلومات وتغذيته بمواقع الآبار المنتجة وكميات ونوعية المياه المستخرجة وفي ثلاث فترات متباعدة (1967م، 1983م، 2004م)، لخزانات المياه الجوفية في واحة الإحساء (النيوجين – الخبر – وأم رضمة) لدراسة مدى التغير الكمي والنوعي لمياه هذه الخزانات الرئيسية في الواحة، ودراسة تأثير هذا التغير علي الأنشطة البيئية المختلفة، واقتراح الحلول والبدائل المتاحة والتي يجب توافرها لضمان العودة للوضع الآمن لهذه الثروة الوطنية.والهدف من بناء هذه القاعدة ونظام المعلومات تحقيق المتطلبات الآتية :

- إمكانية التحديث المستمر لقاعدة البيانات وتتبع التغير الكمي والنوعي مع تغير الزمن.
- سهولة الاستخدام والحصول علي المعلومات في صور مختلفة(نصية، بيانية وخرائط) بواسطة صناع القرار والباحثين ومهندسي الري والزراعة.
- الربط وتحقيق التكامل بين البيانات المختلفة لزيادة القدرة على التحليل واتخاذ القرار المناسب.
- القدرة علي التنبؤ بحالة المياه الحالية والمستقبلية باستخدام نماذج التنبؤ وتحديد معدلات السحب الآمنة لتجنب استنزافها او تلوثها وإيجاد الحلول المناسبة.