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Spatial Decision Support System for Drinking Water Quality Monitoring and Evaluation in Al-Hassa

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Abstract: Drinking water resources at Al Hassa area are: bottled water, private purification stations (PS) for groundwater and municipality water supply. The water provided by municipality is not suitable directly for drinking, because of its high content of total dissolved solids. Most people at Al Hassa are using the purified water from private purification stations, as bottled water is affordable only to the rich. There are 45 purification stations at Al Hassa region, all of which used Reverse Osmosis (RO) techniques for water purifications. The aim of this paper is to establish a decision support system based on Geographic Information System (GIS) called, drinking water spatial decision support system (DWSDSS) to manage the available data for the private purification stations (location, water source, purification equipments, etc.). Moreover, this system will provide full details about the quality and the quantity of the produced drinking water from these stations. Nowadays, the use of GIS and spatial decision support system (SDSS) are proved to be effective techniques in evaluating spatial data, disseminate information and provide new perspective to problems associated with water resources. In this respect, water samples from 45 private purification stations have been collected, one sample from the source and another sample from the purified water and have been analyzed for their water quality according to the criteria of WHO for drinking water. Different layers of the base map for Al Hassa were implemented from SPOT satellite image using ERDAS Imagine and ArcGIS 9.3. Purification station positions were collected using Trimble ProXR GPS. The spatial and non-spatial data for the PS were tabulated and entered to the geo-database. The results indicate that 95% of the produced drinking water meets the criteria of WHO. On the other hand, 5 % needs some improvement of the membranes of RO units and as well of the chemicals used at theses stations to meet the WHO standards. The results can be visualized through a user interface in different forms as: maps of multi-layers, tables, query windows, map of charts and a suitability map. The results of this study can be considered as a base for continuous monitoring and evaluation for purification stations at Al Hassa.

Key words: Water quality conservation · Purification Station · GIS · SDSS · DWSDSS

INTRODUCTION

Water is an indispensable and irreplaceable prerequisite for life. To cope with the increasing demands, pressures and vulnerabilities placed on hydrologic systems, new concepts, methods and evaluations of water resources are being defined. These concepts and policies integrate socioeconomic and sociopolitical components with new technologies, like GIS, to manage water resources across boundaries. The use of GIS provides a unique tool to evaluate spatial data, disseminate information and provide new perspective to problems associated with water resources.

A fundamental problem in water quality assessment is the development and implementation of the analysis tools. One has to perform a series of steps such as data mining, map generation and simulating and interpreting models, [1].

A decision support system (DSS) can be viewed as “an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured problems” [2]. In the field of water management there is an increasing number of DSS available. The management and planning of drinking water supply is an issue that affects many different organizations and authorities. In this context a DSS can be very useful, not only as a tool for optimizing the use of resources, but also for improving the process of communication and negotiation among and within the concerned parties. By integrating GIS and decision

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support systems an improvement of access to information can be achieved. “Decision makers may become active participants in a regional planning analysis, rather than selectors among a few, preplanned alternatives” [3,4]. Spatial Decision Support Systems (SDSS) provide the integrated environment for solving the decision-making problems in water and environment management related to spatial and analytical analysis with wide range of functions. Geographical Information Systems (GIS) are commonly used for the analysis of spatial problems, while numerical and optimization models are used in the decision problem solving and both of these may be integrated into a user interface to form a SDSS. [5,6].

All drinking-water systems that are required to provide a minimum level of treatment must have a treatment process that consists of disinfection as a minimum, if the system obtains water from a raw water supply which is ground water. Effectiveness of the provided treatment must be adequately monitored. Effective disinfection of adequately filtered influent water or raw water of suitable quality can be accomplished by either chemical or physical means such as the use of chlorine, chlorine dioxide, ozone or ultraviolet light. However, the disinfection processes will not be as effective on influent waters of inferior quality. For ground water which is not under the direct influence of surface water, Ultra Violet (UV) light is acceptable as a primary disinfection process, provided that the UV reactor’s 254nm-equivalent UV pass through dose of at least 40 mJ/cm^2 is maintained throughout the life time of the lamp. [7,8]; At Al-Hassa there are three sources of drinking water, the bottled water, private purification stations for groundwater and municipality water supply. The municipality water is not suitable for drinking, because the high rate of total dissolved solids (TDS's), some peoples used special filtration equipment and using it for drinking. Options such as bottled water are only affordable to the rich. Most people's are using the purified water from private purification stations. These stations need continuous monitoring for water quality evaluation.

Purified Water is water obtained by distillation, ion-exchange treatment, reverse osmosis, or other suitable process. It is pre-pared from water complying with the regulations of the U.S. Environmental Protection Agency (EPA) with respect to drinking water. It contains no added substances.” [9].

Observation is an important element in the development of strategies for incremental improvement of the quality of drinking-water supply services. It is important that strategies be developed for implementing surveillance, collating, analyzing and summarizing data and reporting and disseminating the findings and are accompanied by recommendations for remedial action. Follow-up will be required to ensure that remedial action is taken. [10].

Study Area: The study area encompasses all of Al-Hassa cities and villages. Al-Hassa lies between: 49° 33’ 42”E-49° 34’ 12”E and 25° 27’ 25”N-25° 28’N Figure 1. The population of Al-Hassa at 1415 H reached

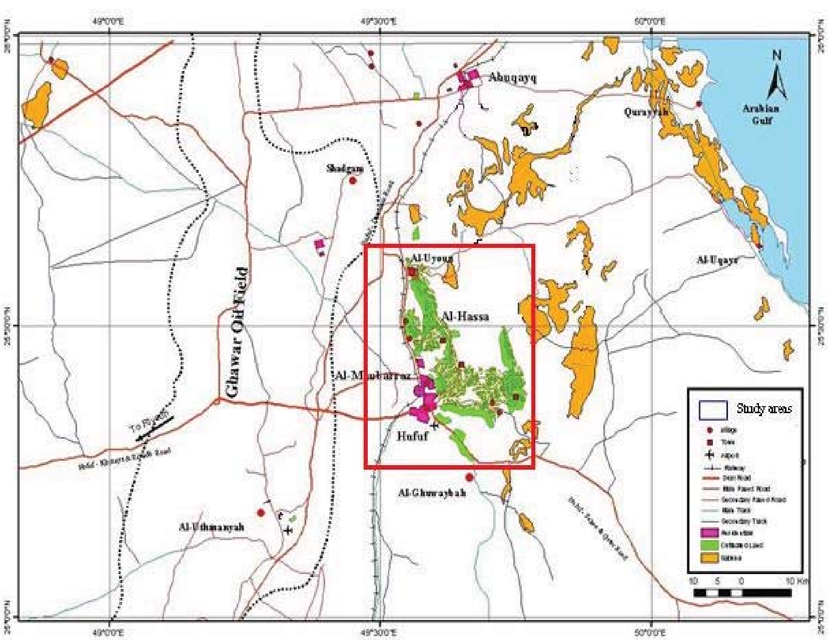


Fig. 1: Study area of Al-Hassa cities and villages

to 790,000, while at 1425 H the population reached to 1,119,413. There are 5 Cities in Al-Hassa Oasis (Al-Hofuf, Al-Mubarraz, Al-Jafer, Al-Omran and Al-Uyoun), 22 Villages and other 55 residential communities called Hejrah (small village).

The aim of this paper is to establish a decision support system based on GIS (drinking water spatial decision support system (DWSDSS) to manage the available data for the private purification stations (location, water source, purification equipments, etc.).

MATERIALS AND METHODS

The GIS software used in this project was ArcGIS (version 9.2) and ERDAS Imagine (Version 8.6) as image processing software. The used GPS is a Trimble GPS system hardware, which made of 8-channel GPS/MSK Beacon Pro XR receiver, TDC1 data logger, Integrated GPS/Beacon Antenna and Camcorder Batteries. The Trimble GPS system software's are: (1) TDC1 Asset Surveyor software (version 3.30) used to navigate and collect GPS field data and (2) Pathfinder Office software used to view, edit and plot data and export data to GIS.

In order to fulfill the research objectives, the methodology is carried out through the following tasks:

- Survey and data collection
- A detailed map for Al-Hassa
- Water sample analysis
- Database design and GIS implementation
- Multi-criteria for water quality evaluation

Survey and Data Collection: A list of the registered drinking water purification stations (WPS's) in Al-Hassa region is received from the environmental health department, Al-Hassa Municipality. The authors start collection of the required data and water samples from each purification station (PS). Figure 2 shows one of this purification stations as an example of the Reverse Osmosis (RO) purification equipment used in those stations. The position of the PS has been collected using the Trimble ProXR Global Position System (GPS) and the required data for each PS were recorded.

Plastic bottles are used for the collection of water samples. The water samples have been transferred directly to the water studies center (WSC) laboratory and stored in a cooled room until analyzed within a short period of time.

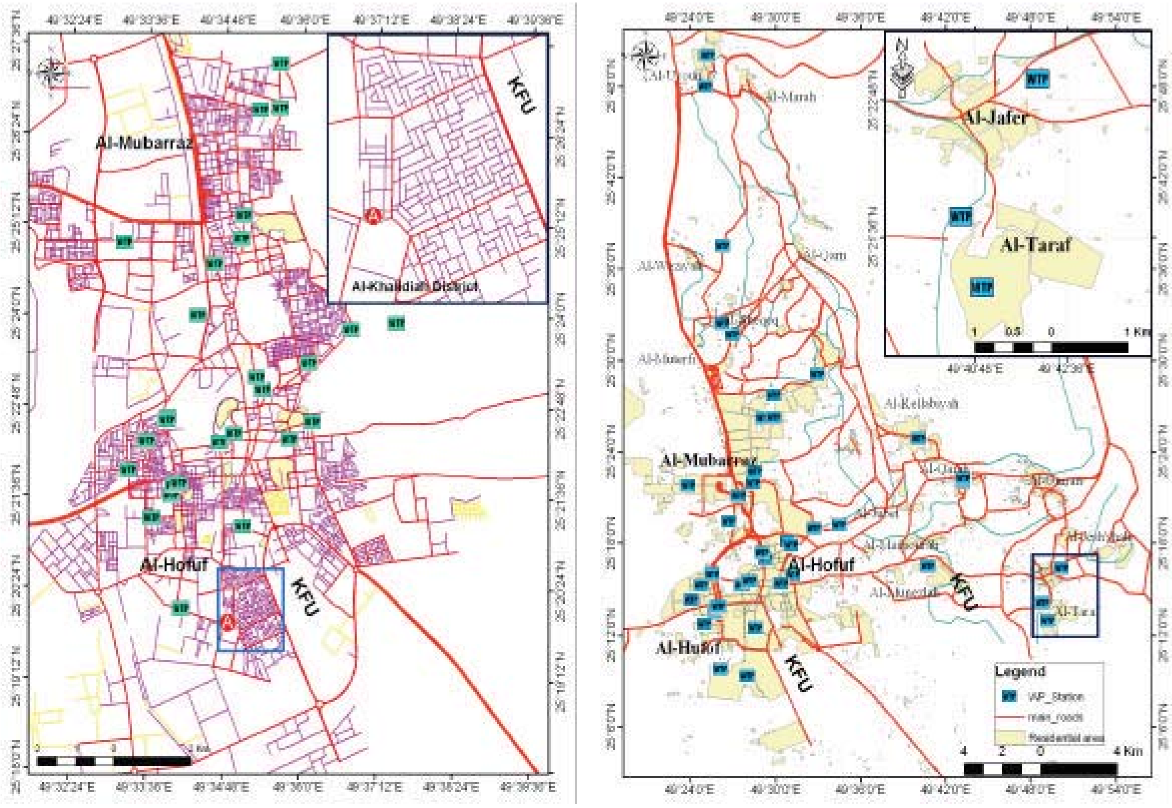
The collected data for the PS was tabulated and transformed to ArcGIS shape file and linked later through relation with other database files in the overall geo-database, Table 1 show some of this data.

A Detailed Map for Al-Hassa: The base map for the study area made of the transportation network and residential area. The source of the base map is a SPOT satellite image dated 2004 acquired from King Abdul-Aziz City for Science and Technology (KACST). The satellite image was rectified, geo-referenced. The geographic features were digitized on screen and different layers are superimposed. Figure 3a and 3b shows the different layers superimposed with purification stations point coverage's.

Fig. 2: An example of the Reverse Osmosis (RO) purification equipment used in the PS

Table 1: some of the collected data for Purification Station at Al-Hassa

St-No	Well-Depth	Purification-M	Technicians	Workers	Cars	Working-H	Sample-Date	Color	Turbidity	Taste	Oder	Remarks
1	87	RO	5	4	4	17	28/10/2008	Normal	Normal	Unsuitable	Sulpher	Excellent Arranged
2	150	RO	3	15	15	16	28/10/2008	Normal	Normal	Normal	Normal	Well Problem
3	120	RO	1	6	6	13	28/10/2008	Normal	Normal	Normal	Normal	G. Arranged
4	65	RO	1	4	4	16	02/11/2008	Normal	Normal	Normal	Normal	G. Arranged
5	-	RO	1	4	2	12.5	02/11/2008	Normal	Normal	Normal	Normal	Moderate
6	84	RO	1	1	2	14	02/11/2008	Normal	Normal	Normal	Normal	Moderate
7		RO	2	6	6	10	04/11/2008	Normal	Normal	Normal	Normal	Moderate
8		RO	1	7	7	13.5	04/11/2008	Normal	Normal	Normal	Normal	Moderate
9	129	RO	3	6	3	17	05/11/2008	Normal	Normal	Normal	Normal	Moderate
10	-	RO	2	10	8	17.5	05/11/2008	Normal	Normal	Normal	Normal	Moderate
11	200	RO	4	20	6	12	05/11/2008	Normal	Normal	Normal	Normal	Ozonizer
12	?	RO	1	14	14	15	28/10/2008	Normal	Normal	Normal	Normal	G. Arranged
13	110	RO	2	12	11	16	28/10/2008	Normal	Normal	Normal	Normal	G. Arranged
14	75	RO	1	40	40	19	28/10/2008	Normal	Normal	Normal	Normal	Bad
15	-	RO	1	5	5	15	28/10/2008	Normal	Normal	Normal	Normal	Moderate
16	130	RO	2	4	4	15	18/11/2008	Normal	Normal	Normal	Normal	Moderate
17	230	RO	1	5	5	10.5	18/11/2008	Normal	Normal	Normal	Normal	Moderate
18		RO	2	0	0	16.5	17/11/2008	Normal	Normal	Normal	Normal	Moderate
19	120	RO	2	8	6	8	17/11/2008	Normal	Normal	Normal	Normal	Moderate
20	120	RO	1	2	2	8	17/11/2008	Normal	Normal	Normal	Normal	Ozonizer
21	110	RO	1	9	9	15	17/11/2008	Normal	Normal	Normal	Normal	Moderate
22	250	RO	4	15	15	15	11/11/2008	Normal	Normal	Normal	Normal	Moderate
23	80	RO	1	5	5	14	11/11/2008	Normal	Normal	Normal	Normal	Moderate
24	160	RO	1	4	4	11	11/11/2008	Normal	Normal	Normal	Normal	Moderate
25	135	RO	4	10	10	17.5	11/11/2008	Normal	Normal	Normal	Normal	Moderate
26		RO	1	4	4	14	10/11/2008	Normal	Normal	Normal	Normal	Moderate
27	260	RO	1	10	10	11	04/11/2008	Normal	Normal	Normal	Normal	Moderate
28		RO	1	15	15	17	02/11/2008	Normal	Normal	Normal	Normal	Moderate
29		RO	2	7	7	16	02/11/2008	Normal	Normal	Normal	Normal	Moderate
30	-	RO	1	2	2	14	05/11/2008	Normal	Normal	Normal	Normal	Moderate
31	-	RO	1	9	9	17	28/10/2008	Normal	Normal	Normal	Normal	Bad Manage
32	-	RO	2	5	5	12.5	02/11/2008	Normal	Normal	Normal	Normal	G. Arranged
33	-	RO	1	3	3	13	02/11/2008	Normal	Normal	Normal	Normal	Moderate
34	-	RO	1	4	4	16	02/11/2008	Normal	Normal	Normal	Normal	Moderate
35	-	RO	1	4	3	16.5	10/11/2008	Normal	Normal	Normal	Normal	Moderate
36	-	RO	2	3	3	15.5	10/11/2008	Normal	Normal	Normal	Normal	Moderate
37	-	RO	1	1	2	6	10/11/2008	Normal	Normal	Normal	Normal	Moderate
38	-	RO	1	1	1	8	04/11/2008	Normal	Normal	Normal	Normal	Moderate
39	-	RO	2	3	3	18	04/11/2008	Normal	Normal	Normal	Normal	Moderate
40	-	RO	2	6	6	12.5	04/11/2008	Normal	Normal	Normal	Normal	G. Arranged
41	-	RO	2	6	6	12.5	04/11/2008	Normal	Normal	Normal	Normal	Ozonizer
42		RO	3	17	12	15	11/11/2008	Normal	Normal	Normal	Normal	Moderate
43		RO	1	2	4	14	11/11/2008	Normal	Normal	Normal	Normal	Moderate
44		RO	1	3	3	12.5	18/11/2008	Normal	Normal	Normal	Normal	Moderate
45	-	RO	1	1	2	10	18/11/2008	Normal	Normal	Normal	Normal	Moderate



(a) (b)

Fig. 3a-b: a) detailed map for Al-Hofuf and Al-Mubarraz Cities
b) Al-Hassa Base map with the different WPS's.

Water Sample Analysis: All the collected water samples were transferred directly to WSC laboratory and reserved in the cold room. Characterization of water quality for drinking involved measuring chemical properties as described by World Health Organization [11,12] pH and the electrical conductivity in deciSiemens per meter (dS/m) were measured. Calcium and magnesium determined by Atomic Absorption (AA). Sodium and potassium was determined using flame photometer. Carbonate and bicarbonate were determined by titration with sulfuric acid, while silver nitrate was used to determine chloride. Nitrate was determined by ultraviolet spectroscopy using spectrophotometer. Fe, Mn, Cu, Zn, Cd, Co and Ni in the water were determined by inductively coupled plasma optical emission spectrometer [12-15] chemical properties of the source water (SW) and purified water (PW) are presented and discussed in the results and discussion section.

Database Design and GIS Implementation

Database Design: The relational database model was used for database design inside ArcGIS environment and the MS-Access database management system (DBMS). Figure 4 shows the relational database design for drinking water monitoring system

Data Entry Form Design: Figures 5 to 7 shows the user interface forms for data entry.

GIS Implementation: A multilayer's GIS geo-database were developed based on a SPOT satellite image dated 2004 acquired from King Abdul-Aziz City for Science and Technology (KACST) and the field survey GPS data for the WPS's. The GIS Software ArcGIS 9.3 and ERDAS IMAGINE 8.3 as an image processing software and Pathfinder GPS software were used for GIS multilayer's implementations. Table 2 shows the names, type and description of the developed GIS multilayer's.

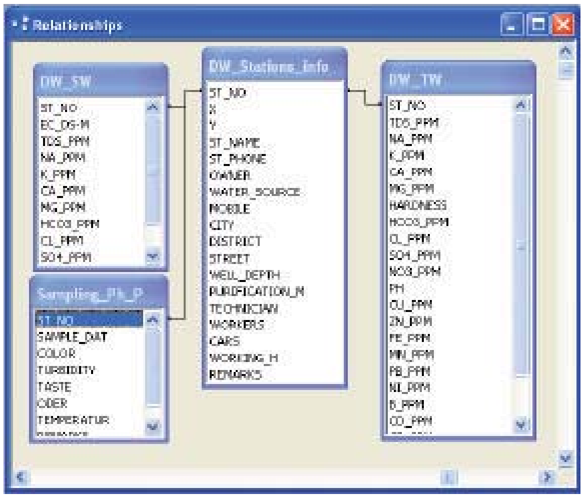


Fig. 4: The relational database design for Drinking Water Monitoring system

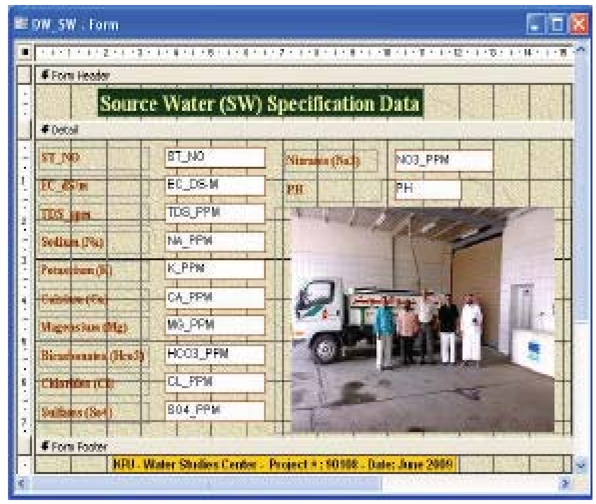


Fig. 6: the design for SW specification data entry form

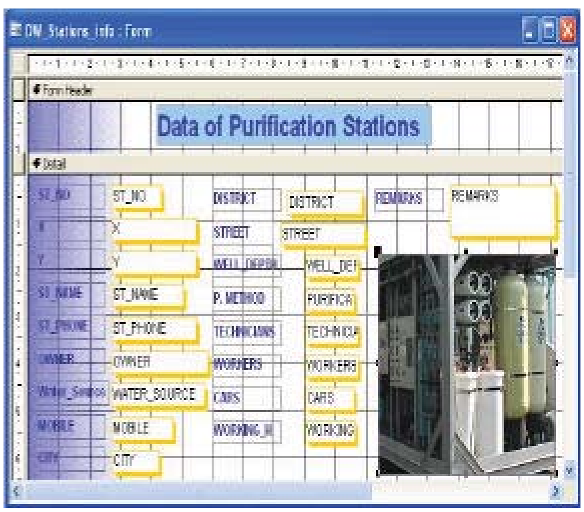


Fig. 5: The design for main WPS's data entry form

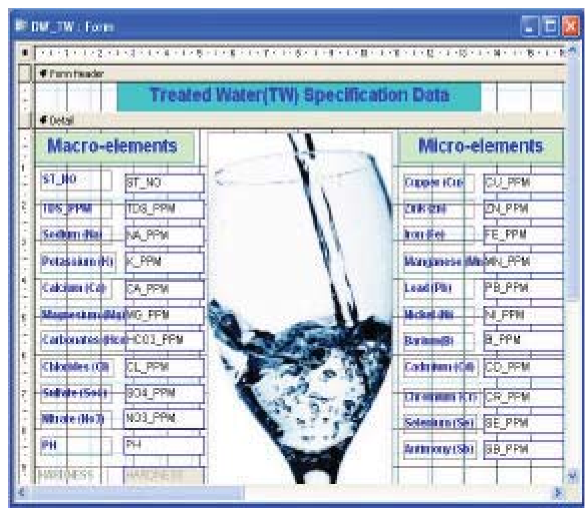


Fig. 7: the design for PW specification data entry form

Table 2: the descriptions of the developed GIS multilayer's

Layer	Type	Description
Highway	Line	Al-Hassa highway roads (Qatar, Dammam and Riyadh
Main_roads	Line	Dammam highway road beside NRCDP location
Secondary_roads	Line	Sub-main road inside Al-Hassa Area
Asphalt_roads	Line	The asphalt roads inside Al-Hofuf and Mubarraz
Gravel_roads	Line	The gravel roads inside Al-Hofuf and Mubarraz
Residential	Polygon	The residential in Al-Hassa
Cemeteries	Polygon	The cemeteries in Al-Hassa
Purifications_S	Point	The location map for the purification stations at Al-Hassa

Multi-criteria for Water Quality Evaluation: The international organization like WHO, EPA and Saudi Arabia and Gulf [16] put the acceptable standards limits for drinking water by identify the maximum acceptable limits only. If we make a rule based system according to these water standards we will have two categories for each element and contaminates (1-Acceptable and 2-Non-Acceptable) [17]. The visual basic (VB) programming language was used to build the inference engine and the rule based (IF…Then statements) for drinking water quality categorizing. The system is designed to be used at different levels of user sophistication. The user interface developed by VB, is a menu driven task manager that allows the selection of different modules such as existing program for evaluating parameters from more sophisticated modules such as GIS and MS-Access. The data management and processing inside this system include different tasks, which can be executed through a user interface and some control buttons. The available tasks for the user and the decision maker include the following:

- Browsing and navigating through the existing data
- Data editing (Add a new water resource data, Delete.
- Rules and facts used in categorizing drinking water resource.
- Searching for a specific well.
- Visualizing maps for water resources and results.

RESULTS AND DISCUSSIONS

Source Water Type: There are three types of water source for the purification stations, Groundwater wells (GW), Municipality water source (MW) and combined water source (GW+MW). Figures 8 to 10 show the results of a DBMS query about the water source for the purification stations. While Figures 11 and 12 shows the results of a spatial query about the water source for the purification stations.

Source and Purified Water Quality Evaluation: The water quality for all the water resources of the purification stations are out of the acceptable ranges for drinking water quality criteria according to WHO, Europe, Saudi Arabia and Gulf countries drinking water quality standards. While the water quality for all the purified water produced by the purification stations are within the acceptable ranges for drinking water quality criteria according to Saudi Arabia and Gulf countries drinking water quality standards. Tables 3 to 7 and Figures 13 and 14 viewing a comparison between the quality of the source water and purified water according the drinking water quality (WQ) standards.

Only 4 purification stations has a little quality problem in salinity (TDS and EC) and pH value according WHO and Europe drinking water quality standards, as shown in Tables 6 and 7 and Figures 15 to 18.

CONCLUSIONS

The water quality for all the water resources (Groundwater, Municipality) of the purification stations at Al-Hassa are out of the acceptable ranges for drinking water quality criteria according to WHO, Europe, Saudi Arabia and Gulf countries drinking water quality standards. On the other hand the water quality for all the purified water produced by the purification stations is within the acceptable ranges for drinking water quality criteria. Only four purification stations have a little quality problem in salinity (TDS) and pH value according WHO and Europe drinking water quality standards.

DW_Stations_S_W : Select Query

ST_NO	ST_NAME	WATER_SOUR	CITY	DISTRICT	STREET	ST_PHONE	OWNER	MOBILE	PURIFICATION
93	Sweet Water	Well	Al-Hofuf	Al-Beheriyah-A	Train St.	5864366	Saad Hamad Hamm	-	RO
94	Al-Mawred	Well	Al-Hofuf	Al-Salhiyah	Al-Sateen (60)	5854445	Mohamed Abdulaz	058298617	RO
95	Al-Rayan	Well	Al-Hofuf	Al-Hamerah	Al-Hufof Hotel	5826200	Gamal Abdullah Al-C	050481326	RO
96	Al-Khars	Well	Al-Hofuf	Umm Khurisan	Al-Malaky St.	5840200	Mashal Ali Al-khars	050989067	RO
97	Al-Salmaniya	Well	Al-Hofuf	Al-Mohamadiya	Al-Mohamadiya		Abdullah Naser Al-sl	050714622	RO
98	Al-Bandariya	Well	Al-Hofuf	Al-Bandariyah	Al-Bandariah &	5811742	Abdullah Salem Al-H	055592966	RO
99	Al-Douha	Well	Al-Hofuf	Al-Haferah	King Fahd Hos	5753320	Salman Hassan Al-C	050392116	RO
100	Al-Khair	Well	Al-Hofuf	Al-Bandariyah	Al-Bandariah &	5881783	Khalid Ahmed Abdul	050391877	RO
101	Al-Salsabeel	Well	Al-Helelah	Al-Helelah	Al-Kellabiyah	5964128	Abdullah Housain Al-	-	RO
102	Al-Bandary	Well	Al-Uyoun	Al-Uyoun	The First Rou	5331317	Abdulaziz Saoud Al-	-	RO
103	Al-Ward	Well	Al-Shegeg	Al-Shegeg	General road	5321338	Fahd Mohamed Al-S	-	RO
104	Al-Shegeq	Well	Al-Shegeg	Old Al-Shegeg	Old Al-Shegeg	5321638	Meshal Salem Al-Eo	505921348	RO
105	Al-Shegeq	Well	Al-Shegeg	Old Al-Shegeg	Old Al-Shegeg	5321638	Meshal Salem Al-Eo	505921348	RO
106	Al-Marwah	Well	Al-Waziyah	Al-Waziyah	Al-Shegeq-Al-U		Fahd Mohamed Al-S	-	RO
107	Al-Zolal	Well	Al-Qara	Al-Qara	M. AlQara	5968263	Hassan Abd-Elmouh	-	RO
108	Al-Basateen	Well	Al-Taraf	South-Taraf	Al-Adwah road	5395201	Hamad Hamdan Al-K	-	RO
109	Al-Aseel	Well	Al-Taraf	Taraf - Zoo	Al-janoubi St.	5381717	Abdullah Abd-Elaziz	-	RO
110	Yanabee Al-J	Well	Al-Monezlah	Behined Skico	Behined Skico	5392064	Ghanem Ahmed Al-(	-	RO
111	Al-Wadi Al-A	Well	Al-Moubaraz	Al-Rashdaiah	Dhahran St	5313370	Mohamed Abdullatif	-	RO
112	Gulbat	Well	Al-Hofuf	Ain Najm	Al-Naeem conc		Abd-Elaziz Al-Mous	504856985	RO
113	Al-Zahra	Well	E-Al-Hofuf	Sultana	East Village &		Fahd Al-Salem	-	RO
114	Wasat Al-Nak	Well	Al-Moubaraz	Al-Maslakh	Eastern round	5878336	Gawad Mohamed El	530670648	RO

Record: 1 of 22

Fig. 8: The result of a query about the GW source (22 WPS's)

DW_Stations_S : Select Query

ST_NO	ST_NAME	WATER_SOUR	CITY	DISTRICT	STREET	ST_PHONE	OWNER	MOBILE	PURIFICATION
115	Barzan	Municipality	Al-Hofuf	Al-Salhiyah	Al-Bahouth Ext		Saleh Eissa Al-Uwai	055573317	RO
116	Al-Jazerah	Municipality	Al-Hofuf	Al-Raqeqah	Abu-Baker Al-S	5730139	Ebrahim Ali Al-Abba	050390965	RO
117	Al-Kawther	Municipality	Al-Hofuf	Al-wasatah - A	Al-Thulitheiah	5802166	Abdulrahman Saled	-	RO
118	Al-Naeem	Municipality	Al-Hofuf	Al-Naeethel -	Old Municipali	5821663	Khaled Mohamed Ha	-	RO
119	Al-Naba Al-S	Municipality	Al-Hofuf	Al-Raqeqah	Harad St.	5752609	Abdullateef Abdullah	050591886	RO
120	Al-Safa	Municipality	Al-Moubaraz	Al-Hazm Alshai	Qasr Sahoud	5876314	Fahd Mohamed Al-S	-	RO
121	Afiah	Municipality	Al-Moubaraz	Al-Hazm	Al-Dhahran St.	5860027	Abdullah Al-Rashed	-	RO
122	Al-Seeh	Municipality	Al-Moubaraz	Al-Rashdiyah	HIDA	5301222	Abd-Elhady Mohame	-	RO
123	Al-Sahab	Municipality	Al-Moubaraz	Al-Shebah	Abu-Sahbal St.		Nabil Al-Shakhs	554834384	RO
124	Mousharafah	Municipality	Al-Moubaraz	Mousharaf	Al-Shebah Roa		Abd-Elaziz Al-Mous	504927078	RO
125	Al-moulhim	Municipality	Mahasen	Mahasen	Abu 100 St.	5922223	Abdullah Khalifah Al-	-	RO
126	Al-moulhim	Municipality	Mahasen	Mahasen	Abu 100 St.	5922223	Abdullah Khalifah Al-	-	RO
127	Al-Hayat	Municipality	Al-Qara	Al-Qara	Al-Qara round	5967712	Mohamed Abd-Rab	-	RO
128	Al-Forat	Municipality	Al-Jafer	Main water two	Al-Subat St.	5393309	Hassan Al-Abaad	-	RO
129	Al-Thulim	Municipality	Al-Uyoun	Al-Uyoun	Al-Bank St.	5331248	Mohamed Salem Al-		RO
130	Yanabee Al-U	Municipality	Al-Uyoun	Al-Uyoun	Old Riyad Bank	5332642	Saad Hamad Al-Fag	-	RO

Record: 1 of 16

Fig. 9: The result of a query about the MW source (16 WPS's)

DW_Stations_S_WM : Select Query

ST_NO	ST_NAME	WATER_SOURCE	CITY	DISTRICT	STREET	ST_PHONE	OWNER	MOBILE	PURIFICATION
87	Al-Mulhim	Well+Municipality	Al-Hofuf	Al-Raqeqah	Abu-Baker Al-S	5755559	Abdulrahman Moha	055580322	RO
88	Yanabee Al-Has	Well+Municipality	Al-Hofuf	Al-Saiyhad-Al-	30 St. - Behin	5751512	Omar Abdulah Al-Ut	056751066	RO
89	Al-khaleej	Well+Municipality	Al-Hofuf	Al-Mazroeiyah	Al-Mazroeiyah	5828717	Abdullah Naser Al-s	050714622	RO
90	Nahr Al-Sa'a	Well+Municipality	Al-Hofuf	Al-Faisaliah	Al-Faisaliah -	5823516	Prince Mansour Bin	050145975	RO
91	Deglah	Well+Municipality	Al-Hofuf	Al-Faisaliah	Old Date St.	5824439	Mohamed Housain A	-	RO
92	Al-Wahah	Well+Municipality	Al-Hofuf	Al-Buhiryah	Train St.	5875630	Mohamed Ahmed E	-	RO
93	Al-Nozha	Well+Municipality	Al-Moubaraz	Al-Rashdiyah	Al-Rashdiyah S	5363080	Rawfaq Ali Al-Haji	-	RO

Record: 3 of 7

Fig. 10: The result of a Query about the Combined (GW+WM) source (7 WPS's)

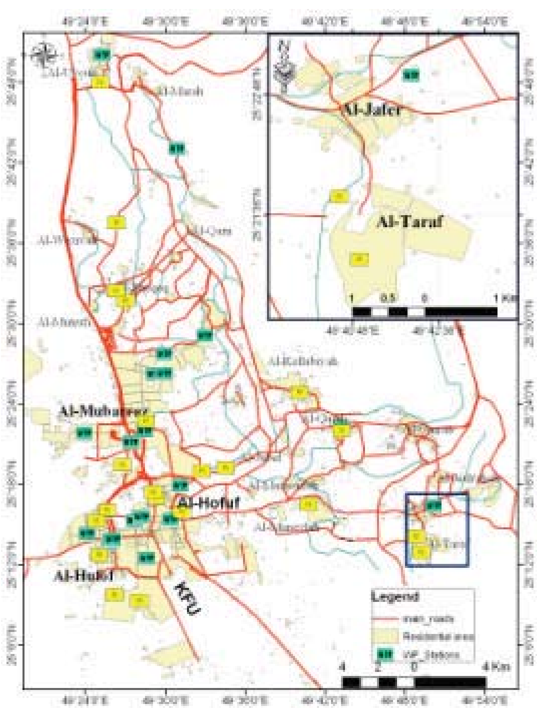


Fig. 11: Query result about the different source water of the WPS's, yellow color for PS of Well GW source

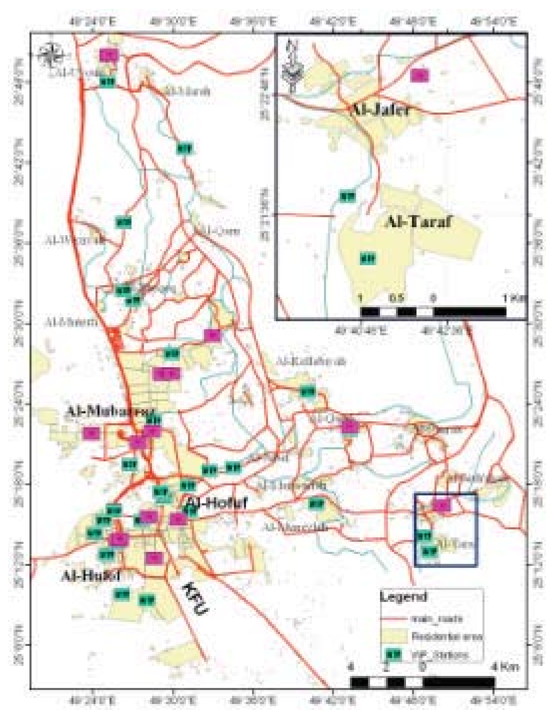


Fig. 12: Query result about the source water of the WPS's, Purple color for MW source

Table 3: Comparison of sources water properties with WQ criteria

Criteria	EC_dS/m	TDS_ppm	Na_ppm	Ca_ppm	Mg_ppm	Hardness	HCO3ppm	CL_ppm	SO4_ppm	NO3_ppm
Max_W_Source	5.50	3520.0	588.57	319.20	146.82	1399.96	855.53	1104.05	1305.12	37.80
Min_W_Source	2.13	1363.2	195.14	101.20	35.31	397.77	350.75	42.60	55.20	7.60
Saudi_A_Criteria	0.78	100-500	100.00	75.00	30.00	200.00	300.00	150.00	150.00	50.00
WHO_Criteria	0.40	160.0	200.00			150-500		250.00	500.00	45.00
Europe_Criteria	0.40	160.0	200.00			150-500		250.00	250.00	50.00

Table 4: Comparison of purified water properties with WQ criteria

Criteria	EC_dS-m	TDS_ppm	Na_ppm	Ca_ppm	Mg_ppm	Hardness	HCO3ppm	CL_ppm	SO4_ppm	NO3_ppm
Max_P_Water	0.68	432.0	44.85	38.40	22.10	186.63	250.25	78.46	35.50	8.20
Min_P_Water	0.12	79.55	11.28	8.95	6.20	2.92	27.48	7.30	14.56	21.00
Saudi_A_Criteria	0.78	100-500	100.00	75.00	30.00	200.00	300.00	150.00	150.00	50.00
WHO_Criteria	0.40	160.0	200.00			150-500		250.00	500.00	45.00
Europe_Criteria	0.40	160.0	200.00			150-500		250.00	250.00	50.00

Table 5: Chemical properties of the source water for some of the WPS's

PS_No	EC(dS/m)	TDS(ppm)	Na(ppm)	K(ppm)	Ca(ppm)	Mg(ppm)	HCO3(ppm)	CL (ppm)	SO4(ppm)	NO3-(ppm)
1	2.72	1741	327.41	22.48	154.49	53.88	466.65	465.05	309.60	9.4
2	2.42	1549	246.92	16.87	159.80	58.56	500.20	401.15	225.60	24.2
3	2.13	1363	248.58	17.86	140.20	35.31	544.43	315.95	166.80	21.4
5	3.2	2048	296.07	24.54	207.36	85.56	544.43	525.40	397.20	22.2
7	2.55	1632	281.63	20.80	135.40	59.37	699.98	429.55	92.40	20.8
9	2.78	1779	200.87	26.60	174.93	109.32	699.98	358.55	298.80	19.4
10	2.65	1696	288.88	35.96	171.49	45.67	500.81	592.85	76.32	25.4
11	3.22	2061	427.34	26.93	164.99	44.20	544.43	599.95	306.00	20.8
12	2.14	1370	208.64	17.31	142.20	48.55	388.88	326.60	279.60	21
13	3.17	2029	345.00	30.70	174.35	74.90	466.65	539.60	424.80	25.8
14	2.17	1389	219.77	16.91	139.00	46.34	466.65	319.50	242.40	23.2
15	2.24	1434	224.43	15.75	137.00	52.70	544.43	326.60	205.20	22.4
16	3.68	2355	367.54	28.77	220.15	96.90	544.43	42.60	1280.40	21
18	3.2	2048	345.00	28.33	186.56	72.02	466.65	578.65	386.40	17
19	3.3	2112	365.05	29.27	189.80	70.65	622.20	596.40	288.00	18.2
21	4.86	3110	505.77	44.19	276.34	130.68	726.51	337.25	1305.12	20
22	2.26	1446	195.14	19.60	156.60	61.03	350.75	557.35	55.20	19.6
23	5.5	3520	588.57	27.80	319.20	146.82	544.43	1104.05	718.80	37.8
24	2.16	1382	253.23	15.99	131.00	36.60	517.28	358.55	144.96	7.6
26	2.64	1690	296.47	24.73	143.40	57.62	699.98	404.70	169.20	22.6
27	2.98	1907	335.57	27.67	175.00	62.52	777.75	543.15	84.00	21.2
28	2.88	1843	373.06	22.78	146.80	44.52	855.53	468.60	75.60	23.8
29	2.33	1491	300.38	17.91	101.20	44.88	699.98	362.10	78.00	22.8

Table 6: Comparison of purified water properties with WQ criteria (Microelements and pH)

Criteria	Cu_ppm	Zn_ppm	Fe_ppm	Pb_ppm	Cd_ppm	Se_ppm	Ni_ppm	pH
Max_P_Water	0.12	0.07	0.10	0.00	0.00	0.00	0.00	8.96
Min_P_Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.4
Saudi_A_Criteria	2.00	3.00	0.30	0.01	0.003	0.01	0.02	6.5:8.5
WHO_Criteria	2.00	3.00	0.30	0.01	0.003	0.01	0.02	6.5:8.5
Europe_Criteria	2.00	-	0.30	0.01	0.005	0.01	0.02	6.5:8.6

Table 7: Chemical properties of the purified water (DW) for some of the WPS's

PS_No	EC_dS-m	TDS_ppm	Na_ppm	K_ppm	Ca_ppm	Mg_ppm	HCO3_ppm	CL_ppm	SO4_ppm	NO3_ppm
1	0.278	177.9	20.47	15.54	12.77	7.08	45.53	50.06	29.93	1.8
2	0.267	170.9	17.07	10.99	15.68	7.92	63.81	35.86	29.47	3.6
3	0.312	199.7	18.47	9.14	19.59	8.16	89.70	32.31	35.50	4.2
4	0.302	193.3	22.54	22.85	15.41	7.08	90.05	32.31	30.42	8.2
5	0.302	193.3	24.73	15.00	13.67	6.60	65.51	46.51	30.53	6.4
6	0.38	243.2	25.25	23.72	21.88	10.68	106.14	50.06	31.20	4.2
7	0.1707	109.2	13.30	13.20	8.05	3.48	21.93	25.21	30.60	2.4
8	0.325	208.0	22.09	21.25	18.02	8.88	79.05	46.51	30.91	4
9	0.257	164.5	16.61	16.29	14.78	6.96	67.64	28.76	31.26	2.8
10	0.203	129.9	13.34	11.52	13.17	5.52	57.58	18.11	27.65	2.8
11	0.207	132.5	16.77	15.07	9.12	5.98	56.12	21.66	25.92	3.2
12	0.265	169.6	17.70	9.66	15.43	6.48	64.56	32.31	32.72	5
13	0.1563	100.0	14.49	8.97	6.54	3.00	17.51	21.66	31.97	5
14	0.228	145.9	17.59	11.47	11.56	5.04	38.76	35.86	30.46	5.6

Table 7: Continued

15	0.238	152.3	20.43	9.99	10.42	5.70	75.90	18.11	30.03	3.2
16	0.249	159.4	21.25	15.99	11.22	5.76	62.53	28.76	31.44	1.8
17	0.1827	116.9	14.26	12.71	9.51	5.10	30.28	28.76	24.99	2
18	0.313	200.3	24.22	19.82	15.80	8.62	66.89	53.61	25.12	3.6
19	0.1547	99.0	12.88	11.35	7.66	4.03	7.30	32.31	24.83	2.2
20	0.285	182.4	21.77	20.82	14.60	7.99	62.59	46.51	24.67	2.6
21	0.1243	79.6	11.28	9.15	6.20	2.92	20.05	14.56	24.21	0.6
22	0.292	186.9	19.37	17.59	16.49	8.88	67.57	42.96	28.91	2
23	0.318	203.5	23.98	8.95	16.60	9.00	98.17	35.86	26.91	1.8
24	0.278	177.9	23.00	20.91	12.82	6.96	49.24	50.06	27.01	4.8
25	0.289	185.0	21.59	19.84	14.86	7.92	79.32	35.86	27.82	4.2
26	0.398	254.7	28.86	14.62	21.01	11.16	85.08	71.36	27.61	6.8
27	0.407	260.5	24.76	11.47	24.98	13.32	127.33	50.06	27.49	3.8
28	0.219	140.2	17.25	9.34	11.38	6.53	41.53	35.86	23.96	5
29	0.237	151.7	14.90	14.49	14.76	6.48	39.51	39.41	29.39	3.4
30	0.221	141.4	15.64	10.46	15.21	5.88	57.86	25.21	26.47	3.2
31	0.226	144.6	17.00	16.40	10.88	5.52	37.41	35.86	30.56	7.4
32	0.211	135.0	14.95	12.85	12.59	6.40	36.14	35.86	24.36	5.4
33	0.1625	104.0	12.42	11.36	8.36	4.73	23.99	25.21	25.04	5.2
34	0.249	159.4	20.96	18.39	11.48	6.40	51.24	39.41	25.92	3.6
35	0.204	130.6	16.69	14.70	9.48	4.68	37.60	28.76	29.45	3.4
36	0.27	172.8	20.39	19.08	13.64	6.60	40.13	50.06	30.34	3.8
37	0.338	216.3	27.14	23.91	15.02	8.28	60.03	60.71	32.92	3
38	0.27	172.8	20.51	19.16	13.55	7.32	56.17	42.96	27.32	3.2
39	0.264	169.0	18.66	18.10	14.66	7.08	51.76	42.96	27.91	6.2
40	0.259	165.8	17.99	17.51	14.42	7.66	51.24	42.96	25.92	2.2
41	0.316	202.2	26.09	23.60	14.31	7.20	128.43	14.56	30.94	2.2
42	0.404	258.6	29.66	27.42	20.94	10.68	84.17	71.36	31.21	5
43	0.217	138.9	16.87	15.55	10.55	5.16	32.94	35.86	29.76	1.2
44	0.675	432.0	44.85	44.48	38.40	22.10	250.25	78.46	21.00	4.4

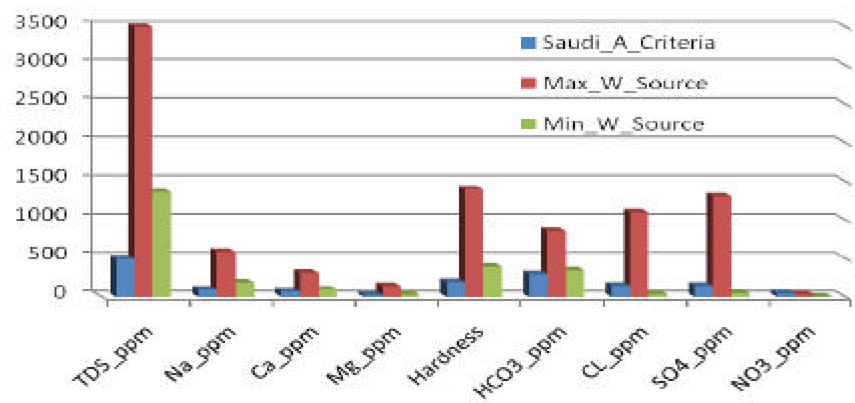


Fig. 13: Comparison of sources water properties with Saudi WQ criteria

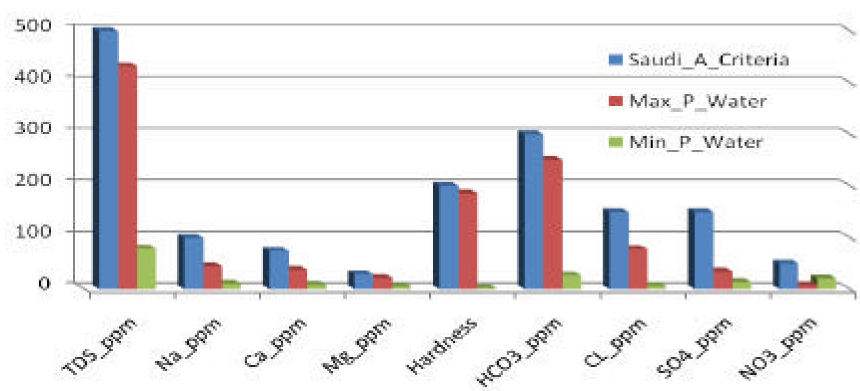


Fig. 14: Comparison of purified water properties with Saudi WQ criteria

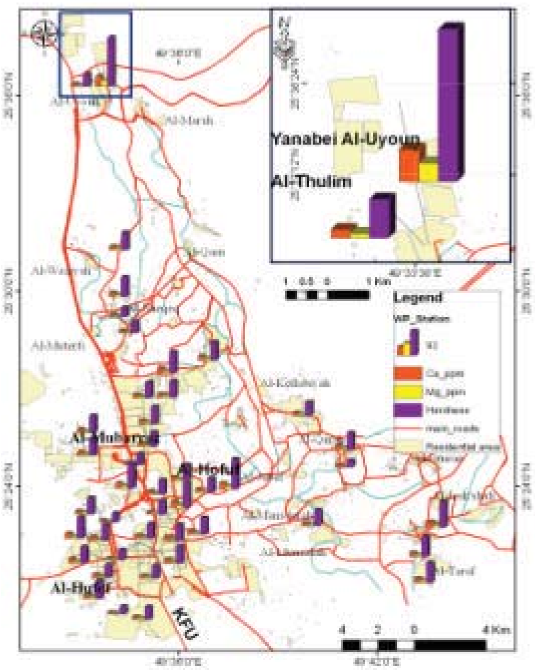


Fig. 15: Spatial representation of Calcium, Magnesium and hardness of the WPS's Drinking

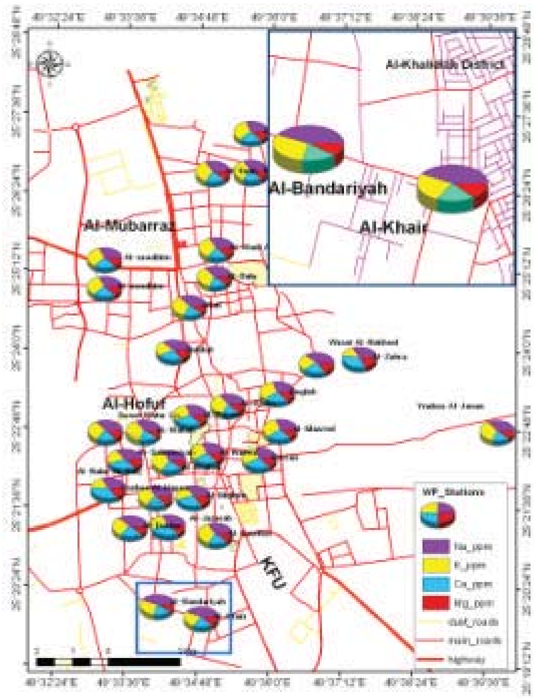


Fig. 17: Map showing a graphical & spatial representation of water properties (Na, K, Ca, & Mg) for each WPS's in Al-Hassa

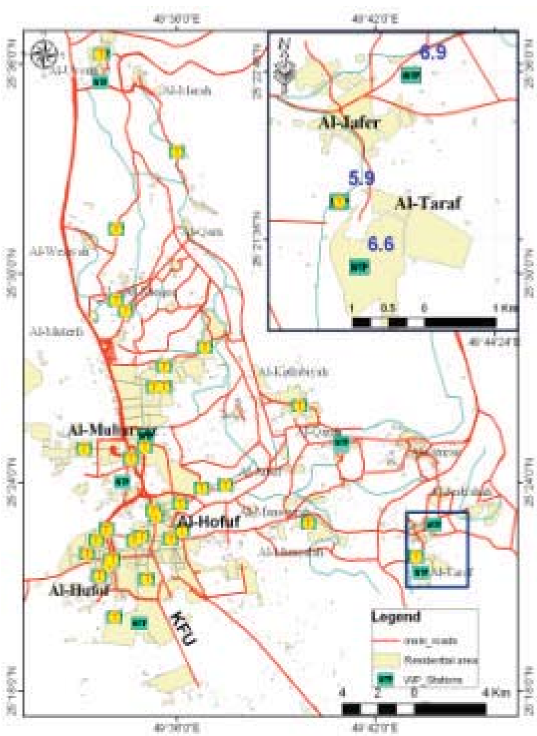


Fig. 16: Query result about the out of ranges pH (less than the optimum level 6.5-8.5)

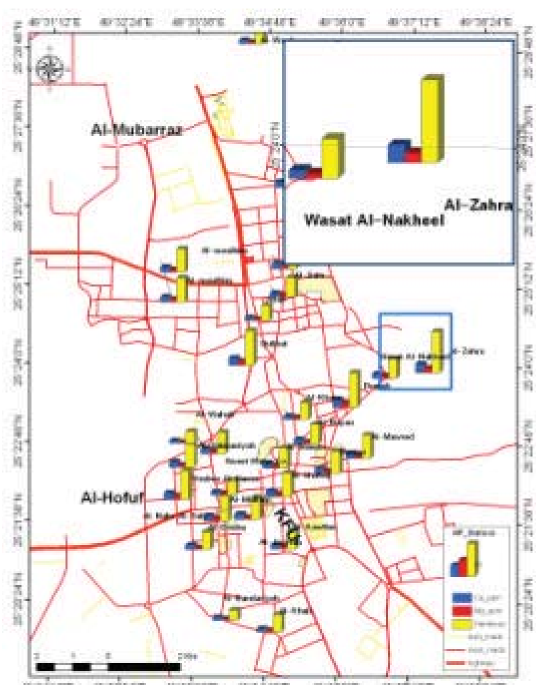


Fig. 18: Map showing a graphical representation of water Hardness, Ca & Mg contents for each WPS's at Al-Hofuf and Al-Mubarraz Cities

The results of this study can be considered as a base for continuous monitoring and evaluation for purification stations at Al Hassa and for any future water quality variation and for developing and implementing effective source protection strategies if we providing the system with continuous periodic results of the produced water specifications. Moreover, the DWSDSS will be valuable for decision makers to ensure that the quality of drinking water is satisfactory and satisfied for people healthy life and to determine the suitability of the purification stations.

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