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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

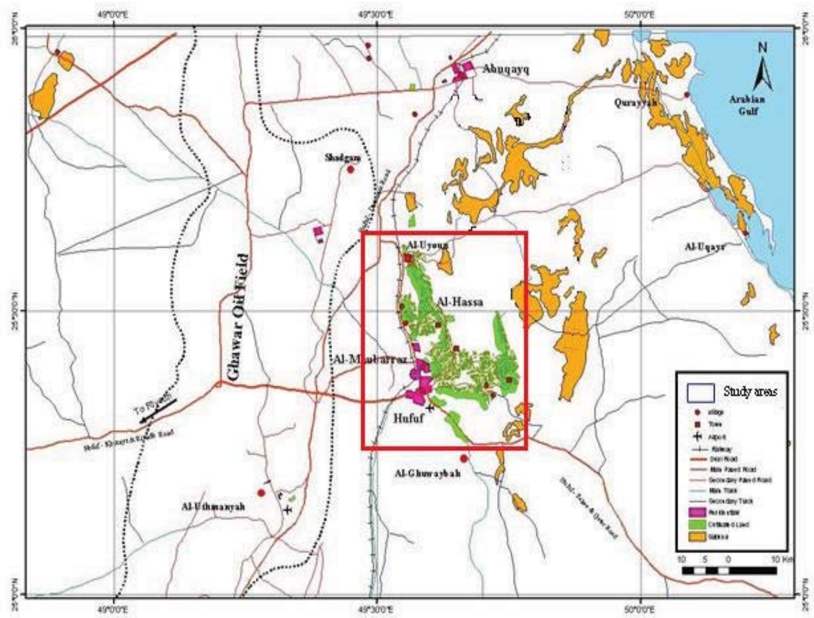



Fig. 1: Study area of Al-Hassa cities and villages

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.

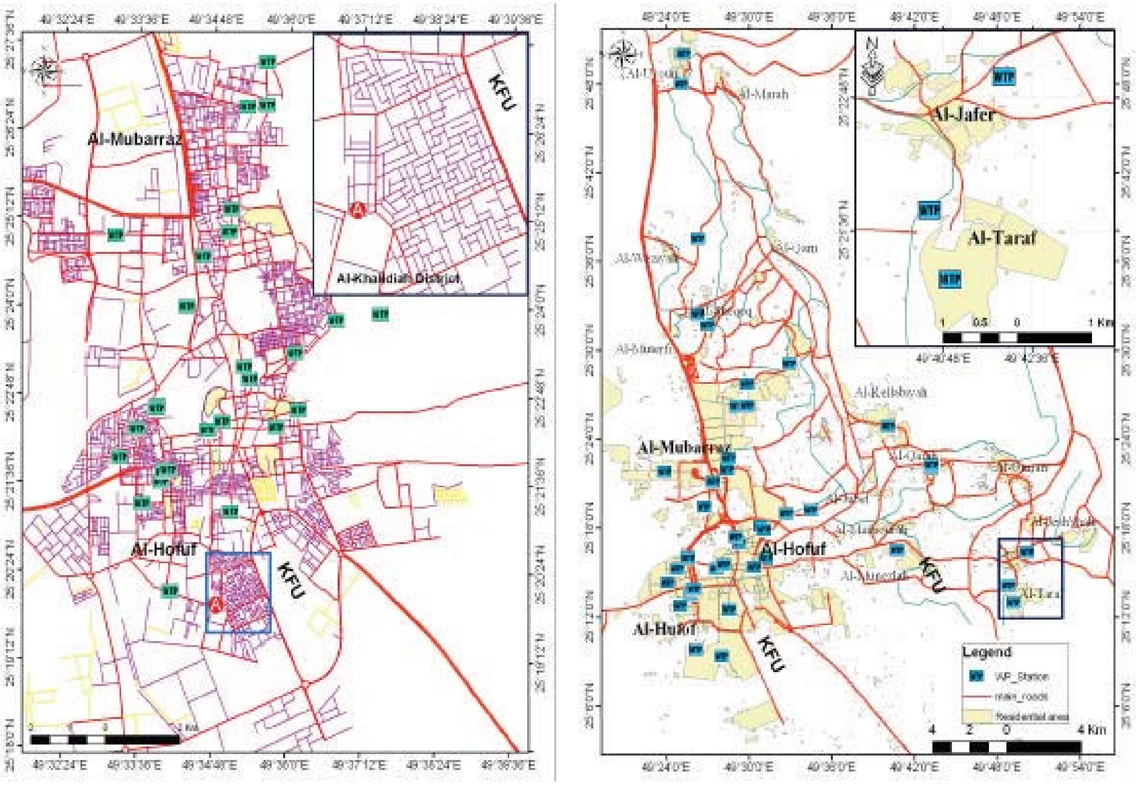
The collected data for the PS was tabulated and transformed to ArcGIS shape file and linked later through relation with other database files in the overall geo-database, Table 1 show some of this data.

**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.

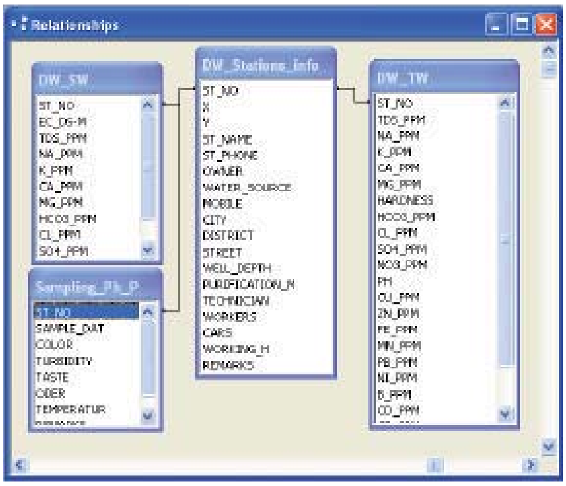



Fig. 4: The relational database design for Drinking Water Monitoring system


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

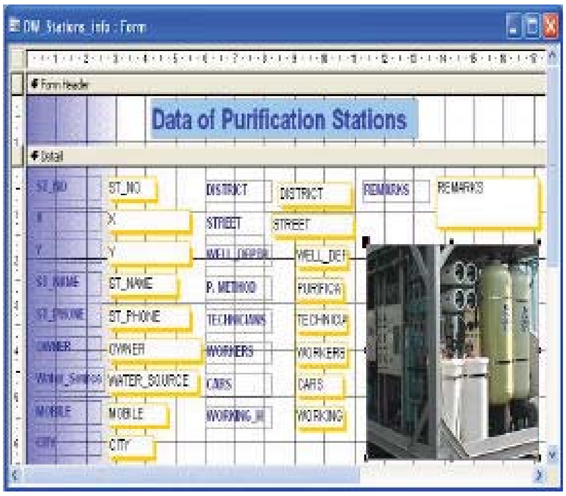



Fig. 5: The design for main WPS's data entry form

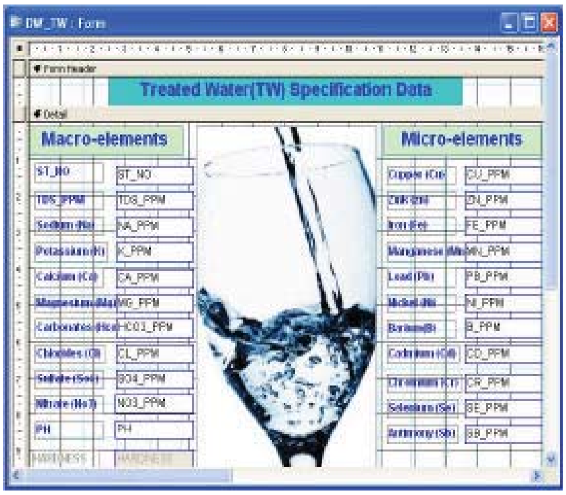



Fig. 7: the design for PW specification data entry form

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-Seteen (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 Khunsan | Al-Malaky St. | 5840200 | Mashal Ali Al-khars | 050989087 | RO |
| 97 | Al-Salmaniya | Well | Al-Hofuf | Al-Mohamadiya | Al-Mohamadiya | | Abdulah Naser Al-sl | 050714622 | RO |
| 98 | Al-Bandariya | Well | Al-Hofuf | Al-Bandariyah | Al-Bandariah & | 5811742 | Abdulah 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 | Abdulah Housain Al- | - | RO |
| 102 | Al-Bandary | Well | Al-Uyoun | Al-Uyoun | The Finst 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 | 5321636 | Meshal Salem Al-Eo | 505921348 | RO |
| 105 | Al-Shegeq | Well | Al-Shegeg | Old Al-Shegeg | Old Al-Shegeg | 5321636 | Meshal Salem Al-Eo | 505921348 | RO |
| 106 | Al-Marwah | Well | Al-Waziyah | Al-Waziyah | Al-Shegeg-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 | Abdulah 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 | 504956986 | 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 Eb | 530870548 | RO |

Record: 1 of 22

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

DW_Stations_5 : 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 | 050380965 | RO |
| 117 | Al-Kawther | Municipality | Al-Hofuf | Al-wasatah - A | Al-Thulitheiah | 5802185 | Abdulrahman Saied | - | RO |
| 118 | Al-Naeem | Municipality | Al-Hofuf | Al-Naeethel - | Old Municipali | 5821653 | Khaled Mohamed H: | - | 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 | HIOA | 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 Row |  | Abd-Elaziz Al-Mous: | 504927078 | RO |
| 125 | Al-mouhim | Municipality | Mahasen | Mahasen | Abu 100 St. | 5922223 | Abdullah Khalifah Al- | - | RO |
| 126 | Al-mouhim | 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 | 5332842 | 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_5_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 Mohai | 055580322 | RO |
| 88 | Yanabee Al-Has: | Well+Municipality | Al-Hofuf | Al-Saiyhad-Al- | 30 St. - Behin | 5751512 | Omar Abdullah Al-Ut | 058751066 | RO |
| 89 | Al-khaleej | Well+Municipality | Al-Hofuf | Al-Mazroeiyah | Al-Mazroeiyah | 5828717 | Abdullah Naser Al-ef | 050714622 | RO |
| 90 | Nahr Al-Sala | 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)

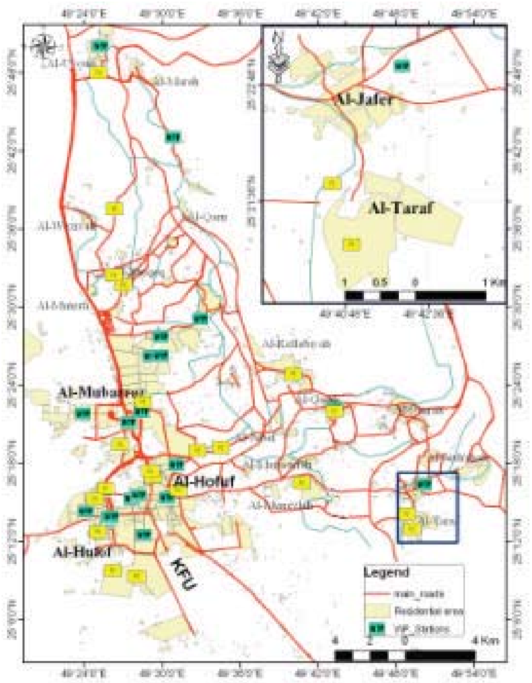



Fig. 11: Query result about the different source water of the WPS's, yellow color for PS of Well GW source

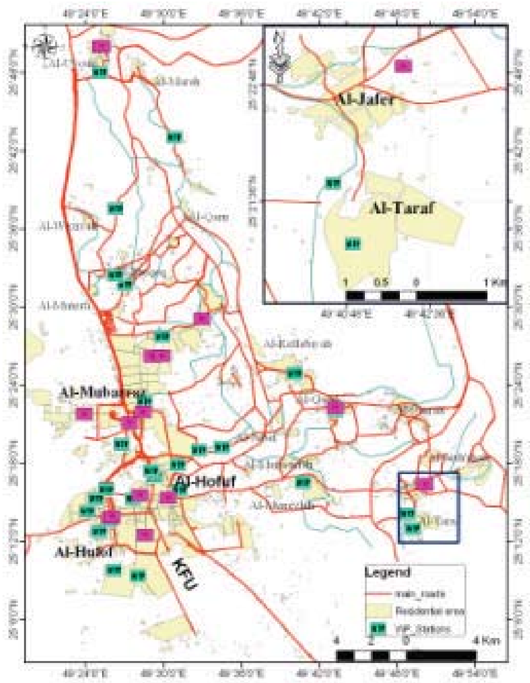



Fig. 12: Query result about the source water of the WPS's, Purple color for MW source

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 |

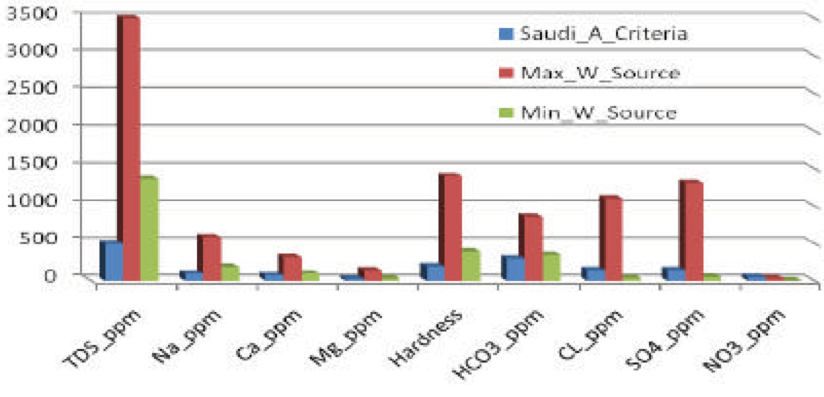



Fig. 13: Comparison of sources water properties with Saudi WQ criteria

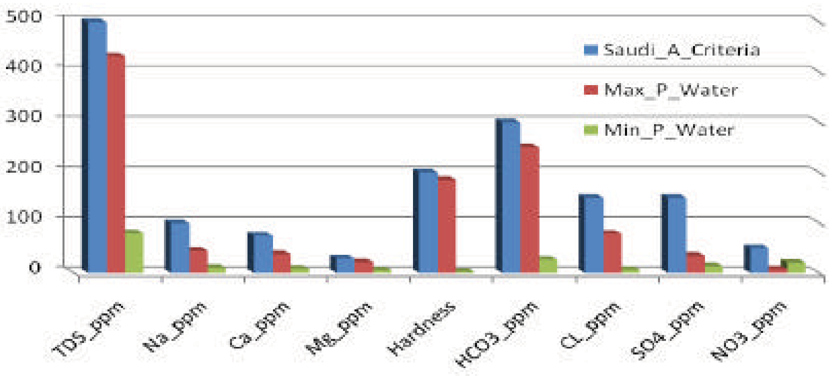



Fig. 14: Comparison of purified water properties with Saudi WQ criteria

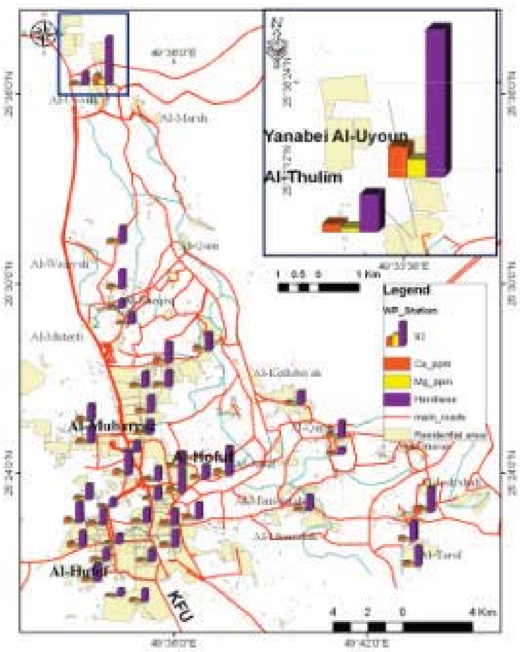



Fig. 15: Spatial representation of Calcium, Magnesium and hardness of the WPS's Drinking

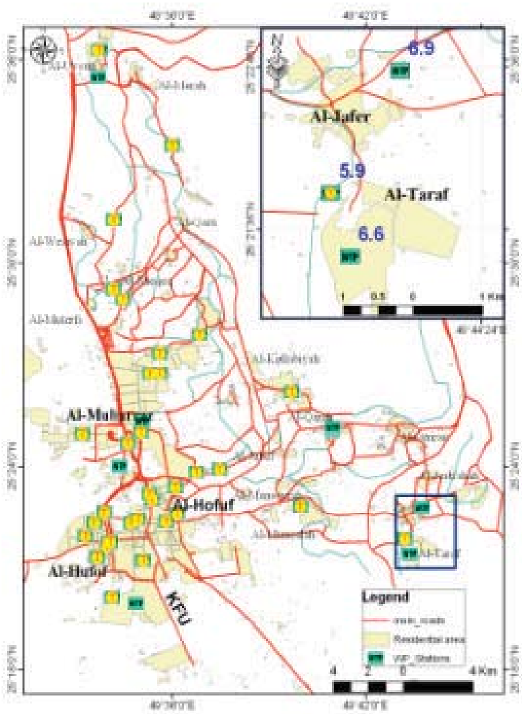



Fig. 16: Query result about the out of ranges pH ( less than the optimum level 6.5-8.5 )

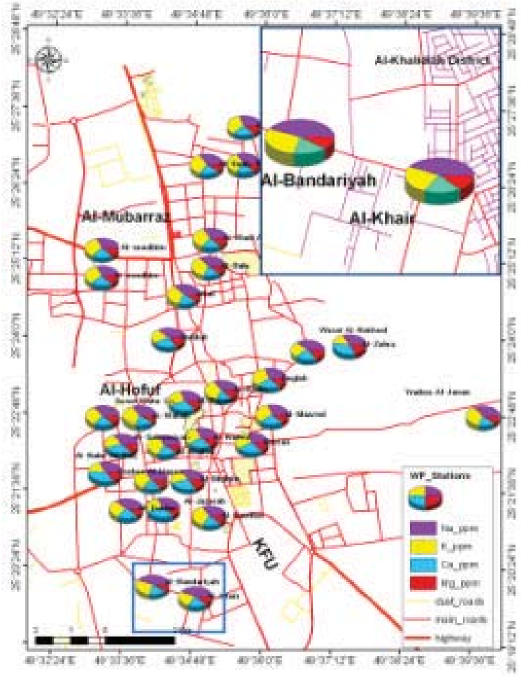



Fig. 17: Map showing a graphical & spatial representation of water properties (Na, K, Ca, & Mg) for each WPS's in Al-Hassa

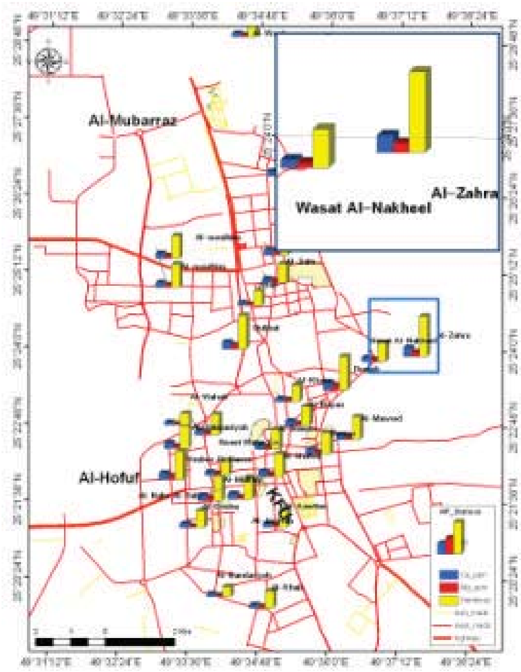



Fig. 18: Map showing a graphical representation of water Hardness, Ca & Mg contents for each WPS's at Al-Hofuf and Al-Mubarraz Cities

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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