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A precise methodology integrates low-cost GPS data and GIS for monitoring groundwater quality parameters in Majmaah region, KSA

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Abstract: GIS/GPS mapping technology provides a very cost effective method of meeting the guidelines and calculating the total information required for decision makers. This paper aims to integrate Geographic Information System (GIS) and data acquired using low-cost GPS in one system and develop a precise methodology that is reliable for environmental studies at Majmaah region. The research focuses on monitoring and mapping the groundwater quality parameters at the study area. Portable GPS instrument with reasonable accuracy was used to measure the coordinates of non-defined water wells in the form of the latitudes and longitudes. A methodology for using these data to locate those positions accurately and merge them in GIS system was developed. The system was developed mainly for environmental studies (characterization of groundwater quality parameters) using a satellite image and the calculated GPS data aiming to produce a dynamic system that is capable of map the changes in any groundwater parameter on different times. However, other uses could be: defining the contaminated soil zones, and the same for flooding areas, as GIS will help in selecting the most appropriate locations to dig new wells, construct dams or produce sensitivity environmental maps for the study area. The resulted contour environmental maps can be helpful to illustrate a clear picture and quantities of needed areas for preservation. The system can be updated and modified easily and remains useful and helpful for supporting the decision making to identify, monitor and plan other environmental studies at the region.

Keywords: GIS, GPS, Water Quality Parameters, Monitoring, ERDAS, Majmaah

1. Introduction

There are increasing concerns about the sustainable development and its impact on the environment. However, there is no enough accurate and up-to-date data for continuous monitoring, identifying, analyzing and mapping the zones of pollution or contamination. In the meantime, one of the main weaknesses in the existing planning system in general is the scatter of the data. Geographic Information Systems (GIS) in conjunction with Global Positioning System (GPS) is considered as a dynamic system supported with databases, maps, locations, rules, etc. Therefore such a system is in need by the planners, authorities and decision makers.

Accordingly, the researchers are keen to develop a GIS for Majmaah region based on reliable geographic and environmental data for planning needs and setting priorities. This system will help Majmaah Governorate to be fully oriented with the environmental situation at the region in terms of quantity and quality of different environmental issues such as water pollution, soil contamination, air pollution, high levels of noisy areas, etc. Within this context, environmental problems are having a great attention by Saudi authorities due to its impact on enhancing the country's economy to compete globally. Moreover, the system is a well-known for its efficiency and providing support for the decision-makers.

The major obstacle that could stand against developing such a system is the lack of enough and accurate data and building a GIS that describes the environmental problems at the region truly. Therefore, there is an urgent need to develop such a system at this early stage of planning. GIS is a powerful system that deals effectively with different types of data and considers as an up-to-date tool for integrating the different types of data into one powerful dynamic system.

Data and numbers as well as maps are not useful unless, one can manipulate and use them to extract useful information supports the decision makers. Upon the supported data, decision makers, can easily oriented their actions in terms of re-plan, design or establish a new project. GIS has a wide range of applications, among them; the production of sensitivity environmental maps that helps in monitoring and planning new settlements and establishment of engineering projects.

Majmaah region (including its surrounding areas) is a promising area for sustainable development. No way, to gather and to integrate different data in one system is better than GIS. However, building such a system requires a huge accurate, trustable data, and expertise in the field of GIS.

In new developing areas such as Majmaah, where there is a lack of information and the data are scattered, even they are available with different sources. The main problem, how to gather all in one?. (GIS will do this). Positions or geographic locations of contaminant areas in terms of coordinate system in the form of *X, Y* and *Z* are other challenges that require surveying measurements. A global Positioning System (GPS), a modern tool, is a way to overcome such problem. It will be appropriated, at this stage, to create and strengthen the GIS and GPS infrastructure (hardware and software). To further enhance the modification, the tools of Dynamics System, can be used.

The study is the first of its kind in Majmaah region and will introduce recommendations for defining the contaminated zones, so the decision makers could be aware and able to take right actions.

The main objective of this paper is to develop a complete system that integrates GIS techniques and GPS together with environmental data for supporting the decision makers for planning and future studies. The present research involves application of the developed system for providing a supporting tool for Majmaah region. The other objectives are:

(1) Offering a dynamic database supported with maps and attributes for characterization of groundwater data at Majmaah region.
(2) To investigate the best integration methodology between GIS and GPS for accurate mapping nevertheless using less accurate GPS instruments.
(3) To provide maps and information to the society and authorities at any time.
(4) To investigate the variation of groundwater parameters and its causes.
(5) To analyze some of the outcomes as indicators of map accuracy, pollution, and contamination.

2. Literature Review

Geographical Information Systems (GIS) has evolved from a mapping and spatial analytical tool in geography to become a full-fledged professional practice. The development of the user friendly interface, powerful and affordable computer hardware and software, emergence of internet technology and public digital data have broadened the range of GIS applications and brought GIS for many disciplines.

Increasing availability of satellite imagery through remote sensing (RS) and its utility in resource planning studies has complemented the GIS. As a result GIS has become more widely used for natural resources management, environmental studies, water resources analyses and planning, regional and urban planning, natural disaster management, traffic studies and transport planning, business planning and management etc. Now, GIS has emerged as an important field of academic study, one of the fastest growing sectors of the computer industry, and, most importantly, an essential component of the information technology (IT) infrastructure of modern society.

GIS has become an increasingly integral component of natural resource management activities worldwide. However, despite some indications that these tools have being receiving attention within the aquaculture community, their deployment for spatial decision support in this domain continues to be very slow [1].

GIS is an effective method for groundwater pollution risk assessment. The DRASTIC model uses seven environmental parameters (Depth of water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and hydraulic conductivity) to characterize the hydro-geological setting and evaluate aquifer vulnerability [2].

Tait, *et.al*. developed a GIS-based risk assessment methodology that incorporated contaminant source, groundwater vulnerability and groundwater abstraction catchment elements in order to priorities areas and boreholes potentially at risk from chlorinated solvent pollution on a regional scale [3]. Applications of GIS in environmental studies were also reported in several works to identify all areas of groundwater vulnerable to nitrate pollution [4] and to create a groundwater vulnerability map by overlaying hydro-geological data [5].

Pollution levels at an abandoned coal mine site at Cankiri, Turkey were evaluated with respect to topography and surface runoff pathways derived using GIS tools [6].

GPS has become as an important tool in land use/land cover study by Satellite Remote Sensing and GIS techniques. A study of land resource and land use pattern assessment of Wadi Limestone Mines and cement plant, IRS 1-D LISS , III and PAN merged data of December 2000 were used. Handheld GPS (Holux GM, 100) was used for correction of raw satellite imagery and identification of smaller land use on the ground features. As GPS was capable of receiving and tracking 12 satellites with 5-25 meters of positional accuracy, the study used image processing in ERDAS Imagine (Ver. 8.3) and spatial GIS data creation and analyses were done in ARC INFO (Ver. 7.2.1) GIS package. Final maps were prepared on 1:25,000 scales [7].

GPS has long been considered such a technology that compliments GIS operations. The integration of GPS technology into GIS activities can be achieved through a variety of means ranging from the transfer of data from GPS systems, for the building of new database, though to the complete integration of GPS technology into existing GIS systems, and to conduct spatial analysis directly in the field. Some researchers [8,9] described the numerous ways that GPS can be integrated with GIS, to provide a particular emphasis on the integration of GPS technology with Map Objects through the use of component technologies..

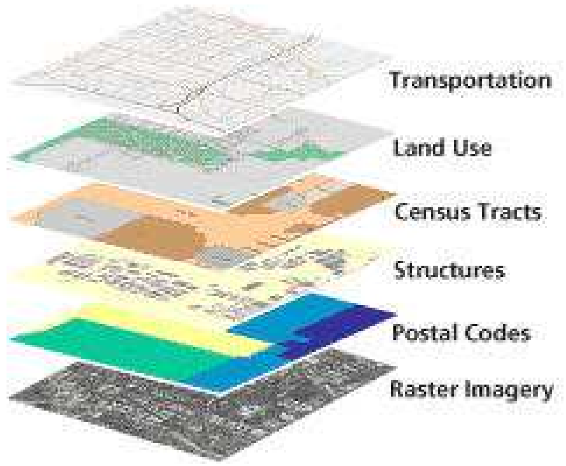


Figure 1. *An Example of GIS outcome*

The rapid development and integration of spatial technologies such as GIS, GPS, and RS, have created many new tools for professionals, but have also widened the "digital divide," leaving many with little understanding of the technology and potential applications. Therefore, debates were raised on benefits and usefulness of extension-related applications of GIS-GPS-RS technologies and how to increase our knowledge and understanding of these new technologies. Examples and recommendations are taken from the literature and from the researches' own experience [10, 11].

3. Methodology

The methodology is developed based on using GIS software [12], ERDAS [13] and low cost GPS instruments [14]. The data used to develop the methodology were gathered in three sequential stages.

Stage One: Collecting the Data

Two types of data are required. The first data is the cadastral maps of the study area including the locations of urban areas, geological maps, groundwater wells, ponds where sewage is discharged, different soil areas, contaminated zones, and characteristics of water quality and soil properties. The second set of data is gathered using GPS instruments for defining the locations of several control points at the study area.

Stage Two

Once gathered and filtered, the data are transformed to the GIS software to build the aimed system. This is the main stage of the research and starts early in parallel with the data collection. A database for all the necessary attributes is constructed and adjusted to be dynamic by adding and subtraction data at any time. Exciting maps are scanned or digitizing using available tools and added to the system.

Stage Three

Upon establishing and testing the system, then, it will be ready to extract several environmental maps that are an overlay of several layers, pre-feed to the system. Interpretation of the produced maps will be good if the results were reasonable and accurate. Several environmental maps are drawn for demonstration to display the effectiveness of the system in supporting the decision makers.

3.1. GIS/GPS Integration Techniques

There are three basic ways that GPS technology can interact with or be integrated into GIS. The level of integration varies from a 'disparate' connection (whereby data is transferred between a GPS system and a GIS system) through to a very 'tight' level of integration (whereby GPS technology is totally embedded directly within GIS application software).

GIS/GPS integration can be categorized into the following three categories:

- Data-focused integration
- Position-focused integration
- Technology-focused integration

The appropriateness of each method is dependent upon: (i) the requirements that the user has for field-based operations, (ii) the level of dependence the user has on GPS, and (iii) to a large extent, the availability of a complete system to meet the specific needs that the user has for a system. This research is using position focused integration, where:

1) Position System

In the most surveying, work the GPS might be used as the main factor for positioning. The positioning accuracy varied for sub meters depends on the application of each surveying work [15]. This study for point positioning static application used low cost GPS receiver with some software for evaluation the accuracy.

2) Satellite Visibility

For successful, high accuracy GPS surveying it is advisable to take the observation in a good window. In the planning of a survey, it is necessary to have a table listing the location of satellites with the 24 hours a day window. Satellite visibility diagrams and tables will be very important for the mission planning to decide the day and the time to start the surveying job for collecting the data. The sky plot shows the satellites paths in function of elevation angle and azimuth for each location for different cut off angles. Satellite Geometry: The Dilution of Precision (DOP) values are highly correlated with satellite geometry, and thus the number of visible satellites. The measure of satellite geometry is the GDOP (Geometric Dilution of Precision) factor. Normally GDOP over one and fewer than eight is considerable. Also the Position Dilution of Precision PDOP factor can be use as indication of precision, good accuracy can be achieve when the PDOP near to one.

3) Overall planning for GPS surveying

Aiming at optimum solutions for GPS implementation, many factors should be taken into considerations. The most important one is the minimum time of mission for the required accuracy (whatever if the positioning is static or kinematic; relative or absolute). The first step for the GPS surveying starts with the overall planning to study the location of each station. The second step is the session time for static or kinematic mode. Also selecting a good window to have good observations, and obtaining the best time for recording these observations by receiving maximum number of satellites with good geometry to optimize the surveying work. Figure (2) shows the effect of mission time with accuracy.

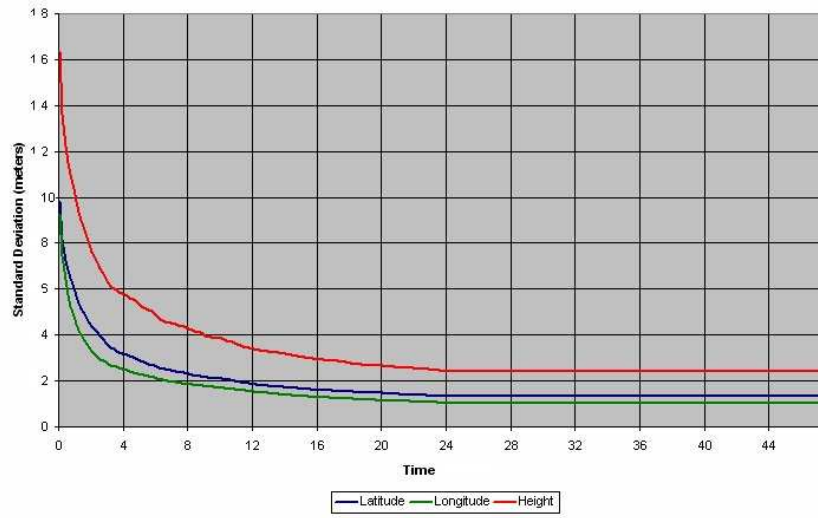


Figure 2. *Effect of the mission time with the positioning accuracy*

Meanwhile, plan the campaign is considering the amount of job, accuracy requirements and the system of coordinates [16].

The first step is to define the approximate position of the area of interest. The position accuracy correlated with the visibility of satellites which is correlated with the GDOP and PDOP [17]. The satellite visibility for the known location is affected by the cut off angle. From the sky plot in Figure (3), one can observe the satellite visibility effects which indicate the sites with obstructions less than 15° above the horizon. Those sites will be good for the current GPS surveying work and will be the main factor when choosing GPS points for surveying to have a clear view.

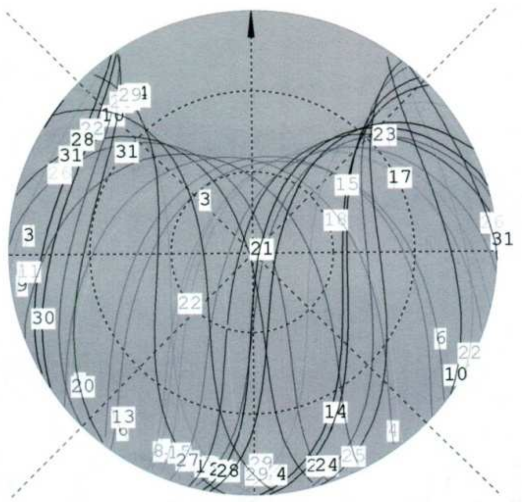


Figure 3. *Sky plot with different cut off angles*

3.2. Positioning Technique

Since the Selective Availability (SA) was set to zero, the point positioning became an interesting field to use. A single point position using a low cost GPS receiver can get accuracy better than 3 m. The positioning algorithm was written and incorporated all the significant errors and bias. The significant errors and bias are satellite clock errors, receiver clock errors, tropospheric and ionospheric bias, relativistic effect, earth rotation effect, and satellite antenna phase center offset. Some simulations were performed to validate the results. The results of the study showed significant improvements in accuracy after the SA was set to zero. This fits to the statement of the White House, USA, that the accuracy will be ten times better than before. Using a low cost GPS receiver and self algorithm, it could be seen that most of the position accuracy could be better than 5m for horizontal and 10m for vertical. The 3m accuracy level in some epochs could be reached.

GPS receivers measure pseudo ranges $R_i^j(t)$ that can be modeled as:

$$R_i^j(t) = \rho_i^j(t) + c\left(\delta^j(t) - \delta_i(t)\right) + \Delta I(t) + \Delta T(t) + MP(t) + \varepsilon \quad (1)$$

Where:

t = time of epoch

$R_i^j(t)$= pseudo range measurement

$\rho_i^j(t)$ = satellite-receiver geometric distance

c = speed of light

δ_j= satellite clock bias

δ_i = receiver clock bias

ΔI = ionosphere propagation error

ΔT = troposphere propagation error

MP= multipath

ε= receiver noise

(Ranges in meters, time in seconds)

ΔI and ΔT are correction terms because GPS signal propagation is not in a vacuum.

MP = multipath noise, reflection of GPS signal off surfaces near antenna.

Position equation for receivers and satellites can be written as:

$$[(Xr - Xs) / Rrs] * dX + [(Yr - Ys) / Rrs] * dY + [(Zr - Zs) / Rrs] * dZ - Cr = Prs - Rrs + Es \; ; \; s = 1 \qquad (2)$$

The low cost GPS receiver provided the geographic coordinates or UTM coordinates as a row data. The corrected coordinates from satellite visibility and GPS window and time of each session more than 30 minutes recording the data every 30 second then make the correction with the running average technique.

The Procedure is as follows:

- Make initial values for the *Er, Nr* for the receiver position.
- Enter the values in the above set of equations and solve them for *dX*, and *dY*.
- Update the position estimate.

$$Er\ new = Er + dE$$

$$Nr\ new = Nr + dN$$

If, *dE* and *dN* are greater than that same criterion (for a GPS position calculation based on pseudo-ranges criteria. The measurements are repeated.

The geographic and UTM coordinates with the accuracy of each coordinates are shown in Table (2).

4. Study Area and Data Collection

Majmaah city is located within the northern part of the capital Riyadh with latitude N 25^o and longitude E 46^o.

Majmaah located on Riyadh-Sedir-Qassim Motor-Highway is about 185 kilometers northwest of Riyadh and about 140 kilometers south of Qassim city. The city with, 60,000 capita, is considered as one of the most promising developed cities in KSA, Its great strategic location which links between different cities accompanied with Motor-Highway which connects the central region with a number of Gulf States will attract many residents to work in especially after the establishment of Majmaah University and Sedir Industrial City. Figure (4) shows a location map of the city.

Figure 4. *Location map of Majmaah region*

4.1. Data Collection

- Study area has been defined as longitudes and latitudes with an area 10 km x 6 km.
- Environmental data (water quality data) have been collected from 15 groundwater wells at Majmaah city.
- Laboratory analyses were performed using the collected data and the results were analyzed and stored in dB for next step.
- Other types of environmental data were collected using GPS from some areas within the study area, such areas around the discharge area near the Majmaah sewage plant.
- GPS instrument used to determine the required *X, Y*, and *Z* of the required points.
- At the study area, GPS was used to determine the wells coordinates and bottle samples were collected for laboratory analyses as described before. Figure (5) shows some pictures taken during data collection and laboratory analysis.

Figure 5. *Data collection and laboratory analysis*

- The data used throughout this research were collected from 15 groundwater wells from a farm area in Majmaah city.
- For each sample, the well longitude, latitude and height were determined using the precise technique of GPS receiver, then the coordinates transformed and processed to UTM (Universal Transverse Mercator coordinates).
- Water samples were analyzed (first set) at the Environmental Engineering Laboratory, CEE Department, Majmaah University. Most of the well samples were completely analyzed for about 20 water quality parameters, such as: *pH, TDS, DO, EC, Cl, F, Zn, Ca, Mg, Cd, Cu, Ag,* and *Fe*, etc.
- Before using the collected water quality data, one needs to screen the data to determine; the minimum, maximum, mean and extreme values before starting the advanced calculations using multivariate statistics.
- Preliminary statistical analysis involves measuring of location, shape and spread. Each variable has been tested separately and a summary of the overall variables is given in Table (1).
- Not to mention, some important parameters such as *Temp*, *K*, and *Na* were not analyzed yet.
- Statistics were carried out using Microsoft Excel and StatGraph Software 2.1 [17].
- Table (2) lists the coordinates of the wells as recorded using GPS instrument at some farms in Majmaah area. The coordinates were recorded first as longitudes and latitudes and then converted to *X, Y* coordinate system. Difference was recorded for Eastern and Northern calculations as ϬE and ϬN.
- Figure (6) shows the locations of the wells.

Table 1. *Statistical Analysis and standards of tested wells at Majmaah*

Parameter	Mean of 15 wells	SAS	EPA or Canada*	WHO
pH	8.153	6.5-8.5	6.5 – 8.5	6.5- 8.5
Zn, (mg/l)	0.072	5000 (µg/l)	5.0 (mg/l)	3.0 (mg/l)
TDS, (mg/l)	232.3	1500 (mg/l)	500 (mg/l)	1000 (mg/l)
S, (mg/l)	2.533	400 (mg/l)	250 (mg/l)	400 (mg/l)
Ag, (mg/l)	0.027	-	0.1 (mg/l)	0.1 (mg/l)
NO_3, (mg/l)	0.018	-	1.0 (mg/l)	
Hg, (µg/l)	0.373	1.0 (µg/l)	0.002 (mg/l)	0.001 (mg/l)
Pb, (µg/l)	10.667	10 (µg/l)	0.015 (mg/l)	0.01 (mg/l)
Fe, (mg/l)	0.130	1.0 (mg/l)	0.3 (mg/l)	0.3 mg/l
Cn, (mg/l)	0.008	70 (µg/l)	0.2 (mg/l)	0.1 (mg/l)
Cu, (mg/l)	0.200	1000 (µg/l)	1-1.13(mg/l)	2.0 (mg/l)
Cr, (mg/l)	0.031	0.05 (mg/l)	0.05 (mg/l)	0.05 (mg/l)
Cl, (mg/l)	0.433	600 (mg/l)	250 (mg/l)	250 (mg/l)
Cd, (µg/l)	4.720	3.0 (µg/l)	0.005 mg/l	0.003(mg/l)
AL, (mg/l)	0.050	100-200(µg/l)	0.05 -0.2 mg/l	0.2 (mg/l)
DO, (mg/l)	5.533	-	-	-
Ca, (mg/l)	0.329	-	200 (mg/l*)	75 (mg/l)
Mg, (mg/l	0.143	-	50 (mg/l*)	50 (mg/l)
Ec, (µS/mm)	363.0	-	-	-

Table 2. *Coordinates of the wells at the study area*

Well No.	λ	∅	E, m	dE, m	N, m	dN, m
1	25° 53.411'	45° 21.375'	464314.3	3.5	2863571	3.7
2	25° 48.773'	45° 24.483'	459099.7	4.1	2855056	4.2
3	25° 48.769'	45° 24.463'	459132.3	4.2	2855018	4.3
4	25° 48.456'	45° 24.109'	459722.8	5.1	2854439	4.8
5	25° 48.956'	45° 25.790'	456916.2	3.2	2855370	3.4
6	25° 48.684'	45° 25.564'	457292.0	3.2	2854867	3.2
7	25° 48.836'	45° 25.951'	456647.0	3.8	2855150	3.7
8	25° 49.269'	45° 25.951'	456649.0	3.6	2855999	3.6
9	25° 49.087'	45° 25.792'	456917.0	4.1	2855612	3.9
10	25° 49.183'	45° 26.067'	456455.0	2.9	2855791	4.2
11	25° 48.622'	45° 26.468'	455781.0	3.1	2854758	2.8
12	25° 48.563'	45° 26.572'	455607.0	3.5	2854649	3.2
13	25° 48.371'	45° 26.776'	455606.0	2.7	2854295	3.4
14	25° 48.298'	45° 26.916'	455031.0	4.5	2854162	4.3
15	25° 47.930'	45° 27.306'	454377.0	4.1	2853485	4.2

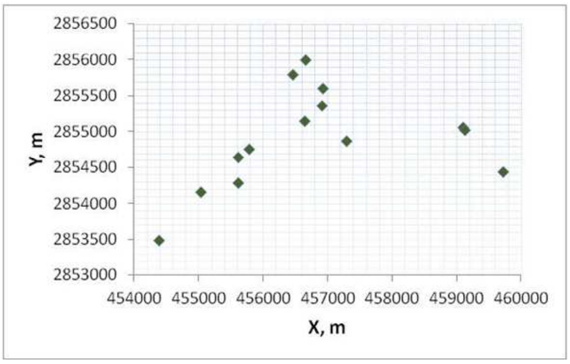


Figure 6. *Location of tested groundwater wells*

5. Results and Discussions

The collected data with GPS, laboratory analyses and satellite image for the study area, were used in both `ERDAS and GIS software's to generate environmental maps. Results were obtained after following certain step.

Figures 7 to 9 show examples of work performed over the satellite image of Majmaah region. Other results are available in the form of Tables and environmental maps showing the distribution of different water quality parameters in the study area.

It should be noted that the levels of water quality parameters were compared with the recommended standards of local guidelines of SAS [18], EPA [19] and WHO [20]. The comparison revealed that most of the wells levels were below the MPL.

Figure 7. *Satellite imagery for study area in ERDAS IMAGINE 2014*

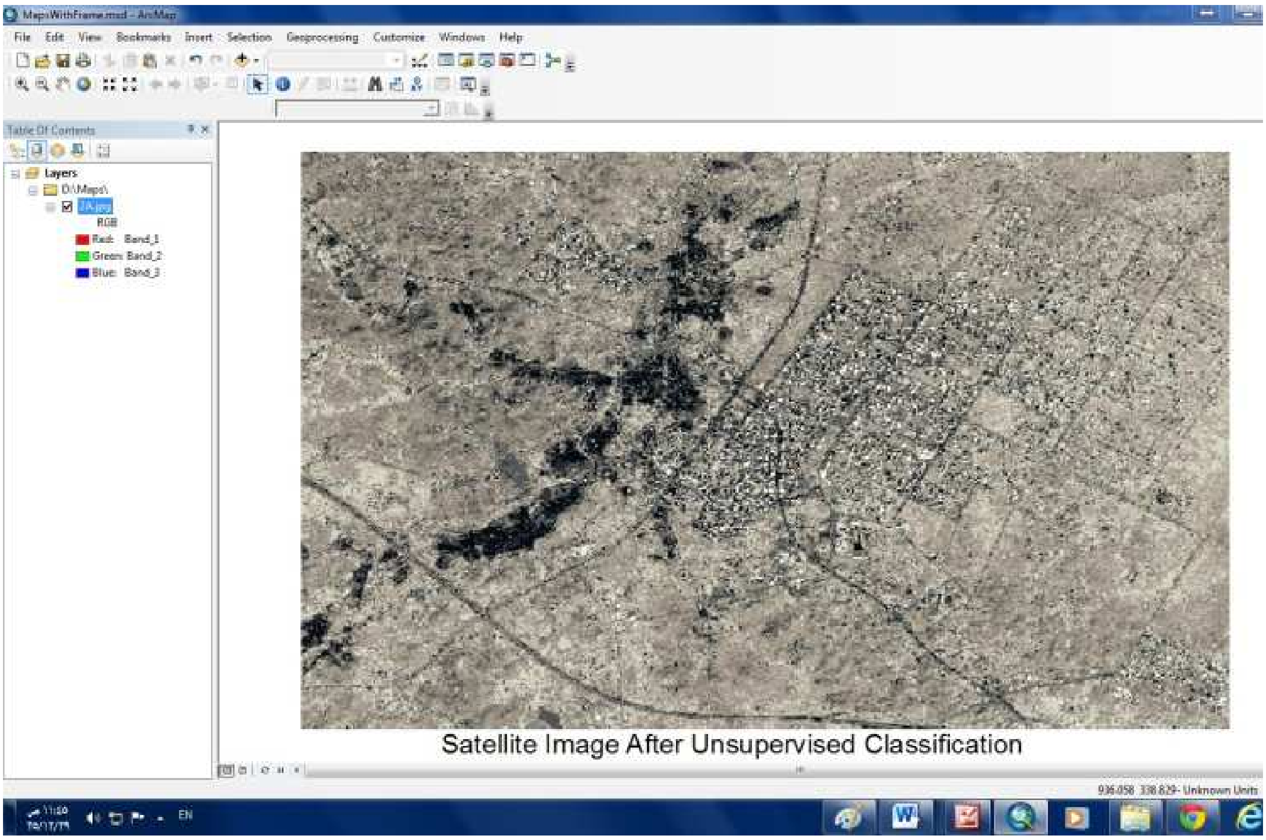


Figure 8. *Satellite imagery after unsupervised classification*

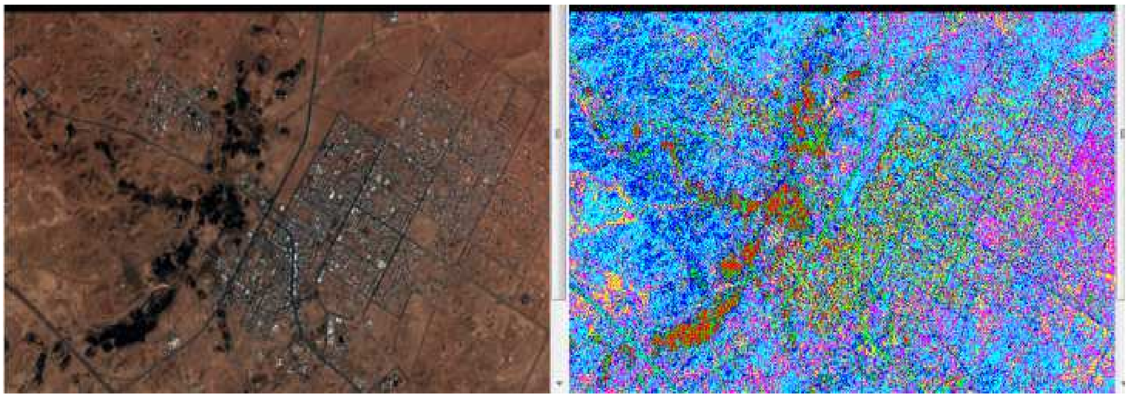


Figure 9. *Satellite imagery after coloring the various classes*

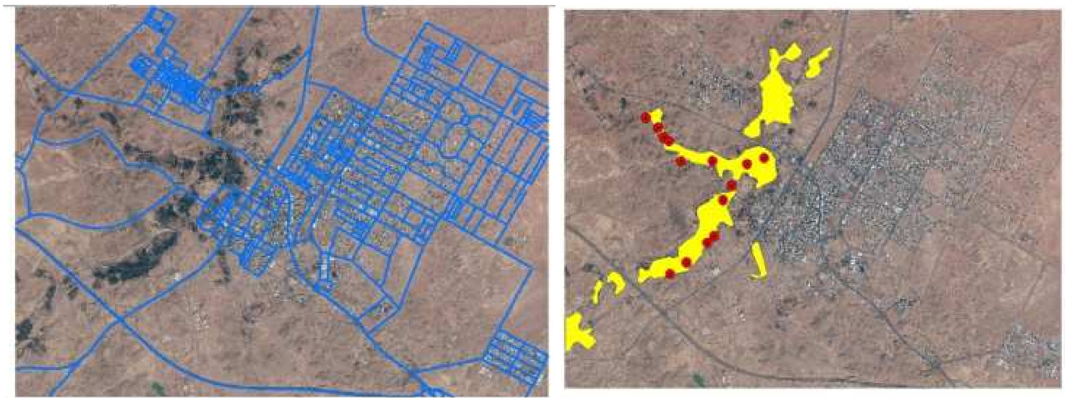
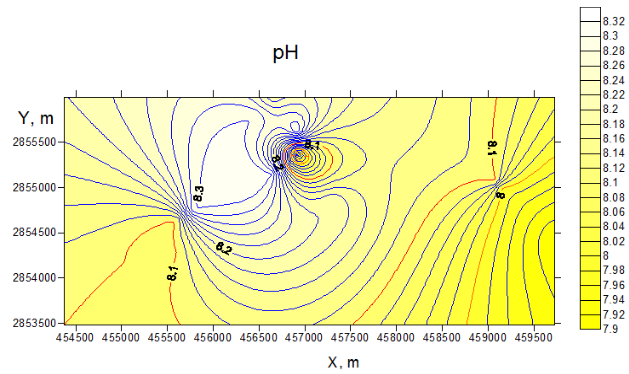
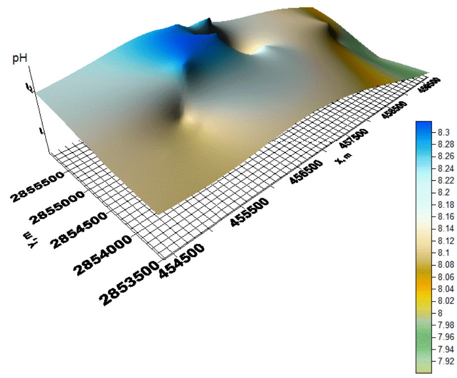
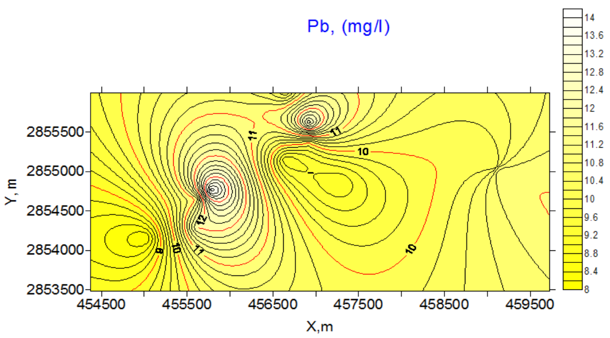
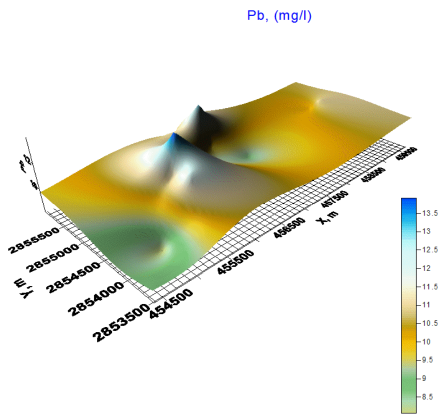


Figure 10. *Roads and cultivated area near the wells*









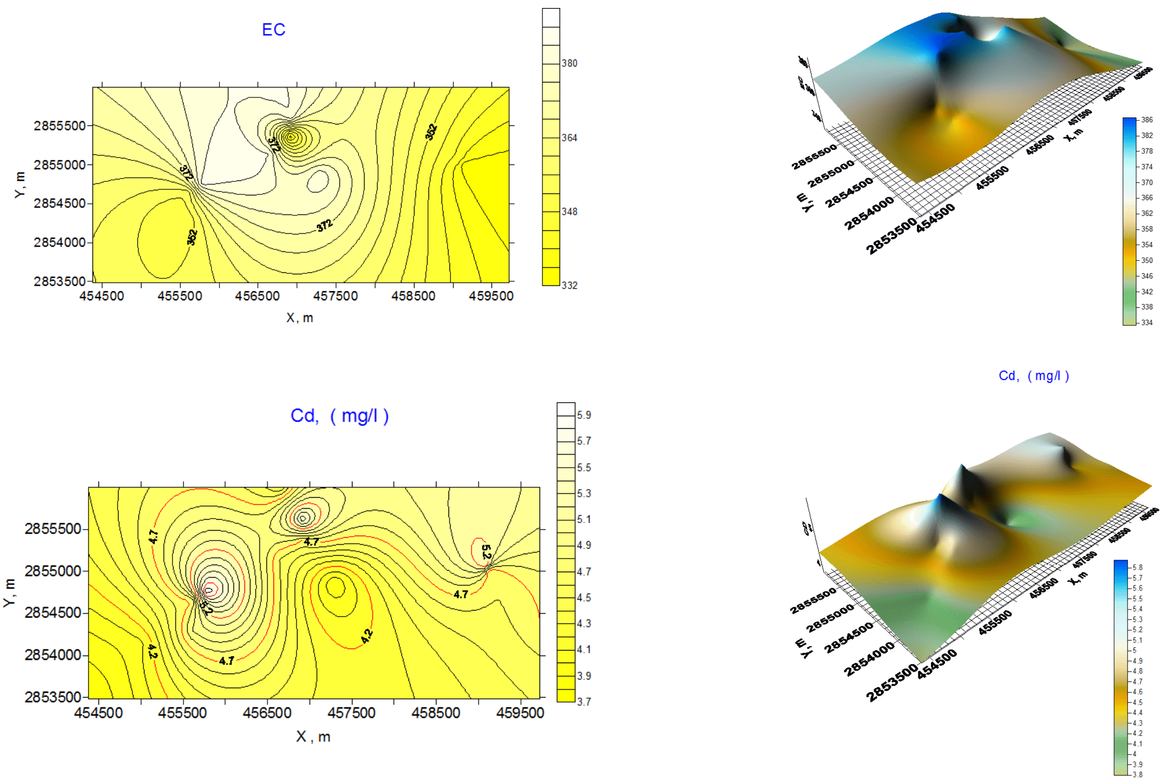


Figure 11. *Contour maps and 3D representation of some water quality parameters at the study area*

Distribution of the water quality parameters (within the study area) in the form of contour maps and 3D representation are presented in Figure (11) as an example. Results revealed that attention should be paid to *Pb* and *Cd* as they were above MPL.

6. Conclusions

The data recorded by low-cost GPS at several locations in Majmaah region were used juxtaposing a satellite image for the same area with an integrated methodology that combined in addition to the adjusted coordinates, environmental data (in this case; water quality parameters collected and analyzed from 15 groundwater wells) to demonstrate how GPS, GIS can be integrated for useful applications in environmental study at Majmaah region, KSA. A methodology was developed to transfer the coordinates of inaccessible points using GPS receivers (WGS84) to the UTM coordinates system with higher accuracy. As the developed spatial GIS is dynamic, other environmental studies rather than the water quality can be added including; soil types, effect of discharging waste water treatment plant, places of industrial areas and its environmental impacts, desertification, etc.

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Abbreviations and Nomenclature

λ = Latitude
GPS = Global Positioning System
$\emptyset$ = Longitude
MPL = Maximum Permissible Level
CEE = Civil and Environmental Engineering
N = Northern coordinates
DOP = Dilution of Precision
PDOP = Position Dilution of Precision
E = Eastern coordinates
pH = measure of the acidity or alkalinity
EPA = Environmental Protection Agency
TDS = Total Dissolve Solids
GDOP = Geometric of Dilution of Precision
UTM = Universal Transverse Mercator
GIS = Geographic Information Systems
WHO = World Health Organization

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