Assessment of Groundwater Quality Parameters Using Multivariate Statistics- A Case Study of Majmaah, KSA

Sameh S. Ahmed[1, 2]

[1]Mining and Metallurgical Engineering Department, Faculty of Engineering, Assiut University, Assiut, Egypt

[2]Department of Civil and Environmental Engineering, College of Engineering, Majmaah University, Majmaah, KSA

Email address:
s.mohamed@mu.edu.sa

Abstract: This paper aims at evaluating the groundwater quality parameters at part of Majmaah City, Saudi Arabia. The study uses multivariate statistics methods (Principal Component Analysis, PCA and/or Factor Analysis, FA) to determine the most important water quality parameters at the study area, aiming at introducing an environmental assessment of its current situation. Water quality parameters that showed levels above the standards would be spotted and reasons behind this contamination will be investigated. Real data are collected from 15 groundwater wells near farms part in Gewy area. The results of the water analysis data were subjected to intensive statistical tests and interpretations ware made in the highlight of physical factors. The paper also introduces a cost effective methodology to minimize the number of water quality parameters to the most important variables based on the multivariate statistical results. The interrelationship between different water quality parameters at the study area was also investigated. Moreover, Geostatistics techniques and GPS data, for the same wells, were utilized for characterization of some water quality parameters in 2D and results are introduced in the form of contour maps and 3D representation of these variables. The obtained results are presented as environmental maps for the water quality parameters at the study area and give, for the first time, a characterization of the water quality at the selected portion of Majmaah city.

Keywords: Water Quality, Multivariate Statistics, Geostatistics, Majmaah, PCA

1. Introduction

Worldwide, there is an increasing concern with the quality of drinking water. In fact, water is a source of life if not the most important. The water is the more material presence on the ground, covering more than three-quarters of the globe. Water is very important for our life. Therefore, water quality must be set to standards in terms of its concentrations, i.e. it should be free from apparent turbidity, color, and odor and from any objectionable taste. This means that it may be consumed in any desired amount without concern for adverse effects on health [1].

In spite of the lack of fresh water available, and doubled the need for fresh water than ever before, there is still enough of these needs, if properly used. Unfortunately, the distribution of fresh water is not equal to the Earth's surface. There are some areas poor in water resources, and others are rich in water. When the rain falling on the ground, It does not fall evenly, some areas barren desert, and some of them fall by the rains and flooding river [1]. There are areas suffering from water shortage, not of a few, but for the misuse of sources.

Globally represent, a problem of lack of potable water for drinking and agriculture, the most serious problem humankind has ever faced, and that despite the fact that water covers about 75 % of the planet. However, approximately 97.5 % of this water is unfit for the purposes of the Human Being the salt water or contaminated industrial waste liquid, and thus makes it more difficult is that 70% of the remaining part of this fresh water available in the world (2.5%) is present in the form of snow is difficult exploited in an economically [1].

The groundwater is the main source of fresh water in Saudi Arabia, covering 96% of any surface water source tortured perennial lack of fluctuation in rainfall (Figure 1) and the nature of the geological formations. Therefore, water sources are rainwater and groundwater, as the study of water resources that depend on the proportion of 95 % of the underground water in need of necessary and urgent to study and objective

evaluation on the grounds that the aspirations of the future will bear fruit only if it is built on the foundations and realistic than the country's wealth water. [4].
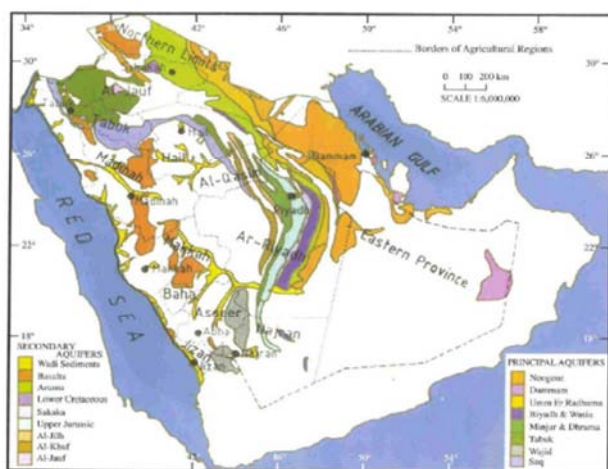

Figure 1. *Average annual rainfall in the KSA [3].*

Renewable surface water and groundwater resources together with an assessment of water withdrawal are summarized from the FAO in Table 1, [4].

Table 1. *Annual water Resources and water use in KSA (FAO 2000) [4].*

Resource	Renewable
Surface water (MCM)	2,200
Ground water (MCM)	2,200
Overlap (between sw and gw)	-2000
Total (MCM)	2,400
Dam Capacity (MCM)	99
Total/Capita (MCM)	
Withdrawals	
By sector	
Agriculture (MCM)	20,800
Domestic (MCM)	2,130
Industry (MCM)	710
Total withdrawals (MCM)	23,640
Total withdrawals/capita (CM)	960
By source	
Surface water (MCM)	1,100
Groundwater (MCM)	21,400

Table 2. *Water use in Saudi Arabia, MCM/yr. [Source: Country Report 1].*

	Domestic & industry	% of total	Agriculture	% of total	Total
1980	502	21.3	1850	78.7	2352
1990	1650	6.06	25589	93.94	27239
1997	2063	11.17	16406	88.83	18469
1999	2200	10.61	18540	8939	20740
2004	2740	13.52	17530	86.48	20270
2009	3170	17.36	15090	82.64	18260

The quality of water may be described in terms of the concentration and state (dissolved or particulate) of some or all of the organic and inorganic material present in the water, together with certain physical characteristics of the water. It is determined by in situ measurements and by examination of water samples on site or in the laboratory. The main elements of water quality monitoring are, therefore, on-site measurements, the collection and analysis of water samples, the study and evaluation of the analytical results, and the reporting of the findings. The results of analyses performed on a single water sample are only valid for the particular location and time at which that sample was taken. One purpose of a monitoring program is, therefore, to gather sufficient data (by means of regular or intensive sampling and analysis) to assess spatial and/or temporal variations in water quality.

This main objective of this work is to provide a clear and comprehensive picture for the overall groundwater quality at specific area. Other objectives are:

(a) To determine and rank the levels of water quality parameters in the study area.
(b) To introduce environmental maps for the distribution of different water quality parameters in the form of contour maps and 3D representation of the variables so that a clear picture can be drawn for the decision makers.
(c) To classify groundwater in the area into spatial water quality types by developing a robust water quality index (WQI).

2. Background and Review

2.1. Groundwater Quality Parameters

Water quality is affected by a wide range of natural and human influences. The most important of the natural influences are geological, hydrological and climatic, since these affect the quantity and the quality of water available. Their influence is generally greatest when available water quantities are low and maximum use must be made of the limited resource; for example, high salinity is a frequent problem in arid and coastal areas. If the financial and technical resources are available, seawater or saline groundwater can be desalinated but in many circumstances this is not feasible. Thus, although water may be available in adequate quantities, its unsuitable quality limits the uses that can be made of it [1].

The quality of groundwater can be measured by determining several components in the field or designate values recorded through chemical analysis in the laboratory and then compare the values with local to international standards to determine the degree of efficiency or quality. The most important items that are measured to determine the quality of groundwater are: temperature –pH, electrical conductivity – dissolved oxygen - alkaline –calcium -sodium - potassium – magnesium – chloride - nitrite – phosphate, etc.

2.2. Water Quality Standards

Since there is a wide range of natural water qualities, there is no universal standard against which a set of analyses can be compared. If the natural, pre-polluted quality of a water body is unknown, it may be possible to establish some reference values by surveys and monitoring of unpolluted water in which natural conditions are similar to those of the water. However, there is a universal standard such as WHO, SAS and EPA.

2.3. Groundwater in KSA

The Kingdom of Saudi Arabia is known as one of the most water scarce countries in the world. It relies on three types of water resources – renewable water resources, non-renewable groundwater resources and desalinated seawater, See Table (3).

Table 3. Available water resources in KSA in 2003-2004 (MCM) [4].

Surface water	5000-8000 (2,239 available for use)
Groundwater resources	2,269,000 (84,400 renewable groundwater in shallow aquifers)
Groundwater recharge	3,985 (1,96 to shallow aquifers in the Arabian Shelf)
Desalination	1,050
Treated wastewater	240

3. The Study Area

Majmaah city is located within the northern part of Riyadh. It lies at latitude N 25° and longitude E 46°, [5].

The governorate is about 185 kilometers northwest of Riyadh on the path through Riyadh, Sudir-Qassim quick high way and away from Qassim city with about 140 kilometers. The city with, 60,000 capita, is considered as one of the most promising developing cities in KSA, Its great strategic location (link between different cities, andthe international road, which connects the central region with a number of Gulf states) will attract a number of residents to work especially after the establishment of the University and Sudir industrial city.

The samples of groundwater at the study area were collected using GPS for the well coordinates and bottle samples were gathered for laboratory analyses. [6]

3.1. Data Collection

Table (4) lists all the raw data collected from the 15 water wells at the study area. These data represent first set of samples (A).

Table 4. Raw data of water quality parameters collected from the study area.

Well	pH	EC, (µs/cm)	TDS, (mg/l)	S, (mg/l)	Ag, (mg/l)	NO₃, (mg/l)	Hg, (mg/l)
1	8.4	383.10	245.184	3	0.03	0.019	0.4
2	8.1	341.80	218.752	2	0.03	0.017	0.4
3	8	334.20	213.888	3	0.03	0.019	0.4
4	7.9	333.60	213.504	3	0.03	0.019	0.4
5	7.9	336.80	215.552	2	0.02	0.016	0.3
6	8.2	383.30	245.312	2	0.02	0.015	0.3
7	8.3	383.80	245.632	2	0.02	0.015	0.3
8	8.2	385.10	246.464	2	0.03	0.018	0.4
9	8.3	383.50	245.440	3	0.03	0.023	0.4
10	8.3	383.30	245.312	3	0.03	0.019	0.4
11	8.3	385.70	246.848	3	0.04	0.025	0.5
12	8.1	354.00	226.560	3	0.03	0.019	0.4
13	8.1	349.10	223.424	3	0.03	0.02	0.4
14	8.1	351.60	225.024	2	0.02	0.014	0.3
15	8.1	356.30	228.032	2	0.02	0.013	0.3

Well	Pb, (mg/l)	Fe, (mg/l)	F, (mg/l)	CN, (mg/l)	CU, (mg/l)	Colour, (TCU)	CR, (mg/l)
1	12	0.14	-0.15	0.008	0.21	111	0.03
2	10	0.12	-0.14	0.009	0.23	117	0.04
3	11	0.13	-0.15	0.008	0.21	103	0.03
4	11	0.13	-0.15	0.008	0.20	102	0.03
5	10	0.13	-0.14	0.008	0.20	103	0.03
6	9	0.11	-0.12	0.007	0.17	87	0.03
7	9	0.11	-0.14	0.008	0.20	104	0.03
8	10	0.12	-0.14	0.008	0.19	98	0.03
9	13	0.16	-0.17	0.009	0.24	124	0.04
10	11	0.13	-0.15	0.008	0.20	105	0.03
11	14	0.17	-0.18	0.010	0.25	134	0.04
12	11	0.13	-0.14	0.008	0.20	105	0.03
13	12	0.14	-0.15	0.008	0.21	108	0.03
14	8	0.09	-0.1	0.006	0.14	71	0.02
15	9	0.14	-0.11	0.006	0.15	85	0.03

Well	Cl, (mg/l)	Cd, (mg/l)	Ba, (mg/l)	Al, (mg/l)	DO, (mg/l)	Ca, (mg/l)	Mg, (mg/l)
1	0.5	4.9	5	0.051	5.5	0.27	0.13
2	0.5	5.3	6	0.055	5.6	0.27	0.13
3	0.4	4.6	5	0.048	5.5	0.5	0.24

Well	Cl, (mg/l)	Cd, (mg/l)	Ba, (mg/l)	Al, (mg/l)	DO, (mg/l)	Ca, (mg/l)	Mg, (mg/l)
4	0.4	4.7	5	0.05	5.4	0.29	0.14
5	0.4	4.7	5	0.049	5.4	0.24	0.12
6	0.4	3.9	4	0.045	5.6	0.26	0.12
7	0.4	4.6	5	0.048	5.6	0.45	0.19
8	0.4	4.4	5	0.046	5.6	0.27	0.13
9	0.5	5.6	6	0.057	5.6	0.25	0.12
10	0.4	4.7	5	0.048	5.6	0.31	0.14
11	0.6	5.9	6	0.06	5.6	0.4	0.15
12	0.4	4.7	5	0.048	5.4	0.3	0.13
13	0.5	4.9	5	0.05	5.6	0.56	0.14
14	0.3	4.1	4	0.042	5.5	0.27	0.13
15	0.4	3.8	4	0.046	5.5	0.29	0.14

3.2. Global Positioning System (GPS)

Table (5) lists the coordinated of the well as recorded by the student's using GPS instrument in the field. The coordinated were recorded first as longitudes and latitudes and then converted to X, Y coordinate system. Figure (4) shows the locations of the wells.

Table 5. Coordinates of the wells at the study area.

Well	N	E	X, m	Y, m
1	25 53.411'	45 21.375'	464314	2863571
2	25 48.773'	45 24.483'	459099	2855056
3	25 48.769'	45 24.463'	459132	2855018
4	25 48.456'	45 24.109'	459722	2854439
5	25 48.956'	45 25.790'	456916	2855370
6	25 48.684'	45 25.564'	457292	2854867
7	25 48.836'	45 25.951'	456647	2855150
8	25 49.269'	45 25.951'	456649	2855999
9	25 49.087'	45 25.792'	456917	2855612
10	25 49.183'	45 26.067'	456455	2855791
11	25 48.622'	45 26.468'	455781	2854758
12	25 48.563'	45 26.572'	455607	2854649
13	25 48.371'	45 26.776'	455606	2854295
14	25 48.298'	45 26.916'	455031	2854162
15	25 47.930'	45 27.306'	454377	2853485

4. Methodology

The data used throughout this work were collected from 15 groundwater wells from a farm area in Majmaah city. Water samples analyzed (first set) at the Environmental Engineering Lab, Civil and Environmental Engineering Department. Most of the well samples have a complete analysis for about 20 water quality parameters, such as: *pH, TDS, DO, EC, Cl, F, Cu, Ag*, and *Fe*. The following steps describe the methodology.

- GPS instrument was used to determine the X, Y and coordinates of the tested wells, as there were no coordinates available for those points.
- Laboratory analysis to be conducted over three samples for 22 water quality parameters, and results were sorted for further studies.
- Statistical analysis over the WQP from each well has been done aimed at revealing the nature of the different variables.
- A comparison study between the mean values for the

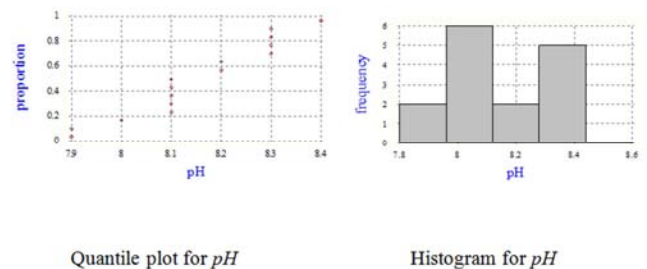tested WQP and the national and international standards will be introduced.
- PCA has been used for variables reduction.
- Surfer software was used to generate contour maps and 3D representation of each variable.

5. Preliminary Results

The next step is to screen the data to determine the statistical values before using multivariate statistics. Statistics were carried out using Excel and StatGraph Software 2.1 [9, 10].

5.1. Summary Statistics for pH

Figure (2) shows graphical results of conducting quantile plot (left) and histogram (right) for one variable (pH), while Figures (3 and 4) give the other results.

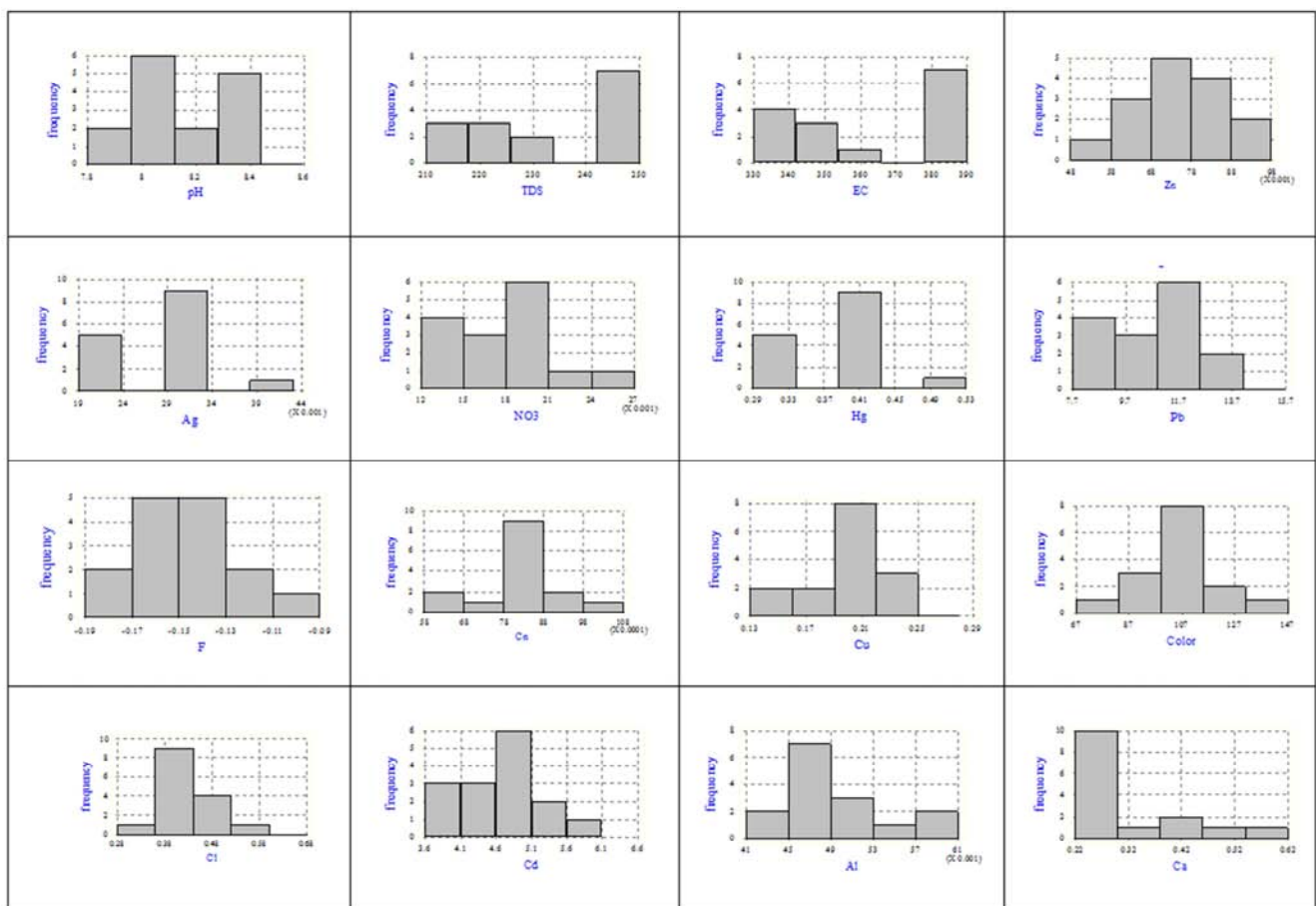Quantile plot for *pH*   Histogram for *pH*

Figure 2. Statistical graphical representation of pH variable.

5.2. Discussion of the Summary Statistics

The statistical analysis shown in Table (6) was made for 22 water quality parameters taken from 15 groundwater wells at a location in Majmaah city. At the first screening stage all the results of the lab. analysis of the different water quality parameters have checked for the extreme values and the wrong values were corrected or excluded from the next step of analysis. Therefore, we should mansion that there were several values recorded with vital mistakes, for example, the record of Dissolved Oxygen in well number 12 was primary recorded in the lab analysis sheet as 504 mg/l. Recheck the value revealed that this value is 5.4 mg/l. Preliminary statistics lead to exclude the following parameters from the multivariate statistics, those are: *F, S, Cr, Color* and *Ba* as they have abnormal distribution.

Table 6. Statistical Analysis of tested wells at Gewy, Majmaah.

Parameter	Mean	Median	Mode	St. Dev.	Variance	Kurtosis	Skew.	Min.	Max.
pH	8.153	8.10	8.100	0.151	0.023	-0.691	-0.219	7.900	8.400
Zn	0.072	0.07	0.070	0.011	0.000	-0.443	-0.118	0.050	0.090
TDS	232.329	228.032	245.312	13.645	186.178	-1.885	-0.147	213.504	246.848
S	2.533	3.00	3.000	0.516	0.267	-2.308	-0.149	2.000	3.000
Ag	0.027	0.03	0.030	0.006	0.000	-0.171	0.091	0.020	0.040
NO3	0.018	0.02	0.019	0.003	0.000	0.271	0.484	0.013	0.025
Hg	0.373	0.40	0.400	0.059	0.004	-0.171	0.091	0.300	0.500
Pb	10.667	11.00	11.000	1.633	2.667	-0.157	0.395	8.000	14.000
Fe	0.130	0.13	0.130	0.020	0.000	0.884	0.131	0.090	0.170
Cn	0.008	0.01	0.008	0.001	0.000	1.015	-0.300	0.006	0.010
Cu	0.200	0.20	0.200	0.030	0.001	0.388	-0.469	0.140	0.250
Cr	0.031	0.03	0.030	0.005	0.000	1.401	0.282	0.020	0.040
Cl	0.433	0.40	0.400	0.072	0.005	0.948	0.676	0.300	0.600
Cd	4.720	4.70	4.700	0.573	0.329	0.276	0.405	3.800	5.900
Al	0.050	0.05	0.048	0.005	0.000	0.717	0.876	0.042	0.060
DO	5.533	5.60	5.600	0.082	0.007	-1.022	-0.740	5.400	5.600
Ca	0.329	0.29	0.270	0.100	0.010	0.825	1.419	0.240	0.560
Mg	0.143	0.13	0.130	0.032	0.001	6.271	2.454	0.120	0.240
Ec	363.013	356.300	383.300	21.320	454.537	-1.885	-0.147	333.600	385.700

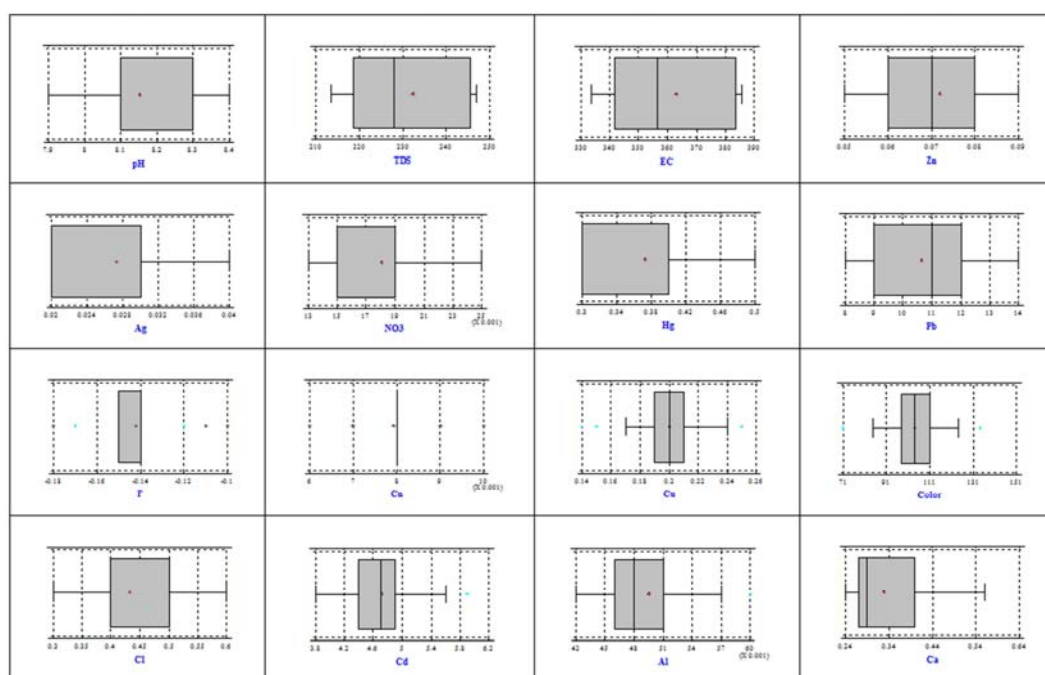*Figure 3. Histograms of the water quality parameters at the 15 wells.*

Figure 4. Box-and-Whisker Plot of the water quality parameters at the 15 wells.

5.3. Comparing the Water Quality Data with the Standards

Table 7. Comparison study between the measured water quality and the standards.

No	Variable	Average Measured values	SAS standards	EPA [11] standards	WHO [12]standards	Notes
1	pH	8.153	6.5-8.5	6.5 – 8.5	6.5- 8.5	
2	Zinc (Zn)	0.072 mg/l	5000 µg/l	5 mg/l	3 mg/l	
3	TDS	232.3 mg/l	1500 mg/l	500 mg/l	1000 mg/l	
4	Sulfate (S)	2.53 mg/l	400 mg/l	250 mg/l	400 mg/l	
5	Silver (Ag)	0.027 mg/l	-	0.1 mg/l	0.1 mg/l	
6	Nitrite (NO$_3$)	0.018 mg/l	-	1.0 mg/l		
7	Mercury (Hg)	0.373µg/l	1 µg/l	0.002 mg/l	0.001 mg/l	
8	Lead (Pb)	10.67µg /l	10 µg/l	0.015 mg/l	0.01 mg/l	> MPL
9	Iron (Fe)	0.130 mg/l	1.0 mg/l	0.3 mg/l	0.3 mg/l	
10	Cyanide (Cn)	0.008 mg/l	70 µg/l	0.2 mg/l	0.1 mg/l	
11	Copper (Cu)	0.200 mg/l	1000 µg/l	1-1.13 mg/l	2.0 mg/l	
12	Chromium (Cr)	0.031 mg/l	0.05	0.05	0.05	
13	Chloride (Cl)	0.433 mg/l	600 mg/l	250 mg/l	250 mg/l	
14	Cadmium (Cd)	4.72µg /l	3.0 µg/l	0.005 mg/l	0.003 mg/l	> MPL
15	Aluminum (Al)	0.05 mg/l	100-200 µg/l	0.05 -0.2 mg/l	0.2 mg/l	
16	Dissolved Oxygen (DO)	5.53 mg/l	-	-	-	
17	Calcium (Ca)	0.33 mg/l	-	200 mg/l*	75 mg/l	
18	Magnesium (Mg)	0.143 mg/l	-	50 mg/l*	50 mg/l	
19	EC	363.0µS /mm	-	-	-	
20	Color	103.80 TCU	15 TCU	15 TCU	15 TCU	> MPL

6. Multivariate Statistics Methods

Multivariate statistical methods: Principal Components Analysis (PCA) and Factor Analysis (FA) methods can be used to reduce Number of variables and detect relationships between them. The large set of water quality parameters can be further studied using one or both of these methods to determine the interrelationship between the parameters [13].

6.1. Multivariate Statistics

1) To identify the hidden dimensions or constructs that may not be apparent from direct analysis.

2) To identify relationships between variables, it helps in data reduction.

3) It helps the researcher to cluster the product and population being analyzed.

Principal Component Analysis (PCA)

This is the most common method used by researchers. PCA starts extracting the maximum variance and puts them into the first factor. After that, it removes that variance explained by the first factors and then starts extracting maximum variance for the second factor. This process goes to the last factor [14]. In this research paper; the results of PCA are demonstrated

while FA results are reserved for further publication.

6.2. Results and Discussions of PCA

The correlation matrix controlling all variables using SPSS is presented in Table (8). Correlations are highlighted using 4 different colors for ranges (0.2 to 0.8 and above). PCA analysis is given in Table (9), This procedure performs a principal components analysis. The purpose of the analysis is to obtain a small number of linear combinations of the 17 variables which account for most of the variability in the data. In this case, 4 components have been extracted.

Table 8. Correlation matrix controlling all variables using SPSS [15].

	pH	Zn	TDS	Ag	NO₃	Hg	Pb	Fe	Cn	Cu	Cl	Cd	Al	DO	Ca	Mg	Ec
pH	1																
Zn	.060	1															
TDS	-.033	.221	1														
Ag	-.119	.645	.245	1													
NO₃	.062	.835	.360	.767	1												
Hg	-.095	.657	.238	.921	.770	1											
Pb	.119	.840	.411	.664	.899	.705	1										
Fe	.230	.664	.335	.519	.762	.547	.889	1									
Cn	.093	.773	.267	.627	.799	.656	.804	.661	1								
Cu	.154	.794	.276	.567	.747	.597	.841	.728	.900	1							
Cl	.281	.677	.252	.498	.696	.492	.781	.754	.784	.815	1						
Cd	.266	.808	.217	.544	.767	.574	.834	.735	.893	.923	.839	1					
Al	.335	.706	.194	.448	.683	.456	.778	.773	.816	.816	.853	.934	1				
DO	.294	-.109	-.414	-.145	-.107	-.222	-.168	-.106	-.117	-.057	.031	.007	.108	1			
Ca	.192	.286	-.110	.145	.225	.135	.266	.221	.231	.309	.321	.280	.257	.195	1		
Mg	.072	.217	.083	.098	.188	.090	.235	.207	.225	.248	.129	.185	.200	-.088	.650	1	
Ec	-.033-	.221	1.000	.245	.360	.238	.411	.335	.267	.276	.252	.217	.194	-.414	-.110	.083	1

Table 9. Principal Component Analysis.

Component Number	Eigenvalue*	Percent of Variance	Cumulative Percentage	Component Number	Eigenvalue	Percent of Variance	Cumulative Percentage
1	8.79189	51.717	51.717	10	0.15602	0.918	97.408
2	2.36680	13.922	65.639	11	0.14240	0.838	98.246
3	1.49645	8.803	74.442	12	0.12077	0.710	98.957
4	1.38797	8.165	82.607	13	0.06893	0.405	99.362
5	0.72077	4.240	86.846	14	0.05797	0.341	99.703
6	0.58768	3.457	90.303	15	0.03654	0.215	99.918
7	0.41371	2.434	92.737	16	0.01391	0.082	100.000
8	0.33459	1.968	94.705	17	0.00003	0.000	100.000
9	0.30356	1.786	96.491				

* Eignevalue: is an non-zero vector whose direction does not changes when leaner transformation is applied

Table (10) gives the component weights of the main four components. Figure (4a) shows the scree plot using STAT Graph software and. From this figure, one can note that only four components can be drawn from the given data (those with eigenvalues > 1.0).

Scatter plot of the first two components and plot of component weights are shown in Figures (4b) and (4c) respectively, while Figure (4d) displays the components in space using STAT Graph.

	Comp. (1)	Comp. (2)	Comp. (3)	Comp. (4)
EC	0.1322	-0.4898	-0.3725	-0.1096
Fe	0.2854	0.0106	-0.0820	-0.1072
Hg	0.2521	-0.1233	0.3498	0.2028
Mg	0.0897	0.1348	-0.4391	0.5829
NO₃	0.3066	-0.0544	0.1192	0.0529
Pb	0.3213	-0.0438	-0.0076	-0.0005
pH	0.0551	0.2949	-0.3630	-0.3868
TDS	0.1321	-0.4904	-0.3717	-0.1089
Zn	0.2936	0.0354	0.1159	0.0786

Table 10. Component Weights.

	Comp. (1)	Comp. (2)	Comp. (3)	Comp. (4)
Ag	0.2458	-0.1155	0.3487	0.2098
Al	0.2900	0.1774	-0.0765	-0.2171
Ca	0.1057	0.3283	-0.3222	0.4832
Cd	0.3101	0.1327	-0.0011	-0.1385
Cl	0.2887	0.1226	-0.0677	-0.1803
Cn	0.3056	0.0364	0.0684	-0.0140
Cu	0.3083	0.0756	-0.0141	-0.0370
DO	-0.0426	0.4481	0.0318	-0.2175

The above table shows the equations of the principal components. For example, from table (10), the first principal component has the equation

0.24584*Ag + 0.289998*Al + 0.105667*Ca + 0.310126*Cd + 0.288733*Cl +0.305632*Cn + 0.308319*Cu - 0.042581*DO + 0.132234*EC + 0.285392*Fe +

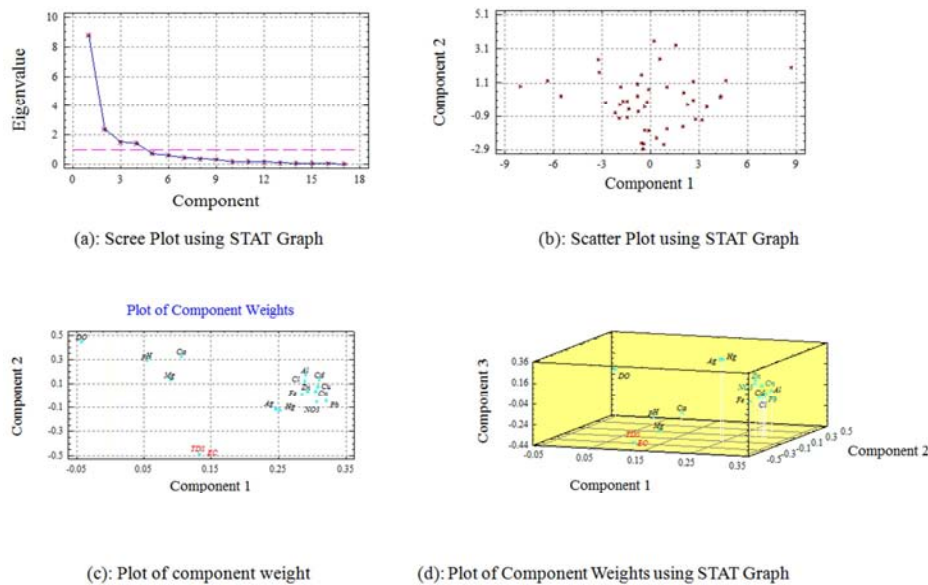0.252125*Hg + 0.0897126*Mg +0.306629*NO₃ +0.321259*Pb + 0.0551099*pH+ 0.132119*TDS + 0.293593*Zn

(a): Scree Plot using STAT Graph

(b): Scatter Plot using STAT Graph

(c): Plot of component weight

(d): Plot of Component Weights using STAT Graph

Figure 4. *Plots of PCA using STAT Graph.*

6.3. Interpretation of Multivariate Statistics Results

PCA method has defined four main components for the tested set of data. This is can be seen from the scree plots of figure (4a). The implementation of PCA method led to reduction in the number of variables.

The values obtained from data reduction using PCA method reveal that the first component (factors) involves: *Cd, Cn, Cu, NO3* and *Pb* in one group. The variables: *Ca, DO, EC* and *TDS* are the main variable in group two. Also, group three consists of seven variables that might have interrelationship among them, those are: *Ca, Ag, EC, Mg, pH*, and *TDS*. The fourth group has two main variables: *Mg* and *pH*.

It is logically interpreting the strong interrelationship between *TDS* and *EC* as the one variable can be extracted directly from the other. Also it was expected that *Ca* and *Mg* laying in one group. However the hidden relations between the variables forming the first group are difficult to be interpreted.

6.4. Mapping using Geostatistics Techniques

Geostatistics is the statistics of spatially or temporally correlated data. The technique has been used to be a practical approach to the problems of ore reserve estimation and mine planning. It has been also used for other applications concerned with petroleum and gas resources estimation.

One of the characteristics that distinguish earth sciences data from most other data is that the data belongs to same location in space. Spatial features of the data set such as the location of extreme values, and the overall trend are of considerable interest [16]. These features, in other words the variables Z(x), are functions describing natural phenomena that have geographic distributions, such as any water quality parameter (for example pH, EC, etc). Kriging is the most famous geostatisics technique being used for this purpose. In this work, Kriging is performed using SURFER software [17].

Figure (5) shows contour map and 3D representation of three pH variables (*pH, TDS* and *Zn*), as examples, at the study area. Surfer 8 software was used to generate the maps based on Kriging technique and the measured X, Y coordinates for 14 wells after excluding well number 1 due to its far position from the rest of the wells.

7. Conclusions

Water quality parameters of groundwater wells at part of Majmaah city has been characterized using multivariate statistical analyses. The main findings of this paper are:

Results of the preliminarily statistical analysis revealed that only 17 variables are suitable for carrying out multivariate statistical analysis to reduce the number of measured variables to principle components or factors. Variables: *F, S, Cr, Color* and *Ba* were excluded from multivariable analysis.

A comparison study between the mean values for the tested WQP and the national and international standards is introduced, where most of the recorded parameters were below the standards except two variables showed a slight values above the maximum permissible levels, these are: Lead (*Pb*) and Cadmium (*Cd*).

PCA has been used for variables reduction, where four PCA were extracted and the variables defining each group are reported.

An attempted to interoperate the resultant groups were made, despite the physical interpretation is not deep.

Surfer software was used to generate contour maps and 3D representation of each variable within the study area.

The methodology introduced throughout this project would assist the water quality monitoring programs by providing a quick analysis and dynamic system for water quality characterization at any defined area.

Nevertheless, the study has been carried out over a small portion, the steps and introduced procedure can be easily applied elsewhere for similar purpose.
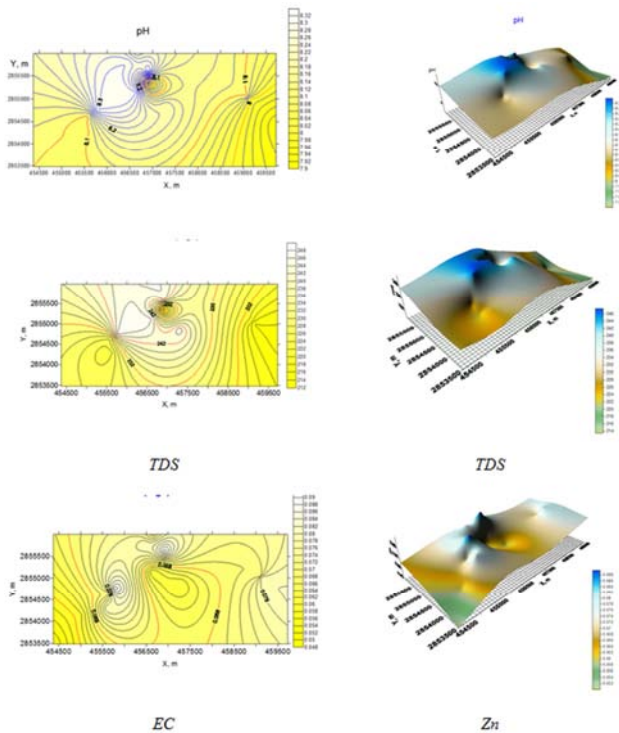
Acknowledgements

Figure 5. *Contour map and 3D for pH, TDS and EC variables at the study area, (examples of the results).*

References

[1] EPA, (2001), "Parameters of Water Quality – Interpretation and Standards" Report, 133P, ISBN 1-84096-015-3.

[2] Mohammed Al-Saud *et. al*. (2011), "Challenges for an Integrated Groundwater Management in the Kingdom of Saudi Arabia" *International Journal of Water Resources and Arid Environments* 1 (1): 65-70, 2011.

[3] Walid Abdelrahamn (2006), "Groundwater Resources Management in Saudi Arabia" Special presentation at water conservation workshop, Khoper, KSA, December 2006.

[4] FAO, (2009), "Groundwater Management in Saudi Arabia", A Report by FAO, 14P.

[5] "Mergeb Menikh Mountain at Majmaah Governorate", A heritage historical report issued by museums and heritage agency as a Book (in Arabic).

[6] Sameh S Ahmed and Mahmoud T. Azmi (2014), "A precise methodology integrates low-cost GPS data and GIS for monitoring groundwater quality parameters in Majmaah region, KSA". International Journal of Environmental Monitoring and Analysis, 2014: 2 (5): 279-288, November 2014. doi: 10.11648/j.ijema.20140205.18.

[7] Gregory T. French (1997), "Understanding the GPS, An Introduction to the Global Positioning System" First edition, April 1997.

[8] GPS Coordinate Converter, Maps and Info, http://boulter.com/gps/.

[9] Excel 2010, "Microsoft Office 2010".

[10] STATGRAPHICS plus, (1996): Statistical Graphics Corp.

[11] EPA, (2012), *"Drinking Water Standards and Health Advisories"*, *2012 Edition,* EPA 822-s-12-001, Office of water, U.S Environmental Protection Agency. April 2012.

[12] World Health Organization, (2004), "Guidelines for Drinking-water Quality", Vol. 1, 3rd Edition, Geneva, ISBN: 9241546387.

[13] http://www.statsoft.com/Textbook/Principal-Components-Factor-Analysis.

[14] http://www.statisticssolutions.com/academic-solutions/resources/directory.

[15] SPSS 16.0 for windows, (Release 16.0.0, Sept 2007) http://www.winwarp.com.

[16] Issak, E. H. and Srivastava, R. M. (1989), "An Introduction to Applied Geostatistics", Oxford Univ. Press, New York, 561 p.

[17] SURFER version 8.00, (2002), "Surface Mapping System", Golden Surfer Inc.