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GROUNDWATER EVALUATION IN AL-GOFRA OASIS, MIDDLE LIBYA, USING STATISTICAL METHODS

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With its two main aquifers that feed five villages and serve about 60000 capita, Al-Gofra Oasis, middle Libya, has seldom been subjected thoroughly for water quality evaluation. This paper aims at addressing the current situation of the groundwater at the oasis, studies the sources of pollution to the aquifers and introduces a methodology based on multivariate statistics for better monitoring and regular evaluation of the water quality at that oasis. Multiple Regression Analysis was used to correlate the field water quality data with the laboratory measured chemical parameters. Groundwater is the main/only source of water in that region. The aquifer in Sokna and Wadan is confined and its rocks consist of sand, clay and sandstone. The quality of water in this aquifer is fairly good and the Total Dissolved Solids (TDS) range between 1200 to 1500 ppm. The aquifer in Hun is deep confined aquifer and the quality of water is poor, where the TDS ranges between 4000 and 5000 ppm.

KEYWORDS: *Water quality; TDS; regression statistics; Al-Gofra oasis*

INTRODUCTION

Nowadays, there is a great concern of the groundwater over the entire world. Some people believe that the next World War will be for the sake of water. In arid areas (like Libya) where groundwater is the main source for developing the county, there is a need for better management and conservation of the available water resources. Despite the lack of adequate treatment of water for drinking dependency on sea desolation, wells and boreholes water are usually used as supplements for the scarce pipe borne-water for drinking with little or no treatment. Industrial growth is swift increasing globally and also is the water demand for industrial processes [1]. The problem has two sides, one is the quantity of the water and the second is the quality of the water. This study investigates the present situation of the groundwater quantity and quality at Al-Gofra oasis, Libya.

DESCRIPTION OF THE STUDY AREA

Al-Gofra Oasis is located 270.0 km south of Surt-Gulf and about 1-3 km north of mountain Al-Harug Al-Aswad. It lies between longitudes 14^{o}E and 19^{o}E and latitudes 26^{o}N and 30^{o}N in its eastern part and 28N and 30N in its western part. It consists of five small villages: Hun, Wadan, Sokna, Al-Fokara, and Zalla (**Figure 1**). The population is approximately 60,000 capita and distributed over all these villages.

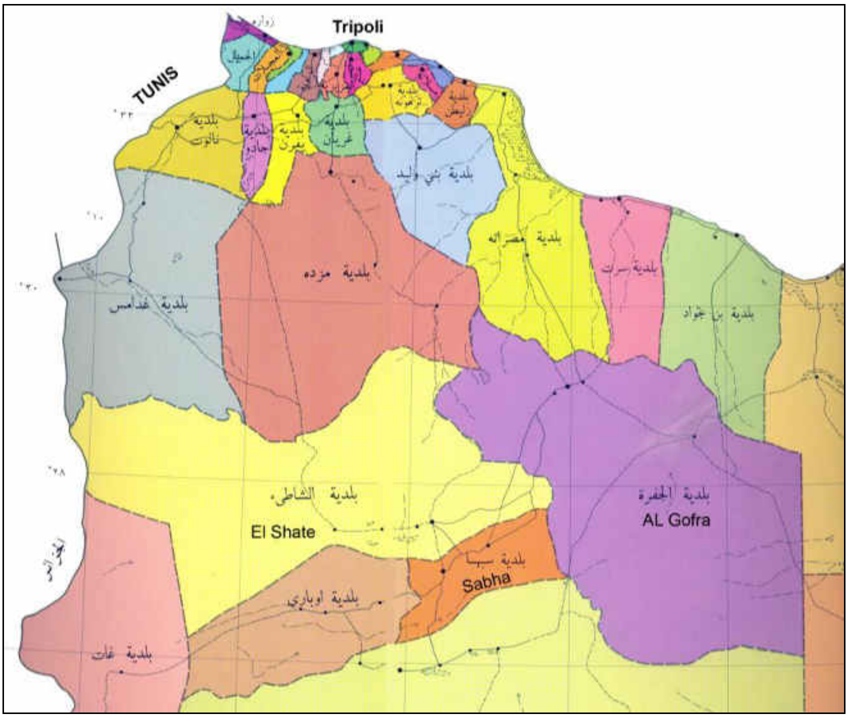

Figure 1: Al-Gofra Oasis, middle Libya.

Climate in this region is typical desert climate. The average temperature in the summer is 44 ^{o}C and in winter it drops to 3^{o}C (**Figure 2**) with a drastic change between day and night.

Relative humidity is very low in summer and reaches 35% in the winter. Hot wind blows from the south and is considered an active factor in carrying sand particles. Exceptional flooding occurs once every 20-25 years; rainfall is very low with small yearly average value (**Figure 3**) and occurs in scattered showers from late October until early April.

The general profile of the region has a rough texture and slopes gently south to north, with an average slope along the oasis of 2.0 m/km. The maximum elevation is about 470 m above mean sea level (a.m.s.l) in Al-Fokaha and lowest elevation is 200 m (a.m.s.l) in Zallaa, elevations of Sokna, Hun and Wadan are 300, 260 and 250 (a.m.s.l) respectively.

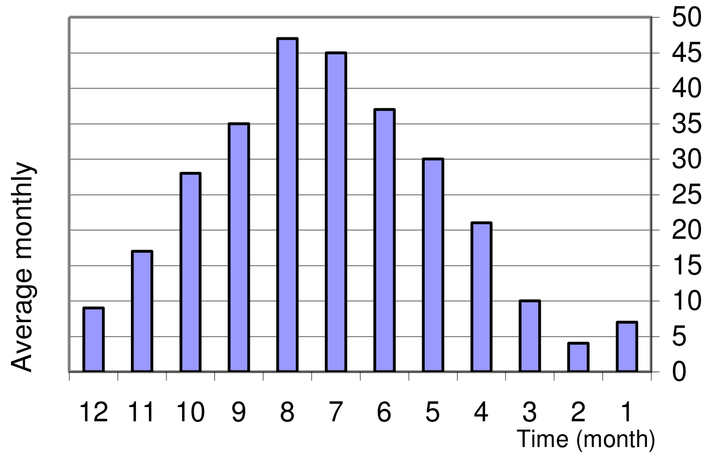

Figure 2: Average monthly temperature (^oC).

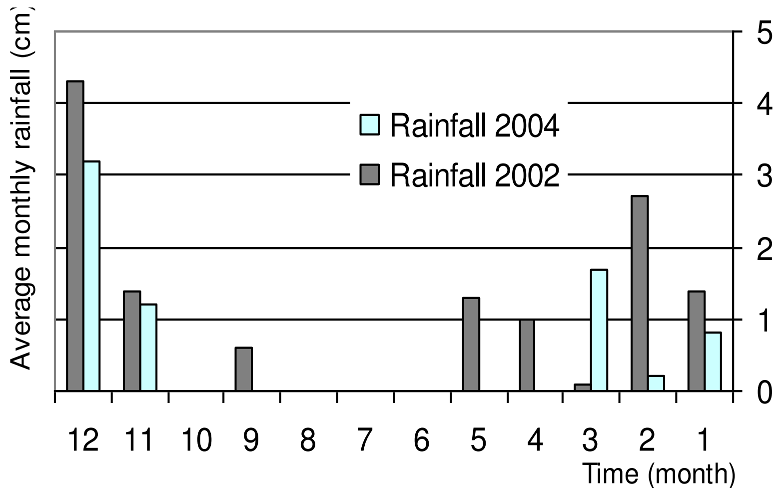

Figure 3: Average monthly rainfall in 2002 and 2004**.**

GEOLOGY OF AL-GOFRA OASIS

There have been no detailed studies concerning the structural geology of Al-Gofra oasis. All the following interpretations are based on well-log information for the wells along the oasis and on surface observations.

The aquifer in Sokna and Wadan is confined and its rocks consist of sand, clay, gypsum and sandstone. The quality of water in this aquifer is good and the Total Dissolved Solids (*TDS*) ranges between 1200 to 1500 ppm. The rock aquifer in Hun is limestone and it is a deep confined aquifer. The quality of water is poor, where the TDS ranges between 4000 and 5000 ppm. The aquifer in Zalla is unconfined aquifer and its rocks are sandy rocks. The groundwater level in Zalla aquifer ranges between 30 and 150 m. Also, the aquifer in Al-Fokaha is an unconfined aquifer and its rocks are sandstones. The groundwater level in that aquifer ranges between 40 and 190 m.

Quality of water in both aquifers (i.e. Zalla and Al-Fokaha) are fairly good, where *TDS* ranges between 1600 and 2000 ppm.

Al-Gofra aquifers are a part of the continental series belonging to the Lower Cretaceous and Upper Jurassic and extend over more than 50 % of Libya. This series is also well developed in Algeria, Egypt and Sudan. These aquifers are considered to be the most important one in dealing with the water resources in Al-Gofra oasis [2]. **Figure 4** shows the location of Hun area and the geological formation of the main aquifers from water quality assessment point of view.

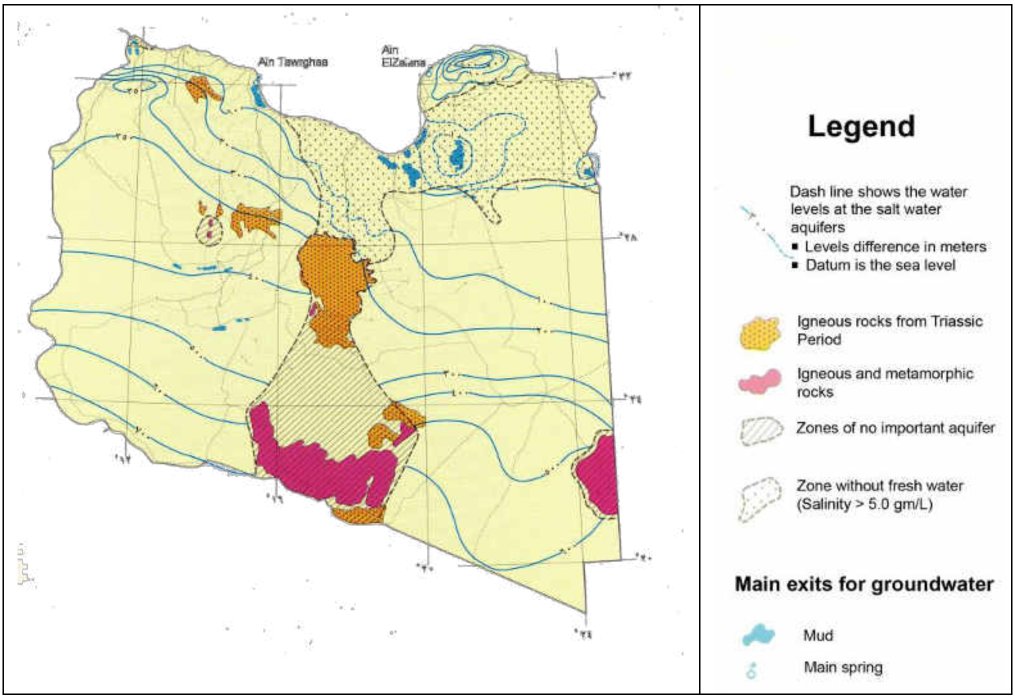

Figure 4: Geological formation and water table levels at the main aquifers of Libya.

WATER CONSUMPTION IN AL-GOFRA

The only sizeable water resource available in the area is groundwater. This groundwater is used for domestic supply, agriculture and watering animals. Since 1970 hydro-geological investigations have been carried out in an attempt to develop the groundwater and more than 5 deep wells (more than 800 m) have been drilled along the oasis, two of them in Zallaa and Al-Fokaha and the rest in Sokna. All these wells are artesian aquifers and have an average yield of about 150.0 l/s.

Discharge and Recharge of Groundwater in Al-Gofra

Discharge of water from the Al-Gofra aquifers is continuously increasing every year due to increasing water consumption. There is no obvious natural discharge from the aquifers in the study area. About 5 wells have been drilled along the Al-Gofra oasis. The GWA has estimated the amount of irrigation water required per hectare as 9000 m^3/ha/year. The land call for the development is about 3000 ha. This leads to a total water requirement of 27.0 x 10^6 m^3/year. The GWA has estimated that the maximum discharge from the aquifers should be 11.0 x 10^6 m^3/year. A rough estimate of the hydraulic gradient along the Oasis has been found to be 5 x 10^{-4} towards the north. Therefore, the natural flow was estimated to be 2.2 x 10^{-1} m^3/m^2/year with transmissivity of 1.8 x 10^{-2} m^2/s. However, if new information shows this value to be underestimated, it would result in an increase of the water resources available. Consequently, the main part of the water from the deep aquifers in the oasis is coming from storage.

Most of the groundwater in the oasis is either fossilized water or water recharged at great distances from the area. Surface flow is almost absent and occurs occasionally. Water from occasional flood runoff flows slowly along the bed area and results in some recharge to the shallow aquifer as in Al-Fokaha. The shallow groundwater in the area is characterized by perched water bodies along the oasis. These water bodies overlie the regional groundwater. There has been no study on the amount of water recharged to the shallow aquifer.

Storage Coefficient and Transmissivity

The hydraulic parameters of main aquifer (Wadan-Sokna) have been determined by step-flow and recovery tests carried out on Sokna's wells in 1985 by GWA of Libya [3]. The results are fairly consistent, with transmissivity ranging from1.6x10^{-2} to 2.3x10^{-2} m^2/s as in **Table 1**. The storage coefficient (Storativity) was determined only with well-2 flowing and Well-3 as an observation well. The value of storage coefficient was found to be 2x10^{-4}. The geometric characteristics of this aquifer are rather homogenous and extend over several thousand square kilometers. Therefore, there is no reason to expect important changes of the behavior of this aquifer except over long periods of time or due to new resources (industrial activities).

Table 1: Hydraulic parameters of Wadan-Sokna aquifer [3].

Well No.	Trasnsmissivity (x10^{-2}) m^2/s	Storage coefficient	Estimated discharge (l/s)
1	1.6	2.1x10^{-4}	41
2	2.3		33
3	2.05		30
4	1.94		166
5	2.1		28

The above values of transmmisivity and storage coefficient were used to calculate the effect of well discharge on the piezometric head. No lateral boundary is expected to affect the long-term behavior of the aquifer, and results based on these parameters can be considered as minimum values that would increase with the contribution from the overlying or underlying strata.

WATER QUALITY AND SOURCES OF POLLUTION

There are many sources of pollution, which can be concluded as: sewage disposal on land using septic tanks and drains in rural areas. Septic tanks and cesspools are the largest of all contributors of wastewater to the ground and are the most frequently reported sources of groundwater contamination over the world [4].

In many areas this sludge, which contains a large number of potential contaminants, is spread on agricultural lands. In some regions liquid sewage that has not been treated or that has undergone partial treatment is sprayed on the land surface. Application of liquid sewage and sewage sludge to the land provides nutrients such as nitrogen, phosphorus, and heavy metals to the soil. One of the potential negative impacts of this type of sewage disposal is degradation of groundwater quality [5]. The second source of pollution is the agriculture activities. Agriculture is probably the most important of all the activities of man that influence the quality of groundwater. Among the main agricultural activities that can cause degradation of groundwater quality are the usages of fertilizers and pesticides and the storage or disposal of livestock or fowl wastes on land. The most widespread effects result from the use of fertilizer. The drain water that can percolate downward to the groundwater table, in the regions of unconfined aquifers, has double or triple of its original *TDS*. In less developed countries, animal or human wastes are widely used as organic fertilizer but in industrialized countries most fertilizers are manufactured chemically [4].

At Al-Gofra oasis, agriculture activities, nature of soil, waste disposal, over pumping of groundwater and possibility of seawater intrusion are the main potential sources of groundwater pollution at the study area.

ANALYSIS OF DATA AND DISCUSION

Since all wells tap the same aquifer, chemical analysis was carried out for all five wells in Sokna. Immediate analysis was done in the field to obtain dependable results because the composition of the sample may change before reaching the laboratory. The results of that analysis are shown in **Table 2**.

Table 2: Field analysis of groundwater in Wadan-Sokna aquifer.

Well No.	Temp. (^oC)	Cond.*10^3 (25 ^oC)	pH	HCO_3 (mg/L)	CO_2 (mg/L)	H_2S (mg/L)
1	57	2.74	7.4	353	68.9	0.95
2	55	1.61	7.1	384	75.9	0.56
3	52	1.56	6.9	360	86	0.64
4	56	1.60	7.2	390	70.9	0.72
5	55	1.47	6.6	366	83.9	0.56

As a general indication of Total Dissolved Solids (*TDS*), specific conductance values are often useful in a practical manner. For conversion between conductance values and *TDS*, the following relation is used [6].

$$TDS = AC \tag{1}$$

Where:
A = conversion factor and its value between 0.55 and 0.75;
C = conductance in microsiemens (μs) or micromhos (μmho) and
TDS is expressed in g/m^3 or mg/L.

Certain chemical analyses were also made in the laboratory from samples collected from the same wells. The results of these analyses are shown in **Table 3**. They indicate that the water quality for the aquifer is relatively uniform except Well-1. The small variation could be related to the inter-bedded shale layers and/or to experimental error [7]. The chemical analysis of the groundwater indicates that the water is acceptable for the irrigation and domestic usage [8].

Table 3: Chemical constituents of groundwater in main (Wadan-Sokna) aquifer.

Chemical Parameters (mg/L)	Well 1	Well 2	Well 3	Well 4	Well 5
$CaCO_3$	675	510	530	508	545
Ca	250	142	163	155	160
Mg	70.5	50	48	53	47
Na	280	190	185	193	180
TDS	1918	1127	1090	1120	1030
TSS	130	101	110	108	99
TS	1680	1201	1200	1228	1129
Fe	22	13	8	11	9
SO_4	515	430	410	390	400

Descriptive statistical analysis of the measured data has been used in the primary stage to reveal the mean values of each parameter and highlights the extreme values and ranges (**Table 4**). Calculations were made using STATGRAPHICS [9].

Table 4: Statistical parameters of the physical and chemical constituents of groundwater in main (Wadan-Sokna) aquifer.

Water quality parameter	Mean	Standard Kurtosis	Standard Skewness	Range	Minimum	Maximum
Temp, (^oC)	55	1.985	-1.045	5	52	57
EC $*10^3$, (25 ^oC)	1.796	2.188	1.985	1.27	1.47	2.74
pH	7.04	-0.002	-0.496	0.8	6.6	7.4
HCO_3 (mg/L)	370.6	-1.065	0.286	37	353	390
CO_2 (mg/L)	77.12	-1.222	0.184	17.1	68.9	86
H_2S (mg/L)	0.686	0.816	1.288	0.39	0.56	0.95
$CaCO_3$ (mg/L)	553.6	1.846	1.806	167	508	675
Ca (mg/L)	174	1.996	1.860	108	142	250
Mg (mg/L)	53.7	1.766	1.770	23.5	47	70.5
Na (mg/L)	205.6	2.157	1.970	100	180	280
TDS (mg/L)	1257	2.190	1.986	888	1030	1918
TSS (mg/L)	109.6	1.116	1.361	31	99	130
TS (mg/L)	1287.6	2.054	1.898	551	1129	1680
Fe (mg/L)	12.6	1.258	11.483	14	8	22
SO_4 (mg/L)	429	1.505	1.630	125	390	515

Table 4 gives a summary statistics for each of the selected data variables. It includes measures of central tendency, and measures of shape. Of particular interest here are the standardized skewness and standardized kurtosis, which can be used to determine whether the sample comes from a normal distribution. Values of these statistics outside the range of -2 to +2 indicate significant departures from normality, which would tend to invalidate many of the statistical procedures normally applied to this data. No variables show standardized skewness values outside the expected range. But, the following variables show standardized kurtosis values outside the expected range: *EC, Na, TDS* and *TS*. Those variables were transformed for normalization as explained in **Table 5**.

Table 5: Transformation of some variables for normalization.

Variable	Suitable transformation	Standard Kurtosis	Standard Skewness
EC	1/(Y)	1.998	-1.859
Na	Can not be transformed		
TDS	1/(Y)	2.000	-1.864
TS	LOG(Y)	1.962	1.834

Due to the limited number of available data (5 wells and each parameter has been recorded once) it has been decided to use Simple Regression and Multiple Regression Analysis methods to determine the relation between the physical water quality parameters (measured in-situ) and the chemical water quality parameters (measured in laboratory). The goal is to minimize the laboratory work by finding a relationship between the two groups. The first group considered here is the field data, and the second being the chemical parameters obtained from the laboratory analysis.

Simple Regression models have been examined considering each of the field parameters as dependent variable and each of the laboratory parameters as independent variable; again the aim is to evaluate the correlation between water quality pairs (field and laboratory). The results of this part showed that *EC* is correlated strongly with *Ca*, *Mg, Na,* SO_4, *TDS, TS, TSS* and H_2S. No correlation between *EC* and *Temp*, *pH,* HCO_3 and CO_2. An example of the obtained results is the output of running *EC* against *Ca,* the results of fitting a linear model to describe the relationship between *EC* and *Ca* is given by the equation below of the fitted model:

$$EC = -0.265102 + 0.0118454*Ca$$

The P-value of the model is = 0.0077, and since this value in the ANOVA table is less than 0.01, there is a statistically significant relationship between *EC* and *Ca* at the 99% confidence level. The R-squared statistic indicates that the model as fitted explains 93.17% of the variability in *EC*. The correlation coefficient equals 0.9653, indicating a relatively strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.16006. This value can be used to construct prediction limits for new observations.

Figure 5 shows the output results of fitting a multiple linear regression model to describe the relationship between *Temp* and 2 independent variables.

Multiple Regression Analysis

Dependent variable: Temp

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	60.5822	4.83451	12.5312	0.0063
Mg	0.465426	0.11834	3.93296	0.0590
TSS	-0.278974	0.0930038	-2.9996	0.0955

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	12.6703	2	6.33513	9.53	0.0950
Residual	1.32973	2	0.664866		
Total (Corr.)	14.0	4			

R-squared = 90.5019 percent
R-squared (adjusted for d.f.) = 81.0038 percent
Standard Error of Est. = 0.815393
Mean absolute error = 0.416266
Durbin-Watson statistic = 1.69609

Figure 5: A capture of the results of Multiple Regression Analysis.

The equation of the fitted model is

$$Temp = 60.5822 + 0.465426*Mg - 0.278974*TSS$$

Since the P-value in the ANOVA table is less than 0.10, there is a statistically significant relationship between the variables at the 90% confidence level. The R-squared statistic indicates that the model as fitted explains 90.50% of the variability in Temp. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 81.0038%. The standard error of the estimate shows the standard deviation of the residuals to be 0.815393. This value can be used to construct prediction limits for new observations. The mean absolute error (MAE) of 0.4163 is the average value of the residuals.

Full results of Multiple Regression Analysis are given in the **Tables 6** and **7**. It should be mentioned that all the possible relations have been examined and only the positive ones are reported here.

Temperature variable is correlated only with the pair (*Mg, TSS*). All the other trials to find a suitable model have failed statistically. It might be due to nature of the observed data and the low number of wells. The constants in the provided equations definitely will change as the observations change. But the idea of having a multiple regression model that would help in prediction will still be there.

Table 6: Multiple regression analysis (one dependent and two independent variables) for the provided data.

Variable	Relation with	P-value > 0.1	Multiple Regression Equation
Temp	Mg, TSS	0.0950	Temp = 60.5822 + 0.465426*Mg - 0.278974*TSS
EC	$CaCO_3$, Mg	0.0099	EC = -1.61221 + 0.00245698* $CaCO_3$ + 0.0381382*Mg
	$CaCO_3$, Ca	0.0677	EC = 0.0368217 - 0.0010882*$CaCO_3$ + 0.0135724*Ca
	$CaCO_3$, TSS	0.0506	EC = -2.68445 + 0.00411285* $CaCO_3$ + 0.0201057*TSS
	$CaCO_3$, SO_4	0.0495	EC = -2.57782 + 0.00320635* $CaCO_3$ + 0.00605778*SO_4
	Ca, Mg	0.0143	EC = -0.891102 + 0.036216*Mg + 0.00426611*Ca
	Ca, Fe	0.0062	EC = 0.0498091 + 0.0464302*Fe + 0.00667339*Ca
	Ca, SO_4	0.0253	EC = -1.51984 + 0.00509826*SO_4 + 0.00648671*Ca
	Ca, TSS	0.0593	EC = -1.01971 + 0.0119659*TSS + 0.00864512*Ca
	Mg, TSS	0.0264	EC = -1.40568 + 0.0463411*Mg + 0.00650694*TSS
	Fe, TSS	0.0129	EC = -1.09991 + 0.0201931*TSS + 0.0541863*Fe
	SO_4, TSS	0.0231	EC = -2.93809 + 0.0190517*TSS + 0.00616788*SO_4
	Mg, Fe	0.0278	EC = -0.874503 + 0.0465579*Mg + 0.0135192*Fe
	Fe, SO_4	0.0533	EC = -1.12141 + 0.00550567*SO_4 + 0.0440852*Fe
pH	$CaCO_3$, Mg	0.0446	pH = 6.84308 - 0.00566218*$CaCO_3$ + 0.0620391*Mg
	Ca, Mg	0.0940	pH = 5.15904 - 0.0102688*Ca + 0.0683002*Mg

On the other hand, Multivariate statistics methods, Principal Component Analysis (PCA) and Factor Analysis (FA) could be applied only when the number of observations is not less than 30 [10].

Figure 6 shows the classification of the Libyan aquifers according to the salinity of the water.

Table 7: Multiple regression analysis (one dependent and three independent variables) for the provided data.

Variable	Relation with	P-value >0.1	Multiple Regression Equation
Temp	Mg, TSS, Fe	0.066	Temp = 57.662 + 0.934848*Mg - 0.41994*TSS - 0.542687*Fe
EC	$CaCO_3$, SO_4, Mg	0.0455	EC = -1.88512 + 0.0317285*Mg + 0.0013702*$CaCO_3$ + 0.00284095*SO_4
	$CaCO_3$, TSS, Fe	0.0171	EC = -1.42673 + 0.043404*Fe + 0.00207232* $CaCO_3$ + 0.013947*TSS
	Ca, Mg, SO_4	0.0186	EC = -1.53606 + 0.00270737*Ca + 0.0273887*Mg + 0.00324058*SO_4
	Mg, TSS, SO_4	0.0655	EC = -2.08564 + 0.0278812*Mg + 0.00637869*TSS + 0.00392848*SO_4

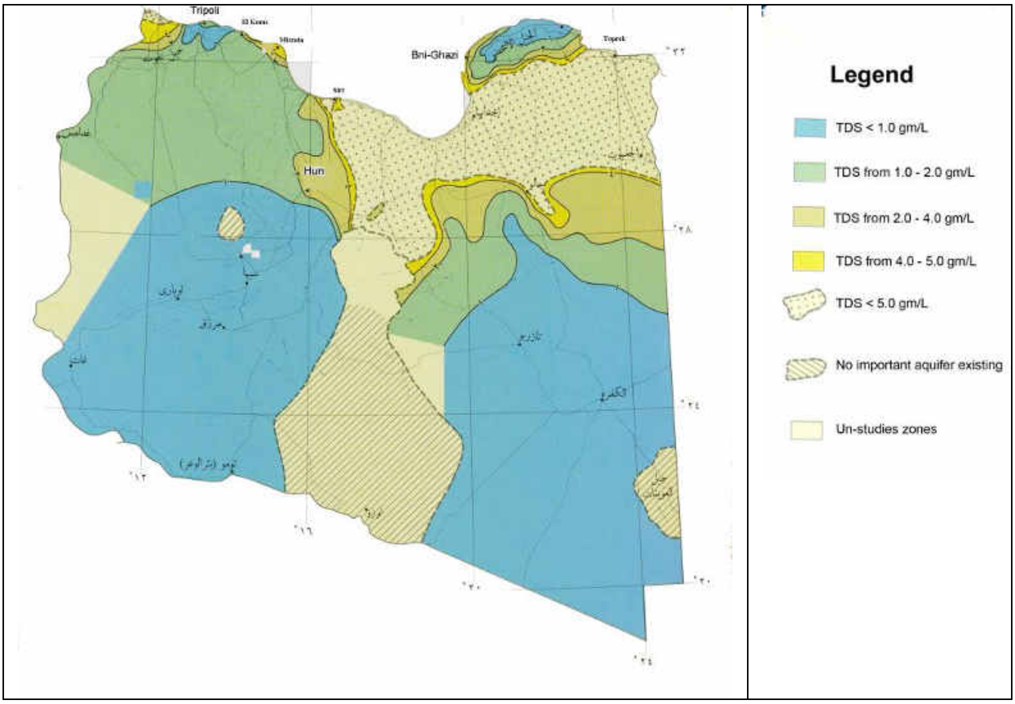

Figure 6: Classification of the Libyan aquifers according to their water quality.

CONCLUSIONS AND RECOMMENDATIONS

In this paper, water resources in Al-Gofra Oasis have been evaluated. The main source of water in that region is the groundwater. Despite the fact that one of the two aquifers (Wadan – Sokna) is fairly good (*TDS*: 1200 – 1500 ppm) the other one (Hun) has high (*TDS*: 4000 – 5000 ppm) which needs special water treatment to cure the different *TDS*. The approach introduced in this paper would assist the frequent monitoring of the different water quality parameters and will encourage the authorities to get early warning of any contaminant that might affect the main sources of groundwater. The regression statistics methods over the provided data showed that there is a strong relationship between *EC* and most of the chemical parameters. Measuring some physical parameters such as *Temp, pH* and *EC* and using some indicators appropriate regression equation will assist in predicting the possible values of the other chemical parameters. This will save time and costs in the monitoring program. Not to mention, the values of the calculated regression coefficients in the above work are subjected to the availability of the data, the more the data the better the prediction of the strong correlation.

Water resources development in Al-Gofra can be developed and used in many different ways. However, the following should be considered:

- Construct a water treatment plant for groundwater in Hun and Wadan, where TDS is very high and water can not be used for domestic or agriculture without treatment.
- Use the recycle water from wastewater treatment plants for agriculture.
- Use the Geographic Information System (GIS) and Remote Sensing techniques to develop hydrological maps for water resources in that region and observing the change of water amount and its direction of movement.
- Develop the irrigation methods to optimize the amount of water used in irrigation.

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تقييم المياه الجوفيّة في واحة الجفرة – وسط ليبيا باستخدام الطرق الإحصائية

رغم أهمية خزاني المياه الجوفية بواحة الجفرة بالجماهيرية الليبية حيث يعدان المصدر الرئيسي الذي تتَغذّي عليه خمس قُرى وتَخْدم حوالي 60000 نسمة، إلا انه لم يخضع بعد لعملية تقييمِ بهدف تحديد جودة المياه. هذا البحث يَستهدف دراسة الحالة الحاليةِ للمياه الجوفيّة في الواحة، وتحديد مصادر التلوث وتأثيرها على الطبقات الجوفية واقتراح منهاج يعتمد على استخدام الإحصاء المتعدد المتغيرات في رصد ومراقبة المتغيرات في جودة المياه بالمنطقة. وقد وجد أن المياه الجوفيّة هي المصدر الرئيسي بل والوحيد للماءِ في تلك المنطقة كما أنّ الطبقة الجوفيةَ في منطقتي "سوكنه" و"ودان" تنُحْصر بين صخور تشمل الرملِ والطينِ والحجر الرملي. إنّ نوعيةَ الماءِ في هذه الطبقة الجوفية جيّدة جداً ومجموع المواد الصلبةَ المذابة (TDS) يتراوح بين 1200 إلى 1500 جزء في المليون غير أن الطبقة الجوفيةَ في "هون" فهي طبقة جوفية محصورة على عمق كبير، كما أن نوعية الماءِ سيّئة، حيث يصل مجموع المواد الصلبةَ المذابة إلى حوالي 4000 إلى 5000 جزء في المليون.