HOCHSCHULE FÜR TECHNIK UND WIRTSCHAFT DRESDEN
UNIVERSITY OF APPLIED SCIENCES

Master of Environmental Engineering

# WATER PROJECT REPORT

WATER PROJECT IN EGYPT FOR AGRICULTURAL PURPOSES
AN ELEVATED CONTENT OF IRON

Adi Seno Abyoga (s76543) | 12.04.2017
HTW Dresden – Environmental Engineering

## Abstract

The general aim of the project is to make an analysis for the water quality in El Wahat El Bahariya, Egypt. Elevated iron content has been found throughout various wells, from which water is abstracted and is used for agricultural purposes. With the established water analysis, it is hoped that further analysis and action can be done in order to reduce the iron content as elevated iron content of more than 5 mg/l is not recommended by Food and Agricultural Organization (FAO) for agricultural purposes. An average of 36 mg/l has been found and therefore has passed its limit. Statistical analyses have been made with the help of cross correlation diagrams and box-whisker plots for essential parameters. To visualize the location, a map has been made with the help of Google Earth Pro engine and QGIS including its wells.

**KEYWORDS** : Water Analysis; Water Quality; Groundwater Management; Groundwater Monitoring

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# Table of Contents

# 1. Introduction

Groundwater has been used for clean source of water in many countries. Various demands such as clean drinking water, domestic use, industrial use and agricultural purpose have been supplied and fulfilled by the local groundwater. This implies the importance of groundwater in terms of quality and quantity. Each country has their own regulation in managing the groundwater and in preventing pollution or contamination to the groundwater networks. Although the extent and the degree in which groundwater is managed, it still depends on many parameters both anthropologically or naturally. The underlying geological and soil formation can also affect the chemical content of the groundwater.

This project shows the importance of groundwater for agricultural purposes in Egypt and hence its purpose is threefold. First, this report will give a brief overview about the local condition in El Bahariya oases. The project site is in El Wahat El Baharia. It is a site owned by a company called Al Enmaa. Second, it provides an analysis to the local groundwater system from the wells of Al Enmaa. Third, that it will also provide reasoning and suggestions to the problem that arises in the system.

The groundwater in Bahariya Oases is used in particular to fulfill the water demand for the local agriculture, which later, has been found with an elevated content of Iron (Fe). It has been found that the iron content has reached averagely as high as 40-60 mg/l. This has been considered to be an alarming situation as the elevated iron content is more than the allowable of 5 mg/l for agricultural purposes (Food and Agriculture Organization, 2017). Another source has also mentioned that if the iron content in the water has reached more than 1.5 mg/l (in its severe case), it could also damage the irrigation system due to its pipe being clogged by iron encrustation, and this is especially often happening in the localized irrigation systems (Ayers & Westcot, 1985). As part of the project is to establish a water analysis. Such linkage can then be constructed and further analysis and solution can then be created.

## 1.1. Theoretical Concept

There are a few common challenges faced by agricultural companies regarding the quantity and quality of water being provided. These sorts of problems are of higher magnitude in arid and semi-arid region as the rainwater lacks. Desert climate generally receives very low annual precipitation.

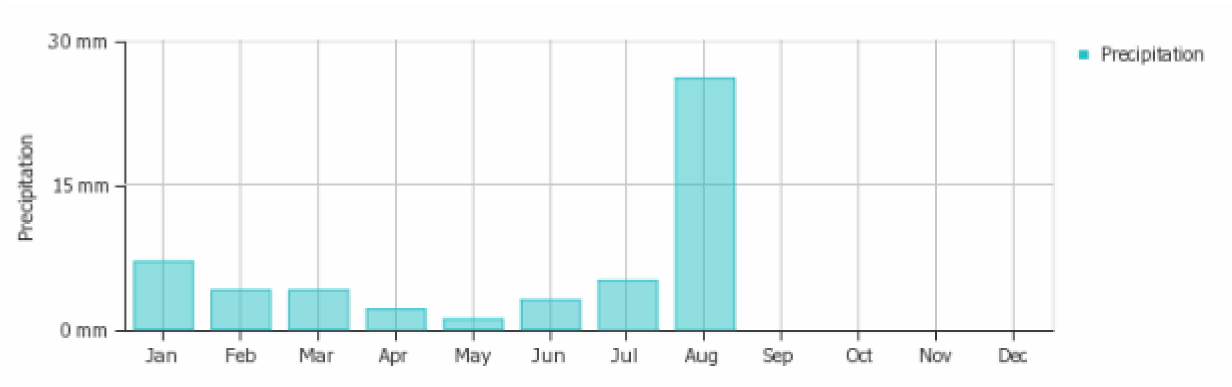



**Figure 1 Average Monthly Precipitation in Cairo, Egypt** *(Weather and Climate .com, 2016)*

As can be seen from figure 1 above, the highest average monthly precipitation can only reach as high as 30 mm or less. Although the location of the project is in Bahariyya oasis, Giza Governorate, Egypt, figure 1 can be used as a rough comparison to the different cities in Egypt. Cairo, which is the capital city of Egypt, is located around 30$^o$ N and 31.2$^o$ E. The city is passed by the river Nile and more closely located to the sea. It can be assumed that the city will receive higher precipitation as compared to other cities. With this in mind, the project location will receive generally much lower precipitation than in Cairo accounting less than 40-50 mm annually with the consideration from figure 1. Most precipitation that occurs would be re-evaporated before it could even reach the ground as the average temperature lies 20$^o$ C and 35$^o$ C. Conventional irrigation that uses water provided from precipitation is almost impossible unlike tropical countries like Indonesia, and as such, groundwater is the major source of clean water throughout different purposes.

Water quantity can become a significantly higher magnitude problem too in the future as over-abstraction of groundwater could induce greater drawdown. One article has mentioned, that originally, major source of clean water in Bahariya oases came from shallow natural spring (Masoud & El Osta, 2016). In addition, before 1963, there were in total 332 natural shallow springs and shallow dug wells with a rate of 33 mcm/year (El Hossary, 2013) and since then, the drawdown has been recorded extensively in the period of 1963 – 1970 to be about 1.2 m annually. As urbanization increased and so its demand of water too. The well that has been built has been accounted up to 905 wells with depth more than 300 m (RIGW (Research Institute for Groundwater), 2010). At the moment, the expected drawdown in 25 years has been predicted to reach from 3 and 26 m and up to 4 and 32 m in 50 years (El Hossary, 2013). This runs under some certain assumptions that have been created by the author, for example, the aquifer hydraulic conductivity was 4 and 20 m/day, transmissivity that varies from 250 and 3700 $m^2$/day, and a storage coefficient of 0.8 x $10^{-1}$ to $10^{-3}$, both under steady state and transient (considering the timeframe) with a variation of discharge between 15 or 20 $m^3$/day.

It has to be noted that these predictions are made without considering the human development and its behavior. More importantly, the local groundwater has been said as a non-renewable source. A more detailed planning that takes into account all involving stakeholders is very important.

Generally, higher cost is expected in agricultural project in Egypt as groundwater abstraction needed more cost than to rely from precipitation. Maintaining such system would require tremendous work. Even after a secure supply of groundwater is provided, water quality should also be monitored regularly. Considering the project location, Bahariya oases' main source of groundwater comes from the Nubian Sandstone Aquifer (NSSA). An assessment of protection zone is very important as NSSA nowadays provides clean water not only for the agriculture but also for clean drinking water. Anthropogenic sources could enter the groundwater especially from agricultural site. It is important to notice the groundwater management in the area is of high significance as the groundwater is not only used for agriculture but also

Another common problem for water supply system is incrustation of technical infrastructure, which primarily occurs on well screens, pipes, and plumbing fixtures. Incrustation is the process in which dissolved minerals in water, such as Iron in this case, precipitate and adhere to surfaces. This frequently occurs when the water undergoes prolong aeration. Overtime, this can lead to clogging of pipes, which restricts available flow area and leads to greater pressure loss through pipe wall friction. To maintain the same flow rate and hence the same water output, more pressure must be applied, which increases the required energy use and its costs. In a system where pump is non-existent, for example a gravitational pump, the flow rate will be permanently reduced.

Such precipitates could originate from the operation of a well, whereby through variations in the groundwater level, $O_2$ from the air can enter the aquifer at an accelerated rate, which disturbs the redox zoning and leads to oxidation of the underlying mineral which can also be seen from figure 2 below.

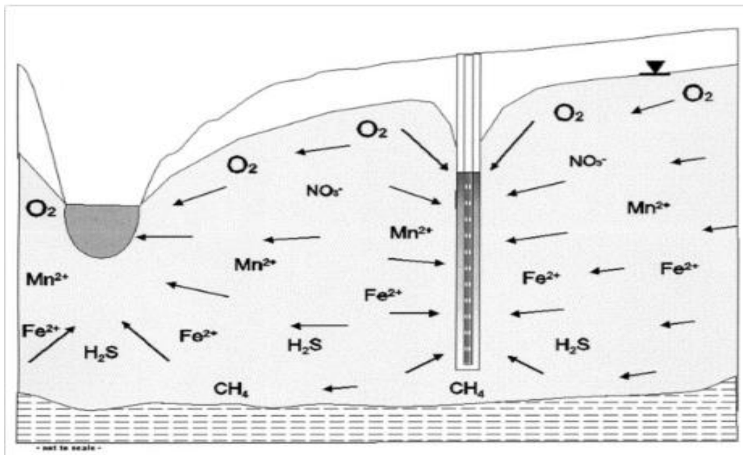



**Figure 2 Schematic flow field and hydrochemical redox zoning of an aquifer influenced by a vertical well. Arrows show general flow directions** *(Houben, 2003)***.**

The originally unstable and more soluble salts will become less soluble and form as a precipitate based on the reaction of:

$4\ Fe\ (OH)_2 + 2\ H_2O + O_2 \rightarrow 4\ Fe\ (OH)_3$ …(1)

However, there are also other minerals that could be oxidized. One common example is pyrite or $FeS_2$, which is generally known to be residing in rocks such as sedimentary or metamorphic one (Rimstidt & Vaughan, 2003). The mechanism of pyrite oxidation is quite complex; however, one part of the reaction is called cathodic reaction which was also mentioned by the same author. It involves aqueous species which accept electron from the Fe(II) of $FeS_2$. The most relevant oxidant is therefore $O_2$ and $Fe^{3+}$. This can occur under the reaction of :

$FeS_2 + 3.5\ O_2 + H_2O \rightarrow Fe^{2+} + 2H^+ + 2SO_4^{2-}$ …(2)

And

$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 16H^+ + 2SO_4^{2-}$ …(3)

This clearly suggests that these two reactions depend mostly on the concentration of $O_2$ and $Fe^{3+}$. Such relation can also be seen, that the products are $SO_4^{2-}$ and $H^+$ which implies the relation between pH and Fe or pH and $SO_4^{2-}$. With increasing concentration of Iron in the analysis, there is a reduction to the pH value or acidification. It should be expected, that the lower the pH value, the more iron content it is. It should also be the same with $SO_4^{2-}$, the more iron content it has, the more $SO_4^{2-}$ it also contains. However, it is yet to be revealed whether the source of such iron and its oxidation is due to pyrite or other minerals.

# 2. Experimental Method

## 2.1. Location

As has been signified before, the location of this project is in El Wahat El Baharia, an agricultural site owned by a company called Al Enmaa in Egypt. The location's coordinates are 28°10'30.41" N and 28°55'57.77" E. This location coordinate is taken more detail with the Google Earth Pro. The global map can also be seen from figure 3 with google maps. It is located just around 370 km south-western of Cairo (the capital city) considering from google maps. A rough sketch from figure 4 has been acquired and the overview of the area can be analyzed although its accuracy and usefulness are in doubt.

It shall be seen, that from figure 3 below, there are in total 54 wells with ranging depth from shallow and deep, which is from 300m to more than 700m. It signifies, that the location has more than one water bearing zone. Another thing that could be implied from this picture, it could be that the first water bearing zone has been depleted and the company has decided to dig deeper on top of the existing wells. In the appendix, each sample corresponds to each well. For example, the sample number one corresponds to the well number one in the figure 3.

In the chapter 3, in the analysis using QGIS and Google Earth Pro, it will be more explained about the location, including the type of aquifer that constitutes the location and how it will have an effect on the overall water analysis. There will also be suggestion at the end of the chapter with regards to the characteristic of this aquifer. Several authors have demonstrated their capabilities in determining the aquifer characteristics (El Hossary, 2013), (Masoud & El Osta, 2016), (Rabeh, Bedair, & Zaher, 2016), (Hamdan & Sawires, Hydrogeological Studies On The Nubian Sandstone Aquifer in El Bahariya Oasis, Western Desert, Egypt, 2011).

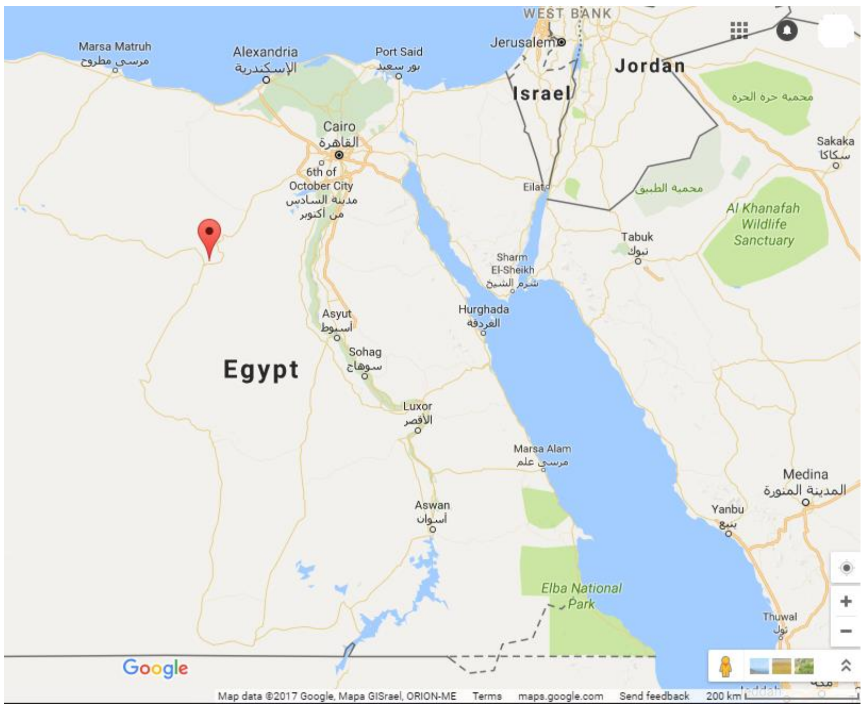



**Figure 3 Global Map of the Location** *(Google, 2017)*

The rough sketch is not too useful as it does not contain the coordinates. For further analysis, Google Earth is done in order to retrieve the actual coordinates. By using the actual coordinates, the area can then be digitized using QGIS and a more useful analysis can be done.

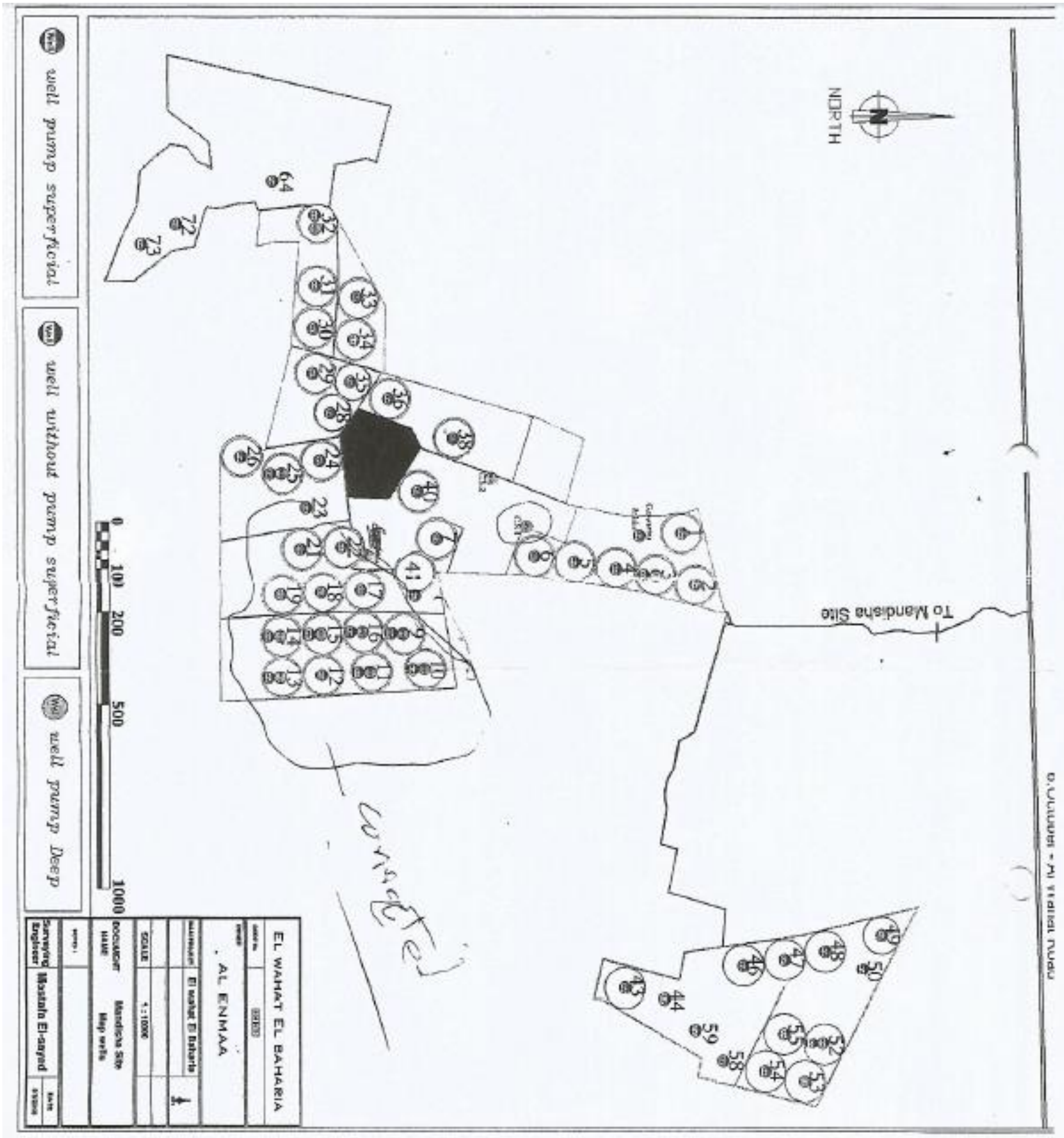



**Figure 4 Rough Sketch of the Well Site in El Wahat El Baharia** *(El-Sayed, 2016)***.**

The rough sketch is not too useful as it does not contain the coordinates. For further analysis, Google Earth is done in order to retrieve the actual coordinates. By using the actual coordinates, the area can then be digitized using QGIS and a more useful analysis can be done.

## 2.2. Experimental Methods

For such analysis and evaluation, the wells are pumped and the water samples are collected. There are several sessions recorded and analyzed. These analyses were made in different laboratories and in different time. It is unknown whether the sampling criteria was fulfilled during the sampling. External factors can affect the final results greatly if the samples were exposed longer in time. However, it is good if all the known procedures are well recorded and therefore, slightest mistakes can be detected. There are five sessions in total, in which they are differed by the laboratories in which the analysis was taken, namely *AgroLab*, which occurred in two different months, *Reference Lab*, *Local Lab*, and an analysis made by the *University of Applied Sciences Dresden (HTWD)*.

The data from the AgroLab particularly has two different periods in retrieving and analyzing the samples, the first one was in March 2016 and the second was in May 2016. The other laboratories, unfortunately, have significantly lower samples to be measured and it did not have the date of the sampling and measuring. During sampling, on-site parameters such as pH, EC, TDS, DO, and Temperature were taken for most of instances. Turbidity was also measured. Most major cations and anions were measured such as $Na^{+}$, $K^{+}$, $Ca^{2+}$, $Mg^{2+}$, $Cl^{-}$, $SO_4^{2-}$, $CO_3^{2-}$, $HCO_3^{-}$, and others with the addition of $Fe^{2+}$ as the main focus of this project along with $Mn^{2+}$. All major cations and anions are measured in unit of mg/l, with an addition to TDS and DO. Meanwhile, pH does not have unit and EC (Electrical Conductivity) is measured in unit uS/cm. In addition, there was also an aggregate of organic activity. It has to be noted that afterwards, the samples that are mentioned in this paper correspond to the wells.

This report will present the overview of the analyses, alongside the electrical balance measured in unit meq/l, statistical analyses, cross relation of cation and anion in a graph with the help of curve fitting and EC – TDS also. Statistical analyses are done to measure and check the validity and accuracy of the data. Range, arithmetic mean, median and standard deviation of the data were measured for each parameter to better understand the error and plausible.

Electrical balance error is measured through using the formula (Grischek, 2016) :

$$Electrical\ Balance\ error = e = \frac{\sum cation\ equivalent - \sum anion\ equivalent}{\sum cation\ equivalent + \sum anion\ equivalent} * 100 \text{ …(equation 1)}$$

With e = electrical balance error.

- If e < 5% the measurement is considered to have a good accuracy
- If e > 5% this indicates the measurement has an analytical or calculation error
- If e < 10% this would be acceptable if the sample is low mineralized water

# 3. Results and Discussion

## 3.1. Location Analysis

In this chapter, more further analysis about the location will be explained. At first, the author tries to have a desk research about the location and its geological strata. Later, software Google Earth Pro is used to translate and determine the exact location. The rough sketch is useful only for certain extent as to help locate which wells corresponds to which wells in the Google Earth image. The exact location is located just below the Bahariya oasis, indicating that the oasis is used as a major source of clean water. It also confirms, that in the past, shallow spring was more common to supply clean water.

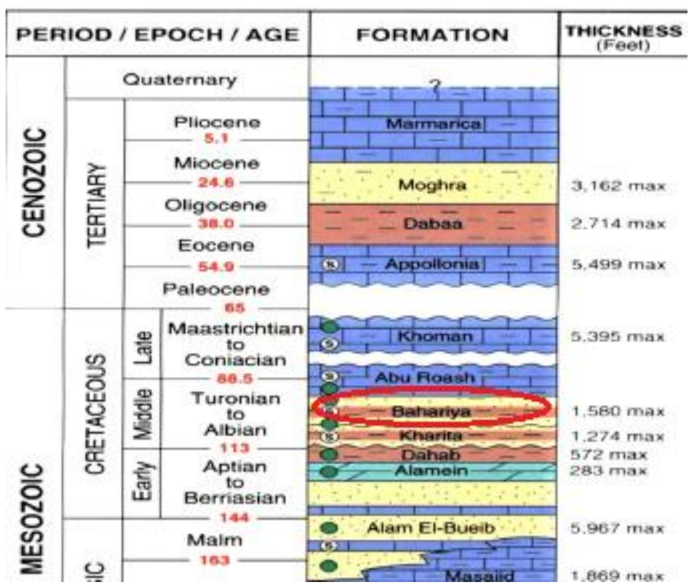



**Figure 5 A Stratigraphic Column of Western Dessert** *(El Sayeda & El Sayed, 2015)*

As can be seen from figure 5, based from the the Bahariya formation has a thickness of around 480 m. However, other has also mentioned that the bulk thickness varies between 100 to 1800 m (Masoud & El Osta, 2016). The author has also mentioned, that the pyrite minerals in the Bahariya sandstones is in the form of fine-grained sand, which will have a darker color flaser bedding (El

Sayeda & El Sayed, 2015). This confirms the source of the elevated iron content that has been found later in the water analysis part and also confirms the fact that the extensive abstraction of groundwater will introduce and circulate water and $O_2$ to the environment. The oxidation of the pyrite is induced by $O_2$ and it has a brown to auburn color of particles. This confirms the incrustation that took place in the piping and plumbing system of the local wells which can also be seen from figure 6 below.

**Figure 6 Iron Incrustation in the Piping System of Local Wells in Al Enmaa** *(Wahab, K., & Sorour, 2017)*

The hydrogeological setting of the location is also the point of interest in this report. According to an author, the aquifer is constituted by continental clastic sediments (Masoud & El Osta, 2016). It is a zone of sandstone that lies between shale and clay. More importantly, the region is considered as multi-layer artesian aquifer (confined) with a thickness of 1800 and is hydraulically connected between each different piezometric heads. This implies leakage between different layers. The author has also mentioned that these clastic sediments consist of mainly fine to medium sandstone with a darkish grey shale intercalations, this is in accordance with other authors who mentioned the pyrite contained in bahariya formation is a fine material with dark bedding (El Sayeda & El Sayed, 2015). For further details, figure 7 presents the idea of the author about the aquifer. As can also be seen from the figure 7, the thickness is also varied from 317 m in the southwest to 818 m in the north east.

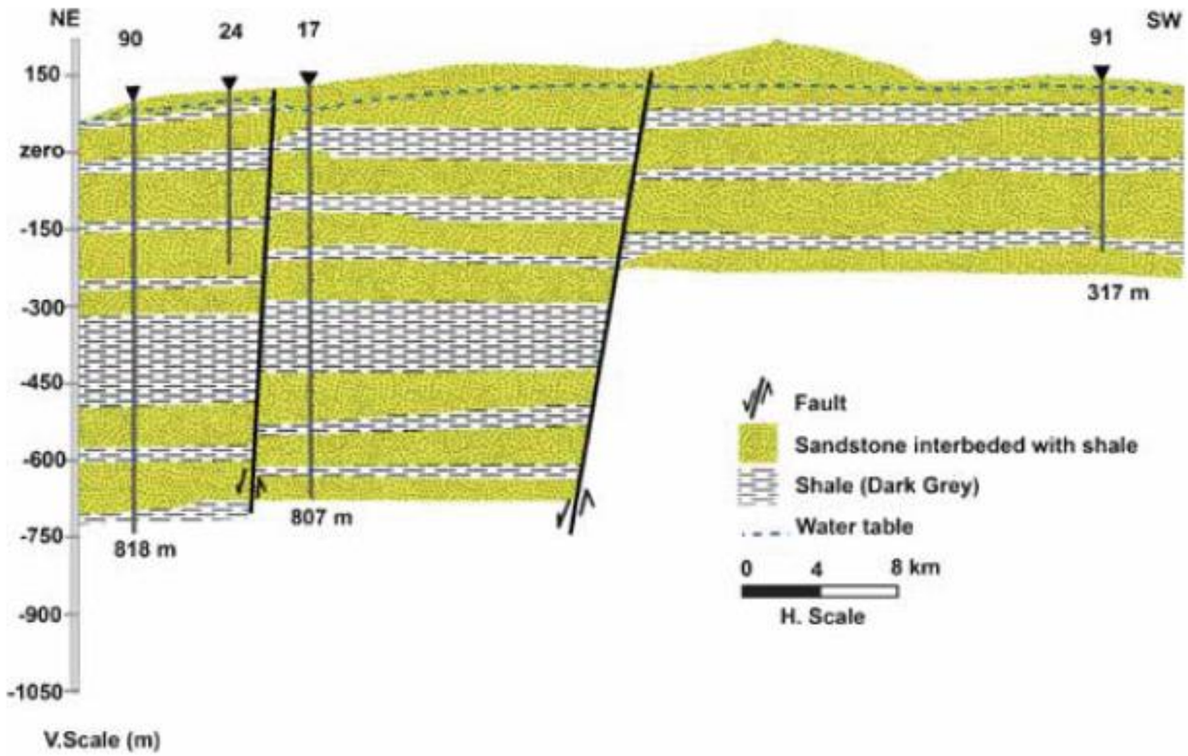



**Figure 7 Hydrogeological cross section (NE–SW) of the study area.** *(Masoud & El Osta, 2016)*

The general flow of the groundwater has also been successfully demonstrated by the author, denoting that the general flow of the region flows from southwest to northeast of the oasis (Masoud & El Osta, 2016).

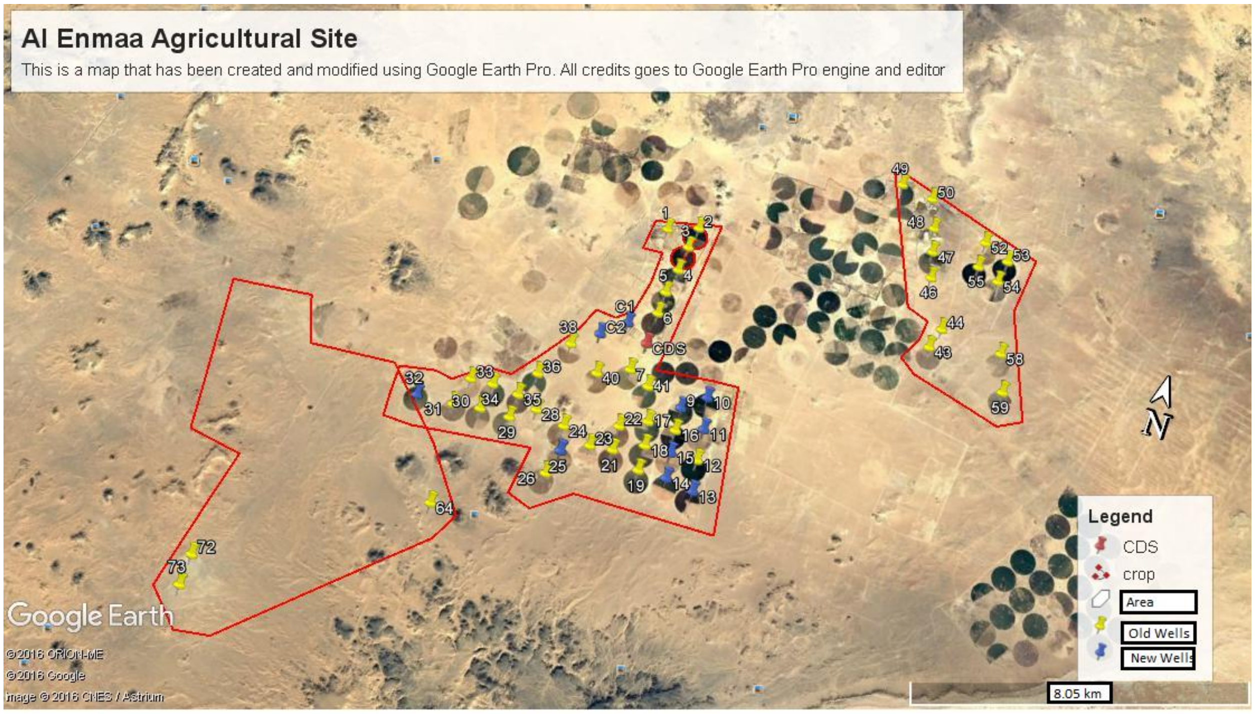



**Figure 8 Google Earth Image of the Location with the Corresponding Wells**

As can be seen from figure 8, the author has demonstrated the translation of the location from the rough sketch provided before using Google Earth Pro engine. There is a modification into the image as can be seen by the legend and scaling of the map. First of all, there are three polygons that are indicated both in the rough sketch and the Google Earth image. Each polygon indicates the area of different wells. However, the image is subject to inaccuracy both from the engine and author. Measurement has also been done in this case. The polygon that contains the most wells has an area of 32.7 $km^2$, the second polygon that contains less wells has an area of 16.2 $km^2$ and the last polygon that has the least wells has an area of 39.8 $km^2$. The distance between well one and well two is measured to be 0.67 km and the radius of one well allocated to the crop is 2 km.

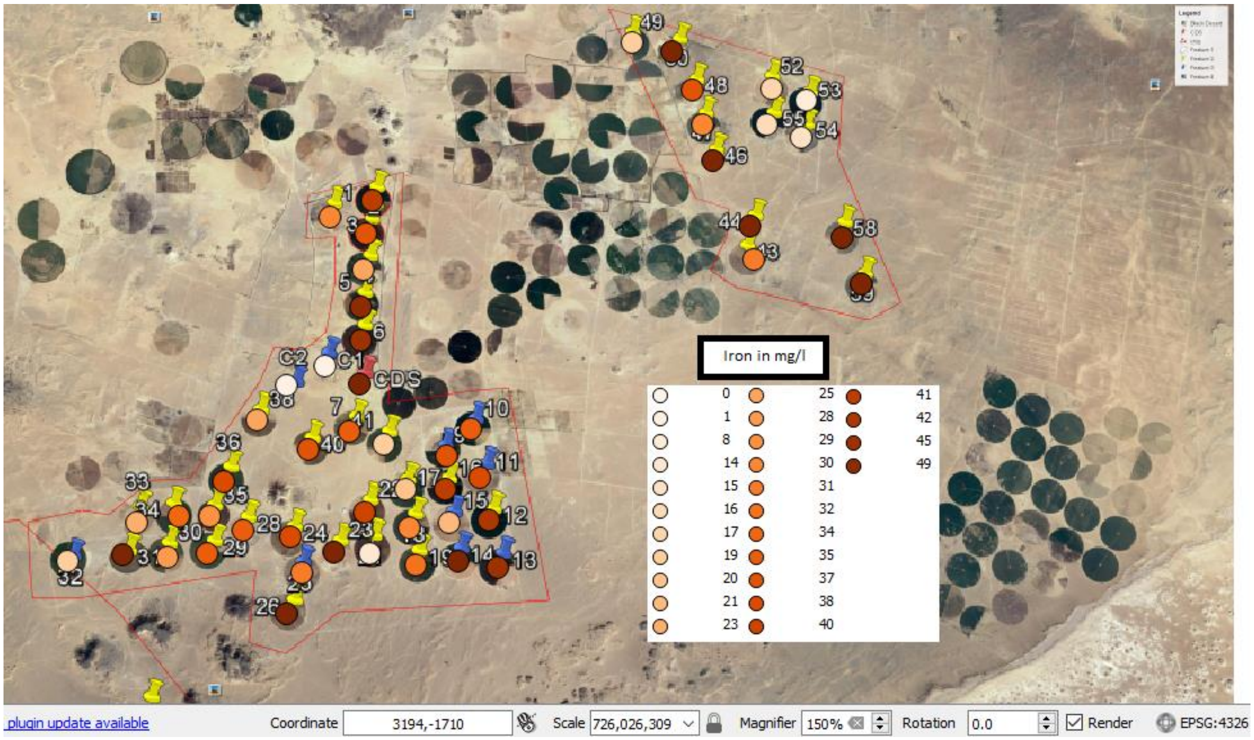



**Figure 9 Categorization of Iron Concentration in mg/l Using QGIS and Google Earth Pro**

Figure 9 shows the categorization of iron concentration using QGIS. The browner the dot means more iron concentration is in that particular well. It varies between 1 mg/l to 50 mg/l. This corresponds to the Agro Lab measurements. Other categorizations such as pH and $SO_4^{2-}$ are also provided in the appendix. With this categorization, it will greatly improve the visualization ability of the analysis. It suggests where iron is most concentrated and where the treatment facility should be placed in order to minimize the costs. However, it has to be noted that the image is subject to inaccuracy. Both Google Earth Pro engine and QGIS were used in creating this image. The other parameters that have been categorized using the same method can be seen in Appendix A and B.

## 3.2. Water Quality Analysis

In this chapter, the analysis of the water quality is assessed. There were few occurrences happening in different time and location. However, only one instance was considered to be of high significance. The other are inserted in the appendix due to the lack of samples but it should be good as a base of analysis to clearly indicate what is happening.

On March 2016, there were 35 samples taken from 35 different wells that were analyzed in Agro Laboratory. Each well corresponds to one sample. This vast amount of data is very useful to construct a statistical analysis. The parameters that were measured on the field are pH, Electrical Conductivity (EC in uS/cm), Total Dissolved Solids (TDS in mg/l), the others are major cations and anions that were stored and brought back to laboratories. Some authors have demonstrated the analysis by having an averaged value for every parameter which is compared side by side with its maximum allowable level in drinking water purposes (Dehghani-Sanij, Khani, Zhang, Narimannejad, & Mohammadnia, 2016).

**Table 1 The Statistical Analysis for Agro Lab in March 2016**

| Parameters | Unit | Min. | Max. | Med. | Mean | Q1 | Q3 | SD | Wells[1] |
|---|---|---|---|---|---|---|---|---|---|
| pH | - | 2.7 | 5.9 | 4.2 | 4.2 | 3.2 | 5.2 | 1.1 | 9, 16, 53 |
| EC | uS/cm | 501 | 1955 | 1040 | 1085 | 785 | 1350 | 375 | 25 |
| TDS | mg/l | 305 | 1350 | 614 | 708 | 537 | 832 | 265 | 25 |
| $Na^+$ | mg/l | 35 | 210 | 82 | 91 | 51 | 106 | 48 | 5 |
| $K^+$ | mg/l | 22 | 43 | 30 | 31 | 26 | 33 | 5.8 | 22, 47 |
| $Ca^{2+}$ | mg/l | 9 | 70 | 27 | 28 | 16 | 35 | 17 | 17 |
| $Mg^{2+}$ | mg/l | 7 | 55 | 31 | 32 | 26 | 42 | 14 | 1 |
| $Fe^{2+}$ | mg/l | 8 | 49 | 31 | 31 | 22 | 38 | 10 | 25, 43 |
| $Mn^{2+}$ | mg/l | 1 | 34 | 4.1 | 5.8 | 3 | 6.3 | 5.7 | 13 |
| $Cl^-$ | mg/l | 64 | 319 | 144 | 164 | 111 | 219 | 76 | 5 |
| $HCO_3^-$ | mg/l | 0 | 32 | - | 5.1 | - | - | 7.6 | - |
| $SO_4^{2-}$ | mg/l | 80 | 620 | 270 | 286 | 154 | 367 | 154 | 43 |

Most major elements were determined, and table 1 also provides an overview of the statistical analysis that has been done (minimum, maximum, median, first and third quartile, arithmetic mean, and standard deviation) have been measured to see the plausibility of the measurement. The lower the standard deviation means that it is closer to the arithmetic mean provided in the table. This means that the data is distributed evenly among the samples, whereas the higher the standard deviation assume that the data is distributed over a wide range of values.

[1] Wells represent the median value.

The groundwater in this particular area is shown to be mildly acidic with a pH range of 2.7 – 5.9. The source of the acidity remains unknown. However, this could suggest the pyrite oxidation mentioned earlier in the introduction. EC varied from 501 – 1955 uS/cm. Based on this range, the groundwater could fall in the range of fresh water to brackish as has been mentioned by an article (Mondal, Saxena, Singh, & Prasad, 2008). After further analyzing the data with the consideration of this classification, 80% of the samples (wells) fell in the range of fresh water. TDS also showed its variation in March 2016, whereby the range of 305 – 1350 mg/l had been recorded. This was also in agreement with the EC that has been recorded before, as the maximum EC of 1955 uS/cm and the TDS is 1350 mg/l.

In addition, the analysis indicated that the most dominating ions were sodium ($Na^+$), magnesium ($Mg^{2+}$), chloride ($Cl^-$), and sulphate ($SO_4^{2-}$). The $Na^+$ and $Mg^{2+}$[2] concentration signified respectively a variation of 35 – 210 mg/l and 31-55 mg/l. This in agreement with the electrical balance analysis and also over- or underestimation of cations and anions with the measured EC which will be discussed shortly thereafter. The $Cl^-$ and $SO_4^{2-}$ varied in the range of 64 – 319 mg/l and 80 – 620 mg/l respectively. After a thorough consideration, it can be clearly seen that the data significantly indicated a wide range distribution of data and considerably high standard deviations. From table 3, it is quite apparent that most of the wells has $Na^+$ as their major cations, as for anions, it varies between $SO_4^{2-}$ and $Cl^-$.

Previously, the value of EC and TDS have been shown. These two parameters indirectly are related to salinity. Higher value can be a good indicator that the groundwater has high salinity, however, this does not tell which salts constitute the groundwater. Looking at table 3, a rough estimation of salts that constitute the groundwater can now be created, which is to be $Na_2SO_4$ and NaCl.

[2] $Mg^{2+}$ originally had a variation of 24 – 320 mg/l, which was later corrected due to systematic errors. Samples 13, 19, 24, 25, 28, 29, 30, 32, 34, 35, 36, 43, 47 were corrected by mostly a factor of 10 and one of them was corrected by a factor of 2. The discrepancies showed before the corrected value was considered to be too big in the data. As such, measures had been taken for this final decision

**Table 2 Ion sequence of Groundwater samples in the study area**

| Wells | Cation Sequence | Chemical type | Percentage (%) |
|---|---|---|---|
| 1, 2, 3, 4, 5, 6 | $Na^+ > Mg^{2+} > Ca^{2+}$ | $Na^+$ | 64 |
| 9,10 | $Na^+ > Ca^{2+} > Mg^{2+}$ | | 64 |
| 11,12,13,15,16 17,18 | $Na^+ > Mg^{2+} > Ca^{2+}$ | $Na^+$ | 62 |
| 19 | $Na^+ > Ca^{2+} > Mg^{2+}$ | $Na^+$ | 48 |
| 21,22 | $Na^+ > Mg^{2+} > Ca^{2+}$ | $Na^+$ | 64 |
| 24 | $Na^+ > Ca^{2+} > Mg^{2+}$ | $Na^+$ | 69 |
| 25 | $Na^+ > Mg^{2+} > Ca^{2+}$ | $Na^+$ | 56 |
| 28,29,30,32 34,35,36 | $Na^+ > Ca^{2+} > Mg^{2+}$ | $Na^+$ | 57 |
| 43,47,48,49 52,53,54,55 | $Na^+ > Mg^{2+} > Ca^{2+}$ | $Na^+$ | 53 |

| Wells | Anion Sequence | Chemical type | Percentage |
|---|---|---|---|
| 1,2,3,4,5,6,9,10,11 12,13,15,16,17,18 | $SO_4^{2-} > Cl^- > HCO_3^-$ | $SO_4^{2-}$ | 68 |
| 19 | $Cl^- > SO_4^{2-} > HCO_3^-$ | $Cl^-$ | 63 |
| 21,22 | $SO_4^{2-} > Cl^- > HCO_3^-$ | $SO_4^{2-}$ | 58 |
| 24,25,28,29,30,32 35,36 | $Cl^- > SO_4^{2-} > HCO_3^-$ | $Cl^-$ | 60 |
| 43,47,48,49,52 53,54,55 | $SO_4^{2-} > Cl^- > HCO_3^-$ | $SO_4^{2-}$ | 74 |

Moving on to the iron concentration. From table 1, it can be inferred that iron concentration has passed the threshold value for both safe drinking water from WHO (which is to be 0.2 mg/l), and agriculture from FAO (which is to be 5 mg/l). The average concentration is 31 mg/l with 10 mg/l standard deviation.

**Table 3 The Statistical Analysis for Agro Lab in May 2016**

| Parameters | Unit | Min. | Max. | Median | Mean | Q1 | Q3 | SD | Wells |
|---|---|---|---|---|---|---|---|---|---|
| EC | uS/cm | 500 | 3600 | 1200 | 1390 | 900 | 1600 | 690 | 2, 21, 28, 31, 34 |
| TDS | mg/l | 290 | 1850 | 635 | 731 | 490 | 820 | 356 | 34 |
| $Fe^{2+}$ | mg/l | 17 | 45 | 32 | 30 | 23 | 37 | 8.3 | 1, 33, 47 |

Considering table 2 above which was also done in Agro Lab, there were 41 samples in total that were retrieved and measured. However, it was also unfortunate that only three parameters were present. There is a slight change observed in these two instances. First of all, standard deviation of the EC and TDS reduced considerably. This could mean there was a variation in the concentration of major cations and anions. However, it could not be directly deduced as the data is lacking. Meanwhile for the iron concentration, the standard deviation has decreased by almost 20% and mean has also decreased only by 4%. This small change simply shows that the concentration of iron remains stagnant in two months' period.

However, considering figure 10 below, there was one more measurement that were done later in November 2016 that showed an anomaly to what has been assumed. During that measurement, the iron concentration has sky-rocketed to an average value of 113 mg/l as can be seen from table 3. It is still unclear to why the value has soared up. Supposing that the measurement had no time measurement, one possible explanation owes to the on-field measurement of iron, which was measured during the beginning of the well pumping as the stagnant water has saturated concentration of the dissolved iron. Other could come from the oxidation of iron during the time when the samples were stored. On the contrary, other parameters are in the same range as other measurements.

**Table 4 Measurement by HTWD Team**

| Parameters | unit | 2016 November | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min. | Max. | Median | Mean | Q1 | Q3 | SD | Wells |
| EC (uS/cm) | uS/cm | 841 | 2360 | 2320 | 1960 | 1943 | 2338 | 646 | 16 |
| Na (mg/l) | mg/l | 78 | 93 | 80 | 83 | 78 | 85 | 6 | 16 |
| K (mg/l) | mg/l | 22 | 57 | 56 | 48 | 47 | 57 | 15 | 16 |
| Ca (mg/l) | mg/l | 20 | 100 | 99 | 79 | 78 | 100 | 34 | 16 |
| Mg (mg/l) | mg/l | 17 | 108 | 106 | 85 | 83 | 108 | 39 | 16 |
| Fe (mg/l) | mg/l | 18 | 146 | 144 | 113 | 112 | 145 | 55 | 16 |
| Mn (mg/l) | mg/l | 3 | 6 | 6 | 5 | 5 | 6 | 2 | 16 |

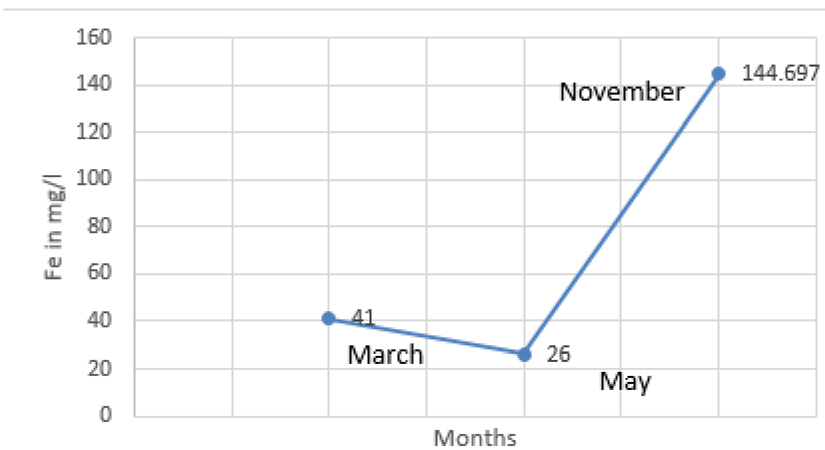
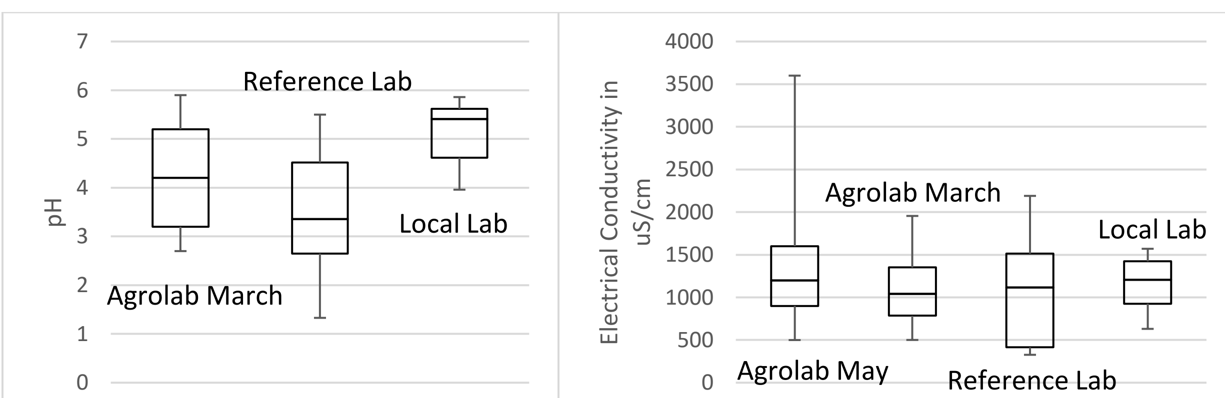



**Figure 10 Measured Iron Concentration from well 16 in three different period in 2016**

To help visualize the statistical values, box and whisker plots have been made with regards to the most essential parameters in this particular instance such as pH, EC, $Fe^{2+}$, $Mn^{2+}$ and $SO_4^{2-}$. One can see clearly that the error bars in some parameters are quite large, owing to either systematical error or precision error.



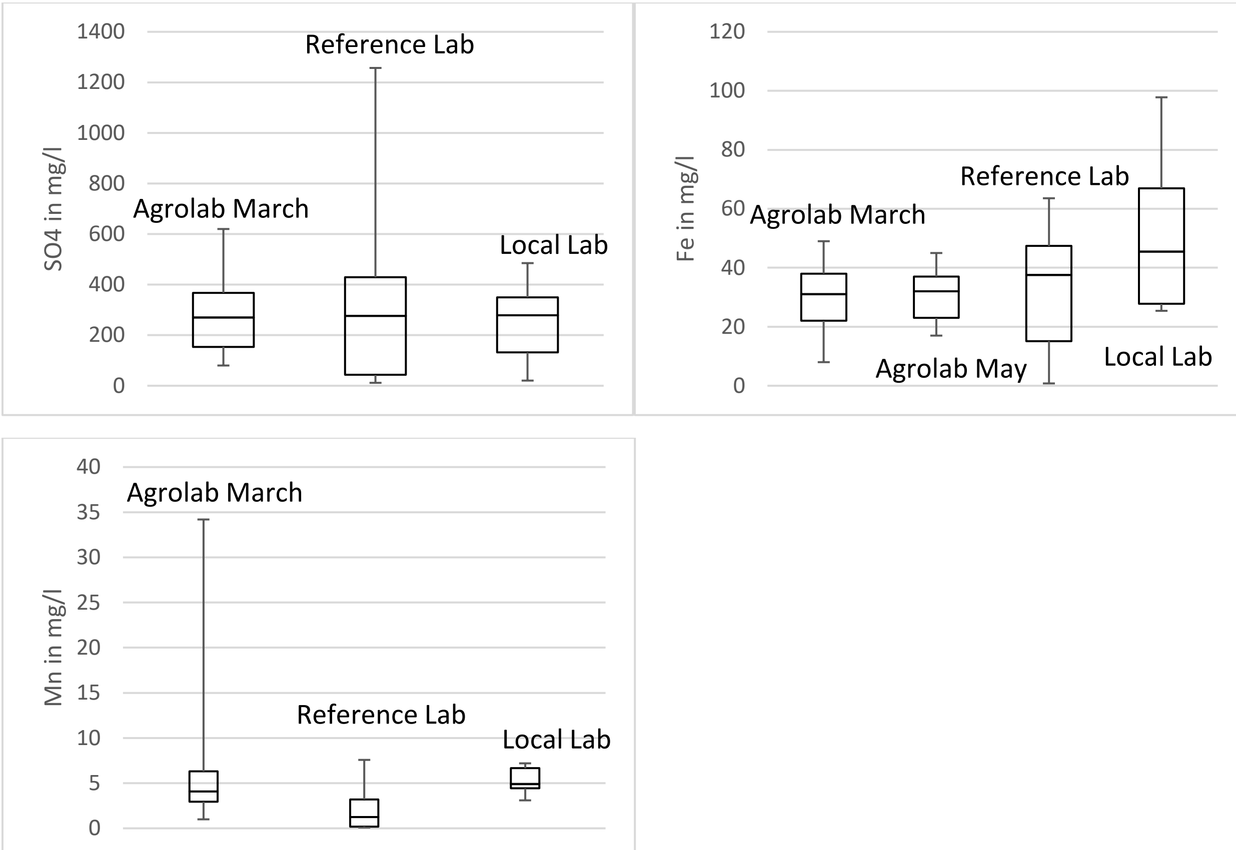



**Figure 11 Box and Whisker Plots of Important Parameters (pH, EC, $Fe^{2+}$, $Mn^{2+}$ and $SO_4^{2-}$)**

One other thing that should be done in water analysis is by creating the electrical balance. In addition, EC measurement that has been done in the field was used also to indicate whether there is an over or underestimation of cations or anions. This is under the assumption that maximum EC is 2000 uS/cm and at around room temperature (Grischek, 2016).

**Table 5 Electrical Balance of Agro Lab Measurement in March 2016**

| Wells | Cation | Anion | EC/100 | e |
|---|---|---|---|---|
| 4 | 15.7 | 17.6 | 16.2 | -5.6 |
| 17 | 14.1 | 14.9 | 15.5 | -2.9 |
| 18 | 11.9 | 12.5 | 14.8 | -2.7 |
| 29 | 6.2 | 5.7 | 5.8 | 3.6 |
| 32 | 5.4 | 4.8 | 5.0 | 5.1 |
| 34 | 7.7 | 6.9 | 7.2 | 5.3 |
| 36 | 12.1 | 12.4 | 12.5 | -1.2 |
| 47 | 6.5 | 6.8 | 7.5 | -2.9 |
| 48 | 7.1 | 7.5 | 7.8 | -2.7 |
| 53 | 6.0 | 6.2 | 7.5 | -1.8 |

The green color signifies that the error for electrical balance lies below the good accuracy consideration (e < 5%) as has been mentioned before. The yellow color indicates that the cation or anion summation lies around the same value as EC and blue color indicates that the measurements has been modified. Unfortunately, out of 35 samples that were measured, only 10 samples considered to be credible enough.

In the Appendix C and D, there are two tables that show the other two measurements from two different laboratories. One was measured in the so-called 'Local Lab' and the other was 'Reference-Lab'. In these two instances, the date of the measurement had not been noted and as such, it was quite vague to be put for the timeline of iron comparison and the lack of wells measured. Nevertheless, they are still useful due to the fact that the on-site measurement's parameters are more complete and there is also turbidity to determine the quality of the groundwater.

First of all, considering the measurement from the Local Lab (Appendix C), there were 10 samples from 10 different wells. Moreover, the wells were labelled more thorough as it signified the difference between shallow and deep wells. The groundwater quality is considered to be of medium to bad quality as the turbidity values are quite high, with the average of 26 NTU. Only three wells that have value below 5 NTU and each of them is shallow well.

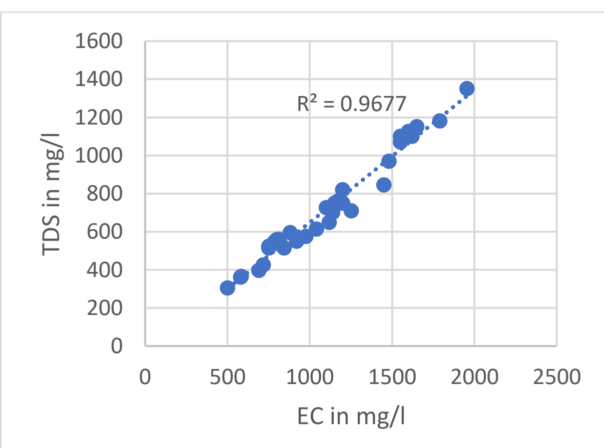
The average temperature measured in this instance was 27$^{o}$ C with a standard deviation of one, which is a credible measurement. pH is generally higher than those measured in Agro Lab, which has a minimum of 4 and an average of 5. This should correspond to lower concentration of $SO_4^{2-}$ and $Fe^{2+}$. However, this is not the case. Iron concentration seemed to have higher concentration in Local Lab than those measured in both instances of Agro Lab. The concentration of $SO_4^{2-}$ also differed by small variance. Investigating further, the alkalinity concentration is rather high with an average 215 mg/l along with high concentration of $Ca^{2+}$ with $CO_3^{2-}$ and $HCO_3^{-}$. This suggests that the pH is being neutralize in this instance. It could also mean that either there was error during the sampling, or data measurement. It has to be noted once again, that there was no time recorded and how the sampling procedure underwent. The measurement is subject to inevitable error. The dominating ions are averagely as follow $Na^{+}$, $Ca^{2+}$, $Mg^{2+}$ and for anion is as follow $SO_4^{2-}$, $Cl^{-}$, and $CO_3^{2-}$.

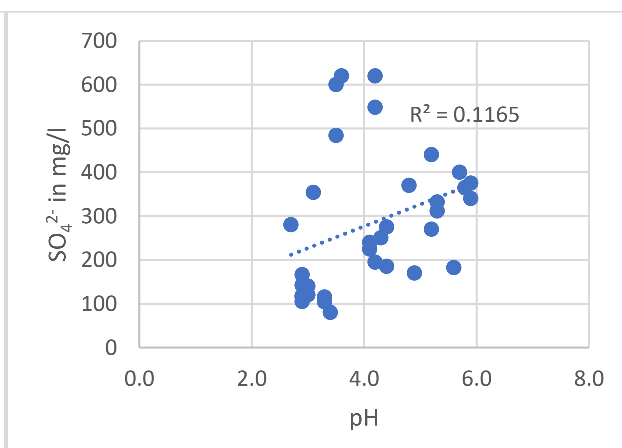
Meanwhile, the measurement from Reference Lab (Appendix D) has also a variation to its parameters. pH is considered to be higher as compare to other, averaging 6 with a maximum value of 8 and median value of 7. Here the data is also provided with the alkalinity, which is considered to be high as well. That fact alone would assume that the groundwater has an ability to neutralize the acidity from pyrite oxidation ($H^{+}$ created as product).

Moreover, one should also check the cross-correlation diagram to have a better visual understanding. Several graphs will be presented to see whether the data is also plausible. As can be seen from figure 10 below, the coefficient of determination almost reached one, which indicates the measurement for both TDS and EC was credible. The other reason as why to TDS and EC have a strong correlation compare to other is that there is a known relation between TDS and EC governed under this formula (Al Dahaan, Al-Ansari, & Knutsson, 2016) :

TDS = ke * EC …(equation 2)

Where both TDS and EC is in mg/l and ke is a correlation factor between 0.55 – 0.8. This known relation is sometimes being applied to probe for a measuring device. However, other cross-correlation diagrams did not have such a good value.



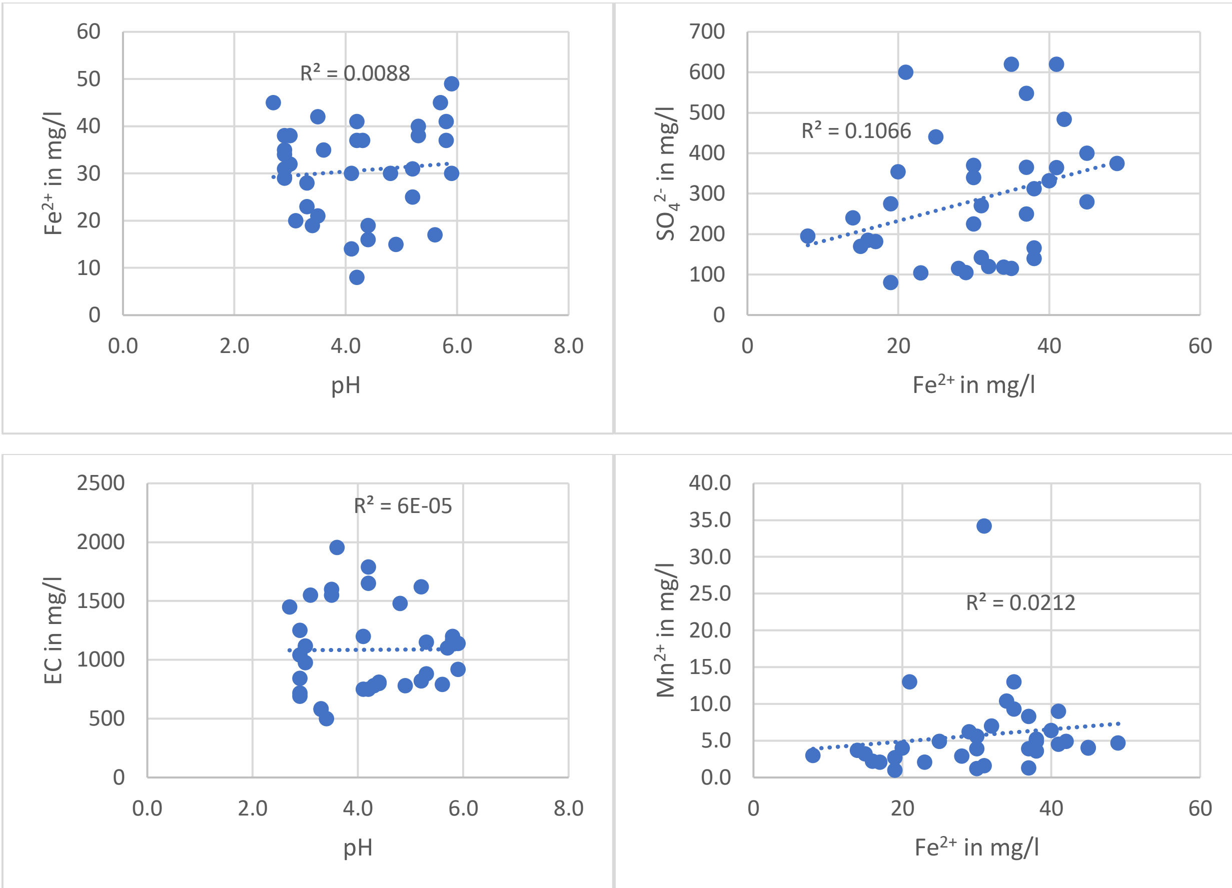



**Figure 12 Cross Correlation Diagrams of Several Parameters in Agro Lab March 2016**

## 3.3. Suggestion About Treatment

In this sub-chapter, several methods for iron-removal will be presented. Many processes are generally effective in decreasing the iron concentration in groundwater. However, such processes depend on the characteristics of the groundwater both physically and chemically. One cannot assume that one specific process should be possible for every condition.

The most common method which has been used extensively in many countries including both in Germany and in Egypt is the so-called aeration method. The aeration method is a method in which the groundwater is pumped and abstracted to the surface which is passed and entered through a structure (this could vary depending on which purpose it is being used) to let the water have a direct contact with air. The air is rich in $O_2$ which is used to oxidize further the ferrous iron ($Fe^{2+}$). $Fe^{2+}$ will later precipitate which then can be filtered since the particle has increased in size. Such method can be used in many purposes not only removing iron concentration. However, the size of the structure can sometimes be quite big, which also escalate the project cost considerably high.

There has already a project done in Egypt in the city of Farshout in Qena Governorate (Nile Valley aquifer) (Abdel-Lah, Mahmoud, & Abadai, 2002) which is located 600 km south of Cairo. There, a study has been made and particularly and aeration tower has been used as a structure. Using the same principle by the definition above, the authors have demonstrated that under the reaction below, the aeration method has been successful in decreasing the iron concentration :

$2Fe^{2+} + O_2 + 2H_2O \rightarrow 2FeO_2 + 4H^+$ …(4)

In addition, prior to the aeration tower that is introduced in this study, several filtering systems have also been developed. One was put before groundwater enters the tower and the other is located after it has been treated (which filters the precipitate). In the Appendix E the schematic of the aeration tower can be seen in more details. The iron concentration has been successfully reduced to 0.1 mg/l from 4 different wells which has an average of 1.5 mg/l. It is important to notice that the system was intended to also implement the addition of Potassium Permanganate ($KMnO_4$) to reduce the elevated iron content and calcium carbonate ($CaCO_3$) to increase the pH. In the end, they were not implemented as many have complained due to unwanted chemicals.

There have been many discussions as to whether the removal of iron through using microorganisms can be effective or not. Some authors have made a review about the topic and it relates mainly to the activity of microorganisms that consume $Fe^{2+}$ as a source of energy under the reaction (Sharma, Petrusevski, & Schippers, 2005) :

$4Fe^{2+} + O_2 + 10H_2O \rightarrow 4Fe(OH)_3 + 8H^+ + \text{Energy}$ … (5)

Keep in mind that most of the measurements have varying values of pH from acidic to quite neutral. This, unfortunately, would not be suitable for using iron bacteria or to use biological iron removal as most of iron bacteria have tendency to have higher survivability and growth rate (Gad, Dahab, & Ibrahim, 2016) (Sharma, Petrusevski, & Schippers, 2005). However, one possibility is to build a treatment plant on the surface and introduce a chemical that will increase pH to the desired level such as using $CaCO_3$. The authors have also reported that such method has many advantages (although it has its limitations too) especially regarding the lower project cost as the facility could be much smaller due to higher applied filtration rates or a structure that integrates both aeration and filterat system. There have been many case studies too. One example was able to decrease the iron concentration into an undetectable range of less than 0.05 mg/l (Smith & Smith, 1994).

## 4. Conclusion and Recommendations

This report has successfully fulfilled its threefold purposes. On the first part, this report has shown the analysis owing to its location. There arises a problem in which elevated iron concentration is found throughout groundwater system where the company Al Enmaa has used for source in providing clean water for agricultural purpose. Bahareya Oasis is located in 370 km southwest of Cairo. The stratigraphic column has been shown and the bahareya formation has thickness ranging from 100m to 1800m. The groundwater has been extensively used from 1963 as the shallow spring could no longer fulfill the demand for clean water (the springs were depleted). Drawdown has declined since then with a rate of about 1.2 m annually and expected to have 32 m maximum drawdown in the next 50 years. It has been reported that pyrite exists in bahariya formation in the form of fine-grained sand which have dark bedding and can cause brown to auburn column (which confirms the iron incrustation in the piping system).

Moreover, software such as Google Earth Pro engine and QGIS were used to reproduce the rough sketch provided. Categorization of iron concentration and other parameters have been made in order to bring clarity to the most concentrated region. In order to have a better visualization, topographical map and piezometric contour can also be provided.

Water analyses have been thoroughly made and it was found out that the average concentration of iron is 36 mg/l over four instances excluding the anomaly that has been found in November 2016 instance (where the iron concentration has soared up to 113 mg/l). The statistical analyses were also conducted in which many errors have been produced. This could owe to both precision error (statistical error) in the calculation and systematical error during sampling and measurement.

Statistical parameters such as minimum, maximum, median, mean, first and third quartile and standard deviation values are presented. To help visualize, cross-correlation diagrams have been made along with box and whisker plot. Chemically, the electrical balance has also been done along with the over- or underestimation using division of Electrical Conductivity. Overall, only few samples that are considered to be credible enough due to them being categorized under 5% error for the electrical balance. Suggestions and reasons as why to the problem arises have been made with the consideration of analyses. In the future, it is hoped that the report will provide clarity to the current problem residing in the location.

## Acknowledgment

The author wishes to express his sincere thanks and gratitude to Prof. Dr.-Ing. Thomas Grischek from the faculty of Civil Engineering, HTW Dresden for the constant guidance and help through the completion of the project and report and to Prof. Dr.-Ing. Frank Schwarzbach and his wife Mrs. Schwarzbach, Faculty of Geoinformatics, HTWD for the guidance for QGIS analysis. The author would like also to express his deep thanks to the company Al Enmaa in providing the measurement data.

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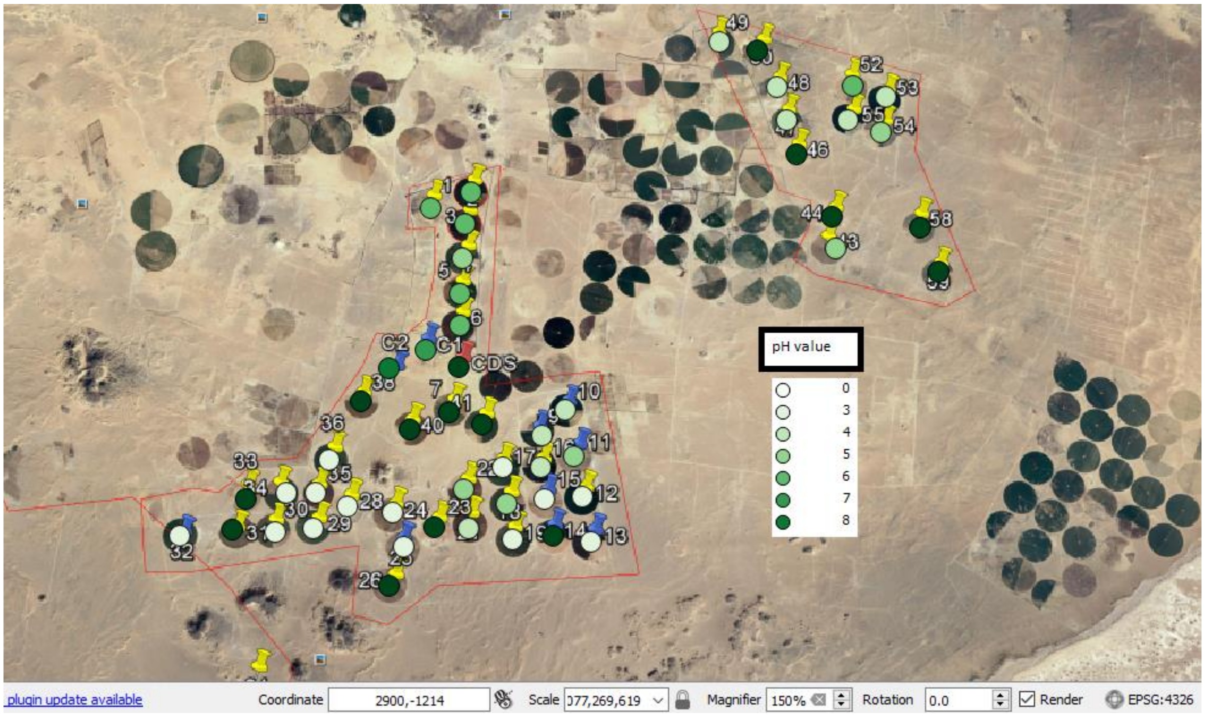
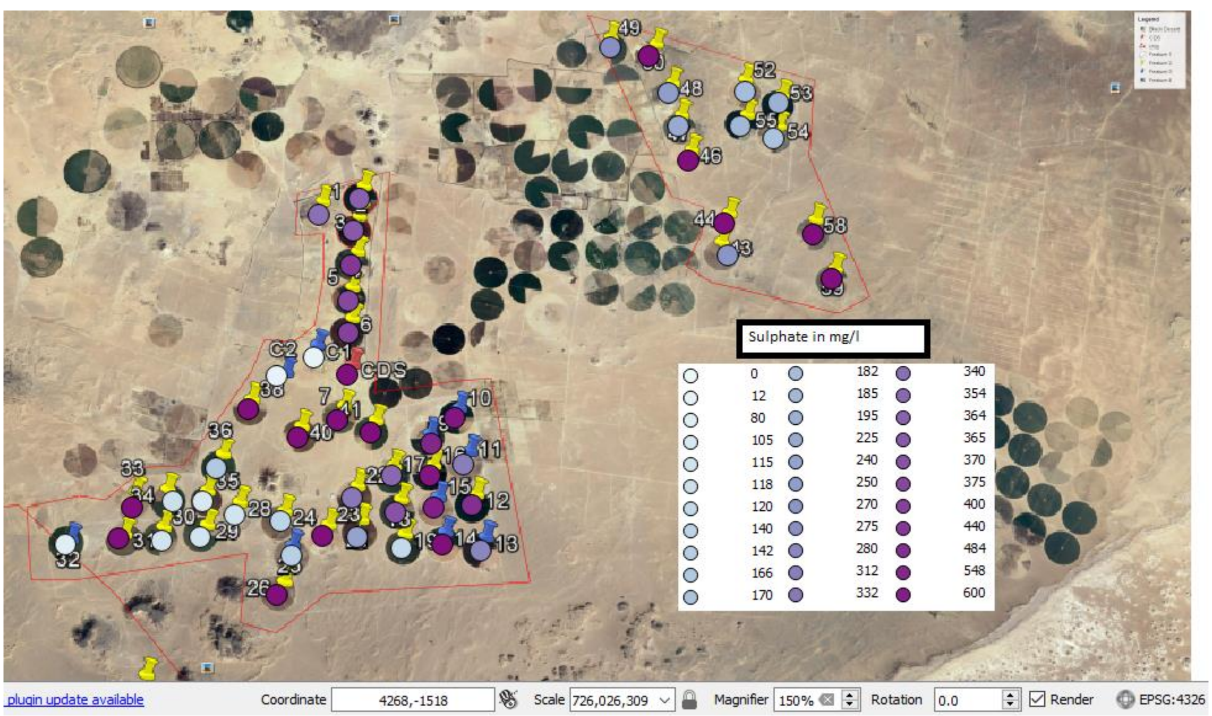



**Appendix A pH Categorization using QGIS and Google Earth Pro**




**Appendix B Sulphate Categorization in mg/l using QGIS and Google Earth Pro**

## Appendix C The Statistical Analysis for Local Lab (unknown date)

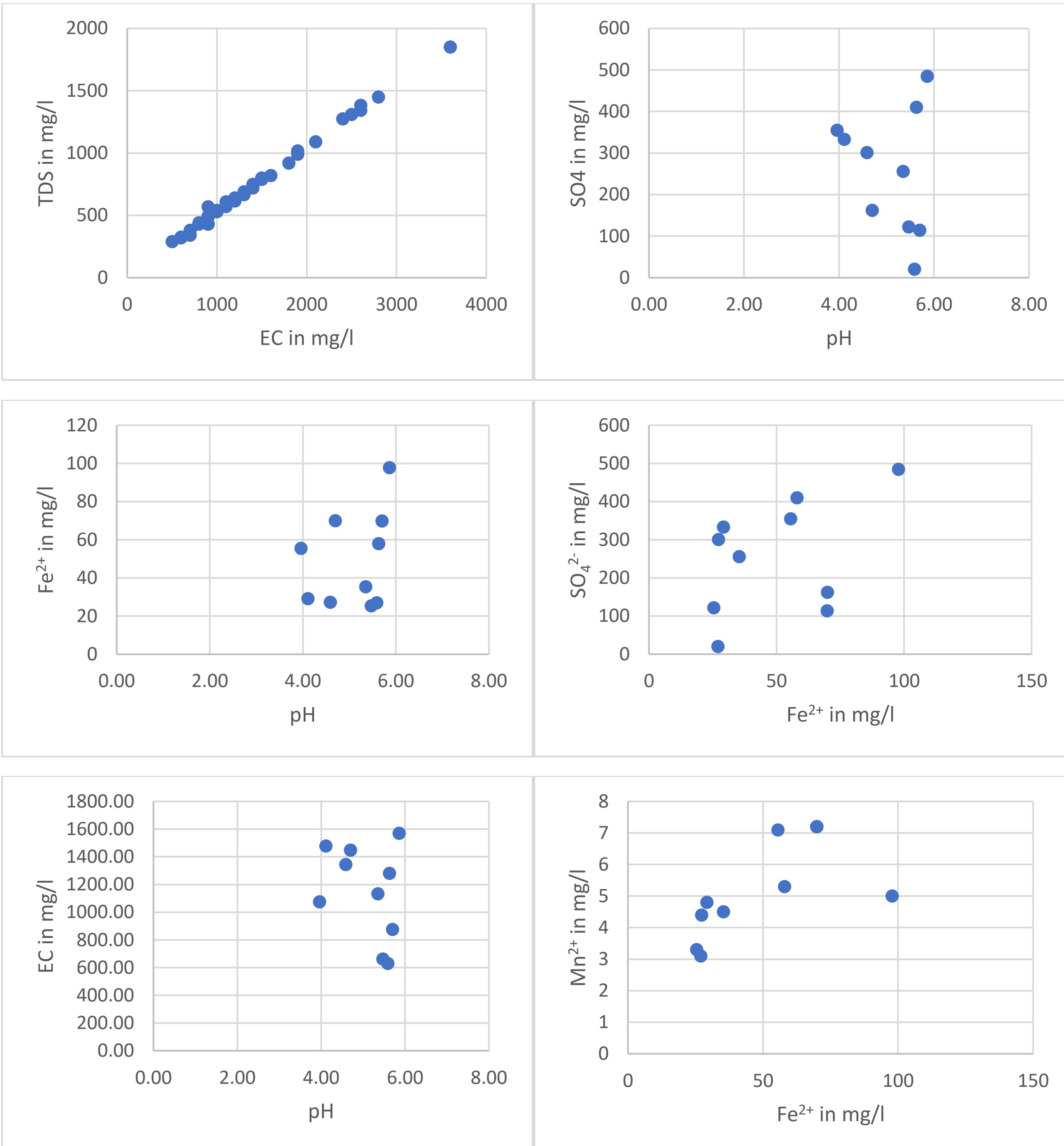
| Parameters | unit | Statistical Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min. | Max. | Median | Mean | Q1 | Q3 | SD | Wells[3] |
| pH | - | 4 | 6 | 5 | 5 | 5 | 6 | 1 | DSW32, SW35 |
| EC | uS/cm | 631 | 1570 | 1208 | 1150 | 926 | 1422 | 319 | SW35, 40 |
| TDS | mg/l | 379 | 942 | 725 | 689 | 553 | 854 | 192 | SW35, 40 |
| DO | mg/l | 2 | 5 | 3 | 4 | 3 | 4 | 1 | DSW32, SW35 |
| T | °C | 26 | 28 | 26 | 27 | 26 | 27 | 1 | SW29, 41 |
| Turbidity | NTU | 2 | 140 | 12 | 26 | 5 | 18 | 40 | SW1, 31 |
| Alkalinity | mg/l | 112 | 316 | 218 | 215 | 190 | 243 | 63 | DW3, SW36 |
| Total Hardness | mg/l | 141 | 461 | 311 | 289 | 234 | 329 | 90 | DW3, SW31 |
| Ca Hardness | mg/l | 122 | 312 | 191 | 190 | 147 | 210 | 52 | SW1, 35 |
| Mg Hardness | mg/l | 19 | 149 | 111 | 100 | 190 | 243 | 54 | SW35, 36 |
| $Na^{+}$ | mg/l | 65 | 216 | 153 | 151 | 130 | 175 | 40 | SW1, 40 |
| $K^{+}$ | mg/l | 25 | 61 | 45 | 43 | 33 | 51 | 11 | SW36, 40 |
| $Ca^{2+}$ | mg/l | 15 | 235 | 77 | 96 | 58 | 86 | 67 | SW31, 35 |
| $Mg^{2+}$ | mg/l | 12 | 97 | 38 | 45 | 31 | 50 | 26 | SW35, 36 |
| $Fe^{2+}$ | mg/l | 25 | 97 | 45 | 50 | 28 | 67 | 23 | SW35, 41 |
| $Mn^{2+}$ | mg/l | 3 | 7 | 5 | 5 | 4 | 7 | 1 | DW3, SW36 |
| $Cl^{-}$ | mg/l | 98 | 349 | 209 | 221 | 173 | 283 | 75 | DW3, SW6 |
| $CO_3^{2-}$ | mg/l | 65 | 210 | 119 | 125 | 98 | 135 | 42 | DW3, SW36 |
| $HCO_3^{-}$ | mg/l | 57 | 114 | 100 | 97 | 92 | 106 | 15 | DW3, SW36 |
| $SO_4^{2-}$ | mg/l | 20 | 485 | 279 | 256 | 132 | 350 | 140 | SW31, 35 |
| $NO_3^{-}$ | mg/l | 3 | 200 | 27 | 47 | 28 | 70 | 55 | SW31 |

[3] D and S denote 'Deep' and 'Shallow'

**Appendix D The Statistical Analysis for Reference Lab (unknown date)**

| Parameters | Unit | Statistical Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min. | Max. | Median | Mean | Q1 | Q3 | SD | Wells[4] |
| pH | - | 3 | 8 | 6 | 6 | 4 | 7 | 2 | DW11, 15 |
| EC | uS/cm | 327 | 2190 | 1116 | 1089 | 414 | 1513 | 656 | DW10, SW5 |
| TDS | mg/l | 196 | 1314 | 670 | 653 | 248 | 907 | 394 | DW10, SW5 |
| DO | mg/l | 1 | 6 | 3 | 3 | 3 | 5 | 1 | DW11, 15 |
| T | centigrade | 24 | 32 | 29 | 29 | 28 | 30 | 2 | CSW1, DW13 |
| Turbidity | NTU | 3 | 442 | 18 | 115 | 11 | 164 | 156 | DW13, SW5 |
| TOC | ug/l | 43 | 258 | 150 | 150 | 116 | 184 | 64 | DW13, SW16 |
| Alkalinity | mg/l | 12 | 118 | 28 | 49 | 17 | 80 | 36 | DW10, SW5 |
| Total Hardness | mg/l | 89 | 663 | 168 | 245 | 109 | 294 | 187 | DW10,13 |
| Ca Hardness | mg/l | 20 | 207 | 61 | 91 | 27 | 149 | 72 | DW10, 13 |
| Mg Hardness | mg/l | 69 | 466 | 104 | 154 | 82 | 147 | 125 | DW13, SW5 |
| $Na^+$ | mg/l | 11 | 212 | 55 | 76 | 15 | 121 | 67 | DW10, 11 |
| $K^+$ | mg/l | 28 | 65 | 35 | 39 | 29 | 46 | 12 | DW10, SW5 |
| $Ca^{2+}$ | mg/l | 8 | 83 | 24 | 36 | 11 | 60 | 29 | DW10, DW13 |
| $Mg^{2+}$ | mg/l | 12 | 50 | 21 | 25 | 17 | 29 | 11 | DW13, DW15 |
| $NH_4^+$ | mg/l | 0 | 1 | 0 | 0 | 0 | 0 | 0 | CSW2, DW15 |
| $Fe^{2+}$ | mg/l | 1 | 64 | 38 | 32 | 15 | 47 | 21 | DW10 |
| $Mn^{2+}$ | mg/l | 0 | 8 | 1 | 2 | 0 | 3 | 2 | DW10 |
| $Cl^-$ | mg/l | 31 | 427 | 127 | 152 | 36 | 213 | 127 | DW10,11 |
| $SO_4^{2-}$ | mg/l | 12 | 1257 | 276 | 358 | 43 | 429 | 392 | DW10, SW5 |
| $F^-$ | mg/l | 0 | 1 | 1 | 0 | 0 | 1 | 0 | CSW1, 2, DW10 |
| $Br^-$ | mg/l | 0 | 1 | 0 | 0 | 0 | 1 | 0 | DW10 |

[4] D, S and C denote 'Deep', 'Shallow' and 'Cow'



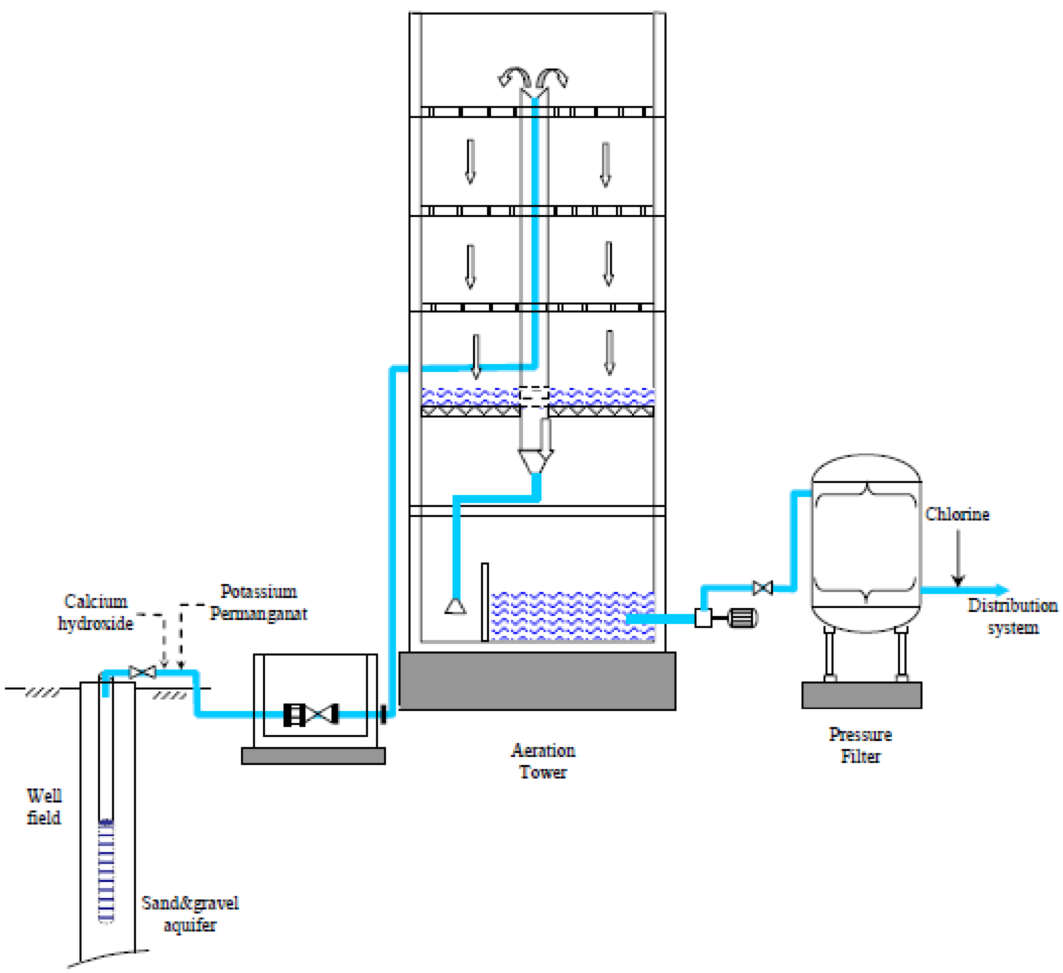

**Appendix E Cross Correlation Diagrams of Several Parameters in Local Lab (unknown date)**

**Appendix F Electrical Balance of Local Lab Measurement**

| Wells | Cation | Anion | e | EC/100 |
|---|---|---|---|---|
| SW1 | 15.3 | 13.9 | 4.8 | 8.8 |
| DSW32 | 11.2 | 11.9 | -3.0 | 6.6 |
| SW41 | 19.4 | 20.5 | -2.8 | 10.8 |

**Appendix G Electrical Balance of Reference Lab Measurement**

| Wells | Cation | Anion | e | EC/100 |
|---|---|---|---|---|
| SW5 | 13.59 | 13.27 | 1.18 | 13.16 |




**Appendix H Aeration Tower in the study case** *(Abdel-Lah, Mahmoud, & Abadai, 2002)*

| *location* | **pH** | **TDS** | **Fe** | **Mn** | **$NO_3$** | **$NO_2$** | **$PO_4$** | **$SO_4$** | **$Cl_2$** |
|---|---|---|---|---|---|---|---|---|---|
| *Well 1* | 7.7 | 610 | 2.63 | 0.52 | 3.52 | 0.013 | 0.38 | - | - |
| *Well 2* | 7.5 | 450 | 0.62 | 0.45 | 7.10 | 0.026 | 0.50 | 120 | - |
| *Well 3* | 7.6 | 460 | 0.35 | 0.38 | 5.30 | 0.013 | 0.46 | 195 | - |
| *Well 4* | 7.5 | 560 | 2.67 | - | 4.40 | 0.063 | 0.30 | - | - |
| *Treated* | 7.9 | 480 | 0.10 | 0.35 | 6.15 | 0.50 | 0.33 | 125 | 1.75 |
| *Service* | 7.6 | 510 | 0.19 | 0.31 | 5.90 | 0.58 | - | 150 | 0.14 |

**Appendix I Water Analysis in the Study Case** *(Abdel-Lah, Mahmoud, & Abadai, 2002)*