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Effect of Temperature Variation on Electrical Conductivity (EC) Modern Sensor and Visibility of using it

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ABSTRACT
Groundwater extraction in Egypt is being expanded in response to limited Nile water quotas, rapid population growth, and the necessity of regional development beyond the Nile Valley and Delta. However, the monitoring of iron (Fe) and manganese (Mn) concentrations is currently restricted by the high cost of chemical reagents and spectral analysis. As a result, water quality assessments are conducted only at 15 to 30day intervals. This leads to the application of constant potassium permanganate dosages regardless of interim fluctuations in mineral levels. Consequently, an alternative real-time monitoring method is required to enable immediate adjustments to treatment chemical dosages based on instantaneous ion concentrations

KEY WARDS: Iron Ion Detection, Electroconductivity, Ground Water treatment, Real time, Temperature variation.

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I. INTRODUCTION

Several previous studies have investigated the relationship between dissolved metal ion concentrations and electrical properties.

Iron and manganese are among the most important minerals found in Egyptian groundwater. This paper focuses on a groundwater treatment plant in Kaha, Qalyubia, Egypt, where iron ions are prevalent.

Previous studies have established the relationship between iron ion concentration and electrical potential [1,2].

This paper explores the relationship between electrical conductivity [3] and iron ion concentration, and then calibrates this relationship to monitor the plant's temperature constant. The relationship between iron ion concentration and electrical conductivity was determined by measuring iron ion concentration in the laboratory and correlating it with conductivity measurements using an advanced sensor.

An electrical conductivity sensor (SKU: A4-2 – TDS) was selected due to its small size, ease of installation at the plant, and rapid response time.

This relationship is significantly affected by temperature differences. Therefore, it is necessary to identify and demonstrate this difference to obtain accurate readings for calculating the quantities of iron-treatment agents, such as potassium permanganate or other substances.

II. Literature Review

2.1. Relation affect between Temperature and Electrical Conductivity

The measured EC values at various temperatures need to be reported and corrected regarding to a standard temperature because EC is dependent on temperature.

An arbitrary constant is commonly used for temperature compensation assuming that EC-temperature relation is linear (for example 2% increase of EC per 1 ˚C). EC-temperature relation was slightly nonlinear in a temperature range 0 – 30 ˚C, but the linear equation approximated the relation reasonably well. The temperature compensation factor corresponding to 25 ˚C ranged between 0.0175 and 0.0198. When the mean value 0.0187 was used **[4]**. EC of water samples is commonly used to examine for the dilution gauging of stream discharge **(Dingman et al) [5].**

The following equation is commonly used to represent the relation of temperature change with the electro-conductivity

$$EC_t = EC_{25} [1 + a (t - 25)],$$

Where

EC_t is electrical conductivity at temperature t (˚C),

EC_{25} is electrical conductivity at 25 ˚C,

and a ($˚C^{-1}$) is a temperature compensation factor.

At Groundwater textbooks frequently cite '2% increase of EC per 1 ˚C increase of temperature' **(Matthess, Hem) [6,7]**, which translates into a = 0.02, while geophysicists commonly use a = 0.025 **(Keller et al) [8,9].**

The previous equation, with a = 0.02 as applied to groundwater, is transformed into the following formula

$$EC_t = EC_{25} [0.5 + 0.02t] \ldots \textbf{equ (1)}$$

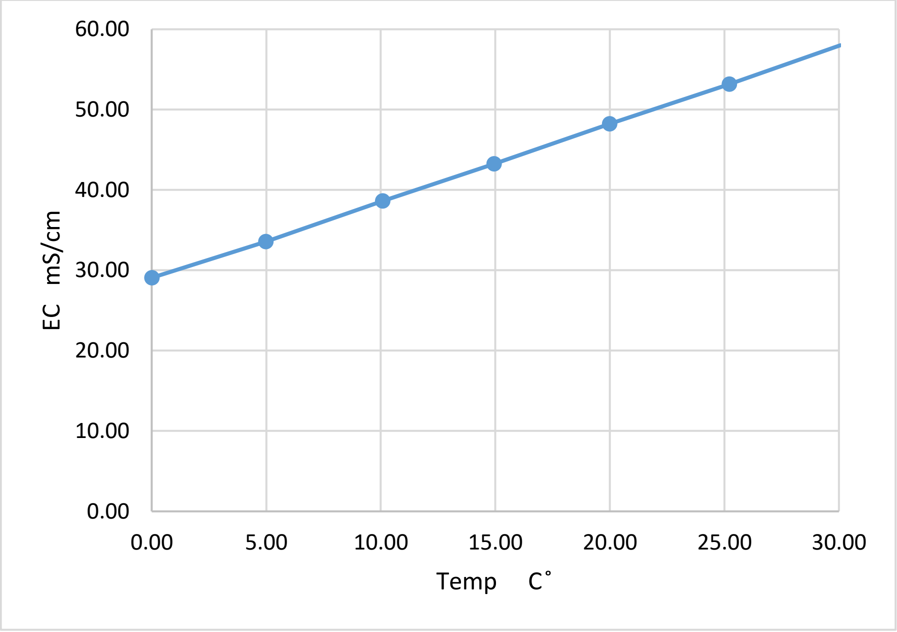


Figure 1. Relation between FE and Temperature for ground water

2.2. *Temperature Variance effect at the Measurements*

From equations (3), (4), and (5), the correlation between electrical conductivity and iron ion concentration, relative to temperature variance, is translated as follows

$$EC_{25} = \frac{ECt}{[0.5 + 0.02t]} \ldots \textbf{equ (2)}$$

III. Calibration of temperature compensation factor (a)

3.1. *Case Study (Kaha water treatment station)*

Kaha water treatment station is a good case helping us trying to get its temperature compensation factor (a) by repeating analyze samples in varied temperature. The location of Kaha station at the southern middle of delta region 19 km south of Banha city (Qalyubia governorate).

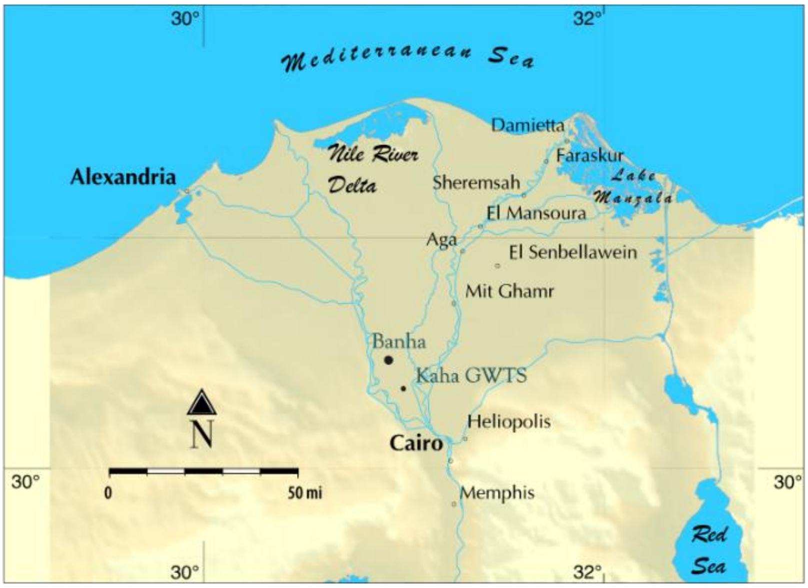


Figure 2. Allocation of Kaha Ground Water Treatment Station.

Table 1. Wells' data for Kaha treatment plant, Qalyubia Governorate, Egypt

Well No	D (m)	Q (m3/hr)	Q(l/s)	Hp	H (m)	H_{act} (m)	$Diam_{out}$ (mm)	$Diam_{well}$ (mm)	Est Year
1	100	100	27.8	40	54	40	160	250	2001
2	124	100	27.8	40	54	40	100	250	2001
3	126	100	27.8	40	54	40	100	250	2001
4	128	100	27.8	40	54	40	100	250	2001
5	125	260	72.2	75	39	35	160	355 pe	2013
6	100	260	72.2	75	39	35	160	355 pe	2013

Where:

D: Well depth, Q: Available Balanced Withdraw discharge, Hp: Pump horse power, H: maximum delivered pump head, H_{act}: The actual pump head, $Diam_{out}$: the outlet pipe diameter from the pump, $Diam_{well}$: Well diameter, pe: polyethylene pipe otherwise iron pipes were used.

3.2. Experiment conditions

Samples were withdrawn on October 16, 2024, at 10:30 AM, with an ambient temperature of approximately 27°C at the Kaha station, Qalyubia Governorate. Following coordination with the station director and technical staff, wells 1, 2, 3, and 4 were accessed. Each pump was activated for a two-minute stabilization period prior to collection to ensure the removal of accumulated solids or contaminants. Sample volumes of approximately 1000 mL were collected. Wells 3 and 4, located near the station entrance, were sampled first, followed by wells 1 and 2, situated approximately 20 m away. Sampling from well 6 was not possible due to ongoing maintenance.

Samples were analyzed using an electrical conductivity sensor. In this experiment, a sensor (Model SKU: A4-2 – TDS), comparable in size to an AA battery, was employed to measure electrical conductivity (EC), total dissolved solids (TDS), and temperature. The device is illustrated in the **Figure.3** below.

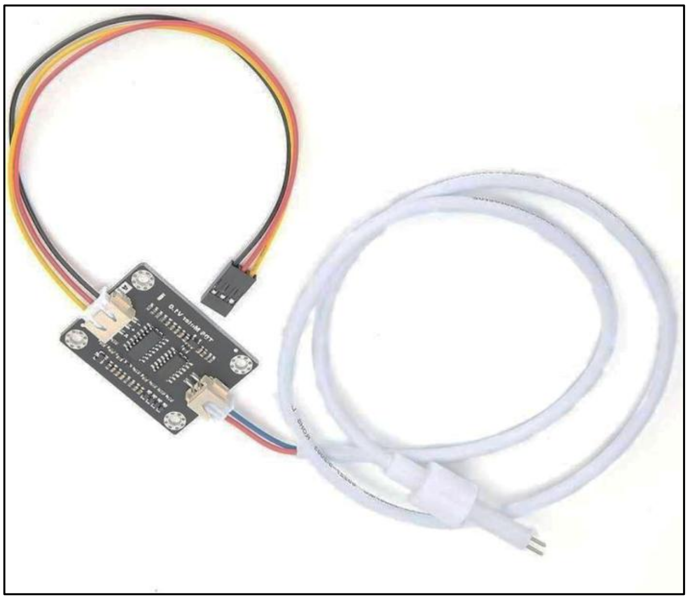


Figure 3. The used sensor to measure the electro conductivity with its module (Arduino).

The sensor must be installed with Arduino Uno chip to treat and convert the analogue readings of the sensor. Using integrated development environment (IDE) that helps simplify the coding process. The IDE is based on C and C++ programming languages.

Firstly, the mathematical relationship between electrical conductivity (EC) and iron (Fe) ion concentration was determined, as established and validated by prior laboratory experimentation. Triplicate one-liter samples were collected from each well. Each sample was partitioned into a 200 mL aliquot for standard radical analysis at the Center of Excellence for Water Research (Faculty of Engineering, Ain Shams University) and an 800 mL aliquot for sensor validation. Iron ion concentrations were measured using standard laboratory spectrometric methods. The remaining volume was further subdivided into eight subsamples for repetitive electrical conductivity measurements using the proposed modern sensor. Thus, the actual in situ correlation between Fe and EC was established. The experiment was carried out for the same samples at the same time and at the room temperature (25 – 26 C˚), and the Arithmetic results represented at the **Figure.4** below

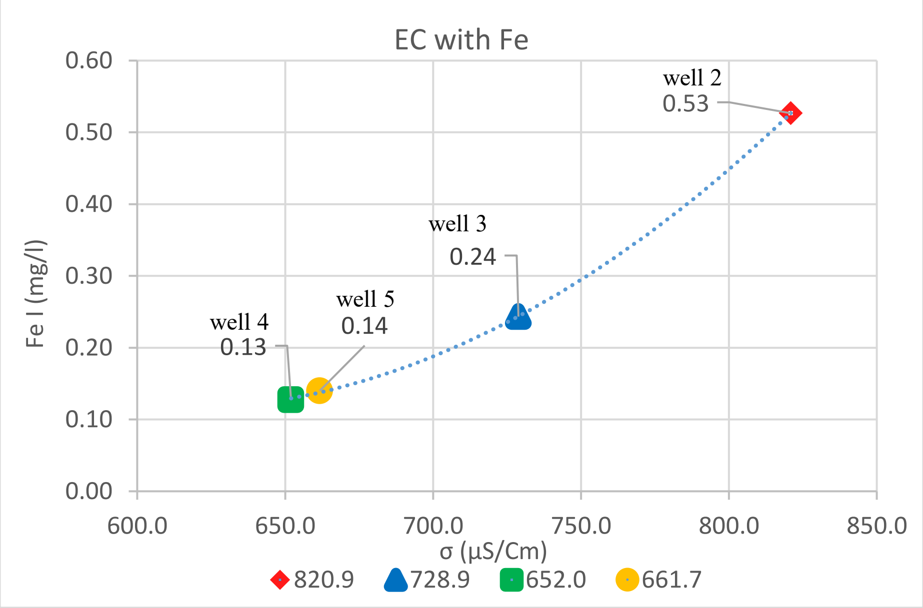


Figure 4. correlation between FE and EC

The relation represented by the following equation

$$\mathbf{y = 7E^{-19}\, x^{6.125}} \text{ ……. } \mathbf{equ\ (3)}$$

that x is EC S/Cm and y is Fe I (mg/l).

The correlation relation factor $R^2 = 0.99$ which means Perfect positive linear association **[10]**.

IV. Results of Experiments

For calibrating temperature compensation factor (a), Electroconductivity for the same samples was measured in two different temperatures once at the room temperature near 26 C°, and the other at temperature near 18 C°. The resulted value for the temperature compensation factor (a).

Using the equation

$$EC_t = EC_{25}\,[1 + a\,(t - 25)]$$

We will express $\mathbf{a} = \frac{(\frac{Et}{E25} - 1)}{t - 25}$

To determine the compensation factor representative of the Kaha treatment station, triplicate samples were analyzed from each well. Samples from Well 1 could not be obtained due to ongoing maintenance. Each collected sample was analyzed two to three times at varying temperatures, as illustrated below. Subsequently, an arithmetic average was calculated for each well, followed by the determination of the final arithmetic mean for the entire station.

Table 2. represents the compensation factor resulted for well number 2 sample no1 regarding the clarified temperature variance.

Well sample No	Temp 25 (Co)	EC25 (µS/Cm)	Temp (Co)	Et(µS/Cm)	Calibrated a
2.1					
1	26.56	824.62	18.46	712.31	0.0168
2	26.56	824.62	18.43	712.37	0.0168
3	26.56	827.69	18.4	712.29	0.0171
4	26.56	827.69	18.4	712.35	0.0171
5	26.56	826.15	18.37	712.33	0.0168
6	26.56	826.15	18.35	715.38	0.0163
7	26.56	832.31	18.32	713.85	0.0173
8	26.53	827.69	18.32	713.85	0.0168

The resulted arithmetic compensation factor for sample (2-1) for average temperature (18.38 ℃) = 0.0169

Table 3. represents the compensation factor resulted for well number 2 sample no 2 regarding the clarified temperature variance.

Well sample No	Temp 25 (Co)	EC25 (µS/Cm)	Temp (Co)	Et(µS/Cm)	Calibrated a
2.2.a					
1	26.25	821.54	19.66	672.31	0.0276
2	26.22	821.54	19.69	672.28	0.0278
3	26.25	816.92	19.72	673.85	0.0268
4	26.22	821.54	19.71	672.30	0.0279
5	26.27	820	19.71	672.31	0.0275
6	26.25	821.54	19.69	673.85	0.0274
7	26.27	821.54	19.66	676.92	0.0266
8	26.3	821.54	19.61	683.08	0.0252

The resulted arithmetic compensation factor for sample (2-2.a) for average temperature (19.68 ℃) = 0.027

Table 4. represent the compensation factor resulted for well number 2 sample no 2 regarding the clarified temperature variance and lower than in the previous table (2.2.b).

Well sample No	Temp 25 (Co)	EC25 (µS/Cm)	Temp (Co)	Et(µS/Cm)	Calibrated a
2.2.b					
1	26.25	821.54	18.82	678.46	0.0234
2	26.22	821.54	18.84	683.08	0.0228
3	26.25	816.92	18.84	681.54	0.0224
4	26.22	821.54	18.84	683.08	0.0228
5	26.27	820	18.82	683.08	0.0224
6	26.25	821.54	18.81	681.54	0.0229
7	26.27	821.54	18.79	681.53	0.0228
8	26.3	821.54	18.76	686.15	0.0219

The resulted arithmetic compensation factor for sample (2.2.b) for average temperature (18.10 ℃) = 0.0227

Table 5. represent the compensation factor resulted for well number 2 sample no 3 regarding the clarified temperature variance.

Well sample No	Temp 25 (Co)	EC25 (µS/Cm)	Temp (Co)	Et(µS/Cm)	Calibrated a
2.3					
1	25.88	796.92	18.35	712.31	0.0141
2	25.9	820	18.35	709.23	0.0179
3	25.96	807.69	18.37	709.23	0.0161
4	25.94	826.15	18.37	712.31	0.0182
5	25.96	816.92	18.38	709.23	0.0174
6	25.99	804.62	18.38	712.31	0.0151
7	26.02	810.77	18.38	712.31	0.0159
8	26.05	810.77	18.37	709.23	0.0163

The resulted arithmetic compensation factor for sample (2-3) for average temperature (18.37 ℃) = 0.0169

All available wells, including Well 2, were tested. The arithmetic mean of the measurements was then determined to represent each dataset. Finally, the calibrated temperature compensation factor for the station was calculated, as detailed in Table 6.

Table 6. illustrates the resulted calibrated temperature compensation factor (a)

Well sample No	Temp 25 (C°)	EC25 (µS/Cm)	Temp t (C°)	Et(µS/Cm)	Calibrated a	Notes
1	Out of service regarding to maintenance					
2.1	26.56	827.0	18.38	713.1	0.0169	
2.2.a	26.25	820.8	19.68	674.6	0.0271	
2.2.b	26.25	820.8	18.82	682.3	0.0227	
2.3	25.96	815.6	18.37	710.8	0.0169	
3.1	26.20	730.3	18.24	576.5	0.0265	
3.2	26.31	730.5	18.58	641.0	0.0158	

3.3	26.36	727.4	18.81	626.1	0.0184	
4.1	26.18	653.8	18.36	580.8	0.0143	
4.2	26.45	650.5	18.87	569.2	0.0165	
4.3.a	25.65	653.2	18.32	594.6	0.0122	
4.3.b	26.08	654.0	19.72	582.1	0.0173	
5.1	25.87	663.4	19.83	586.2	0.0193	
5.2	26.28	661.4	18.70	569.2	0.0184	
5.3	26.30	1036.4	19.18	937.7	0.0134	Damaged
6.1	26.45	1289.6	18.98	1152.5	0.0142	Will not be used due to Coliform Appearance
6.2	26.29	1255.5	18.65	1137.9	0.0123	
6.3	26.08	1161.2	19.68	674.6	0.0655	
Average	**26.18**	**723.74**	**18.82**	**623.58**	**0.0186**	

Then by calculating the Arithmetic value for the whole wells inside the station

a = 0.0186

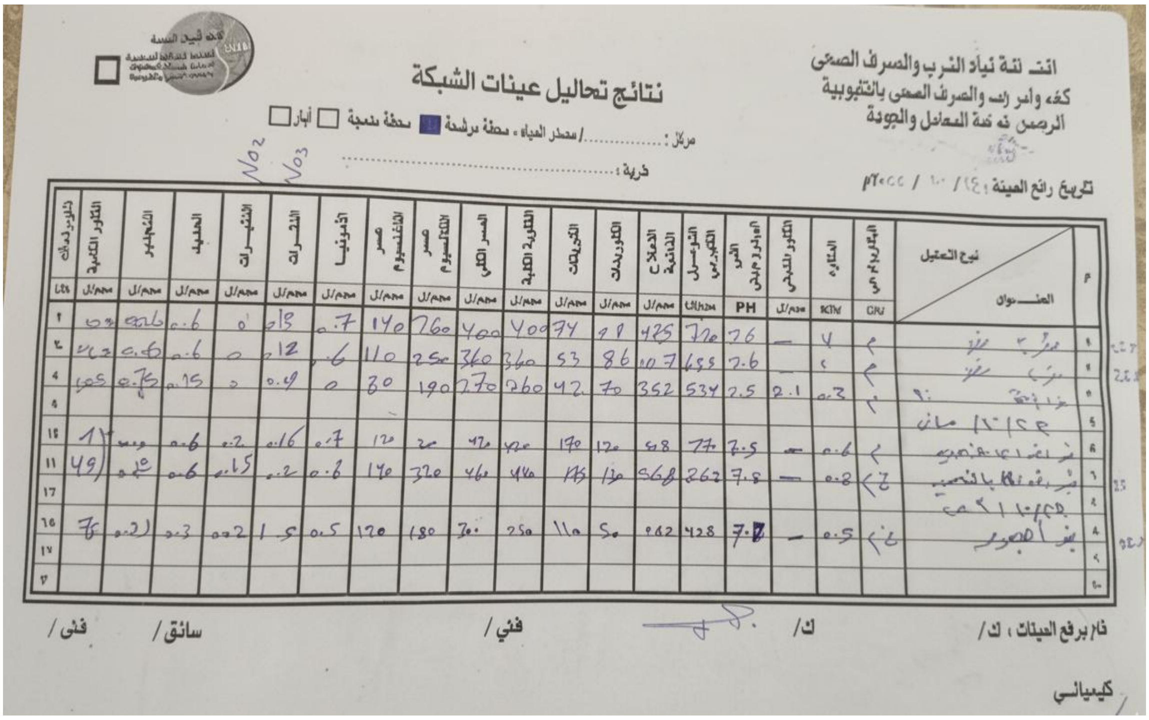
then the calibrated value of Fe in equation (8) will be

$$\mathbf{Fe_c = 7E\text{-}19\ \left(\frac{EC_t}{[0.513 + 0.0186t]}\right)^{6.125}} \ \ldots\ \mathbf{equ\ (4)}$$

V. Economical effect of Using the New Proposed Modern Sensor

Real-time monitoring is critical within the field of water treatment, particularly regarding its direct impact on public health and national security. Consequently, the economic feasibility of this method is a primary factor for its rapid market integration. In this section, the variations in treatment material requirements and energy consumption resulting from the proposed method are clarified.

As previously established, the primary challenge facing current treatment processes is the high cost of dissolved iron analysis, largely due to expensive reagents, which increases the overall operational expenditure. Furthermore, the inherent latency of conventional methods limits sampling frequency, typically resulting in 30-day intervals between analyses. This delay prevents timely adjustments to chemical dosing in response to fluctuating mineral levels.



الشركة القابضة لمياه الشرب والصرف الصحي
كفر الشيخ / شركة مياه الشرب والصرف الصحي بالقليوبية
الإدارة العامة للمعامل والجودة

نتائج تحاليل عينات الشبكة

مركز : ..../مصدر المياه ، محطة ترشيح ■ محطة مدمجة ☐ آبار ☐

قرية : ....

No2 No3

تاريخ رفع العينة : ١٤/ ١٠ / ٢٠٢٢م

م	نوع التحليل / العنوان	[illegible] CRJ	العكارة NTU	الكلور المتبقي مجم/ل	الأس الهيدروجيني PH	التوصيل الكهربي ميكروموز	الأملاح الذائبة مجم/ل	الكلوريدات مجم/ل	الكبريتات مجم/ل	القلوية الكلية مجم/ل	العسر الكلي مجم/ل	عسر الكالسيوم مجم/ل	عسر الماغنسيوم مجم/ل	الأمونيا مجم/ل	النترات مجم/ل	النيتريت مجم/ل	الحديد مجم/ل	المنجنيز مجم/ل	الكلور الكلية مجم/ل	[illegible] Lts
١	[illegible]	م	٧	—	7.6	770	425	98	74	400	400	260	140	0.7	0.13	0	0.6	[illegible]	[illegible]	١
٢	[illegible]	م	‹	—	7.6	655	[illegible]	86	53	360	360	250	110	0.6	0.12	0	0.6	0.6	[illegible]	٢
٣	[illegible]	م	0.3	2.1	7.5	534	352	70	42	260	270	190	30	0	0.9	0	0.15	0.75	[illegible]	4
٤	[illegible]																			4
٥	[illegible]																			15
٦	[illegible]	م	0.6	—	7.5	770	88	120	170	420	420	2	120	0.7	0.16	0.2	0.6	[illegible]	1	15
٧	[illegible]	ج	0.8	—	7.8	262	568	130	145	440	460	320	140	0.6	0.2	0.15	0.6	[illegible]	49	11
٨	[illegible]																			17
٩	[illegible]	غ	0.5	—	7.8	428	262	50	110	250	300	180	120	0.5	1.5	0.02	0.3	0.2	75	16
١٠																				١٧
																				٧

قام برفع العينات ، ك/ ك/ فني / سائق / فنى /

كيميائي

Figure 5. Formal table for analysis results from the station Laboratory 14th October

The Hydraulic design of the Feeder Line out of station is as the following table

Table 7. Kaha station Feeder Line Hydraulic Design

Diam (mm)	Velocity (m/s)	Q max (l/s)
300	1.10	77.75

Where:

Diam: Exist Feeder line diameter from Station.

The velocity in the feeders assumed to be within the rang (1~1.25) m/s.

The working operation hours = 16 hrs/day

1- The Operation at the current case (well 2,3 and 4) are working + Well (1 and 5) are under maintenance

1a- The following table is for the normal using scenario, for station operation without using the module and by using the measurements of the station laboratory

- Withdrawals from wells will be made equally.

Table 8. Calculation of Iron ion concentration by the radical method

Well No	Fe mg/l	Q max (l/s)	Q_{act} (l/s)	Fe_{avg} mg/l
2	0.60	27.8	25.92	0.583
3	0.60	27.8	25.92	
4	0.55	27.8	25.92	

Where: Fe: measured iron ion concentration, Q_{max}: maximum withdraw discharge, Q_{act}: Actual required withdraw discharge, Fe_{avg}: Arithmetic average iron ion concentration for the required discharge.

A stoichiometric ratio of 0.94 g of potassium permanganate is required for the treatment of every 1 g of iron ions **[11]**.

The required amount for Potassium permanganate = 0.582 *0.94* 77.75 * 16 *3600/1000 = 2451g/day

Which average equal = 2607 * 30 /1000 = 73.5 Kg/month

1b- The priority as in the module design is for the lowest well containing Fe Concertation Then the withdraw priority will be for Well 4 then well 3 and finally well 4.

The amounts of Fe concentration changed after 3 days to be as in the following table

Table 9. Calculation of Iron ion concentration by the proposed Module

Well No	Fe mg/l	Q max (l/s)	Q $_{act}$ (l/s)	Fe$_{avg}$ mg/l
2	0.53	27.8	22.15	0.283
3	0.24	27.8	27.8	
4	0.13	27.8	27.8	

The required amount for Potassium permanganate = 0.283 *0.94*77.75 * 16 *3600/1000 = 1191 g/day

Which average equal = 1191 * 30 /1000 = 35.74 Kg/month

Then the saved amount of Potassium permanganate = 37.76 kg/month, Then the saved amount of Potassium permanganate = 40.40 kg/month, which is more than 50% from the normal consumed treatment material.

VI. Conclusion

1- calibrated temperature compensation factor (a = 0.0186) which represent the middle delta of Egypt.

2- After using The correlation between the iron ion and electroconductivity calibrated to suit the changes of temperature throughout the year and represented by the following equation

$$\mathbf{Fe_c = 7E\text{-}19}\ \left(\frac{\mathbf{ECt}}{[0.513+0.0186t]}\right)^{\mathbf{6.125}} \ldots \ \mathbf{equ\ (9)}$$

3- By using the modern sensor in Real time the saved amount is more than 50% from the normal consumed treatment material. This ratio will be increased by entering the aeration treatment and the amount for the manganese treatment.

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