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DESIGNING A MONITORING SYSTEM TO ASSESS GROUNDWATER SUITABILITY FOR IRRIGATION BY INTERNET OF THINGS (AL-MOGHRA AQUIFER)

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ABSTRACT

In terms of the importance of utilizing groundwater for irrigational purposes, in Egypt, this research was initiated with the objective of designing a monitoring system to evaluate its suitability for irrigation by the Internet of Things "IoT", where Al-Moghra aquifer was taken as a case study. Principally, literature in the field of groundwater and IoT were scrutinized. Several site visits were carried out, where samples were undertaken and analyzed. On the other hand, a wide-ranging monitoring system that implements IoT was developed and implemented to forecast real-time data (salinity, pH, temperature, dissolved oxygen, and conductivity) from in-situ sensors. A comparison was held between the laboratory-analyzed samples and those of the remote sensors. The comparison indicated that the developed monitoring system is capable of replicating data similar to the extracted samples results. Accordingly, the research highlighted that the developed system is an economic comprehensive monitoring system that could be utilized as an early detection to the contamination potential or overuse, the research suggested utilizing such a system, as it will ensure efficient water management.

Keywords: groundwater; water quality; irrigation; Al-Moghra; IoT

INTRODUCTION

Utilizing groundwater for irrigation is prioritized by the government, as it is an important water resource in arid regions such as Egypt, where its agricultural productivity is partially dependent on proper groundwater management.

Accordingly, many indices and water quality parameters are to be designated. Among them, for example, the Water Quality Index (WQI) should be evaluated for its suitability for irrigation. This assessment includes physical, chemical, and biological parameters using GIS technology. Other water quality parameters also indicate groundwater suitability for irrigation. The WQI categorizes water suitability into five categories: excellent, good, permissible, poor, and unsuitable.

Moreover, groundwater is perceived as a vital resource that has to be protected against depletion in both quantity and quality, several national groundwater quality monitoring networks periodically provide groundwater and early warning signs if pollutants are evident. Furthermore, groundwater for physico-chemical characteristics and heavy metals were examined by previous monitoring programs.

Notable work in the field including Batarseh et al., (2021); Doneen (1964); Foster et al., (2003); Ram et al., (22021); Don (1995); and Todd et al., (2004) focused on key water quality parameters for irrigation, such as the Permeability Index (PI), Sodium Adsorption Ratio (SAR), Na %, Magnesium Hazards (MH), and Kelly Ratio (KR). In the realm of mathematical relationships, various studies were notable like Scholler (1967); APHA (2005); Ayers & Westcot (1985); Dominica (1990), EI Baba et al., (2020); Tahlawi et al., (2014); Subba (2006); Szabolcs and Darab (1964); Kelley (1940); Paliwal and Singh (1967), Brown et al., (1972) and Horton (1965). Monitoring programs, like those by RIGW/IWACO (1999), were established to assess groundwater quality, including heavy metal levels in the Western Desert and Nile Valley. In the context of the Moghra Aquifer, studies such as Eltarabily & Moghazy (2021), MWRI (2005), El Abd and El Osta (2014), and Amer (2021) were recognized for their contributions. The aquifer's potential for irrigation was documented, highlighting issues like a 20-meter decline in the water table and impervious layers causing waterlogging problems.

While IoT has been utilized in water resource management, its application in groundwater monitoring is still evolving, particularly in Egypt (Meng et al., 2014). In this study, Al-Moghra Aquifer IoT monitoring system aims to improve regular monitoring and adapt management strategies for sustainability. Recently, Uddin et al., (2023) conducted a study to evaluate groundwater quality for drinking and irrigation purposes near the Rooppur Nuclear Power Plant (RNPP) in Bangladesh. The study utilized the Canadian Council of Ministers of the Environment water quality index (CCME-WQI) model for assessing drinking water quality and nine indices for irrigation water quality. Samples were analyzed for temperature, pH, and electrical conductivity using a YSI Professional Plus Digital Multimeter. The study analyzed Piper and Gibbs diagrams to identify key water quality indicators and natural factors influencing groundwater composition. The study enhances understanding of groundwater chemistry near RNPP. Bhati et al., (2024) offers a cost-effective method to monitor water quality in distribution systems using sensor technology. Essamlali et al., (2024) proved that water quality monitoring is essential for ensuring safe and usable water resources. The Internet of Things (IoT) has transformed this process by enabling real-time data collection from various sources. Machine learning (ML) can analyze this data to predict water quality accurately, aiding decision-making to protect water quality.

Due to the wide range of groundwater indices and the uneconomic cost of designating such parameters by monitoring programs as networks, this research was originated with the impartial of designing a monitoring system to assess its aptness for irrigation by means of IoT, where it implemented Al-Moghra Aquifer as a case study. This was achieved within the framework of utilizing groundwater for irrigational purposes, in Egypt.

MATERIAL AND METHODS

The implemented methods and materials encompassed the following:

Site Visits and Site Description: This segment expounds on site visits, and data assembly as well as their analysis together with the sampling campaign and their analysis. Based on the amassed data, an in-depth description of the study area is elaborated, as follows:

Site Visits and Data Assembly: Three visits were carried out throughout the research duration, where data were assembled. Moreover, videos and photos were captured. Additionally, observations were documented. A semi-structured interview was carried out with local populations of the study area.

Data Analysis: Accumulated data were analyzed to perceive an eye bird view to the complete data picture of the study area.

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Sampling Campaign: This was achieved within the case study area 3 visits, where 4 wells were dug and each visit, a sample was extracted from each well. Accordingly, 12 samples, in total, were extracted from the 4 wells during the research progress.

Description of the study area: Al-Moghra is at the Northeastern Border of Qattara Depression, and it is 45 km away from El Alamein City at 56 km South of the Mediterranean Coast (Figure 1). The study area is an isolated area with unpaved roads, where its groundwater salinity is increasing and limited the cultivation crops to be saline tolerated. It has an area of 930.78 km^2. Its soil is distinguished by its sandy silt and silt clay formations. Irrigation sources include groundwater wells with salinity lying between 2236 to 7830 ppm (Brackish water). Accessible water could irrigate 252 km^2 (Sharaky et al., 2021). The area has 5 water wells that were bored in Muhammad Ali Pasha's regency era at a depth of 34 meters (108 feet) below sea level (https://www.presidency.eg/media/132556/en.png). The wells' elevation end is 34 m lower than sea level (Figure 2). The aquifer coordinates lie between 30°00′ – 30°25′ N and 28°20′ – 29°20′ E (Araffa et al., 2021) (Figure 3). Coordinates of the wells employed throughout this study were 30°18'46.4"N 28°51'38.8"E, 30°18'13.4"N 28°52'17.3"E, 30°17'40.4"N 28°52'56.5"E and 30°18'13.9"N 28°51'40.5"E

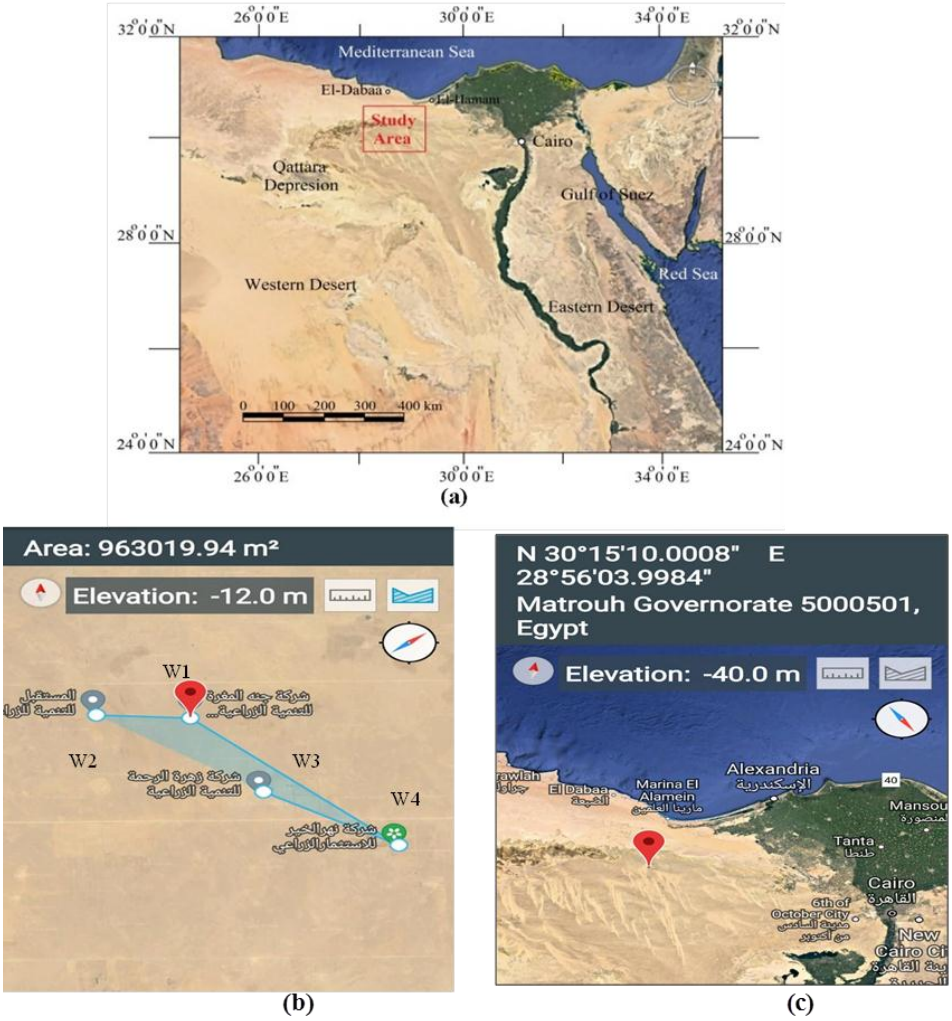

Figure (1): Study area location and its landforms (Google earth 2023)

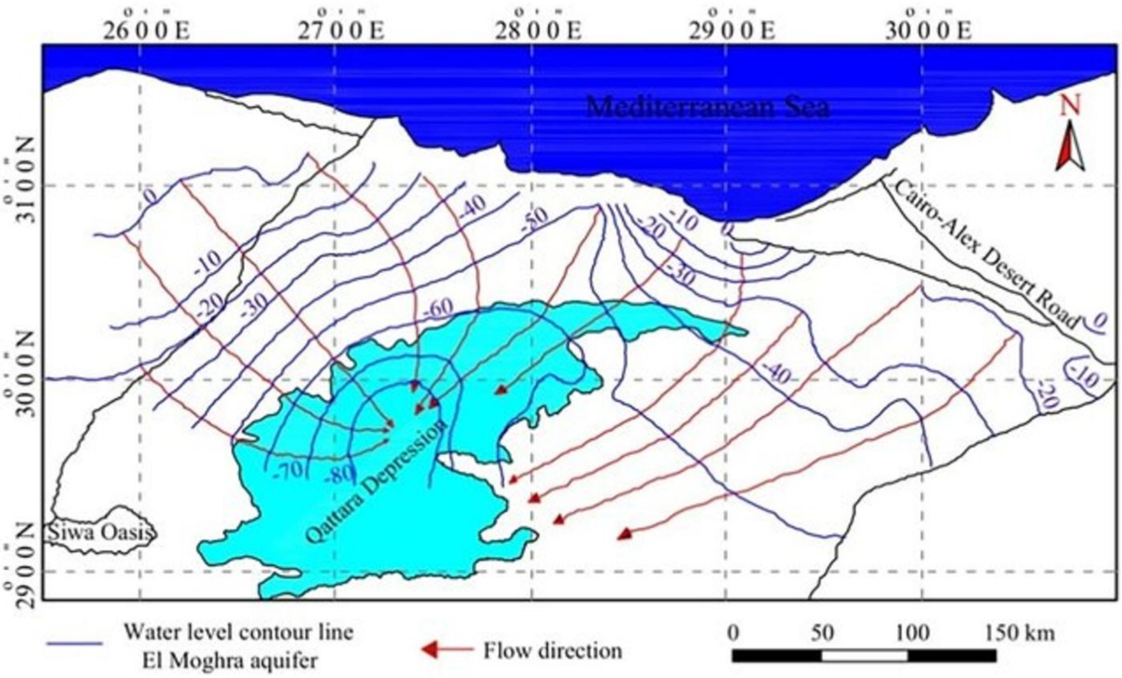

Figure (2): Potentiometric surface map for El- Moghra Aquifer (Abdel Mogith et al., 2013)

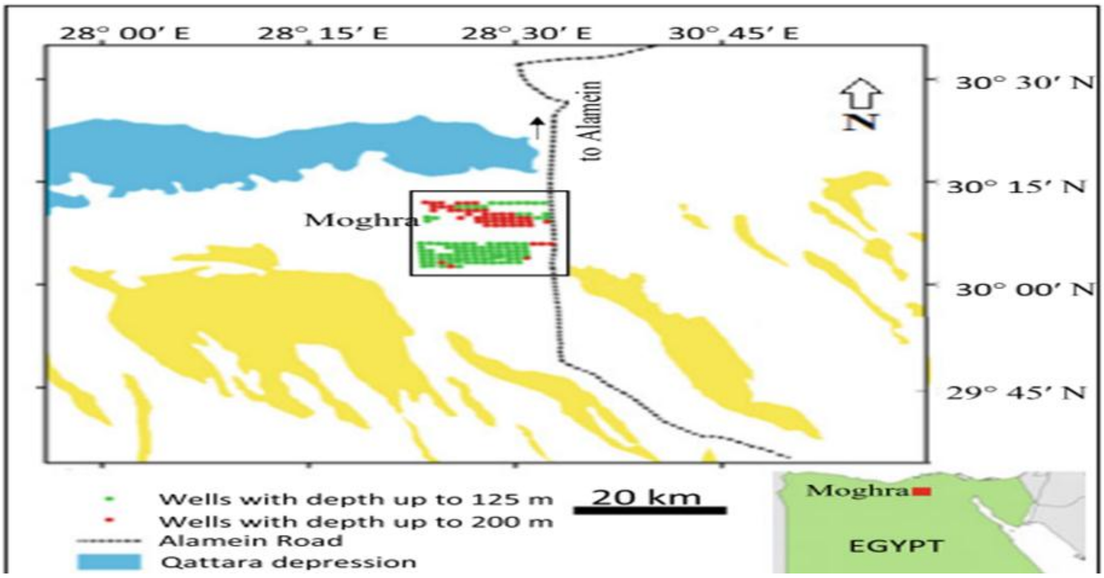

Figure (3): Groundwater wells and sand dune belts of Qattara Depression (Tahlawi et al., 2014)

Field, EXPERIMENTAL and office work

This section expounds the fieldwork and experimental work, where throughout the fieldwork samples were extracted and escorted to the laboratory. Moreover, measurements were undertaken. On the flip side, in the course of experimental work, the samples were inspected in the laboratory. However, throughout the office work, estimations were achieved.

Fieldwork

Three issues should be expounded on in the fieldwork: sampling procedure, sampling method, and field measurements. Twelve samples were taken from 4 wells, with quality control measures in place for each sample during 3 visits, using clean plastic bottles for water samples, acidifying them to pH < 4, and testing for heavy metals. Quality assurance was maintained during the sampling process. Field measurements included temperature, pH, EC, and TDS.

Experimental Work

Throughout the experimental procedure, water samples were inspected in Central Laboratories of the Groundwater Research Institute, where the following were determined: the physical-chemical parameters (pH, EC, TDS); the soluble cations inspection detected Ca^{+2}, Mg^{+2}, Na^{+} and K^{+}; soluble anions inspection (CO_3^-, HCO_3^-, $SO_4^{-2}$and Cl^-); nutrient analysis (NO_3^- and PO_4^{-3}); heavy metals examination (Cd^{+2}, Cu^{+2}, Fe^{+2}, Mn^{+2} and Pb^{+2}).

Office Work

Throughout the office work, calculations were achieved, and recommended by the Groundwater Research Center, as follows:

Computation of SAR

Sodium Adsorption Ratio "SAR" was estimated via equation (1) (Ayers and Westcot 1985). Table 1 is provided to specify the cultivated plant type, according to the ranges specified by Kumar et al., (2015). Table 2 provides the estimated SAR values of 4 wells for each visit (i.e. 3 readings).

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$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}} \quad (1)$$

Computation of Ionic Charge-Balance

This was estimated by equation (2) and the results are arranged in Table 3. Table 3 holds ontic charge-balance for 4 wells so as their compatibility for irrigation status, where Dominica (1990) and EI Baba et al., (2020) suggested that ontic charge-balance is governed by Eh-electro-neutrality condition. This is attributed to the fact that it links redox potential to electro-neutrality to designate the chemical balance, within which the reaction of electron-transfer and charge-neutrality are of great importance. However, he specified the acceptance criteria for acceptable difference “Meq/L” to be 0-3 ±0.2%, 3-10 ±2% and 10-800 ±5%

$$E= \frac{\sum Cations - \sum Anions}{\sum Cations + \sum anions} x100 \quad (2)$$

Where:

E: ion-charge-balance [%], if E is < 10%, water is acceptable.

Σ Cations: sum-of-cations (i. e. Ca^{+2}, Mg^{+2}, Na^{+} and K^{+})

Σ Anions: sum-of-anions (i. e. CO_3^- , HCO_3^- , SO_4^{-2} and NO_3^- ,)

Computation of CAI

“Chloro-Alkaline Index” was estimated by relation (3). Table (4) lists its values for the 4 wells with 3 readings for each well, where Tahlawi et al., (2014) suggested the employment of equation (3). On the flip side, Scholler (1967) utilized it to assess the ion exchange during groundwater movements within the aquifer, where the exchange of calcium and magnesium in the rocks is denoted by a negative CAI that indicated a base-exchange type. However, high CAI indicates that cation-anion exchange-type reaction occurred without base-exchange-type reaction, (Tahlawi et al., 2014).

$$CAI = (Cl^{-} - (Na^{+} + K^{+})) / Cl^{-} \quad (3)$$

Where: m eq/L: measures all ions and the presence of Na so as K

Vol. (54); No. (2); Feb. 2025
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Computation of Na%

Na% was calculated via equation (4), where Tables 5 (a & b) present the grouping of water compatibility for irrigation status based on Na% range. The Table holds the compatibility status for the 4 wells with 3 readings for each well.

$$Na\ \% = [\ (Na^{+} + K^{+})/\ (Ca^{+2} + Mg^{+2} + Na^{+} + K^{+})]\ \ x\ 100 \qquad (4)$$

Computation of PI

The “Permeability Index”, was achieved by equation (5) and results are enumerated in table (6). Table (6) holds PI values of 4 wells with 3 readings for each well.

$$PI = [(Na^{+} + \sqrt{HCO3})/(Ca^{2+} + Mg^{2+} + Na^{+})]x100 \qquad (5)$$

Computation of MH

Magnesium Hazard was estimated by equation (6). Table (7) lists MH values for 4 wells with 3 readings for each well.

$$MH = [(Mg^{+2})/\ (Ca^{+2} + Mg^{+2})]\ x\ 100 \qquad (6)$$

Where: meq/l: measuring unit of concentration

Computation of KR

Kelley Ratio was estimated via equation (7); whereas the KR parameter was developed by Kelley (1940) and Paliwal and Singh (1967). Table 8 lists the computed KR values for the 4 wells with 3 readings for each.

$$KR = Na^{+}\ /\ (Ca^{+2} + Mg^{+2}\ ) \qquad (7)$$

Computation of WQI

Water Quality Index was estimated according to Horton (1965); Brown et al., (1972) and Hussain et al., (2012). They advocated that the term "WQI" is a ranking scheme that evaluates the impact of water quality parameters on irrigation. Table (9) lists the main irrigation parameters and their ranges, according to FAO limitations and measurement units (Ayers and Westcot 1985), whereas the relative weight for every parameter was obtained by equation (8). Table (9) holds the weight so as relative weight W_i and RW_i, for the water parameters.

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$$Rw_i = W_i / \sum_i^n Wi \quad (8)$$

Where:

Rw_i: parameter relative weight

W_i: parameter weight that denotes its impact on water compatibility for irrigation purposes.

ΣW_i: sum of parameter weights (Table 9)

Computation of PWQI

Partial Water Quality Index "PWQI" was estimated by equation (9) and the WQI for each parameter was designated and listed in Table 9.

Where:

$$q_i = C_i / Ws \quad (9)$$

Where:

q_i: PWQI of parameter "i"

C_i: parameter "i" concentration

W: Ayers and Westcot 1985 parameter "i" for water quality standard.

Computation of WQI

WQI was estimated by equation (10) and the results are arranged in t

Table 10 that lists both PWQI and the Concentration Index "CI" for the 4 wells together with the overall WQI.

$$GWQI = \sum_{i=1}^{n} q_i w_i \quad (10)$$

However, it is worth wise to note that in the present research, the employed parameters to calculate WQI were selected in accordance with Ayers and Westcot 1985, which include the following: pH, TDS, EC, Ca, Mg, Na, SAR, Cl, SO_4, Fe, Mn.

As for the **computation of relative weight**, equation (11) was employed

$$RWi = \frac{w_i}{\sum_{\Delta}^{n} w_i} \quad (11)$$

Where:

Wi : parameter relative weight, as presented before in table (9)

Converging on the computation of partial water quality index, was estimated by equation (12), as follows:

$$Qi = C_i / W_s \tag{12}$$

Where:

Qi: partial water quality index parameter

Ci: parameter concentration

Ws: water quality standard after Ayers and Westcot (1985)

Table 1. SAR range classification

CLASSIFICATION (SAR) RANGE	TYPE OF PLANT COMPATIBLE TO THIS CATEGORY
When SAR is 2-8, the crops are very sensitive to SAR.	Fruit- Citrus-Nuts
When SAR is 8-20, the crops are moderately sensitive to SAR.	beans
When SAR is 20-50, the crops are moderately tolerant to SAR.	Clover-Oats-rice
When SAR is 50-100, the crops are tolerant to SAR.	Tomatoes-Beets-Wheat

Table 2. SAR for 4 wells

SAR (MEQ\L)							0-10			EXCELLENT		
							10-18			Good		
							18-26			Doubtful		
							> 26			Unsuitable		
Well no	WELL 1			WELL2			WELL3			WELL4		
SAR	19.33	22.71	15.85	18.7	22.76	15.78	19.01	20.16	14.93	17.36	21.07	13.3
Synergy	Doubtful	Doubtful	Good	Doubtful	Doubtful	Good	Doubtful	Doubtful	Good	Good	Doubtful	Good

Table 3. Ion charge-balance and their compatibility for the 4 wells

WELL NO	WELL 1			WELL 2			WELL 3			WELL 4		
reading	2.05	3.4	1.47	0.253	5.95	3.36	0.806	2.67	3.45	0.747	5.67	1.61
Synergy	√	√	√	√	√	√	√	√	√	√	√	√

The acceptance criteria for the percent difference or acceptable difference" Meq/L" are, as follows:

- 0-3 ±0.2%, 3-10 ±2% and 10-800 ±5%

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Table 4. Values of Chloro-Alkaline Indices "CAI" for 4 wells

WELL NO.	READING	VALUE	STATUS
well1	1	0.346939	base exchange
	2	0.328561	base exchange
	3	0.457473	base exchange
well2	1	0.391892	base exchange
	2	0.337147	base exchange
	3	0.39115	base exchange
well3	1	0.384328	base exchange
	2	0.09255	base exchange
	3	0.402479	base exchange
well4	1	0.378762	base exchange
	2	0.33908	base exchange
	3	0.430912	base exchange

Table 5a. Classification of water status according to Na% range

NA % (SODIM PERCENTAGE)	**WATER STATUS**	**NA% RANGE**
	Excellent	<20
	Good	20–40
	Permissible	40–60
	Doubtful	60–80
	Unfit	>80

Table 5b. Groundwater state of compatibility for irrigation for the 4 wells

WELL NO	WELL 1			WELL2			WELL3			WELL4		
reading	1	2	3	1	2	3	1	2	3	1	2	3
Na%	91.55	81.56	70.05	78.86	81.91	74.64	78.65	80.77	73.58	77.99	81.60	71.91
Synergy	Unfit	Unfit	Doubtful	Doubtful	Unfit	Doubtful	Doubtful	Unfit	Doubtful	Doubtful	Unfit	Doubtful

Table 6. PI values for 4 wells

WELL NO	READING NUMBER	PI VALUE	SYNERGY
WELL1	Reading 1	92.22184	GOOD
	Reading 2	81.92977	GOOD
	Reading 3	70.33969	MODERATE
WELL2	Reading 1	79.19661	GOOD
	Reading 2	82.33844	GOOD
	Reading 3	75.10806	GOOD
WELL3	Reading 1	78.92614	GOOD
	Reading 2	80.85014	GOOD
	Reading 3	74.06409	MODERATE
WELL4	Reading 1	78.35221	GOOD
	Reading 2	82.13203	GOOD
	Reading 3	72.47108	MODERATE

Table 7. Magnesium hazard

WELL NO.	READING NUMBER		
	1	2	3
WELL1	13.60762	17.81549	31.29718
WELL2	33.31912	17.49616	32.5138
WELL3	32.92988	10.49675	31.69436
WELL4	34.61652	14.45315	30.65617

Table 8. Kelly ratio

WELL NUMBER	READINGS NUMBER	KR
Well 1	1	3.45
	2	4.34
	3	2.849
Well 2	1	3.648
	2	4.45
	3	2.89
Well 3	1	3.596
	2	4.807
	3	2.73
Well 4	1	3.453
	2	4.364
	3	2.057

Table 9. Weight and relative weight W_i and RW_i for the different parameters

PARAMETER	WI	RWI
pH	3	0.086
Ec	5	0.142
TDS	5	0.142
Ca	2	0.061
Mg	2	0.061
Na	3	0.086
SAR	3	0.086
Cl	3	0.086
So4	3	0.086
Fe	3	0.086
Mn	3	0.086
$\sum_1^n W_i$	35	

Table 10. Partial Water Quality Index and Concentration Index for 4 wells and the overall WQI

PARAMETER	FAO	WELL 1		WELL 2		WELL 3		WELL 4	
		CI	PWQI	CI	PWQI	CI	PWQI	CI	PWQI
pH	6.582	7.33	1.11364327	7.4	1.12427833	7.55	1.14706776	7.45	1.1318748
TDS	2000	5810	2.905	5524	2.762	5760	2.88	5118	2.559
Ec	3	9.06	3.02	8.62	2.87333333	8.99	2.99666667	7.99	2.6633333
Ca	20	390.77	19.5385	281.8	14.09	300.34	15.017	266.66	13.333
Mg	150	61.55	0.41033333	140.66	0.93773333	147.46	0.98306667	141.18	0.9412
Na	200	1560	7.8	1540	7.7	1610	8.05	1410	7.05
SAR	7	19.35	2.76428571	18.7	2.67142857	19.01	2.71571429	17.34	2.4771429
Cl	250	2450	9.8	2590	10.36	2680	10.72	2326	9.304
SO4	250	820	3.28	810	3.24	856	3.424	815	3.26
Fe	0.3	0.069	0.23	0.107	0.35666667	0.068	0.22666667	0.078	0.26
Mn	0.1	0.102	1.02	0.108	1.08	0.097	0.97	0.248	2.48
WQI			51.8817623		47.1954402		49.130182		45.459551

Employment of An Advanced Technique “IoT”

IoT is an advanced responsive dynamic technique, from the standpoint of innovation. It is a key spring into the interaction among devices so as services to achieve a "smart environment”. While IoT is a novel technique, its rapid alterations make it a focal technology in the digital world, as it is integrated into various fields.

DesignING Monitoring System by IoT

In this research, IoT structure was utilized to enable prompt data transfer to a central platform that integrates an algorithm to explore the data to assess the suitability of groundwater for irrigation, to water quality standards.

IoT was utilized to observe 4 wells instantaneously. This was executed by allocating wired sensors connected to a microcontroller to transfer instantaneous data by internet to a particular laptop. The implemented IOT included the following:

- ***End devices*** or hosts that function as an interface between the users and the network (i.e. Voice Over Internet Protocol "VOIP" phones). This is the backbone of IoT, as its servers border the devices.
- **Intermediate network devices** link bordering devices to enable communication and data access.
- **Sensors** measure groundwater quality such as TDs, Ammonium, pH and temperature.

In this research, 4 indices were the main concern (i.e. temperature, humidity, pH and salinity). Accordingly, the 2 implemented sensors are elaborated, as follows:

Water Temperature Sensor

The system detects groundwater temperature to designate its influence on water organisms, as a nerve index that governs other indices, where high temperature harms fish and zooplankton. Additionally, it reduces oxygen level that increases the water salinity and toxicity.

The designed system integrated a groundwater temperature (i.e. DHT11 waterproof sensor; figure 1 in the appendix), which is economic and measures temperature and humidity.

pH Sensor

pH sensor was utilized to measure the basicity of water (figure 2 in the appendix), and provides the pH value of 0 to 14, where low values denote acidity and high values specify alkalinity. However, ideal value is 6 to 8.

However, for drinking water, it is 7.4. pH is calculated by hydrogen ion negative logarithm; equation (12):

$$pH = -\log(H^+) \qquad (12)$$

The designed ESP32 system encompassed:

- Gravity pH sensor

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- ESP32 board
- Arduino analog pin
- Probe P0 pin

The sensor transmits the groundwater pH as a voltage. It is empowered by a 5V voltage current of intensity of 5mA to 10mA, where the designed DIY IoT utilizes *pH* Sensor and ESP32 Wi-Fi Module and the data are displayed on OLED Screen. The data is sent to a mobile application not to OLED screen, as it visualizes the prompt data sent by ESP32 with its 12-bit controller that measures high precession rather than that of Arduino.

The sensor with its high-resolution probe extracts and detects the sample pH instantaneously and transmits it to remote servers via 5 long cables dipped into the water, where its bill of materials is listed in figure 3 of the appendix and table 11.

The calibration process is only required if the probe is changed, where some precautions should be considered. However, it is characterized by its TDS range (i.e. 0 -19990 ppm), and its resolution is 0.01 pH. As for its interfacing & testing, the glass bubble of the probe head should be kept in plastic protection to avoid being hit by solid objects and should not be rubbed.

Table 11. Materials of the developed IoT

S.N.	COMPONENTS NAME	QUANTITY
1	ESP32 Wi-Fi Module	1
2	Ph Sensor Kit	1
4	9V DC Supply	1
5	Connecting Wires	10
6	Breadboard	1

Developing a Basic Test Code

A basic code was developed to convert analog output of the sensor into a particular *pH* value (scheme 1 in the appendix).

The *pH* values produced by IoT and laboratory examination are listed on table (12) and the QR of the mobile application is provided on figure 4 in the appendix.

Creating a mobile application

An app was developed on a mobile device to interact with physical objects or systems connected to the internet. It is linked to IoT that includes a network of devices, and sensors that exchange data without human interference. Figure 5 in the appendix offers the instantaneous data of the ESP32 board.

Table 12. Laboratory vs IoT for the 4 wells (pH and Temperature)

DATE 26.04.2022				
Produced in/by	**Laboratory results**		**IoT**	
Well number	***pH* Lab.**	Temp.C^O	*pH* IoT	Temp.C^O
1	7.42	25	7.7	24
2	7.55	26	7.6	25
3	7.46	24	7.5	22
4	7.51	25	7.6	23

Employing Statistical Package for Social Sciences (SPSS)

The experimental work results and IoT results were analyzed by utilizing ***S***tatistical Package for Social Sciences "SPSS". It was utilized to analyze the water quality data (i.e. highest so as lowest values, average values and standard deviation); equation (13)

$$\sigma^2 = (\epsilon[(x\_i - u)]^\wedge 2/n) \quad (13)$$

Where :

σ^2: variance

x_i: reading value

u: average of the measurments

n: number of reading

RESULTS

The results are presented on figures (4) to (6) and listed in tables (2) to (10) and (13) to (16).

- SAR range value is presented on table (2).
- E results are listed in table (3).
- CAI results are listed in table (4).
- Na% are presented on table (5).
- Table (6) lists PI results.
- Table (7) encompasses MH results.
- Table (8) holds the Kelly ratio.

- Table (9) represents the weight and relative weight Wi and RWi for the different parameters, where the maximum weight was assigned for the parameters E and TDS.
- Table (10) holds the Partial Water Quality Index and the Concentration Index for 4 wells so as its overall WQI that ranged between 45 and 51.
- Tables (13) to (16) show laboratory results for 4 wells.
- Figure (5) presents the calcium average and Mg %.
- Figure (6) represents the average pH values for the 4 wells.
- Figures (7a) and (7b) represent TDS results from the laboratory and TDS results from the field, respectively.

The water indices results are presented in Figures (4) to (6) and Tables (2) to (10) and (13) to (16). The SAR values ranged from 13.3 to 22.76 meq/l, classified as doubtful and good. CAI values ranged from 0.3 to 0.4 with an average of 0.35. Na% indicated water tolerance for irrigation. PI results varied between 70 and 92. MH results also indicated water tolerance for irrigation. The Kelly Ratio ranged from 2.3 to 4.8, indicating irrigation compatibility. Table 9 shows the weight and relative weight of Wi and RWi for various parameters, with maximum weight assigned to parameters E and TDS. Table (10) contains the Partial Water Quality Index and concentration index for 4 wells, with an overall WQI between 45 and 51. Tables (13) to (16) show laboratory results for 4 wells. Figure 5 shows the expected calcium average of 24.25 and Mg less than 50%, indicating water tolerance for irrigation. Figure 6 represents the average pH values for the 4 wells, with well number 3 achieving the highest pH value of 7.55, within an acceptable range. Figures 7a and 7b represent laboratory TDS results and field TDS results, respectively

The results of sampling planning were analyzed and it became clear that planning is important as measurements varied from visit to visit. Accordingly, it was important to follow an appropriate sample planning strategy as valuable data should be collected at the right time to improve sample accuracy. This was evident: pH changed during the 1st, 2nd, and 3rd sampling campaigns and ranged from 7.33 to 7.55, 7 to 8.13, 7.42 to 7.55. The TDS value varied between 5118 and 5810, 3786.6 and 5882, and 5160 and 5920 ppm during the

1st, 2nd, and 3rd sampling campaigns, respectively. The heavy metals (〖Fe〗^(+2) and 〖Mn〗^(+2)) varied between 0.068 and 0.107, 0.097 and 0.248, 0.015 and 0.189, 0.013 and 0.114, 0.051 and 0.246, respectively, during the three sampling campaigns. 0.111 and 0.290.

The WQI results were analyzed and presented on table (10). The table lists the water quality parameters that were used to assess the groundwater, in terms of the different utilization purposes, especially for irrigation, where the parameters that were measured in the field were EC, TDS, Fe^{+2} and Mn^{+2}. Results indicated that:

- WQI values indicated that water was not compatible for irrigation, accordingly, there is a need for a specific management strategy to mix it with fresh water.
- Heavy metals (i.e. Fe^{+2} and Mn^{+2}) indicated that the groundwater could be utilized for other activities (i.e. fish farming).

TDS and pH results were analyzed; discussed and presented on tables (13) to (16), where they designated the maximum, minimum, average and standard deviation. Apparently, there were discrepancies between data measured in the field and those produced by the laboratory analysis. Table (17) lists the statistical parameters of TDS of laboratory results vs field measurements.

DISCUSSION

In arid regions with low rainfall, groundwater salinity increases due to agriculture, limiting crop options. Irrigation water quality standards were established in 1985 by the FAO. High sodium, calcium, and potassium levels may be due to hydrogeological conditions and physicochemical parameters like pH, EC, and TDS. Previous studies by Korany et al., (2018) examined similar water types.

The WQI results were analyzed and presented in table (10), The table lists the water quality parameters that were used to assess the groundwater, in terms of the different utilization purposes, especially for irrigation classification of WQI of the four wells. A similar justification was given by Hagage et al., (2022). the excellent sample is at the southeast of the study area comparable with Abdel Mogith et al, (2013).

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The sodium content in irrigation water is typically expressed as a sodium percentage (Na%). According to Wilcox (1955), it is a key factor in evaluating water suitability for irrigation. The Na% is calculated using equation (4), With a concentration of 70.05 to 91.55 meq/L, all groundwater samples are classified as doubtful to unsuitable. An increase in sodium content leads to soil hardness and reduced permeability (Tijani et al., 1994).

Sodium Adsorption Ratio (SAR) is a measure used to evaluate the appropriateness of water for agricultural irrigation equation (1). In a study by Bauder et al. (2014), it was found that 41.6% of the groundwater samples analyzed were considered suitable for irrigation, while 49.4% were considered questionable as shown in table (2). Elevated SAR values (>9) in irrigation water can have a notable impact on soil permeability and surface sealing, as noted by Mohanavelu et al (2021).

Based on the permeability index (PI), a water suitability classification for irrigation water was developed by Doneen (1964). The PI values in the study area range from 70.34 to 92.22, with an average of 78.99. According to the World Health Organization's classification and Gautam et al (2023), 75% of the samples fall under class 1 (PI > 75%) and 25% belong to class 2 (PI between 25% and 75%). Based on Doneen's chart, the groundwater in the study area is generally suitable for irrigation purposes.

In most waters, calcium and magnesium maintains a state of equilibrium. A ratio namely index of magnesium hazard eq (6) was developed by Paliwal (1972). In the study area, the magnesium hazard values fall in the range of 10.49675to 34.61652 % as shown in table (6), 100 % of the samples collected showed MH ratio <50 % (suitable for irrigation).

TDS and pH were analyzed and presented in tables (13) to (16), showing the maximum, minimum, average and standard deviation values. Discrepancies between field measurements and laboratory analysis results were observed, as shown in table (17), which compares the statistical parameters of TDS from laboratory and field data. TDS values ranged from 3786.6 to 5920 mg/l, with an average of 5431 mg/l. High TDS values in most samples were attributed to elevated concentrations of sodium, chloride and sulfate ions, as Eltarabily & Moghazy (2021). Groundwater pH ranged from 7.33 to 7.55, with an average of 7.4325, indicating neutral conditions. These results are consistent with Eltarabily &

Moghazy (2021) and are likely influenced by the alkaline chemical composition of the water. With permeable soil, good drainage and the use of agricultural fertilizers, groundwater can be suitable for irrigating salt-tolerant and semi-tolerant crops.

Agriculture is a sector that requires significant water resources, and the integration of IoT has become essential for the real-time monitoring of various parameters, particularly in difficult environments such as those with saline groundwater. Nevertheless, the deployment of IoT solutions for groundwater monitoring encounters obstacles, including the limitations of current communication technologies (such as 3G, Bluetooth, WiFi, and Zigbee) in regions lacking infrastructure or mobile network coverage necessary for cloud connectivity. In certain instances, wired sensors are employed in water tanks following the outputs of water pumps, as there are constraints on the use of ultrasonic sensors for measuring water levels in deep, narrow wells.

While IoT offers important opportunities to improve groundwater sustainability, it faces challenges that impose difficulties on its application, where interconnection is still a key aspect, particularly in remote areas without cellular networks. Moreover, the importance of attaining reliable durable sensors under tough environmental status, which will affect the accuracy of data and the system efficiency. Additionally, its implementation and maintenance cost, making its implementation unfeasible in underdeveloped areas. Moreover, the importance of robust handling of the data and its storage, where skilled personnel are needed to interpret the data, will impose additional challenges of IoT groundwater monitoring.

Despite the above limitations, several recommendations could be drawn from the study to maximize the benefits related to the use of IoT in efficient water management. First, it is of high importance to magnify the employment of IoT in the field of groundwater observation in other areas, as its flexibility makes it compatible for many agricultural environments. In addition, an empowerment in IoT observation system by including other parameters such as heavy metal concentration and pesticides would be highly beneficial especially if rationalized climate data such as rainfall and temperature are simultaneously integrated. Other options could be included like connecting ESP to a Wi-Fi network programmed mobile app connected to Wi-Fi and ordering Mobile app by voice to give instructions. It is of note that a capacity building training for farmers to comprehend IoT data will be a priority. To this end, government should financially support the employment of IoT system by grants together with the establishment of central platform from different IoT monitoring systems to enhance the integration of farmers and policymakers putting in consideration monitoring long-term health effects.

Table (13): Laboratory measurements for well 1

SERIAL			1	2	3	ST.DIV	AVG
Sample code			استاد ناصر / 1				
Date of arrival			15/8/2021	11/10/2021	26/4/2022		
Physicochemical parameters							
Ph		……	7.33	7.11	7.42	0.15947832	7.28666667
Carbonate	CO3	mg/I	0	0	0	0	0
bicarbonate	HCO3	mg/I	219	195	239	22.0302822	217.666667
Total alkalinity		mg/I	219	195	239	22.0302822	217.666667
Electrical Conductivity (EC)		mmhos/cm	9.06	9.19	9.24	0.09291573	9.16333333
Total Dissolved Solids(TDS)		mg/I	5810	5882	5920	55.8688941	5870.66667
Major cations							
Calcium	Ca	mg/I	390.77	331.22	337.64	32.685919	353.21
potassium	k	mg/I	40	32	32	4.61880215	34.6666667
magnesium	mg	mg/I	61.55	71.8	153.81	50.5677931	95.72
Sodium	Na	mg/I	1560	1750	1400	175.214155	1570
Major anions							
Fluoride	F	mg/I	0.37	0	1.3	0.66980097	0.55666667
Chloride	Cl	mg/I	2450	2654	2639.50	113.824792	2581.16667
Nitr	NO2	mg/I	0.2	0.2	0.2	3.3993E-17	0.2
Nitra	NO3	mg/I	0.53	1.24	0.885	4.75619946	3.62333333
phosphate	PO4	mg/I	0.2	0.2	0.2	3.3993E-17	0.2
sulfate	SO4	mg/I	820	713.4	751.9	53.9805829	761.766667
Trace Metals							
Aluminum	AL	mg/I	0.008	0.096	0.007	0.05109795	0.037
Antimony	Sb	mg/I	0.009	0.009	0.009	0	0.009
Arsenic	As	mg/I	0.006	0.006	0.006	1.0623E-18	0.006
Barium	Ba	mg/I	0.016	0.045	0.019	0.01594783	0.02666667
Cadmium	Cd	mg/I	0.002	0.002	0.002	0	0.002
Chromium	Cr	mg/I	0.002	0.009	0.002	0.00404145	0.00433333
Cobalt	Co	mg/I	0.003	0.008	0.003	0.00288675	0.00466667
Copper	Cu	mg/I	0.006	0.028	0.012	0.01137248	0.01533333
Iron	Fe	mg/I	0.069	0.121	0.051	0.03635015	0.08033333
Lead	Pb	mg/I	0.007	0.007	0.007	0	0.007
manganese	Mn	mg/I	0.102	0.035	0.111	0.04152509	0.08266667
Nickel	Ni	mg/I	0.004	0.010	0.004	0.0034641	0.006
Selenium	Se	mg/I	0.007	0.007	0.007	0	0.007
Tin	Sn	mg/I	0.66	0.006	0.006	0.37758708	0.224
Zinc	Zn	mg/I	0.012	0.005	0.088	0.0460326	0.035

Table (14): Laboratory results for well 2

TSERIAL		1	2	3	ST.DIV	AVG
Sample code		2				
Date of arrival		15/8/2021	11/10/2021	26/04/2022		
Physicochemical parameters						
pH	……	7.40	7	7.55	0.284312035	7.316666667
Carbonate CO3	mg/I	0	0	0	0	0
bicarbonate HCO3	mg/I	195	200	248	29.26317367	214.3333333
Total alkalinity	mg/I	195	200	248	29.26317367	214.3333333
Electrical Conductivity (EC)	mmhos/cm	8.62	9.01	8.95	0.21	8.86
Total Dissolved Solids (TDS)	mg/I	5524	5766	5730	130.5730957	5673.333333
						#DIV/0!
Calcium Ca	mg/I	281.5	316.79	322.8	22.31290434	307.03
potassium k	mg/I	35	28	27.6	4.161730409	30.2
magnesium mg	mg/I	140.66	148.09	155.52	47.30060888	121.12
Sodium Na	mg/I	1540	1710	1380	165.0252506	1543.333333
Major anions						#DIV/0!
Fluoride F	mg/I	0.38	0.323	0.59	0.1406165	0.431
Chloride Cl	mg/I	2590	2622	2311.90	170.5508819	2507.966667
Nitrite NO2	mg/I	0.2	0.2	0.2	3.39935E-17	0.2
Nitrate NO3	mg/I	0.57	3.8	8.9	4.199837298	4.423333333
phosphate PO4	mg/I	0.2	0.2	0.2	3.39935E-17	0.2
sulfate SO4	mg/I	810	724.7	694.9	59.73851354	743.2
Trace Metals						#DIV/0!
Aluminum AL	mg/I	0.008	0.013	0.014	0.00321455	0.011666667
Antimony Sb	mg/I	0.009	0.009	0.009	0	0.009
Arsenic As	mg/I	0.006	0.006	0.006	1.0623E-18	0.006
Barium Ba	mg/I	0.017	0.030	0.017	0.007505553	0.021333333
Cadmium Cd	mg/I	0.002	0.002	0.002	0	0.002
Chromium Cr	mg/I	0.002	0.007	0.002	0.002886751	0.003666667
Cobalt Co	mg/I	0.003	0.011	0.003	0.004618802	0.005666667
Copper Cu	mg/I	0.010	0.020	0.006	0.007211103	0.012
Iron Fe	mg/I	0.107	0.189	0.124	0.04327817	0.14
Lead Pb	mg/I	0.007	0.007	0.007	0	0.007
Manganese Mn	mg/I	0.108	0.107	0.140	0.018770544	0.118333333
Nickel Ni	mg/I	0.004	0.012	0.004	0.004618802	0.006666667
Selenium Se	mg/I	0.007	0.007	0.007	0	0.007
Tin Sn	mg/I	0.66	0.006	0.006	0.377587076	0.224
Zinc Zn	mg/I	0.008	0.006	0.031	0.013892444	0.015

Table (15): Laboratory results for well 3

SERIAL		1	2	3	ST.DIV	AVG
Sample code		كيوان /3				
Date of arrival		15/8/2021	11/10/2021	26/04/2022		
Physicochemical parameters						
pH	……	7.55	8.13	7.46	0.36363902	7.713333333
Carbonate CO3	mg/I	0	0	0	0	0
bicarbonate HCO3	mg/I	200	126	239	57.3962833	188.3333333
Total alkalinity	mg/I	200	126	239	57.3962833	188.3333333
Electrical Conductivity (EC)	mmhos/cm	8.99	13.52	8.74	2.69047084	10.41666667
Total Dissolved Solids (TDS)	mg/I	5760	3786.6	5600	1096.0784	5048.866667
Calcium Ca	mg/I	300.34	497.11	325.21	107.149864	374.22
potassium k	mg/I	40	45	25.9	9.90471268	36.96666667
magnesium mg	mg/I	147.46	149.18	150.9	52.4977765	118.8866667
Sodium Na	mg/I	1610	2670	1300	718.401002	1860
Fluoride F	mg/I	0.35	0.44	0.53	0.09	0.44
Chloride Cl	mg/I	2680	2991.9	2219.70	966.655901	2991.9
Nitrite NO2	mg/I	0.2	0.2	0.2	3.3993E-17	0.2
Nitrate NO3	mg/I	0.57	12.2	9.7	6.12187063	7.49
phosphate PO4	mg/I	0.2	0.2	0.2	3.3993E-17	0.2
sulfate SO4	mg/I	856	1131.8	650	241.741211	879.2666667
Trace Metals						
Aluminum AL	mg/I	0.007	0.020	0.042	0.01769181	0.023
Antimony Sb	mg/I	0.009	0.009	0.009	0	0.009
Arsenic As	mg/I	0.006	0.006	0.006	1.0623E-18	0.006
Barium Ba	mg/I	0.020	0.032	0.019	0.00723418	0.023666667
Cadmium Cd	mg/I	0.002	0.002	0.002	0	0.002
Chromium Cr	mg/I	0.002	0.010	0.002	0.0046188	0.004666667
Cobalt Co	mg/I	0.003	0.010	0.003	0.00404145	0.005333333
Copper Cu	mg/I	0.009	0.023	0.013	0.0072111	0.015
Iron Fe	mg/I	0.068	0.126	0.246	0.09078179	0.146666667
Lead Pb	mg/I	0.007	0.007	0.007	0	0.007
manganese Mn	mg/I	0.097	0.114	0.147	0.02542309	0.119333333
Nickel Ni	mg/I	0.004	0.011	0.004	0.00404145	0.006333333
Selenium Se	mg/I	0.007	0.007	0.007	0	0.007
Tin Sn	mg/I	0.66	0.006	0.006	0.37758708	0.224
Zinc Zn	mg/I	0.070	0.009	0.231	0.11469234	0.103333333

Table (16): Laboratory results for well 4

SERIAL			1	2	3	ST.DIV	AVG
Sample code			4/ سليمان				
Date of arrival			15/8/2021	11/10/2021	26/04/2022		
Physicochemical parameters							
pH		……	7.45	7.53	7.51	0.363639015	7.47
Carbonate	CO3	mg/I	0	0	0	0	0
bicarbonate	HCO3	mg/I	205	200	248	57.39628327	188.3333333
Total alkalinity		mg/I	205	200	248	57.39628327	188.3333333
Electrical Conductivity (EC)		mmhos/cm	7.99	7.99	8.06	2.690470839	10.41666667
Total Dissolved Solids (TDS)		mg/I	5118	5120	5160	1096.078397	5048.866667
Major cations							
Calcium	Ca	mg/I	266.66	288.31	317.99	107.1498637	374.22
potassium	k	mg/I	35	25	24.2	9.904712683	36.96666667
magnesium	mg	mg/I	141.18	148.88	140.58	52.49777646	118.8866667
Sodium	Na	mg/I	1410	1470	1150	718.4010022	1860
Major anions							
Fluori	F	mg/I	0.36		0.85	0.09	0.44
Chloride	Cl	mg/I	2326	2262	2063.30	966.6559005	2991.9
Nitrite	NO2	mg/I	0.2	0.2	0.2	3.39935E-17	0.2
Nitrate	NO3	mg/I	0.46	1.2	0.83	6.121870629	7.49
phosphate	PO4	mg/I	0.2	0.2	0.2	3.39935E-17	0.2
sulfate	SO4	mg/I	815	617.5	680.5	241.7412115	879.2666667
Trace Metals							
Aluminum	AL	mg/I	0.009	0.037	0.030	0.017691806	0.023
Antimony	Sb	mg/I	0.009	0.009	0.009	0	0.009
Arsenic	As	mg/I	0.006	0.006	0.006	1.0623E-18	0.006
Barium	Ba	mg/I	0.022	0.053	0.019	0.007234178	0.023666667
Cadmium	Cd	mg/I	0.002	0.002	0.002	0	0.002
Chromium	Cr	mg/I	0.002	0.007	0.002	0.004618802	0.004666667
Cobalt	Co	mg/I	0.003	0.010	0.003	0.004041452	0.005333333
Copper	Cu	mg/I	0.009	0.025	0.016	0.007211103	0.015
Iron	Fe	mg/I	0.078	0.015	0.206	0.09078179	0.146666667
Lead	Pb	mg/I	0.007	0.007	0.007	0	0.007
manganese	Mn	mg/I	0.248	0.013	0.290	0.025423087	0.119333333
Nickel	Ni	mg/I	0.004	0.012	0.004	0.004041452	0.006333333
Selenium	Se	mg/I	0.007	0.007	0.007	0	0.007
Tin	Sn	mg/I	0.66	0.006	0.006	0.377587076	0.224
Zinc	Zn	mg/I	0.021	0.005	0.166	0.114692342	0.103333333

Table (17): Laboratory TDS results vs field measurements statistical parameters

WELL NO.	DATE						STATISTICAL ANALYSIS						ST. DIV	
	15.08.2021		11.10.2021		26.04.2022									
	Lab	Field	Lab	Field	Lab	Field	Max		Min		Ave		Lab	Field
1	5810	5850	5882	5780	5920	5370	5920	4350	5810	3870	5876	5667	55.87	259.29
2	5524	5650	5766	5700	5730	5200	5760	4200	5524	3700	5673	5517	130.57	275.38
3	5760	5550	5680	5385	5600	5220	5760	4050	5600	3720	5680	5385	80	165
4	5116	5220	5120	5290	5160	5090	5160	3790	5116	3590	5132	5200	24.33	101.49

Table (18): Groundwater quality classification using the Water Quality Index Soleimani et al., (2018)

WQI VALUE	WATER QUALITY	% OF WATER SAMPLES
<50	Excellent	25
50 - 100	good	75
101 -200	Poor	0
201- 300	Very poor	0
>300	Unsuitable	0

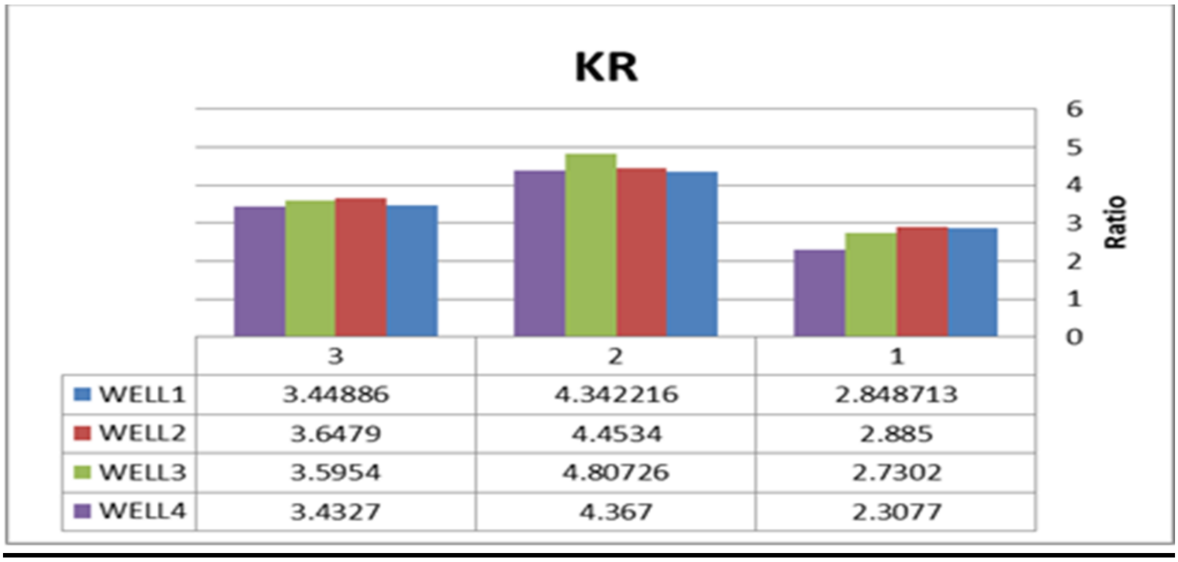

Figure (4): KR values are not compatible for irrigation

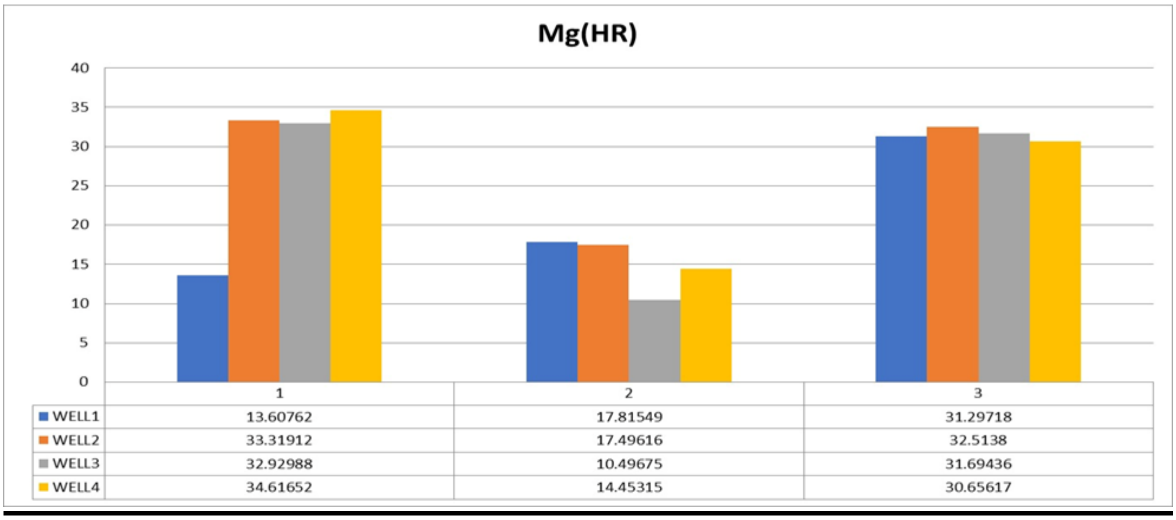

Figure (5): MH values compatible for irrigation

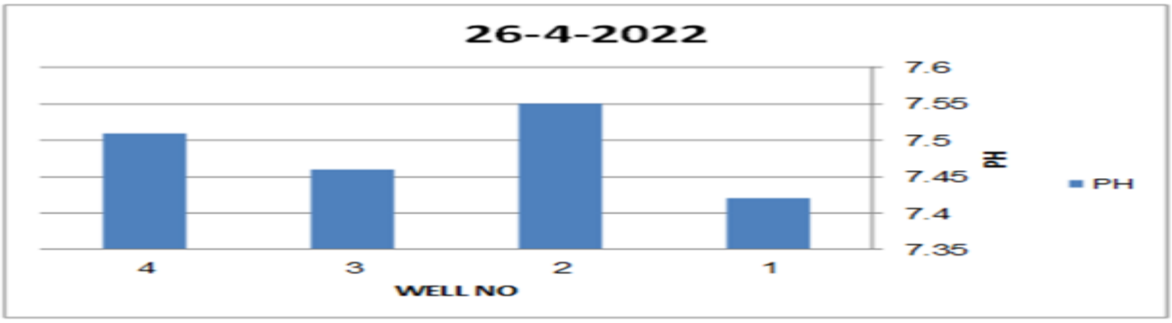

Figure (6): pH of the 4 wells

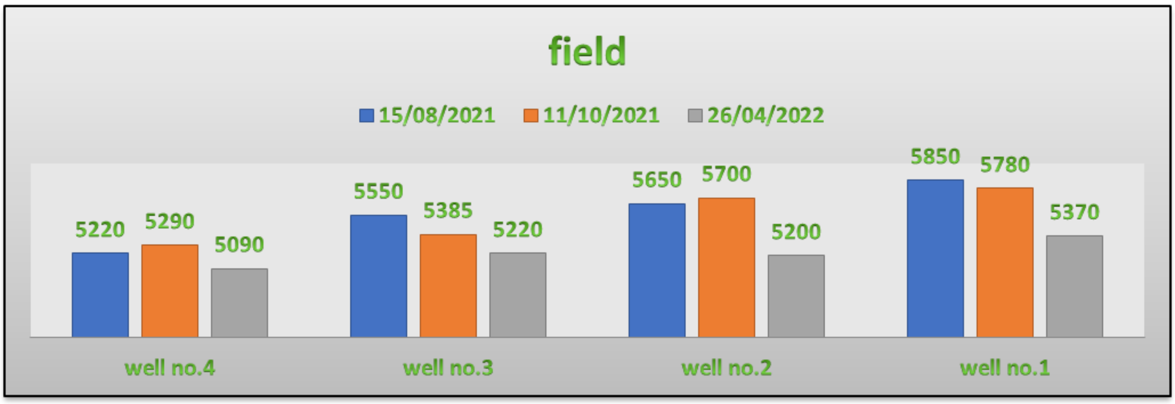

Figure (7a): TDS results from the laboratory

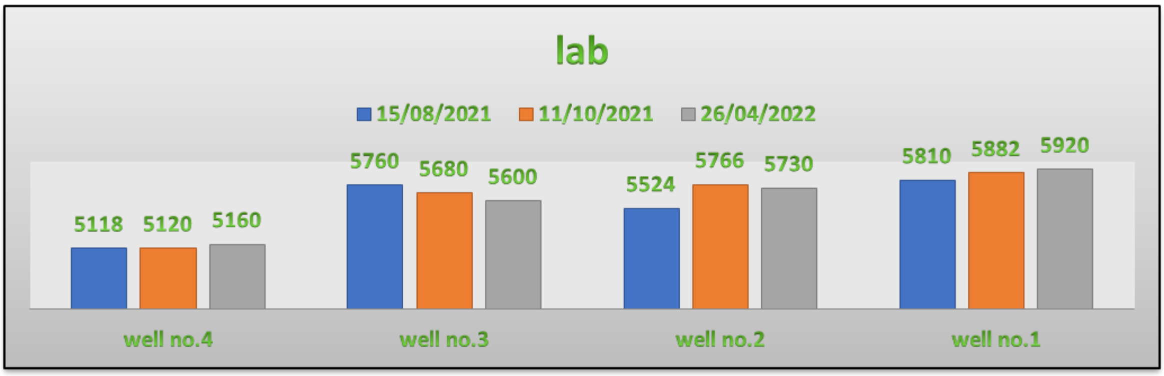

Figure (7b): TDS results from the field

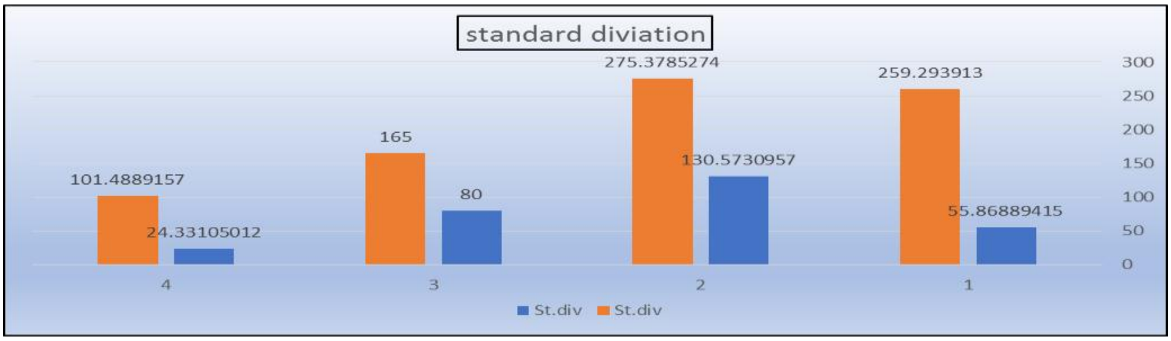

Figure (8): Laboratory TDS results versus IoT results standard deviation

CONCLUSIONS

IoT proved its capability in solving the difficulties of instantaneous observation systems of groundwater quality and could visualize the water suitability for irrigation. It enabled a precise estimate to key parameters such as EC, pH and s chloride levels, where such parameters visualize the suitability of groundwater for irrigation at AL-Moghra Aquifer. As being a robust technique, IoT could assist decision-makers to provide a prompt response to any descent in groundwater quality. Moreover, it is a cost-effective technique for groundwater observation, as it reduces manual testing, so as time, while maintaining data accuracy. To this end, IoT could foster water usage by designating the contamination.

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تصميم نظام مراقبة لتقييم مدى صلاحية المياه الجوفية للري باستخدام إنترنت الأشياء (حوض المغرة)

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المستخلص

نظرا لأهمية المياه الجوفية لأغراض الري في مصر، تم البدء فى هذا البحث بهدف تصميم نظام مراقبة لتقييم مدى ملاءمته للري من خلال إنترنت الأشياء " IoT ، حيث تم اختيار خزان المغرة كحالة دراسية. وتم فحص الدراسات السابقة في مجال المياه الجوفية وإنترنت الأشياء. ثم أجريت عدة زيارات ميدانية لمنطة الدراسة حيث تم أخذ عينات وتم تحليلها. ومن ناحية أخرى تم استحداث واستخدام نظام مراقبة واسع النطاق بواسطة إنترنت الأشياء لتحليل البيانات في الوقت الفعلي (مثل الملوحة ودرجة الحموضة ودرجة الحرارة والأكسجين المذاب والتوصيل الكهربائى) بواسطة أجهزة الاستشعار الموجودة في الموقع. تم إجراء مقارنة بين العينات التي تم تحليلها في المعامل وتلك المسجلة بواسطة أجهزة الاستشعار.

وأشارت المقارنة إلى أن نظام المراقبة المتطور قادر على استنتاج بيانات مماثلة لنتائج العينات المختبرة، وعليه فقد سلط البحث الضوء على نظام مراقبة متطور شامل واقتصادي يمكن استخدامه للكشف المبكر عن احتمالية التلوث أو الإفراط في الاستخدام. وبناء على ذلك توصى الدراسة بالاستفادة من هذا النظام لأنه سيضمن إدارة فعالة للمياه.

الكلمات المفتاحية: المياه الجوفية، جودة المياه، الري، المغرّة

Appendix

Figure (1) DHII waterproof sensor for measuring temperature

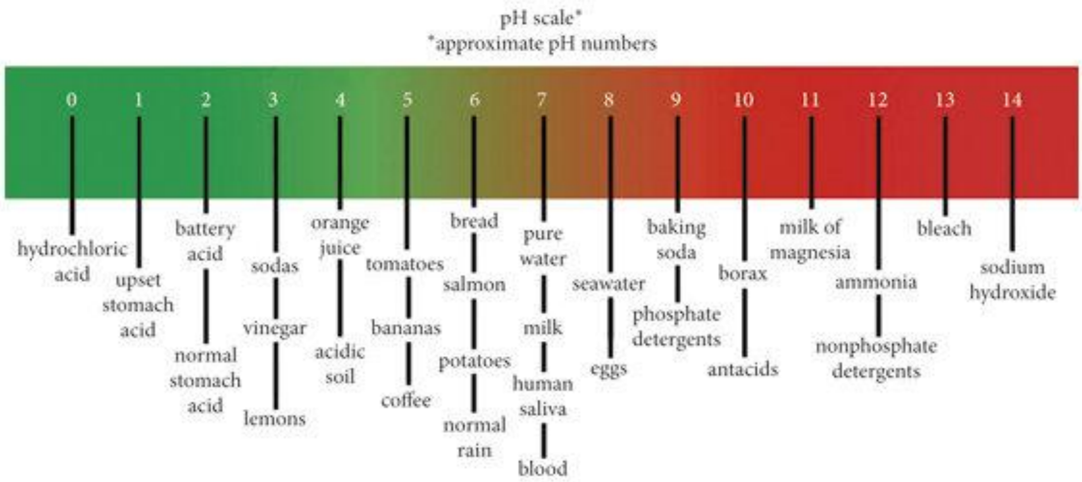

Figure (2) pH scale

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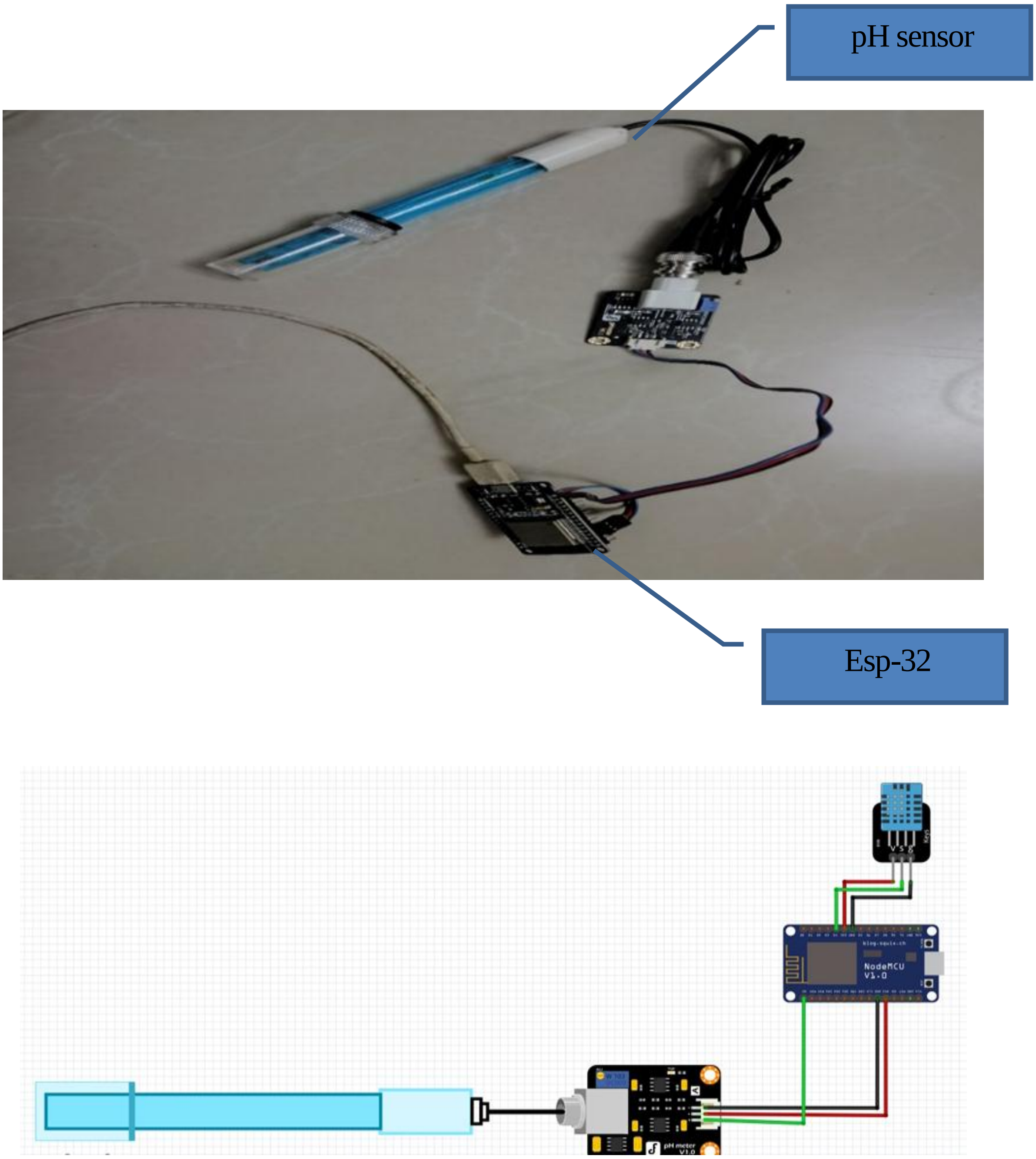

Figure (3) pH sensor and its pin out

Scheme (1): Established Code

```
#INCLUDE <ARDUINOJSON.H>
#INCLUDE <ESP8266WIFI.H>
#INCLUDE <FIREBASEESP8266.H>
#INCLUDE <DHT.H>
#INCLUDE <WIFIMANAGER.H>
#INCLUDE <TICKER.H>
#INCLUDE <DOUBLERESETDETECT.H>
//DHT11
#DEFINE DHTPIN 2
#DEFINE DHTTYPE    DHT11
DHT DHT(DHTPIN, DHTTYPE);
//DHT11 END
TICKER TICKER;  //OBJ
#DEFINE DRD_TIMEOUT 2.0  //TIME
#DEFINE DRD_ADDRESS 0X00  //ADDRESS
DOUBLERESETDETECT DRD(DRD_TIMEOUT, DRD_ADDRESS);
VOID TICK()
{
//TOGGLE STATE
INT STATE = DIGITALREAD(BUILTIN_LED);
DIGITALWRITE(BUILTIN_LED, !STATE);
}
//WIFI END
#DEFINE FIREBASE_HOST "HTTPS://PROJECT-75634-DEFAULT-RTDB.FIREBASEIO.COM"
#DEFINE FIREBASE_AUTH "ICMQARJBCTRKSX4AOJVTSXPSFARTOQBXSUG3FO9B"
//DEFINE FIREBASE DATA OBJECT
FIREBASEDATA FBDO;
STRING PATH = "";
//PH SENSOR
CONST INT POTPIN=A0;
FLOAT PH;
FLOAT VALUE=0;
VOID SETUP()
{
SERIAL.BEGIN(115200);
SERIAL.PRINTLN();
WIFIMANAGER WIFIMANAGER;
PINMODE(BUILTIN_LED, OUTPUT);
TICKER.ATTACH(0.5, TICK);
IF (DRD.DETECT()){
SERIAL.PRINTLN("** DOUBLE RESET BOOT **");
WIFIMANAGER.RESETSETTINGS();
}
SERIAL.PRINTLN("** NORMAL BOOT **");
WIFIMANAGER.SETTIMEOUT(60);
IF(!WIFIMANAGER.AUTOCONNECT("ESP8266")) {
SERIAL.PRINTLN("FAILED TO CONNECT AND HIT TIMEOUT");
DELAY(3000);
ESP.RESET();
DELAY(5000);
}
SERIAL.PRINTLN("CONNECTED");
TICKER.DETACH();
//KEEP LED OFF
FIREBASE.BEGIN(FIREBASE_HOST, FIREBASE_AUTH);
FIREBASE.RECONNECTWIFI(TRUE);
```

- IF (!FIREBASE.BEGINSTREAM(FBDO, PATH + "/STATE"))
- {
- SERIAL.PRINTLN("------------------------------------");
- SERIAL.PRINTLN("CAN'T BEGIN STREAM CONNECTION...");
- SERIAL.PRINTLN("REASON: " + FBDO.ERRORREASON());
- SERIAL.PRINTLN("------------------------------------");
- SERIAL.PRINTLN();
- }
- ELSE
- {
- SERIAL.PRINTLN("PASSED");
- SERIAL.PRINTLN("------------------------------------");
- SERIAL.PRINTLN();
- }
- PINMODE(POTPIN,INPUT);
- DHT.BEGIN();
- }
- VOID LOOP() {
- SENSORUPDATE();
- }
- VOID SENSORUPDATE(){
- //PH SENSOR
- VALUE= ANALOGREAD(POTPIN);
- FLOAT VOLTAGE=VALUE*(3.3/4095.0);
- PH=(3.3*VOLTAGE);
- IF (FIREBASE.SETFLOAT(FBDO, "/PH/PH", PH))
- {
- SERIAL.PRINTLN("PASSED");
- }
- ELSE
- {
- SERIAL.PRINTLN("FAILED");
- }
- //END PH
- FLOAT T = DHT.READTEMPERATURE();
- IF (FIREBASE.SETFLOAT(FBDO, "/DHT11/TEMPERATURE", T))
- {
- SERIAL.PRINTLN("PASSED");
- }
- ELSE
- {
- SERIAL.PRINTLN("FAILED");
- }
- }}
- **VOID** LOOP(){
- VALUE= ANALOG EAD(POTPIN);
- SERIAL.PRINT(VALUE);
- SERIAL.PRINT(" | ");
- **FLOAT** VOLTAGE=VALUE*(3.3/4095.

Figure (4): Mobile app QR code (produced by the authors)

Figure (5): A mobile application (produced by the authors)