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IoT Knots

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ABSTRACT

The phenomenon of climate change is a burden passed through generations, and future generations will inevitably suffer if excuses are continuously perpetuated. Climate change is a result of several grand challenges like industry and pollution. Before defining a solution, understanding the problem comes first. The purpose of this study is to collect accurate data and get conclusions to objectively examine and predict climate change. To achieve such a purpose, the solution would be to design an IoT system that can collect data and wirelessly communicate it to a database that changes the raw data into visual representations and infers conclusions. The Egyptian coastal area was modelled to test the feasibility of the solution in real life. The project will measure four parameters of climate change: air quality, temperature, sea level rise, and water acidity. These parameters affect each other and concerning one medium can be inferred from the other. These conclusions were projected on a website that is directly fed by the database. If the data is not accurate, the conclusions would be questionable, so the design requirements would be measuring the percent accuracy and the dynamic range to show the range of usable data in real life and highlight the limitation of the sensor. After testing each sensor, the prototype showed its ability to produce reliable conclusions based on accurate data. The major findings are the flexibility of IoT systems and their importance in mitigating climate change, urging the country to foster more IoT solutions to mitigate climate change.

INTRODUCTION

Egypt has been struggling through several challenges that halts its endeavors to achieve its sustainable development goals. The phenomenon of climate change is connected to most of these grand challenges by the relation of cause and effect. Climate change was originally caused by inefficient industry and pollution, especially air pollution. Egypt emitted about **250 metric tons** of CO_2 in **2021** which has increased drastically in the last three decades as **shown in the following figure (1)**. Additionally, as climate change increases, it exponentially raises the severity of other grand challenges as arid areas. **96%** of Egypt is considered arid which would increase due to increasing drought because of climate change.

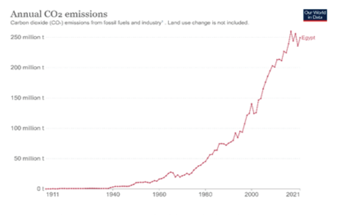


Figure (1): Carbon Dioxide Emissions in Egypt

Another effect of climate change is sea level rise. Due to increasing greenhouse gas emissions and temperature, the sea level rise became **3.2 mm per year**, making the Nile delta region one of the most vulnerable places in the world to climate change. Egypt currently cannot investigate and assemble data about climate change happening on the Mediterranean Sea because of lacking technological base to gather accurate data.

Thus, the main problem required to be solved is using IoT systems coupled with statistical analysis to mitigate the effects of climate changes happening on sea and air by gathering accurate data wirelessly and conveniently.

One of the solutions that utilize an IoT system to make conclusions about climate variability was the Indian Ocean Tsunami Warning and Mitigation System (IOTWMS) **shown in figure (2)**. The solution predicts future tsunamis following detected seismic activities. IOTWMS assesses the risk of tsunamis using a large database that includes information about previous tsunamis and uses models analyzing data to predict the magnitude of the tsunami. Then, it transmits warnings to local broadcasting stations to warn Indian residents. The point of strength of IOTWMS is the extensive database that contains numerous information and accurate predictions based on this data. On the other hand, it requires international collaboration which is, sometimes, not a feasible option.

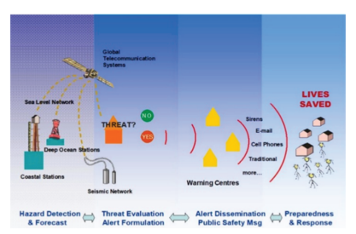


Figure (2): IOTWMS Mechanism

Another prior solution was "AGRO 4.0" **shown in figure (3)**, which worked on improving agricultural conditions in Brazilian rural regions. It employed a fine-tuned sensing system in examining the conditions of crops being affected by climate change and urge users to take appropriate actions to prevent any future issues. Its main point of strength is increasing the yield rates of crops; however, it suffers from signal interferences because of being a bidirectional system, conveying information from sensors to headquarters and vice versa.

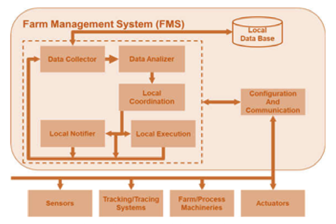


Figure (3): AGRO 4.0 mechanism

To form a complete idea about climate change in Egypt and the intricate connection between its different parameters, the solution was chosen to be an IoT system that wirelessly delivers accurate data from sensors measuring air quality, temperature, water level, and acidity to a database wherein data would be sorted and analyzed using basic statistical methods. The analyzed data will be used to make conclusions about climate change and its major effects on Mediterranean Sea coastal areas. Conclusions based on the data acquired are trustable only if the data is accurate, so the prototype will have two design requirements: the accuracy of the data which will be measured by determining the difference between a reference value and a measured value; the dynamic range which is the difference between the maximum value and minimum value and conveys the limitation of the sensor.

After testing the prototype, it produced accurate results with suitable dynamic ranges and reliable conclusions that future actions could be based upon. Thus, it achieved the design requirements. To achieve those design requirements, careful consideration in choosing the material was needed as shown in the following section.

MATERIALS

Name						
ESP 8266 (Wi-Fi module)	Air quality sensor MQ135	pH sensor	Temperature sensor DHT22	Water depth (level) sensor	JavaScript Programming Language	Firebase Real-time Database
Quantity						
1	1	1	1	1	N/A	N/A
Description						
Microcontroller that accesses Wi-Fi networks and sensors' data	Detects CO_2, ammonia gas, and other gases.	Calculates water's pH.	Measures temperature and detects changes.	Measures water level up to 10m.	Handles user input and data's reception and representation using chart.js library.	Stores data and handles data access.
Image						

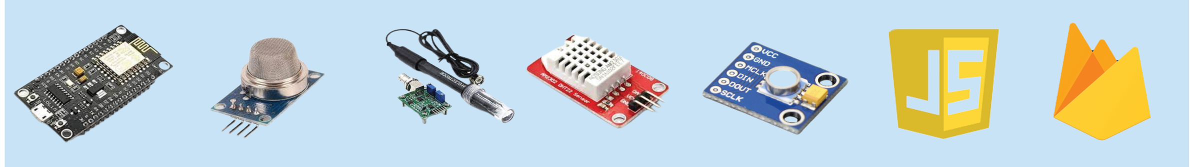


Table (1): Materials Table

METHODS

1. A non-relational database was made using "Google Firebase" (**shown in Figure (4)**) to store the data from the sensors in JSON format and handle data fetch requests.

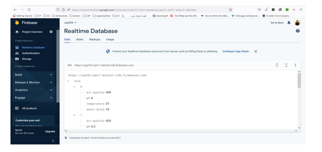


Figure (4): Firebase Database

2. The pH sensor, air quality sensor, water level sensor, and temperature sensor were all connected to the bread board (placed at the middle of the container) that connects them to the ESP **as shown in figure (5).**

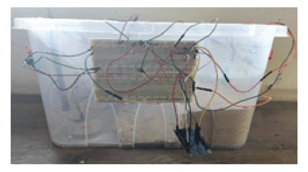


Figure (5): Connection of sensors to ESP

3. The ESP was connected to the database to send the sensors' data wirelessly via Wi-Fi connection each two seconds **as shown in figure (6).**

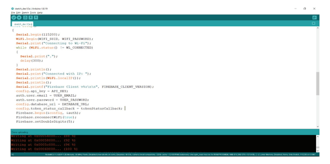


Figure (6): Arduino code of ESP Database Connection

4. To make the model, **shown in figure (7)**, depict the Mediterranean Coastal areas and greenhouse effect, the plastic container was filled with sand and water that symbolize coastal areas, ice cubes that symbolize the melting ice at the two poles, and a candle that models the increasing CO_2 and temperature.

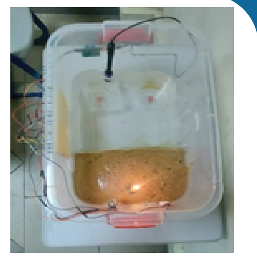


Figure (7): Model depicting climate change

5. To receive the model's readings, an interactive front-end interface was built using HTML, CSS, and JavaScript and connected to the firebase database.

6. The interface was improved by adding the functionality of displaying the fetched JSON data from the firebase server by utilizing the Chart.js Library as **shown in figure (8).**

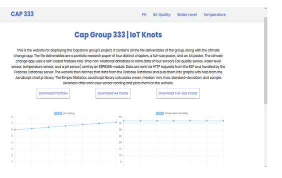


Figure (8): Graphical user interface

Design Requirements:

1)Percent Accuracy

2) Dynamic Range

Test Plan:

1. To measure the accuracy of each sensor's measurement, a suitable reference measurement was chosen. For the pH, temperature, and water level sensors, reference values of **pH 4** buffer solution, **23°C** temperature, and **20 cm** of water were used respectively. The absolute of the average of three observed values (V_O) was subtracted from the reference value (V_R), divided by the reference value, and multiplied by 100 and then subtracted from 100 to calculate percent accuracy. The equation is 100 - ($|V_R - V_O|/V_R$ X 100) = percent accuracy

2. The pH sensor, air quality, and temperature sensors were tested by increasing the parameter and decreasing it to the threshold of the sensor when no change in value is noticed. The maximum measured value and minimum value were subtracted to calculate the dynamic range of the sensors. Then, the dynamic range was compared to the range of respective parameters in the Mediterranean Sea.

RESULTS

Negative Results:

At first, a MySQL database, with a Nodejs API that manages the requests, was used to store the sensors' data, and the database worked optimally on the computer; however, on uploading it to a hosting, the team faced problems with the limitations of the used free hosting (infinityfree.net). All free hosting providers don't allow receiving HTTP requests (GET and POST) from things that aren't browsers (ESP8266 & the used interactive front-end). In addition, they don't provide the ability to host both MySQL and Nodejs together. Since paying for hosting would surge the project's costs up, firebase was the optimal choice: it didn't require an API as it handled requests with minimal setup and was free for the small project. After using the Firebase Database, the project worked optimally on the internet and positive results were achieved.

Positive Results:

The results of the following table shows that the pH sensor, water level, and temperature sensors achieved high accuracy with low percent error after testing them with reference values of **4 pH** buffer solution, **20 cm** water, and **23 °C** temperature respectively. The positive results show that the prototype can achieve accurate and reliable results as **shown in table (2).**

Sensor Name	Reference Value	Measured Value	Percent Accuracy
pH	4 pH	3.9pH, 4.2pH, 4.3pH	96.67%
Water Level	20cm	20cm, 21cm, 23cm	93.33%
Temperature	23 °C	23°C, 25°C, 20°C	98.55%

Table (2): Results of the Sensors' Accuracy

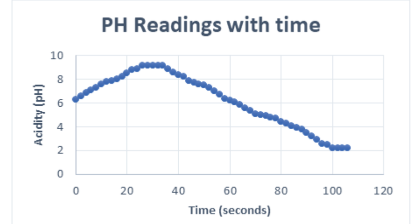


Figure (9): Dynamic Range of pH

The dynamic range of the sensors was calculated and compared to the range of the parameters in Port Said. The dynamic range of the pH sensor was measured to be **7 pH (9.2 pH – 2.2 pH)** as **shown in figure (9)**, the temperature had a range of **79°C (from 3°C to 82°C)** as **shown in figure (10)**, which is suitable for the Mediterranean Sea whose pH is between **8.03 and 8.53 pH** and the temperature of air in Port Said which is in the range of **12°C - 32°C**. The following graphs show that the sensors have a very suitable dynamic range and can be feasibly implemented in coastal areas.

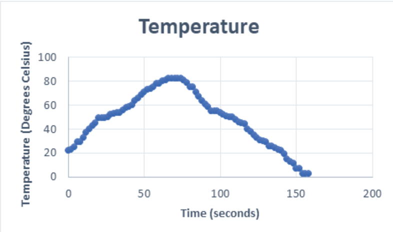


Figure (10): Dynamic Range of Temperature

ANALYSIS

Interdependent parameters:

Understanding climate change is a complex process that involves the reaction between numerous parameters. When one parameter changes, it can affect one or more parameters. Thus, the project measures four parameters: air quality, temperature, sea level, and pH to deepen the understanding of these interdependent parameters and the effect they have on each other. When taking actions to mitigate climate change based on the data of the prototype, the decisions can be more accurate and precise than other projects that measure only one or two parameters.

Effect of air quality on temperature:

Measuring air quality includes detecting greenhouse gas emissions. The Earth absorbs half the energy incoming from the sun and the rest is radiated back. When photons hit greenhouse gas molecules, they absorb the light causing the bonds between the atoms to vibrate. This traps the energy that was exiting into space and, in turn, heats the atmosphere. Additionally, greenhouse gases only absorb the rays radiated back from the earth, so, it acts as a "greenhouse" gradually increasing the temperature as **shown in figure (11).** That's why the model's cycle starts with the ignition of a candle that stimulates greenhouse emissions, altering both the temperature registered by the used temperature sensor and the air quality reading registered by the air quality sensor.

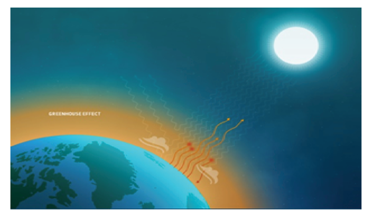


Figure (11): Greenhouse Effect & Increasing Temperature

Effect of temperature on water level:

As temperature increases, the sea level increases through two mechanisms. The first mechanism is, the melting of ice: when the temperature increases, the ice begins to melt, increasing the level of the sea. Second, thermal expansion: when the temperature of water increases, its volume expands which also leads to an increase in sea level. That part is simulated in the prototype by the melting of an ice cube after exposure to the greenhouse effect by the candle flame, increasing the water level sensor's reading.

Effect of air quality (CO_2) on sea's acidity (Chemistry LO 2.03):

Sea water naturally absorbs carbon dioxide from the atmosphere, and as the amount of CO_2 increases in the atmosphere, the amount absorbed by the ocean increases. Carbon dioxide (CO_2) dissolves in water and reacts to form carbonic acid (H_2CO_3) which is weak and dissociates into hydrogen ions (H^+) and bicarbonate ion (HCO_3^-) as shown in the **following figure (12)**. Therefore, as CO_2 increases in the atmosphere, the pH of the sea decreases. That's why the pH sensor's reading drops with the increasing CO_2.

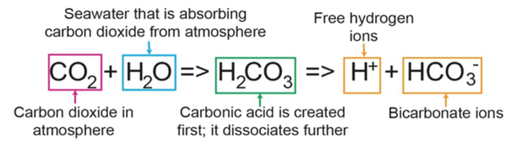


Figure (12): Reaction of Carbon Dioxide With Water

Communication (Physics LO 3.04 & 3.05):

ADC (Analog to Digital conversion):

For the sake of easiness and convenience, the project requires all its sections: sensors, the database, and the user interface to be wirelessly connected. This could not be accomplished unless they all were linked through the internet or, in other words, an IoT system. Different sorts of signals which can have any value are gathered by each of the four sensors in the prototype, known as analog signals. The used temperature sensor might give any value within its range. However, analog signals generally are vulnerable to attenuation and interference with noise. **The following graph (13)** displays how noise affects informational signals. Thus, Analog sensors must be converted into digital signals that can only be either "1" or "0". ESP8266 is a microcontroller board that acts as a hub that assembles analog data from sensors; it has an Analog-Digital-Converter (ADC), and the only way to achieve this conversion by following three steps: 1- Sampling of analog signals at regular time intervals, adjusting to Nyquist law of sampling 2- Quantization into discrete units 3- Encoding to binary numbers. The process is **shown in figure (14).**

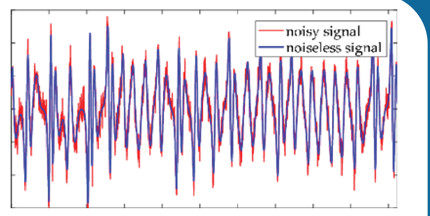


Figure (13): Effect of noise on Informational Signals

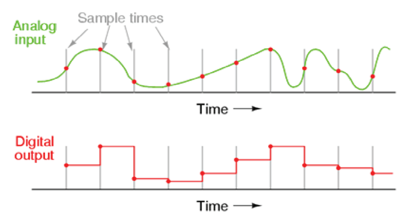


Figure (14): Analog to Digital Conversion

Antenna and Coverage Range :

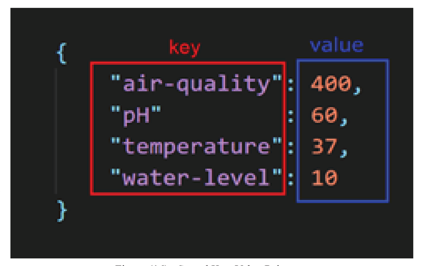
ESP8266 has a Wi-Fi chip that encodes digital signals into a radio frequency to be transmitted wirelessly. The signals are then decoded to convert them back into digital signals. To transmit and receive signals, an antenna is embedded inside the microcontroller board. In the case of transmission, it converts electrical impulses into radio frequencies since electromagnetic waves are much faster and more reliable than electrical signals. When the electrical impulses vibrate electrons inside the antenna, they generate electromagnetic radiations which travel in the form of radio waves [WI-FI]. But in the case of reception, the Antenna does the reverse of that conversion pro-cess. The coverage range of the antenna (d) depends on the length of that antenna (h) and the radius of the planet (R). The higher the length of the antenna, the wider the effective area of transmission **as shown in figure (15).**

$$d = \sqrt{2hR}$$

Figure (15): Calculating Coverage Distance Through Length of Antenna

Firebase Database (CS LO 2.02):

Databases are collections of stored data, usually organized on a computer or a server. There are two main types of databases: relational databases (data organized into rows and columns) and non-relational databases (data organized into many types). The database used in our project is a non-relational database that stores data into key-value pairs **shown in figure (16)**. Non-relational databases are easier to setup, and more scalable than relational databases. Among the available non-relational databases, a Google service, with the name "firebase", was chosen as the project's database. That's because it's free for the small-sized solutions as this project, efficient with codes, and runs in real-time which means that whenever the data changes on the server, that change appears on each user's device.



```
key                 value
{
  "air-quality" : 400,
  "pH"          : 60,
  "temperature" : 37,
  "water-level" : 10
}
```

Figure (16): Stored Key-Value Pairs

The Firebase database consists of a collection for each day that the prototype is used on, and that collection contains a set of updates. Each of those updates consists of a reading from each of the used four sensors: air quality, water level, humidity, and pH. Those collections represent the database's main data that appears on the website.

Connection Logical Flow:

Readings from the sensors are sent by the ESP board to the database. Since the ESP8266 board is a cheap Wi-Fi chip that is built with microcontroller capabilities and connects to internet, it has the responsibility of implementing the communication part of the IoT System. Despite having the ability to connect to internet, an ESP wouldn't directly connect to the database but require coding a full API program. That requirement gives Firebase an additional strength point as it works as an API with minimal setup. Each two seconds, the ESP board gets readings from the sensors and saves them into the Firebase Database Collection. Those data become available for the website to fetch and put into graphs. The full data cycle is **shown in figure (17).**

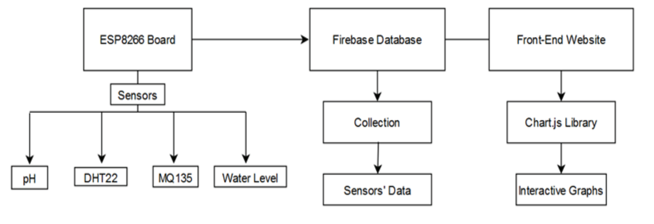


Figure (17): Connection Logical Flow Chart

Graphical User Interface (GUI) (CS LO 1.05 & 1.06):

Both the Firebase Database and the accompanying utilities form the backend of the program which is the part of the program that is written and doesn't appear to the user. On the other hand, the parts that appear to the user are called the frontend, and in this project, the frontend is an interactive HTML, CSS, and JavaScript website that works on all types of devices. The website consists of a landing page and a page for each sensor. As with those of the ESP8266 board, the website's requests would be handled by the Firebase Database, and the resources requested by the board would be sent in the form of a JavaScript Object that could be stored into an Array and depicted by the Chart.js library into line graphs – code **shown in figure (18)**. Some statistical parameters were inferred by the use of the Simple Statistics Library as well, that library has functions for mean, median, max, min, and standard deviation, utilizing them for the usage of users and for getting other statistical analysis parameters like the Standard Error of the Mean.

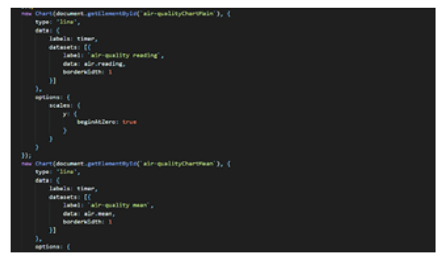


Figure (18): Code of Chart.js Library

Descriptive statistics (Math LO 1.02):

Descriptive statistics aids in deciphering patterns or trends in data. Describing data sufficiently requires three things. First requirement is the measure of central tendency, which is a descriptive summary of the dataset through a single value that reflects the center of the data distribution. For measuring central tendency, the project measures the mean and median of the data. The mean is calculated by dividing the summation of the elements in a set by the total number of elements. The median is the data value which lies at the middle of the dataset values.

The second requirement is the shape of the data. The project represents the collected data as a graph. By calculating the mean and median of the data, the shape of the graph can be inferred and understood algebraically. If the mean is smaller than the median then the graph is skewed left, which means that higher value data has higher frequency in the dataset and vice versa. If the water level parameter is greatly skewed to the left, this means that the water level is increasing at an alarming rate. The system of the project can conclude that actions should be taken to limit the rapid increase of the parameter.

The third requirement is the measure of the spread of the data and variability. Standard deviation can be used to measure the dispersion of the data from the mean using the equation in **figure (19).** Data variation can serve as an indicator of rapidly changing parameters. Climate change causes an increase in the variation of earth parameters. The project measures the increase of temperature over time. Temperature increases in nature with time. But a notable increase in the variation of temperature data means that the temperature parameter is increasing far more than the natural standards. The project can conclude that the parameter may outgrow the capability of nature to restore it to natural standards.

$$SD = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N}}$$

Figure (19): Equation of Standard Deviation

Inferential statistics:

The project makes conclusions about climate change using data taken from sample models. Inferential statistics can be used to measure the difference between the sample measurements and real measures involving large amounts of data. One of the operations of inferential statistics is the Standard Error of the Mean (SEM). It gives an estimate of how accurate the mean of the sample used in the test is when comparing it to the real mean of the whole set of data. The standard error of the mean can be calculated by dividing the standard deviation by the square root of the sample size as **shown in figure (20).**

$$SEM = \frac{\sigma}{\sqrt{N}}$$

Figure (20): Equation of the Standard Error of the Mean

After analyzing the results, it was found that the prototype achieved the design requirements of accuracy and suitable dynamic range. Deducing from this the project can be applied systemically in Egypt to mitigate climate change using IoT. This will lead to improving the technological base and making informed and objective decisions.

CONCLUSIONS

Egypt's pursuits toward prosperity and sustainability are opposed by challenging climatic fluctuations. The northern coast of Egypt is indeed the most affected region by the negative impacts of climate change because of interactions between several variables. The lack of advanced communication systems aiding in taking appropriate decisions worsens the effects of climate change. By implementing IoT approaches, the project, which provides an enriched database with data collected by sensors, showcased a notable potential for mitigating climate change. The prototype's interactive interface enables intended users to make objective decisions concerning climate change. The prototype has successfully satisfied its design requirement: sensors' dynamic range was considerably wider than the range of the coastal areas, and the data was accurate, having negligible error values.

RECOMMENDATION

Fluke 985 Particle counter:

One of the essential objectives of the project is to determine the concentrations of greenhouse gases and other fractional solid particles suspended in the atmosphere. It is strongly recommended to use Fluke 985 particle counter, illustrated in **figure (21)**, for delicate measurement of the gases' concentrations. Unlike the air quality sensor, Fluke 985 could detect very tiny particles with a range of 0.3-10 µm, providing the project with the capability to observe changing trends in gas concentrations. It has a counting rate of 5 counts / minute. It can ensure that all of the assembled data are precise by noticing how the data deviates as more counts are identified. Aside from its cost, Fluke 985 involves ethernet communication which marks it as a non – IoT system. Converting from ethernet to wireless connections is not convenient and might be costly.

Figure (21): Fluke 985 Particle Counter Photo

MySQL:

When the project gets bigger, it will have more data which requires paid Firebase plans that are too expensive. MySQL (**shown in figure 22**) solves that problem as it is a free, open-source relational (data organized into rows & columns) database management system. It is a software built upon SQL (Structured Query Language, the most popular database language) to facilitate data querying and control instead of coding everything in the harder SQL lines. MySQL has a reliable ability to scale with bigger applications; however, it has the problem of requiring a full API that accepts requests. Due to that reason, firebase was preferred for the small project as Firebase can handle data requests with coding an API.

Figure (22): MySQL Database Logo

Real-life Application:

Port Said is the most suitable location to install the project. Located in the northern regions of the Nile delta, Port Said is one of the most two vulnerable spots to experience a severe rise in the level of the Mediterranean Sea. It is a region with low land elevations; moreover, it has high rates of land subsidence and deep depressions in lands due to the removal of underground water. This amplifies the negative impacts of increasing sea levels on population and manufacturing activities. It is estimated that Port Said 's sea level is going to increase by 50 cm by the arrival of the next century. This would force seashores to retread by 21.26% percent, **as shown in figure (23)**. To cover the 30 Km of Coastal Area that Port Said has, a total of 3000 units of the project would be needed as the ESP used in the prototype handles Wi-Fi connection for about 10 meters. Using a total of 3000 prototype units, each at a distance of 10 meters, would cost 3,800,000 Egyptian Pounds to implement the project of covering the whole Port Said coast with the project and getting data for analysis. The project would use the graph patterns to give conclusions for actions that people can take to mitigate the problem.

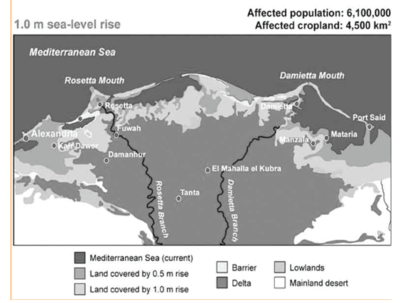


Figure (23): Port Said after sea rise

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