IoT-Based System Using Fuzzy Logic Approach for Measuring Salt Quality

A Case of Zanzibar Salt Farms

Shaame Mshindo Bakar[1], Dr. Pierre Bakunzibake[2], Dr. Ngenzi Alexandre[3]
[1]College of Science and Technology, African Centre of Excellence in Internet of Things, University of Rwanda, Kigali, Rwanda
[2]College of Science and Technology, Department of Electrical and Electronics Engineering, University of Rwanda, Kigali, Rwanda
[3]College of Science and Technology, Department of Computer and Software Engineering, University of Rwanda, Kigali, Rwanda

Article Info

Article history:

Keywords:

IoT
Fuzzy logic
Quality of salt
QOS
PPM

ABSTRACT

The deficiency of quality salt concentration has become a challenge in Zanzibar. The production of sodium chloride salt from the seawater normally has the minimum level of concentration of about 85 to 90% in dry base, which is below of national and international standards requirements from 96 to 100%. The aim of the study is to design and prototype an IoT based system using fuzzy logic approach for measuring sodium chloride salt quality. The system includes with electrical conductivity, total dissolved solids, pH sensors, Arduino Uno microcontroller, GSM and LCD screen display. The fuzzy logic approach was used for data analysis collected from sensors and transmitted to the ThingSpeak cloud server for process and analysis to get the output results. The implementation of this study was expected to measure and estimate the quality of sodium chloride salt, sending sms and email notification to user's email and mobile phone for decision-making. The data were collected using an IoT system prototype and the results obtained from three samples. The average accuracy of the prototype system was about 99.7 percent with percentage error of about 0.3. Therefore, the use of IoT and fuzzy logic approach would be helpful for measuring of salt quality.

Corresponding Author:

Shaame Mshindo Bakar
College of Science and Technology, African Centre of Excellence in Internet of Things, University of Rwanda, Kigali, Rwanda
Email: shaamem3@gmail.com

1. INTRODUCTION

The sodium chloride known as table salt, mostly used in different applications for human and industrial purposes. The salt has various applications such as home for food cooking, food additive in food processing to influence the product taste and it is useful in texture and storage. Therefore, it is important in everyday human life [1]. Zanzibar is the one among the salt producing countries using evaporation process from seawater after being collected in a certain area (special ponds), most salt farms are located in Pemba Island. The salt produced still has low quality of sodium concentration, more process are required to make it a quality salt [2]. The seawater is the main source materials of salt production in Zanzibar, the production process passes in different stages such as collection of seawater to the reservoirs from sea where normal seawater has the salinity approximately 35ppm or 35g of salt per kg of seawater, which is equal to 3.5% [2]. The collected seawater, flowing to the condenser pans where the sun heats the water to increase the salinity by evaporation process until 25-26 Be (Baume scale) where 1Be is equivalent to 10g of sodium chloride per kg of seawater. The salt concentration and crystallization start in this stage, the crystallization process starts with calcium carbonate, followed by calcium sulphate and end with calcium chloride. Therefore, seawater influences the quality of the salt [2], [3]. The salt produced from seawater mostly has an average of sodium chloride concentration of about 85% to 90%, which is below of national and international standards of 96% and 97% respectively [2], [4]. The direct method of sodium chloride production using crystallization process have the problem of the presence of impurities which is quietly a lot, so the concentration of sodium chloride has not yet reached the maximum standard required for salt quality [5]. The existing of compounds such as magnesium chloride, magnesium sulphate, calcium carbonate and potassium chloride that concurrently crystallized during the process of salt production often causes the lower concentration (lower purity) of sodium chloride [5]. The evaporation process may increase the concentration of each solute until the concentration reached the saturation, the solubility in water will influences the deposition process, the lower constant of solubility substance will settle in advance of the element that have larger constant solubility, thus, the high quality production of salt is paramount important. The quality of seawater, the process and technology used in the salt production influence the production of salt quality [1] [4]. This paper focuses to reduce the challenges and problems of salt quality in Zanzibar salt farms by designing a low cost effective of IoT system prototype that will automatically measure, process and analysed the sodium chloride concentration from salt solution. The prototype will provide the output results of the salt solution measured to know the sodium chloride concentration in terms of percentage, the output results is based on different quality grades such as high grade known as good quality and lower grade known as lower quality [2]. There are different parameters recommended by the International Standard Organization (ISO), CODEXSTAN 195 General standard for food additives and East Africa Community standards that can be used in measuring the salt quality such as sodium chloride concentration, hydrogen potential level (pH), moisture content, iodine level, parking and storage and salt impurities such as calcium, magnesium, sulphate copper [4], [6]. This study will focus with only three parameters by measuring the concentration sodium chloride salt, salt impurities, hydrogen potential and the temperature parameter will be used to compensate with electric conductivity to get the real data from the salt solution [7], [8]. The electric conductivity (EC), total dissolved substance (TDS) and hydrogen potential (pH) to identify the salt concentration, impurities and pH levels. Microcontroller for data processing, LCD for displaying output results, the GSM module will be used for data transmission to the cloud server (ThingSpeak) for data analytics and visualization through Matlab analysis and visualization [9], [10]. The fuzzy logic approach as a machine learning will be used for testing the performance and accuracy of the system prototype, it is a rule based expert system used to output the results according to the inputs parameters. The membership functions are used in the fuzzy logic system to estimate the percentage of salt concentration quality as an output according to the input parameters [11]. Moreover, the study will use the regression theory and correlation to make advance data analytics, clearance and relationship between the input parameters [12].

2. METHOD

2.1. System Prototype

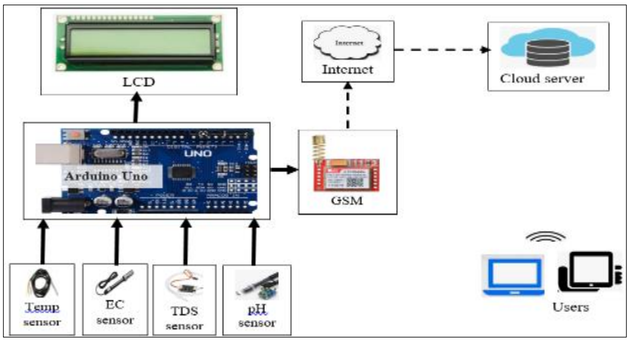

Figure 1. Proposed system architecture

The proposed system composed with both hardware and software tools to achieve its operations. The system architecture consists of EC, TDS pH and temperature sensors connected with Arduino Uno, the

GSM SIM 800L, LCD [13]. The Arduino uno processes data collected from the sensors and sent to the ThingSpeak cloud server by using GSM module with internet service [14]. The thingspeak server storing, processing and analyse the data using Matlab analysis and visualization to provide the output results on thingspeak dashboard and email notification to users [15]. The system architecture designed to meet the requirements to measure salt concentration in percentage in real-time with accurate and cost-effective as figure 1 above. The system components description are as follow:

2.1.1. Arduino Uno microcontroller

It is an open source microcontroller, which is equipped to support Integrated Environment Development (IDE) programming and interfaced with different electronic devices such as sensors, communication modules such as GSM, LCD, shields to implement different IoT projects [16]. It is board based on ATmega328P and consists of 14 digital input/output pins, the 6 pins used as PWM output, 6 analog inputs, USB connection, 16 MHz ceramic resonator, power jack, an ICSP header and a reset button, it can be powered through USB connection or external power supply from 6 to 20V. The external power can be either come AC to DC or from battery [17]. If the power supplied is less than 7V, although the 5V pin may supply less than 5V, the board may be unstable, and the using more than 12V the voltage regulator may overheat and damage the board [17].

2.1.2. Electric conductivity sensor

EC sensor is used to measure the high electrical conductivity of liquids such as seawater, concentrated brine that is the solution of salt concentration level of sodium chloride with inputs voltage of 3-5V main control board, such as Arduino [18]. The EC is measured in mS/cm (milli Simens/cm), the EC uses different conversion factors such as 0.5 which is standard used to convert from EC to TDS in parts per millions (PPM), thus, we used “EC x 500” scale for sodium chloride to convert to salt concentration in PPM [18].

2.1.3. Total Dissolved Substance (TDS) sensor

TDS sensor is the Total Dissolved Solids of organic and non-organic substances present in the solution used to measure the presence of various cations and anions in the water solution with part per millions (ppm) unit [19]. The higher TDS values means the more substances dissolved in the solution. Therefore, the solution contains more impurities and it operates in dc power of (3.3 ~ 5V) [18]. The sodium chloride salt is a part of TDS, e.g. if only sodium chloride dissolved in water, and reading is 500ppm, therefore, there is only 500ppm (mg/L) of sodium chloride salt dissolved in the solution [19]. TDS indicates how many milligrams of soluble solids are dissolved in one liter of water, it uses part per millions (ppm) as unit. Therefore, this sensor is suitable for measuring the sodium chloride concentration and impurities. The ppm is defined as how many parts or grams of salt contents there are per thousand/million parts, or kilograms (1000g), of salt solution or seawater [19].To convert the EC value to salinity ppm, the sodium chloride conversion factor of 500ppm is used [20].

2.1.4. Hydrogen potential (pH) sensor

The pH scale refers to hydrogen potential used to measure acidity or basicity (alkalinity) of an aqueous solution to measures body’s hydrogen ions (H+) concentration. The pH scale goes from 1 to 14, with 7 scale considered neutral [21]. The solution having a pH less than 7 is said to be acidic solution and the one having a pH more than 7 is said to be basic or alkaline solution and it operates on 3.3~5.5V with the output voltage of 0~3.0V. The pH will be used to measure the pH level of the sodium chloride solution [21].

2.1.5. DS18B20 temperature sensor

It is a one-wire digital thermometer based on one-wire interface, which requires only one pin for circuit connection and it operates temperature range of -55˚C to 125˚C with an accuracy +/-0.5˚C. It operates on 3.3~5V and interfaced with any microcontroller. This sensor will be used for compensation with EC sensor to get correct reading in the solution [22].

2.1.6. GSM module (SIM 800L)

SIM800L GSM/GPRS is a miniature GSM modem, which can be integrated with Arduino microcontroller for IoT projects [14]. It is used to accomplish SMS text messages, make or receive phone calls, connecting with internet via GPRS, TCP/IP and it supports SIM card to be connected to the mobile operators, also supports quad-band GSM/GPRS network, so it works everywhere. Its operating voltage is 3.4 to 4.4V, which makes difficult to direct 5V power supply. SIM800L is power-hungry device and it uses 2A during transmission or around 216mA during phone calls or 80mA during network transmission [14]. There are two ways you can add an antenna to your SIM800L module, namely; Helical GSM antenna and any 3dBi antenna with U.FL to SMA adapter on the top-left corner of the module [14].

2.1.7. ThingSpeak Cloud Server

ThingSpeak cloud server to receive data from prototype system, store data, analyse and provide the output results [15]. This study uses ThingSpeak cloud server to store and retrieve data from sensors using HTTP internet protocols. It allow users to aggregate, analyze and visualize of data in real-time data stream. ThingSpeak has the ability to execute the MATLAB code to perform online data processing and analysis [15].

2.2. Layered Architecture of the Proposed System Prototype

The proposed system uses three-layered architecture as Figure 2 shown below. The first layer is perception also known as physical layer consists with temperature, electric conductivity, total dissolved solids, pH sensors for sensing and gathering data from salt solution and microcontroller (Arduino uno) is responsible for data processing [18]. The second layer is the network layer, which consists with GSM module with 3/4G network services used, send data collected from perception layer to application [18]. The third layer is the application layer responsible to provide application specific services to users and other application services such as thingspeak dashboard visualization and SMS for mobile phone[18]. The layers describe the data flow from hardware devices to the application layer with the services in application layer. The study used this layered architecture because, the proposed system needs to provide specific services to users such as email notification and SMS message report to mobile phone [23].

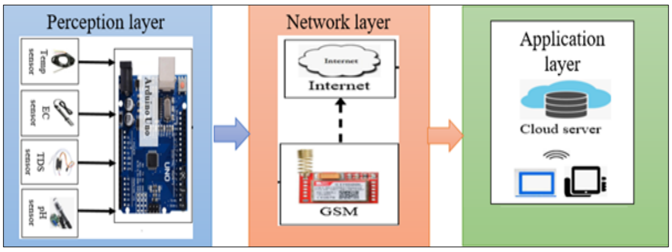

Figure 2. Three layered architecture

2.3. Data Flow Chart of the Proposed System

The arduino uno microcontroller is programmed to read the parameter values of EC, TDS and pH sensors from the solution of sodium chloride salt sample. The data values collected from EC, TDS and pH sensors are processing and analyzing using fuzzy logic rules to obtain the output results [10]. When the condition satisfy, the output results of salt status is displayed on the LCD screen, the SMS report is sent to the user mobile phone and the data is transmitted to the thingspeak cloud server dashboard [15]. The thingspeak Matlab analysis programmed using fuzzy logic conditions to send salt status email notification to user. Moreover, the thingspeak Matlab visualization is configured to analyse the data received from the system prototype and display data visualization on thingspeak dashboard visualization [10]. The figure 3 shows the system data flow.

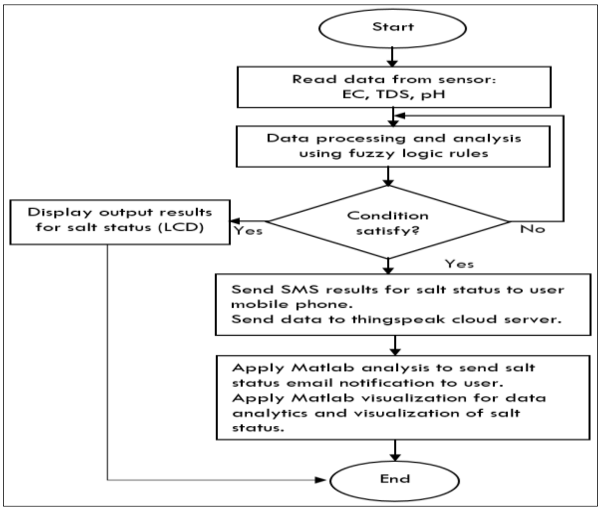

Figure 3. Data flow chart

2.4. Fuzzy Inference System Implementation

The fuzzy inference system is machine learning where the human knowledge is presented as a set of fuzzy linguistic rules for making prediction, approximation and estimation decision [24]. Thus, the combination of fuzzy rule based system can replaces the human expert knowledge. It uses the "IF" … "THEN" condition with "OR" and "AND" operators. The FIS based on four stages on its operation, namely, fuzzification, fuzzy rule, inference engine and defuzzification [25].

2.4.1. Membership Functions Implementation

Table1. Inputs And Output Fuzzy Sets Parameters For Salt Quality Estimation

Fuzzy Input Variables	Input/ Output	Linguistic Values	Numerical Range	Triangular Fuzzy sets
EC	Input	High	8.5-8.9	[8.4 8.5 8.9]
		Moderate	7.6-8.4	[7.7 7.8 8.6]
		Low	6.2-7.5	[7.1 7.7 7.7]
		Unacceptable	1-6.1	[0 7 7.2]
TDS	Input	High	5695-6164	[5695 6000 6164]
		Moderate	5092-5628	[5226 5628 5700]
		Low	4154-5025	[4757 5159 5228]
		Unacceptable	1000-4087	[0 4690 4760]
pH	Input	Low1	0-6.8	[0 4.0 6.9]
		Good	6.9-8.0	[6.8 7.5 8.2]
		Low2	8.1-14	[8.1 10 14]
Quality of Salt (QOS)	Output	Good	96-100	[96 98 100]
		Moderate	85-95	[86.5 93 96]
		Poor	70-84	[70 79 86.7]
		Unacceptable	<70.5	[0,60,70.7]

The EC input MFs: high range is (8.5-8.9), moderate range is (7.6-8.4), low has range of (6.2-7.5) and unacceptable (na) is (1-6.1) as Figure 4 shown. The ranges identifies the EC the conductivity levels of the salt solution interms of milli Siemens per centimeter (mS/cm).

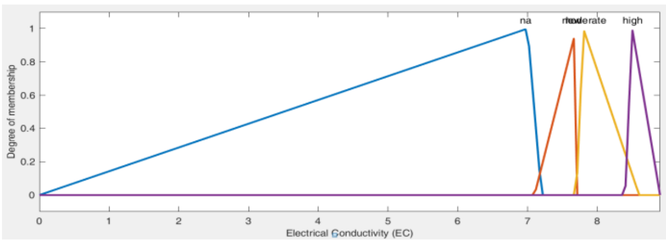

Figure 4. EC input membership functions

The TDS input MFs: high range is (5695-6164), moderate range is (5092-5628), low range is (4154-5025) and the unacceptable range is (1000-4087) as Figure 5 shown. The ranges identifies the salt concentration in terms of part per millions (ppm).

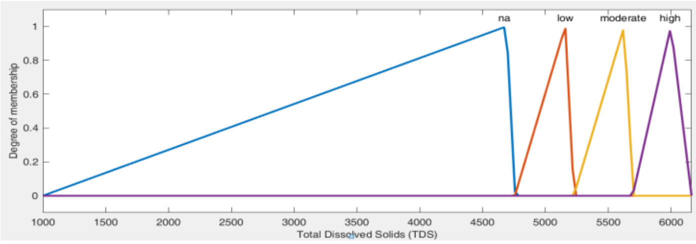

Figure 5. TDS input membership functions

The pH input MFs: The ranges identifies the low1 range is (0-6.8), good range is (6.9-8.0), and low2 range is (8.1-14) as Figure 7 shown. The ranges identifies the pH levels of the salt solution.

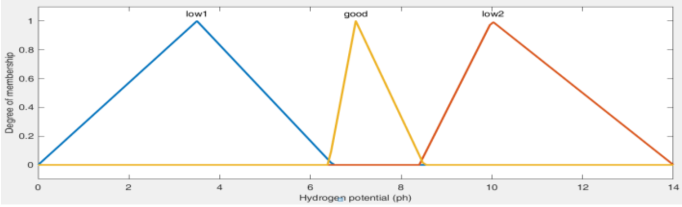

Figure 6. pH input membership functions

The QOS output MFs: The ranges identifies the unacceptable range is <70.5, poor range is 70.5-86.4, moderate range is 86.5-96.5 and good level range is 96.6-100 of the salt range of 0-100% as Figure 7 shown.

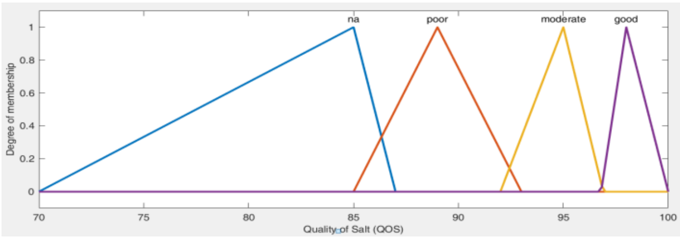

Figure 7. QOS output membership functions

2.4.2. Fuzzy Rules Implementation

The sixteen fuzzy rules were implemented during salt sample experiment using "AND" connectives to measure and estimate the quality of sodium chloride salt as figure 8 shown.

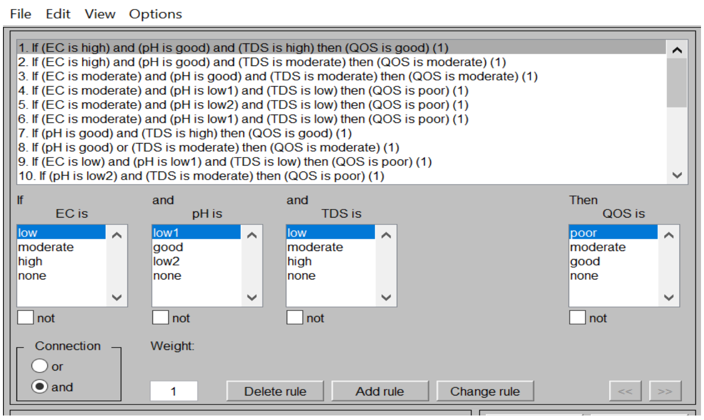

Figure 8. Fuzzy rules system

3. PROTOTYPE SYSTEM AND RESULTS

The prototype implementation based on the embedded device and ThingSpeak cloud server. The data collected through samples (S1, S2 and S3) of sodium chloride salts solution, where EC, TDS and pH sensors used as input parameters. The data collected on the samples processed and analysed locally and display the output results quality of salt interms of percentage (QOS %) of the measured salt on the LCD screen as Fig. 9-10 shown, then the sms message sent to the user's mobile phone using GSM module after data analysed [14]. Furthermore, prototype data transmitted to ThingSpeak cloud server using GSM communication module where data analysed and the results visualized on ThingSpeak dashboard and email notification sent to the user's email [15].

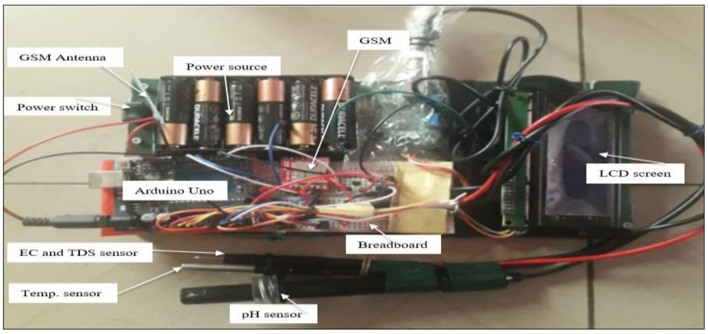

Figure 9. QOS System prototype

Figure 10. QOS LCD prototype results LCD screen

3.1. Data Collection Results and Analysis

In Table 1 represents the data generated by the prototype system during experiment of data collection of samples (S1, S2 and S3). In this study, the sample size was 278 data rows, but we presented only fifteen data rows sample in this paper as Table 1 data sample shown. Each sample has input parameters of EC, TDS and pH values that provide the output results of QOS of sodium chloride concentration in percentage. The average mean of QOS % was calculated for each sample. Therefore, the QOS status average mean of sample (S1) was about 97.8%, sample (S2) was 93.4% and sample (S3) was 82.4%. This implies that, the S1 estimated as good quality salt with high concentration of NaCl, the S2 estimated as moderate quality salt with moderate concentration of NaCl and the last sample (S3) estimated as poor quality with low concentration of NaCl. The mean (average) value, percentage error (% error) and percentage accuracy (% accuracy) of the proposed system can be calculated using the following formulae [26]:

$$\bar{\mathbf{X}} = \frac{\sum Xi}{n}$$

Where $\bar{X}$ is the mean value, Xi is the individual measured value and n is the number of measurements [26]. The percentage accuracy is equivalent to 100% minus percentage Error. Therefore, the system accuracy was about 99.7% as table 2 shown and the percentage accuracy is the percentage accuracy of the system model. This performance results demonstrates that, the system prototype was effectively able to estimate the salt quality concentration on a real-time condition.

Table 2. Data Collection Sample

Sample Repetition		Input Data Collection			Output	% Error	% Accuracy
		EC (mS/cm)	TDS (PPM)	pH level	QOS (%)		
S1	1	8.5	5705	7.5	97		
	2	8.5	5675	7.6	96		
	3	8.7	5845	7.5	99		
	4	8.7	5845	7.6	99		
	5	8.6	5774	7.6	98		
	Mean (QOS %)				97.8		

S2	1	8.1	5422	7.3	92	0.3	99.7
	2	8.2	5509	7	93		
	3	8.4	5605	7.3	95		
	4	8.2	5509	7.3	93		
	5	8.3	5531	7.4	94		
	Mean (QOS %)				93.4		
S3	1	7.2	4825	7.5	82		
	2	7.3	4864	7.4	82		
	3	7.3	4864	7.5	82		
	4	7.3	4864	7.5	82		
	5	7.2	4825	7.5	84		
	Mean (QOS %)				82.4		

3.2. Data Training and Accuracy

The Matlab Toolbox was used to train the sodium chloride salt dataset. The validation of system prototype based on the data generated during data collection. The dataset of 278-sample size used to find the prototype system accuracy, which means the good, moderate or poor quality of salt. When the dataset training was applied on fuzzy logic model, the system training error was about 0.3% as Fig. 11 shown, where % Error is the percentage error of the data trained model, experimental value is the mean value and the true value is the maximum measured value minus percentage deviation value [23]. The percentage accuracy is equivalent to 100% minus percentage Error. Therefore, the system accuracy was about 99.7% as Fig. 11 shown and the percentage accuracy is the percentage accuracy of the system model [12]. This performance results demonstrates that, the system model prototype was effectively able to estimate the salt quality concentration on a real-time condition.

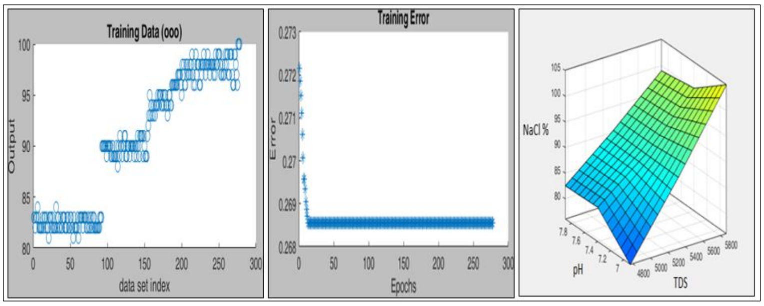

Figure 11. Data training, error and accuracy

3.3. Relationship between Prototype output and Model output Results

The performance of the prototype and model output results were measured interms of percentage. The concentration of the salt quality. The concentration of prototype and model output results for good quality salt ranges from 96-100%. The experimental measurements were carried out five times and the average for each concentration was calculated as table 1 and Figure 12 shown. The regression equation y = 0.9299x + 6.8494 had a determination coefficient R^2 of 0.9461 [12]. Therefore, the performance of the prototype system shows the concentration of the salt quality was directly proportional to the model output results concentration, and this means the prototype system performance was successfully validated.

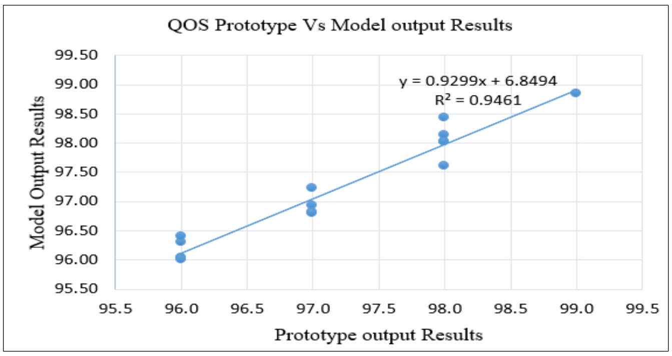

Figure 12. QOS regression concentration index

In fig. 13 and table 1 show the relationship salt concentration and TDS, the linear graph of salt concentration output variables which describe the salt quality of the sodium chloride salt solution, that means, when the TDS values increase also the salt concentration increases [12].

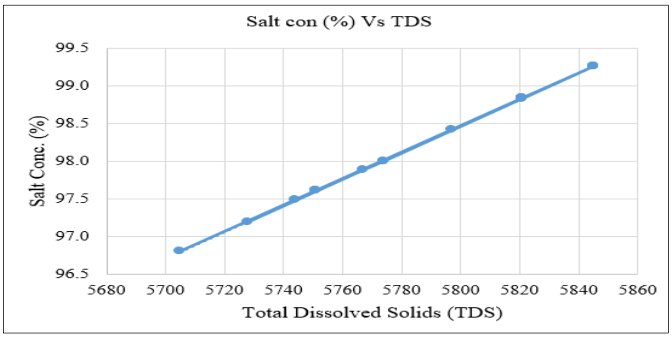

Figure 13. QOS prototype and model performance

3.4. Relationship between Sodium Chloride Salt concentration, EC and TDS variable for Good quality

The use of regression and correlation coefficient of the variables is the easy way of showing the relationship between salt concentration, EC and TDS. The regression and coefficient helps to identify the salt quality grades in the solution sample by interpreting the salt parameter values and the salt concentration values as table 2 and fig. 14-15 shown [12].

Table 3: Relationship Between Sodium Chloride Salt Concentration, Ec and TDS.

Salt con. (%)	98.4	96.8	99.3	97.2	97.6	98	97.5	97.9	97.6
TDS	5797	5705	5845	5728	5751	5774	5744	5767	5751
EC	8.7	8.5	8.7	8.5	8.6	8.6	8.6	8.6	8.5

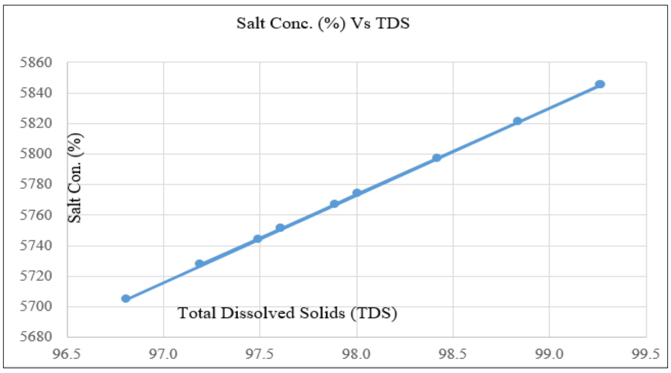

Figure 14. Salt Conc. Vs TDS

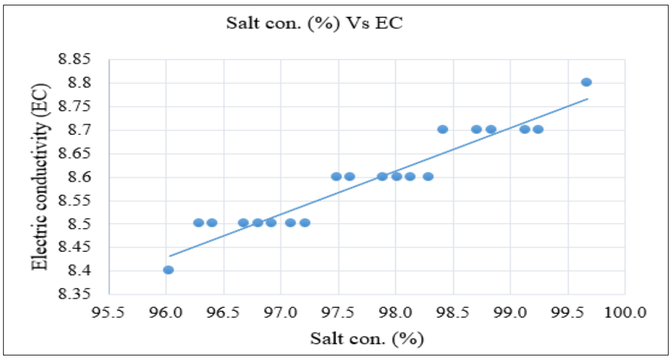

Figure 15. Salt conc. Vs EC

3.5. Thingspeak Dashboard Results

The Fig. 11-13 shows data entry values visualization results on ThingSpeak dashboard received from prototype [27]. The visualization graphs demonstrate the sensor data values collected in different sodium chloride solution samples. The Fig. 11 display the results of EC, TDS and pH sensor entries values collected from the system, these entry values show the variations of data collected from three samples of sodium chloride salt solution.

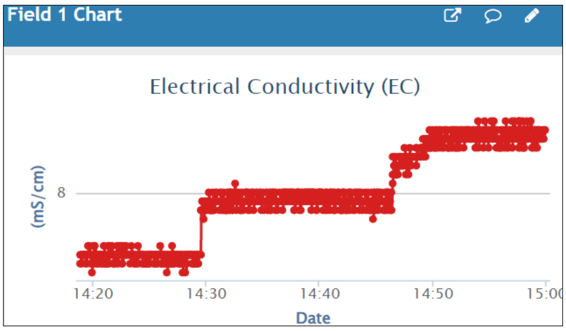

Figure 11. EC, TDS and pH input values visualization

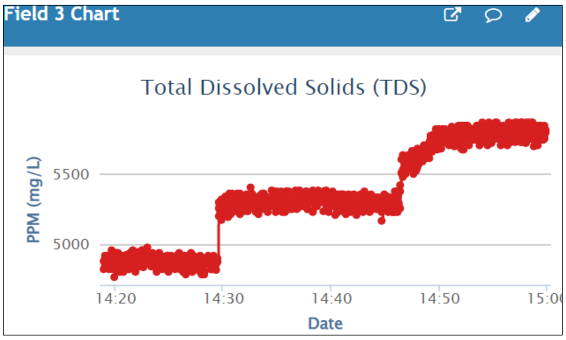

Figure 12. TDS and pH input values visualization

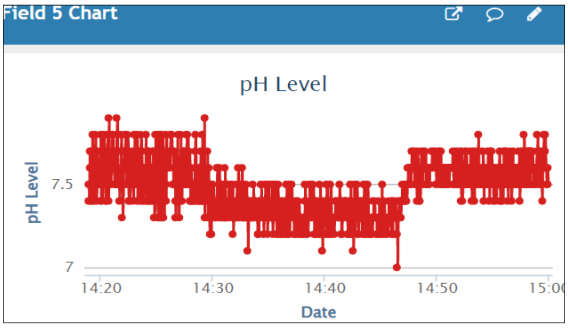

Figure 13. pH input values visualization

In Fig. 14-15 shows the NaCl concentration variation over the EC and TDS changes. It shows the relationship between EC and TDS parameter values, when the EC has low conductivity values, the TDS also shows the low concentration values interms of percentage. Therefore, whenever there is increasing of EC conductivity values the TDS concentration of sodium chloride salt increases as Fig. 12 shown [7] [27].

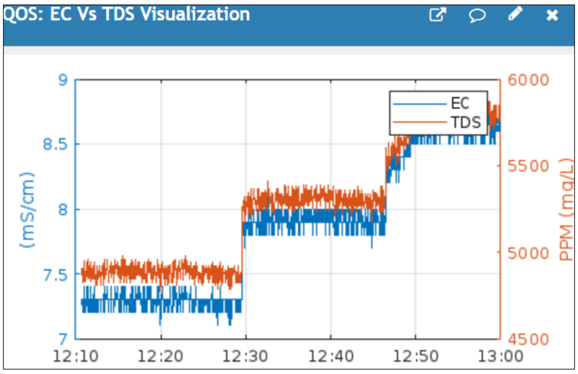

Figure 14. EC Vs TDS visualization

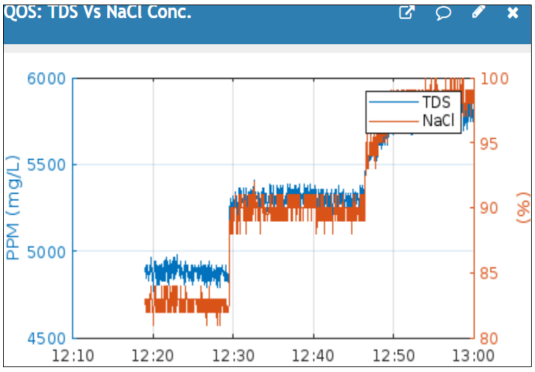

Figure 15. TDS Vs NaCl concentration visualization

4. DISCUSSION OF RESULTS

The prototype system was designed to measure and estimate the salt quality using IoT technology. The prototype can used to reduce and accelerate the process of measuring and estimate the salt quality from the salt solution sample, the system will help the salt farmers and buyers to know the salt status in real-time. The prototype composed with sensors, microcontroller to process data and provide the output results according to the salt sample measured. The GSM module communication used for data and sms transmission to the cloud server and user's mobile phone [14]. The cloud server used to store data, analytics and data visualization, the fuzzy logic system was implemented in the cloud server for email notification to users as Fig. 13 shown [15]. Moreover, the prototype system can send sms report to the user's mobile phone to know their salt status as Fig. 14 shown. The presence of this system in the salt production will increase the salt quality in Zanzibar and will help to reduce the health problems caused by the low quality of salt.

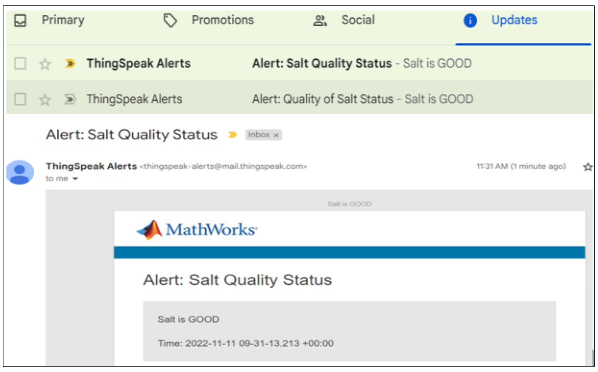

Figure13. Email notification

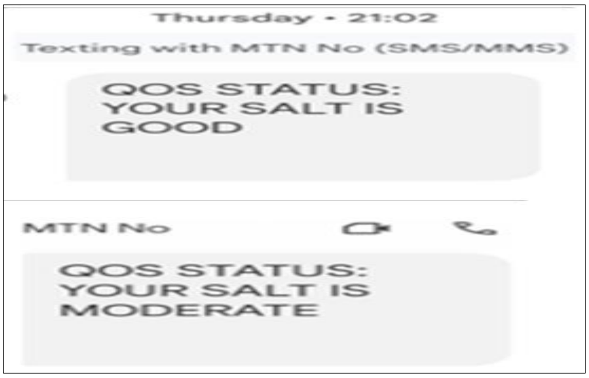

Figure14. SMS notification

5. CONCLUSION

This paper presents an IoT-based system using fuzzy logic approach for measuring and estimate of sodium chloride salt using Mamdani inference system to assist an effective measurement management of salt in the community. The significance of this study is to assist the salt farmers and buyers to know the quality of sodium chloride status for human health. The previous research study propose different methods of measuring and increasing the quality of salt, but, in this study we use an IoT based on the fuzzy logic method to measure and estimate the quality of sodium chloride salt. The thee parameters used in this approach, namely, electrical conductivity (EC), total dissolved solids (TDS) and hydrogen potential (pH) under different samples (S1, S2 and S3) data collection situations to estimate the quality of salt concentration (QOS). The IoT system intended to provide output results according to the situation of the salt measured. The QOS is the output parameter, which represents the percentage of the salt concentration and the result displayed after an appropriate condition applied, such as displaying result on LCD screen to show the quality of salt status and input parameters measured. The samples experiments were conducted for data collection using an IoT system prototype and the results obtained were 97.8%, 93.4% and 82.4% for (S1, S2 and S3) respectively. The average accuracy of the system was about 99.7% with percentage error of about 0.3%. The intended future works is to develop an intelligent fuzzy logic system based on QOS with more input and output parameters.

ACKNOWLEDGMENT

This work was supported by the African Center of Excellence in Internet of Things (ACEIoT), College of Science and Technology, University of Rwanda.

REFERENCES

[1] Jumaeri, T. Sulistyaningsih, and D. Alighiri, “Quality monitoring of salt produced in Indonesia through seawater evaporation on HDPE geomembrane lined ponds,” in *Journal of Physics: Conference Series*, 2018, vol. 983, no. 1. doi: 10.1088/1742-6596/983/1/012166.

[2] L. Wolchok, “Impacts of Salt Production on Pemba,” 2006. [Online]. Available: https://digitalcollections.sit.edu/isp_collection

[3] Ketut Sumada, Retno Dewati, and Suprihatin, “Improvement of Seawater Salt Quality by Hydroextraction Method,” Aug. 2018, pp. 172–176. doi: 10.11594/nstp.2018.0125.

[4] EAST AFRICA STANDARD, “EAST AFRICA SALT STANDARD,” *EAST AFRICAN COMMUNITY*, 2017.

[5] D. Ihsan, Istadi, and M. Djaeni, “Improving Public Salt Quality by Chemical Treatment,” *Journal of Coastal Development* , vol. 5, no. 3, 2002.

[6] CODEXSTAN, “CODEX STANDARD FOR FOOD GRADE SALT,” 2018.

[7] R. Benjankar and R. Kafle, “Salt Concentration Measurement Using Re-usable Electric Conductivity–based Sensors,” *Water Air Soil Pollut*, vol. 232, no. 1, Jan. 2021, doi: 10.1007/s11270-020-04971-7.

[8] Tony Yulianto, Siti Komariyah, and Nurita Ulfaniyah, “Application of fuzzy inference system by Sugeno method on estimating of salt production,” 2017.

[9] Yuang Chen and Thomas Kunz, “Performance Evaluation of IoT Protocols under a Constrained Wireless Access Network,” *2016 International Conference on Selected Topics in Mobile & Wireless Networking (MoWNeT)*, 2016.

[10] V. A. Wardhany, H. Yuliandoko, Subono, M. U. Harun Ar, and I. G. P. Astawa, “Fuzzy Logic Based Control System Temperature, pH and Water Salinity on Vanammei Shrimp Ponds,” in *2018 International Electronics Symposium on Engineering Technology and Applications, IES-ETA 2018 - Proceedings*, 2019. doi: 10.1109/ELECSYM.2018.8615464.

[11] Achmad Ubaidillah, Diana Rahmawati, and Rocky Aiman, “ARCHITECTURE TOOLS MEASURE THE LEVELS OF SALT AND PH OF SEAWATER USING A FUZZY LOGIC-BASED ANDROID,” 2018.

[12] IMSL, “Data Mining and Big Data: A regression model provides a function that describes the relationship between one or more independent variables and a response, dependent, or target variable.,” *https://www.imsl.com/blog/what-is-regression-model#:~:text=A%20regression%20model%20provides%20a,by%20a%20linear%20regression%20model.*, Jan. 22, 2023.

[13] Yılmaz GÜVEN, Ercan COŞGUN, Sıtkı KOCAOĞLU, Harun GEZİCİ, and Eray YILMAZLAR, “Understanding the Concept of Microcontroller Based Systems To Choose The Best Hardware For Applications,” *International Journal of Engineering And Science*, 2017.

[14] LastMinuteEngineers, “SIM800L GSM Module,” *https://lastminuteengineers.com/sim800l-gsm-module-arduino-tutorial/*, Jul. 30, 2022.

[15] Martin Foltin and Michal Blaho, “ThingSpeak-IoT Platform with MATLAB Analytics,” *Humusoft/Mathworks*, 2018.

[16] Elprocus, “Arduino Uno,” *https://www.elprocus.com/atmega328-arduino-uno-board-working-and-its-applications/*, Jul. 30, 2022.

[17] Ali A. Abdulla and Eunyong Shim, *Arduino Basic Training Manual*. 2019.

[18] Jāmiʻat al-Zaytūnah al-Urdunīyah, Universiti Sains Malaysia, and Institute of Electrical and Electronics Engineers, *Internet of Things: Architectures, Protocols, and Applications*. 2016.

[19] M. S. Mahmoud and A. A. H. Mohamad, “A Study of Efficient Power Consumption Wireless Communication Techniques,” *Advances in Internet of Things*, vol. 06, no. 02, pp. 19–29, 2016, doi: 10.4236/ait.2016.62002.

[20] Westlabblogcanada, “Difference between EC and TDS,” *https://www.westlab.com/blog/2018/01/23/what-is-the-difference-between-conductivity-ec-and-tds#:~:text=EC%20is%20looking%20at%20how,where%20the%20main%20difference%20occurs*, Jul. 30, 2022.

[21] DFROBOT, “pH sensor,” *https://www.dfrobot.com/product-1025.html*, Jul. 30, 2022.

[22] Nikhil Agnihotri, “DS18B20 1-wire temperature sensor,” *https://www.engineersgarage.com/arduino-based-water-temperature-monitor-using-ds18b20-1-wire-temperature-sensor/#:~:text=The%20sensor%20outputs%20a%20temperature,precision%20of%200.0625%CB%9AC*, Jul. 30, 2022.

[23] Pallavi Sethi and Smruti R. Sarangi, “Internet of Things: Architectures, Protocols, and Applications,” *Hindawi Journal of Electrical and Computer Engineering*, vol. 2017, no. 9324035, p. 25, 2017.

[24] C. Riverol and M. v. Pilipovik, “Assessing the seasonal influence on the quality of seawater using fuzzy linear programming,” *Desalination*, vol. 230, no. 1–3, pp. 175–182, Sep. 2008, doi: 10.1016/j.desal.2007.11.024.

[25] S. Hajji *et al.*, “Using a mamdani fuzzy inference system model (Mfism) for ranking groundwater quality in an agri-environmental context: Case of the hammamet-nabeul shallow aquifer (Tunisia),” *Water (Switzerland)*, vol. 13, no. 18, Sep. 2021, doi: 10.3390/w13182507.

[26] Chem 111-Packet, “PRECISION AND ACCURACY PRECISION AND STANDARD DEVIATION.”

[27] I. The MathWorks, “ThingSpeak and MATLAB,” *https://thingspeak.com/apps* , Jul. 28, 2022.