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WATER QUALITY ASSESSMENT USING FUZZY-LOGICIN ALBADAA CANAL, BASRAH, IRAQ

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ABSTRACT

The assessment of water is very important because the healthy system supports human life and the development of societies. Water- Quality Index WQI is a measure that gives a single value to estimate the overall quality of water taking into account specific water quality standards and time. In this research, WQI model is proposed using Fuzzy-Logicin MATLAB R2024a through the trapezoidal membership function. Thirteen variables were used to evaluate the quality; these variables were: pH, Total Hardness (T.H), Alk, Ca+2, Na+, Turbidity, Mg+2, Chloride Cl-, Electrical conductivity (E.C), So4-, TDS, TSS, K+ . Water samples taken water from AlAbbas water project, which is directly supplied from AlBadaa canal, the models were taken from 2015 to2023. The study proved the validity of the values by comparing them with the values of the traditional quality index by finding reasonable correlation R2, the Absolute. Average Relative-Error (AAR-E) and Root. Mean Square - Error (RMS-E). The Fuzzy - Logic Model (F-WQI) found reliable with the least error AAR-E= 0.025 and RMS-E= 0.378, the highest R2. The results revealed that the Fuzzy-logic Model is a practical and reliable tool that can be relied upon in assessing water quality.

KEYWORDS

AlBadaa Canal, Fuzzy- Logic System (FLS), Water - Quality Index(F-WQI), Water - Quality. Index (WQI).

1. INTRODUCTION

The Middle East has suffered from changing climate conditions such as lack of rain and drought for decades, which has led to a scarcity of surface water in many countries, including Iraq (Al-Bahrani et al., 2020). Water canal are one of the means of transporting water and delivering it from areas of water abundance, whether a river, lake, or wells to cities where consumption areas located. They are constructed in different ways depending on the intended purpose. Hence came the idea of this project, which is based on transporting fresh water from Gharraf River to the city of Basrah (Al Mahmoud & Hamidy, 2022). Since all forms of live including humans, animals and plants depend on water resources and since they are increasingly threatened by population growth and with the increasing need for high. quality water. for domestic, agricultural and economic uses, there is a growing and continuing need for water quality monitoring and assessment (Al Yousif & Chabuk, 2023).

WQI applying one of the quality indicators to evaluate water quality, it is one of the means that predicts the improvement or deterioration water quality and how natural interactions and human activities affect it, as most activities even natural ones, have multiple quantitative and qualitative effects, and any intermediate indicator must express and evaluate these effects. It explains their mutual influence among (Silvert, 2000).

The Water - Quality Index method gives one value for the quality of source water by combining a group of among the variables that describe the quality of water, and according to this value, the source is classified and the level of its quality is judged through the, approved classification, and one indicator adopted locally and globally (Nasiri et al., 2007).

Hamdan Ahmad studied the important of ground water in the southern part of Iraq, which is an important agricultural area.27 wells were chosen to determine the physiochemical properties using the (WQI). The study found that the quality of groundwater is unsuitable for domestic purposes and unfit for drinking water (Hamdan, 2017).

The digital data were converted into Fuzzy sets by developing asset of Fuzzy rules to link the input and output parameters of the overall WQI for 14 water reservoirs in Sulaymaniyah city in Iraq the validity of the Fuzzy- Logic Inference. Index (F-LII) results was verified by comparison with traditional WQI, the values showed that the water quality calculated from the F-WQI ranged between acceptable and desirable categories (Ghafour, 2023).

Researchers from Malysia and Pakistan (2008) conducted a study on the Semenyih river in western Malysia with the aim of evaluating the river water quality using the Fuzzy-Logic technique and comparing it with traditional methods for classifying river water quality used in Malaysia (WQI) between the period from1997 to 2004 where using the fuzzy model proved that the river is below the expected results calculated by the traditional method (Raman et al., 2009).

In Iran a number of researches studied in 2011 the properties of Karoon River. This study included the development of a new index (F-WQI) that represents the complex and comprehensive variable in a simple way. The fuzzy model represented the water quality with high accuracy in Karoon (Semiromi et al., 2011).

A group of researchers developed a new Water - Quality Index through Fuzzy- Logic research called the Fuzzy -Water Quality Index(F-WQI). It was compared to several indices including the NSF, (NSF-WQI) and AR-WQI. The new Water - Quality Index provides a reasonable correlation (Gonzalez et al., 2012).

Qiao ling Du in 2014 proposed a Fuzzy- Logic method for evaluating the water quality of a water storage reservoir in Northeast China to determine the water quality level through 6 criteria from 2011 to 2012, and the results mainly indicated that the Fuzzy-Logic process could be an alternative method to the traditional methods for determining the Water - Quality Index (Du et al., 2014).

Wen-Cheng Huang. Ruen. Tuen-Tyng in (2015) applied the Fuzzy-Logic index to ponds in Taiwan and compared the results with the (CTST) in Taiwan that calculates the level of trophic state index using three parameters for water quality the results concluded that using Fuzzy-Logic is suitable for determining the quality of water in the aquatic basins in Taiwan, and It can be calculated to determine the water quality resulting from hydrological phenomena. (Ruey-Tyng & Wen-Cheng, 2015).

Research at Beykavavagi pond, Turkey (2015), it developed (F-WQI) using 11 input parameters an attempt was made to remove the uncertainly encountered in traditional ways for this research with difficulties in interpreting values limit random values to Fuzzy Logic. The results were found in an easy and more understandable manner. It is expected that the Fuzzy-Logic method will be more effective in assessing water quality (Asikkutlu et al., 2015).

Research has been carried out around sites in Sinlake (2015). The parameters used are 9 types. The final results of this study indicate that Fuzzy-Logic index was distinguished from the traditional indicators by using multiple classification of water quality within the stag the first in the evaluation process (Ahmad et al., 2017).

Hamdan et al. (2021) attempted to use a Fuzzy-Logic System FLS to evaluate water quality for irrigation purposes in Basra, southern Iraq. The researchers used Richard's diagram to help classify irrigation water. The results showed that the Water - Quality Index varies depending on location and season. The researchers reached 96% agreement when comparing the results with the values obtained from Richard's diagram (Hamdan et al., 2021).

This study aims to develop a Water - Quality Index using Fuzzy-Logic system and compare it with the common WQI procedure for assessing water quality using a set of physical and chemical statistical data for the period 2015-2023 for AlBadaa Canal in Basra Governorate, Iraq.

2. STUDY AREA

AlBadaa canal is one of the industrial water canals that are used to transport fresh water from places of water abundance on the AlGarraf River to the cities of Nasiriyah and Basrah governorate confined between latitudes (300 30 26- 300 32 20) north and longitudes (460 9 50- 470 10 45) which suffer from a shortage of fresh water supplies suitable for human consumption. The length of the project is 238.5 km according to the program (Arc GIS), according to the reports of the Ministry of water Resources, is approximately 7 km for the extension of the canal in the provinces of DhiQar and Nasiriyah, respectively. The study was limited to the water reaching Basrah province at the R-Zero project. Fig. 1 shows the study area. About 144 km of it is lined with concrete and about 94.5 km was lined with selected clay soil with low salinity. The AlBadaa canal is the backbone of water projects in Basrah as a result of the high levels of salts and pollutants in the Shatt Al Arab waters (Al Mahmoud & Hamidy, 2022).

Fig. 1. AlBadaa canal location map

2.1. The important of the project

The research aims to display a reality and efficiency presentation of the AlBadaa canal to meet the needs of water consumption in Basrah city through the use of the Fuzzy-Logical Water Quality Index as a method for determining water quality and verify the results by comparing it with the traditional water quality index. It was opened in 1997 and has maintained its traditional design as an open canal ever since. It has not been closed despite the passage of 28 years since its construction. There are also parts of it that are not lined to this day, which reduces its efficiency in transporting water and increases pollutants in it.

2.2. Hydrological and climatic characteristics of AlBadaa canal

AlBadaa canal receives water from Shatt al Gharraf, one of the rivers branching off from the Tigris River therefore the amount of water drainage of the project varies according to the conditions and the hydrological condition of the Al Gharaf and Tigris rivers AlBadaa canal in Basrah is known for its natural characteristics as part of the topography of plain area with sandy and clayey soil. the general climate of the region semi-arid, characterized by extreme heat and drought which are common features in souther in Iraq which led to an evaporation losses, which affected the efficiency of the canal. The canal also passes through an oil region, which led to the frequent violations of it, which led to a decrease in its functional performationce and an increase in pollutions (Nomas & Hashim, 2021).

3. MATERIALS AND METHODS

Daily surveys are conducted as part of the continuous monitoring program for river and station water, during which raw water samples are collected. and examined in its laboratories following the required steps and as stated in American Public Health Association. New, clean, sterilized containers of sufficient size were used, leaving small spaces, samples were taken from random areas and full information was recorded on them. Samples were kept in cold storage boxes at temperature not exceeding freezing so that they would not spoil samples were transported to laboratories as soon as possible to ensure their safety (Health, 2005).

water samples taken to determine Fuzzy-Logic Water - Quality Index of AlBadaa canal. Samples was taken on a monthly basis all the year round between 2015 and 2023. The study relied 13 parameters which are PH, Turbidity, Total hardness, Alk, Ca, Na, Mg, chloride, E.C, So_4, TDS, TSS, K. the physical and chemical analyzes were carried out in the laboratory of Basrah Water Authority where raw water samples are taken from the canal and tests are conducted in its laboratories and data values used statistical parameters such as minimum, maximum, mean standard deviation of element concentrations. The actual laboratory measured chemicals are shown in Table 1. This data was used in development a model estimating the Water - Quality Index using an adapted fuzzy inference system.

Table 1 Table headings are placed above the table

Parameters	N	Minimum	Maximum	Mean	SD
Ph	108	7	8	7.95	0.220
Turbidity	108	2	45	9.55	8.838
E.C	108	883	1522	1185.82	167.762
Alk	108	100	160	116.85	15.484
T.H	108	60	304	490	406.68
Ca^{+2}	108	62	114	83.83	11.327
Mg^{+2}	108	35	65	48.23	7.172
Na^{+}	108	63	144	88.48	16.291

Parameters	N	Minimum	Maximum	Mean	SD
Cl^-	108	118	350	156.60	33.869
So_4^{-2}	108	148	358	255.72	53.365
T.D.S.	108	538	924	726.75	100.117
T.S.S.	108	18	226	71.12	48.448
K^+	108	4	10	4.6	1.251
WQI	108	65	141	80.95	20.842

4. CALCULATION OF THE WQI

The Water - Quality Index for AlBdaa Canal was evaluated from thirteen parameters calculated from water samples taken from the sites indicated in Fig. 1 to assess the suitability of the Al-Bidda Canal. The Water - Quality Index (WQI) was calculated using the arithmetic weighted Water - Quality Index (AW-WQI) method proposed by (Haridas & Antony, 2019). The water parameters are multiplied by a weighting factor, using a simple arithmetic average, resulting in AW-WQI.

The drinking Water - Quality Index (AW-WQI) is calculated using the following steps:

Find the weight (Wi) for each quality factor according to Eq.1, and the value of each factor is shown in Table 2.

$$W = K / Si \qquad (1)$$

Where: K: is the proportionality constant; Si: the Iraqi water quality factor standard according to (Water, 2001) is shown in Table 2

Table 2. Iraqi quality standard and unit weights

Water quality parameters	Unit	Standard values IQS	Relative weight (Wi)
Ph	Ph unit	6.5-8.5	0.3170
Turbidity (Tur.)	NTU	10	0.2700
E.C	µs/cm	1000	0.0027
Alk	mg/ l	123	0.0219
TH	mg/ l	500	0.0054
Na+	mg/ l	200	0.0135
Mg^{+2}	mg/ l	50	0.0540
Ca^{+2}	mg/ l	125	0.0181
Cl^-	mg/ l	250	0.0108
So_4^{-2}	mg/ l	400	0.0067
T.S.S.	mg/ l	60	0.0450
T.D.S.	mg/ l	1000	0.0027
K	mg/ l	12	0.2250

Calculation of the sub index the ith parameter:

$$Qi = ((mi - Vi) / (Si - Vi)) * 100 \qquad (2)$$

Where: Qi: is the quality rating of the parameter for a total of water quality parameters; mi: is the measured value of the quality parameter; Vi: is the ideal value (Ph and Dissolved Oxygen are assumed to be equal to (7 and 14.6 mg/L, respectively), while the remaining factors are zero).

Calculation of the Water - Quality Index by the following formula:

$$WQI = \sum_{i=1}^{n} \frac{Wi\,Qi}{\sum_{i=1}^{n} Wi} \quad (3)$$

The water quality classes based on (AW-WQI) are displayed i

Table 3 Recommended Iraq standard of the water quality parameter for drinking water. The number obtained from applying the index is classified in five scale categories depending on Iraqi quality standard in Table 3.

Table 3. Classification of water quality according to WA-WQI (Sabeeh et al., 2023)

Quality	Excellent	Good	Medium	Bad	Very bad
Rang	0 – 50	51 – 70	71 – 90	91 – 100	Greater than 100

5. MODELING THE WATER - QUALITY INDEX USING AN ADAPTED FUZZY INFERENCE

Fuzzy-Logic Interferometer System (F-LIS) is a rule-based system that represents and presents various types of knowledge by modeling complex problems in a state of certainty and uncertainty using fuzzy logic Fig. 2 (Ewaid et al., 2018).

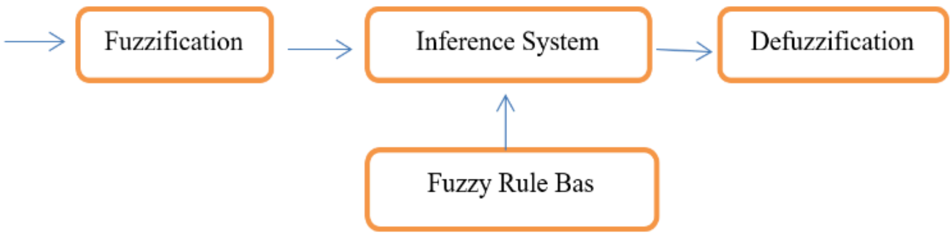

Fig. 2. The system components of F-LIS

This study used a method to develop a Water - Quality Index F-WQI model using MATLAB R2024a to simulate the system. The F-LIS is a method for determine the corresponding between inputs and outputs using Fuzzy-Logic as a basis for decision taken. F-LIS includes three basic steps: inference rules, membership functions, and fuzzy set operations. A membership function is a curved function that describes how each point in the available input space is mapped to a membership function at parameter (0,1), the input space is known as the universe of discourse and the membership rate is known as the output axis (Mamdani, 1976; MathWorks, 2013; Ross, 2010).

In this study, the system included 80 rules, 13 inputs, and one output, which is Water - Quality Index ranging from (0 - 100), Table 3. F-LIS used for the Iraqi river waters and giving results for the water quality that is classified into five types described through the functions of the organic planning for the linguistic variables, Fig. 3.

The input parameters are classified into three classes, high medium and low, which is shown by a trapezoidal membership function to see how to plot points in each variable while the output function F-WQI is divided into 5 classes Excellent, Good, Average, Bad, and Poor. The membership function is designed as shown in Fig. 4.

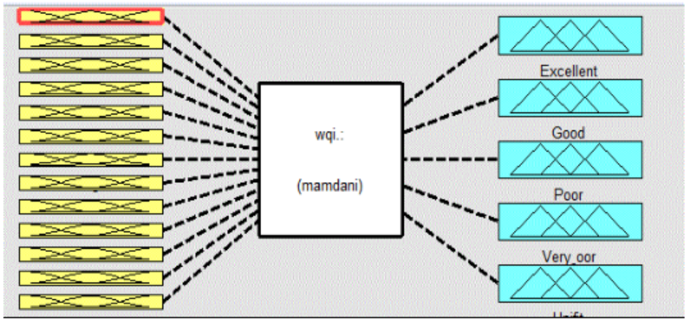

Fig. 3. Membership function of F-WQI

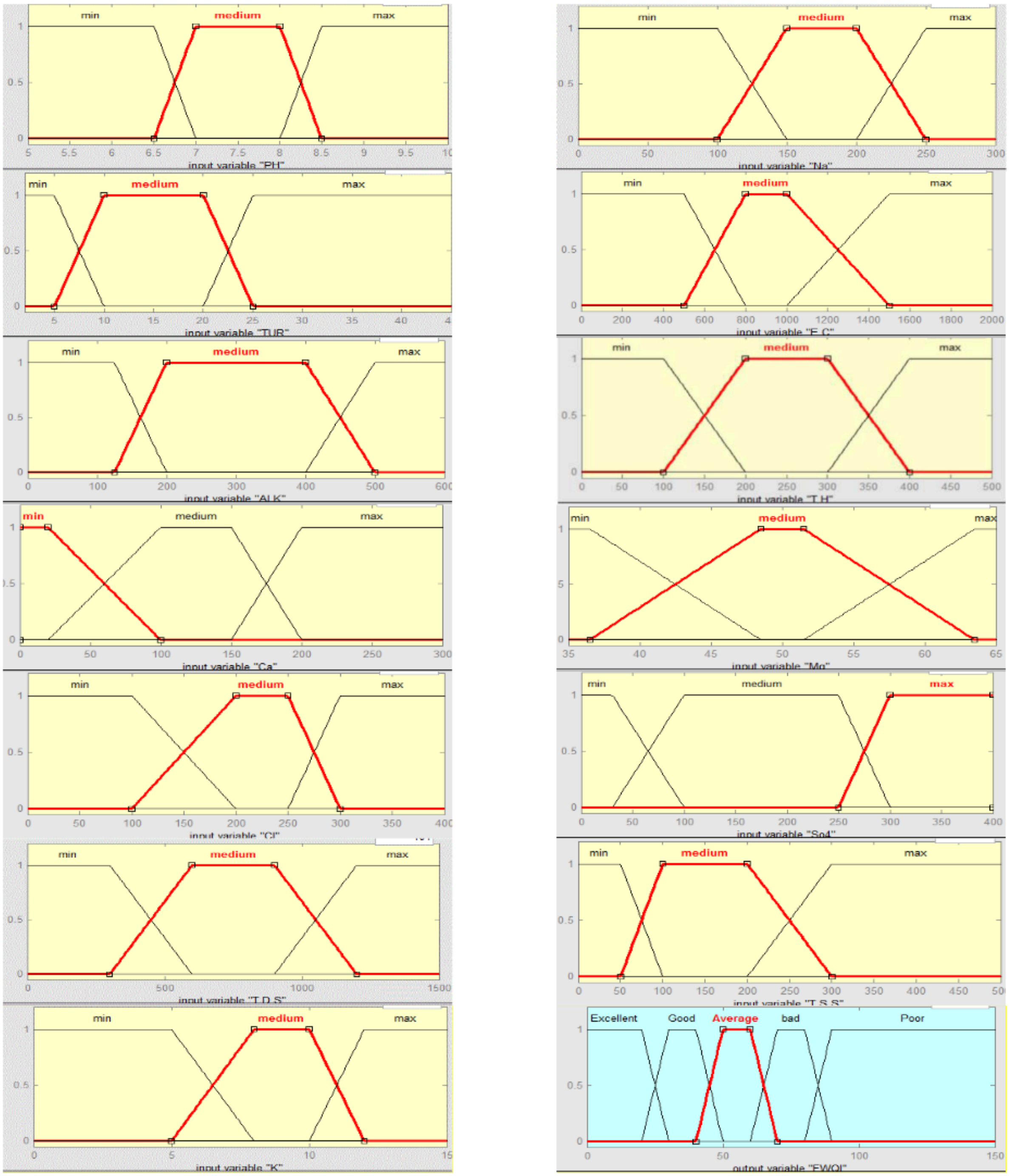

Fig. 4. The membership function for the inputs and the output F-WQI

The embedding method used to generate rules is minimal and the aggregation method is maximal, if-then is the origin of the inference rule generator, which has one or more antecedents, and is joined by the linguistic operator "and" for example: If pH is medium and Tur., E.C, Alk, T.H, Ca, Mg, Na, Cl, So_4, T.D.S, T.S.S, and K are all minimum the water quality is excellent rest of the rules were created in the same way Fig. 5 shows the MATLAB rules viewer which utilized in F-LIS.

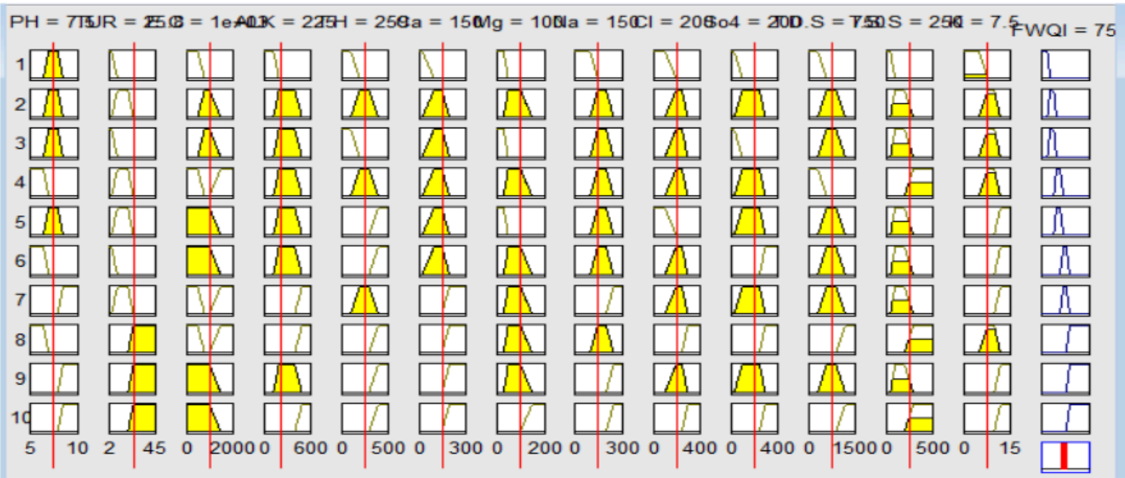

Fig. 5. MATLAB rules viewer shows inputs and output in F-LIS

6. RESULTS

The water quality for AlBadaa canal was evaluated using the application of F-WQI. Data sets (2015-2023) from water resources department of Basrah. The calculated of F-WQI indices according to fuzzy inference system (FIS) are compared with the actual values calculated from Eq. 3. Fig. 6 is considerate that WQI an acceptable indicator in the years (15, 16, 17, 18) but the water efficiency began to decline for the years (19, 20, 21, 22, 23). This is due to variation in the concentration of qualitative variables of the AlBadaa river during the study period. Among them a temporal variable that occur between the seasons of the year, which are the Tigris River and the branch, the AlGarraf stream. This is due to the amount of water revenue that increases during the winter and spring and decreases during summer and autumn, in addition to the climatic conditions and the amount of feeding from the water surface, F-WQI values fall within the permissible limits during the first four years because the permissible are within the standard limits while they are within the poor values for the last five years due to the increase in the value of some competitive indicators.

6.1. WQI Validation

The validity of the results calculated by the WQI method and resulting from the use of the Fuzzy-Logic program was verified in two ways

To verify the validation two indices Fig. 7 was used to validate the proposed models and it was obtained $R^2 = 0.86$ this index that there is a correlation value close to 1, and thus a good, more stringent indicator of classification performance was developed. The fuzzy index has proven effective in avoiding the loss and change of important information in water quality classification, the study period more than the permissible values a portents information in water quality classification examples turbidity, T.D.S, T.S.S, K^+ this include the values that were given much higher than the permissible values during the study area period.

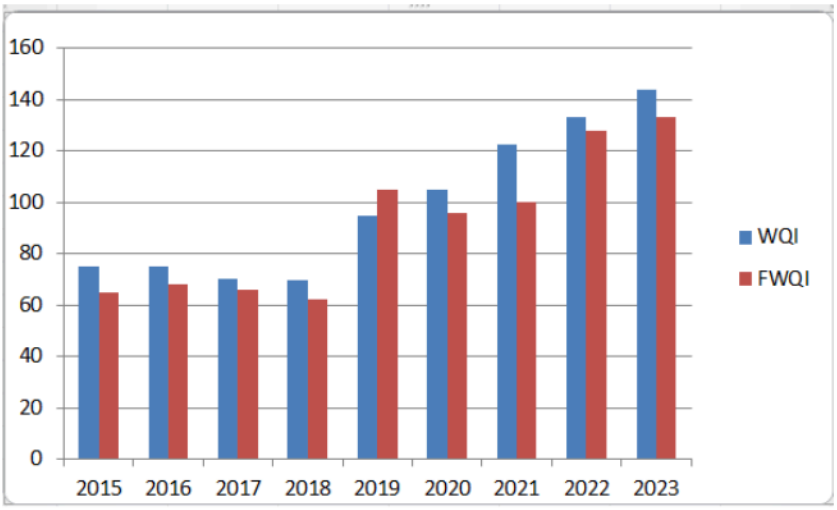

Fig. 6. Comparison between values of F-WQI and observed WQI

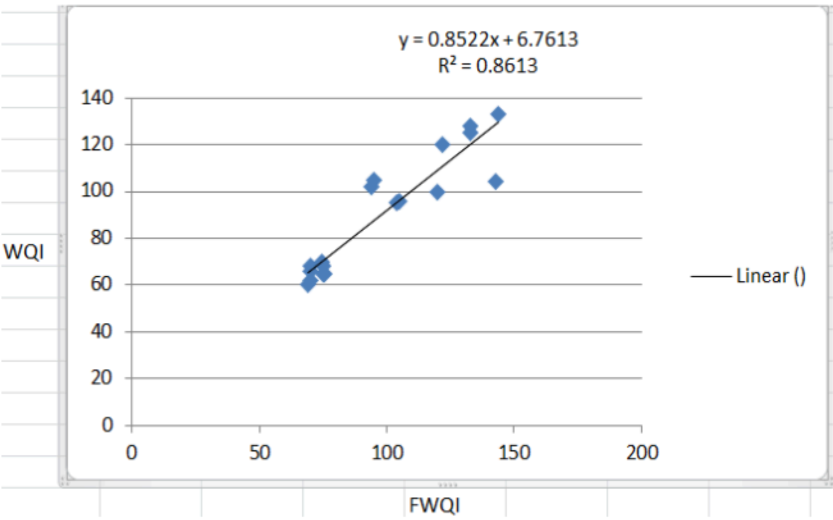

Fig. 7. Linear correlation between the values obtained by F-WQI and WQI

Using Root Mean Square Error (RMSE), Average Absolute Relative Error (AAR-E).

The data were combined to extract a single annual average value consistency extracted from Fuzzy-Logic was statistically verified with the traditional results using RMS-E and AAR-E using Eqs. 4, 5 (Lokman et al., 2025).

$$RMSE = \sqrt{\sum_{i=1}^{n}(Pi - Oi)|}\ /n \tag{4}$$

$$AAR - E\ \% = \frac{1}{n}\sum_{i}^{n}\frac{Pi - Oi}{Pi} * 100 \tag{5}$$

n is the number of observation in the data dataset; Pi is the actual values (WQI); Oi is the predicted value (F-WQI), values of RMS-E, AAR-E as shown in Table 4

Table 4. Statistical comparison of the results

Years	WQI	RMSE	AAR-E
1915	58	0.918	0.051
1916	72	0.117	0.014
1917	62	0.255	0.032
1918	70	0.238	0.028
1919	77	0.228	0.026
1920	105	0.291	0.028
1921	98	0.202	0.020
1922	102	0.296	0.029
1923	121	0.890	0.020
	Sum	0.378	0.025

7. CONCLUSION

The study included the development of index which called F-WQI (fuzzy water quality index), it is a comprehensive and simple representation of complex physical and chemical variables that control the water quality of AlBadaa canal.13 quality criteria were used (ph, Turbidity, E.C, Alk., T.H, mg^{+2}, Na^{+}, Ca^{+2}, Cl^{-}, , TSS. TDS, So_4^{-2}, K^{+}). The fuzzy model proved that water quality is highly potential when compared to the mathematically calculated results in AlBadda Canal. It is believed that the new model will help decision makers and officials in determine the quality of water and studying different variables in the canal. The study showed that most values of F-WQI for AlBadaa canal ranged from good to bad to very bad. There are many reasons that lead to the deterioration of water quality in the canal, including:

Discharge of pollutions from sewage industrial and agricultural waste that flow into the canal during joining to Basrah that led to reduce water quality by increasing in the percentage of pollutants, the values of Mg has reached to 65 mg/l, and E.C 1522 mg/l.

Dense vegetation growth along the canal path.

The erosion of the outer slopes is part of the dam as a result of wind, erosion, which led to an increase in salts and suspended matter Where the TSS rate reached to 226 mg/l, turbidity 45 mg/l.

Some concrete slabs lining the canal fell for long distance, which led to the collapse of soil and the slopes.

The passage of the canal through areas passing through oil wells led to the presence of a danger and increased oil pollution of the water of AlBadaa canal in Basrah needs intensive treatment to control pollution before it is used for human consumption and other life purposes.

The canal is close to gypsum soils that dissolve quickly which lead to decrease in discharge and an increase in the amount of salts as we head south towards Basrah.

High percentage of sediment in the storage basin, most of which are fine, clay particles, silt and sand.

AlBadaa canal is affected by the hot climate of Basrah in the summer, which leads to increased amount of evaporation that reaches 0.1125m3/sec.

Therefore, it is recommended to convert the canal from an open canal to asset of piped to reduce the percentage of loss due to seepage and evaporation and reduce pollutants entering from the areas surrounding it.

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