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Quantifying Canadian Water Quality Index in Alhindya Barrage, Euphrates River

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Abstract. Recently, water quantity is decreasing due to high temperatures in summer and reducing the water quotas of Euphrates River in Iraq from the neighboring countries. These factors may increase turbidity and concentration of elements in Euphrates River especially near Alhindya Barrage, Babylon Governorate, Iraq. Thus, Euphrates River may not be valid for drinking and irrigation purposes in upstream of Alhindya Barrage. The aim of this study was to investigate the water quality upstream of Alhindya Barrage, Euphrates River, using Canadian Water Quality Index (CWQI). The comparison of water quality was investigated in the years of 2008 and 2009 according to data availability. Statistical analysis were performed on measured flowrates and indicated that there is a statistically significant difference between measured flowrates for 2008 and 2009. The results showed that the CWQI of 2008 was 94 which is good to excellent water quality, compared to CWQI of 79 for 2009. This was due to reduction in mean water quantity from 370m^3/s of 2008 to 213m^3/s of 2009. The global warming phenomenon is the main reason for dry seasons and low rainfall intensity and caused bad water quality.

Keywords: Alhindya Barrage, Canadian water quality index, Euphrates River, Global warming, Water quality

1. Introduction

The stressed in worldwide water resources for drinking, food protection, and environmental protection increased due to world population growth. Water shortage problems are even more challenging in arid and semi-arid countries such as Iraq. Due to decreasing in recharge of Euphrates and Tigris Rivers, Iraq is facing water shortage problems in near future [1]. Two main reasons are behind for the water shortage problems in Iraq; dams on Euphrates and Tigris Rivers that built in neighboring countries (Turkey and Iran) that cutoff most of flow to Iraq, and global warming phenomenon [1]; [2]. Therefore, studying the water quality indexes for drinking water purpose in Euphrates and Tigris is needed to ensure drinking water in the near future.

They are several water quality indexes to investigate the water quality for drinking usage. One of the most useful and worldwide used water quality indexes is Canadian Water Quality Index (CWQI). The CWQI was investigated by Canadian Council of Ministers of the Environment. Several local researches were investigated and utilized CWQI or/and Water Quality Index (WQI) in Euphrates and Tigris to inspect the drinking usage for these rivers [3]; [4]; [5]; [6]; [7]; [8]; [9]; [10]; [11]. Al-Saboonchi et al.

[3] studied the Water quality using CWQI in east of Hammar Marsh, Tigris River. They tested serval parameters included; water temperature, dissolve oxygen (DO), Salinity, pH, Total Nitrogen (N^+), Ammonia (NH_3), Nitrate (NO_3), Phosphate (PO_4), and Sodium (Na). The CWQI of east Hammar Marsh was poor during 2005-2006. This leads to that the marsh may depart from natural and desirable levels particularly in respect to Na and N^+ compounds. Al-Saboonchi et al. [3] concluded that the marsh region is still far away from the standards. Al-Mhammed and Mutasher [4] investigated the water quality indicator (WQI) to predict the quality of groundwater for drinking usage in Dibdiba Aquifer, Karbala, Iraq. They tested 20 wells to estimate multiple variables. They concluded that the WQI was between 184.5 to 432.6 mg/l which is higher than the agreeable standard (100 mg/l). Al-Mhammed and Mutasher [4] concluded that the groundwater was not suitable for drinking usage. Abbood et al. [5] studied 15 variables using the CWQI at 10 sections of Main Drain River, Iraq, during 2004-2011. These variables were pH, Sulfate (SO_4^{-2}), NO_3, Chloride (Cl^{-1}), Total Hardness (TH), Calcium (Ca), Magnesium (Mg), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD_5), DO, Conductivity, Na, and Potassium (K). The path of Main Drain River started from Baghdad through Babylon, Qadiysiah, ThiQar, and finished in Basrah. Abbood et al. [5] concluded that CWQI of the river ranged from 26.6 to 35.5 which is indicated the worst water quality due to impact of these pollutants.

Furthermore, Ali et al. [6] performed nine water quality indices through 2015 to 2016 on Tigris River within Waist Government. The results revealed that the water quality of Tigris River ranged from moderate to good pollution. Muftin et al. [7] investigated the influence of power plant at Tigris River, Al-Zafaraniya city, Baghdad, using CWQI. The results of this study conducted that there was a significant impact of the power plant effluents on increase of water temperature, turbidity, electrical conductivity, and phosphate concentrations. Ewaid et al. [8] studied water quality index on ten stations within Tigris River, Baghdad City. Eleven important parameters were investigated and regression analysis was developed. The results indicated that water quality was considered as unsuitable for drinking. Abbas and Hassan [9] assessed the water quality of the Diwanyiah River via CWQI from September of 2015 to June of 2016 at four locations acquired across the river. Abbas and Hassan [9] tested ninth variables including: water temperature, pH, DO, TDS, Turbidity, Alkalinity, NO_3, Nitrogen Dioxide (NO_2), and PO_4. They evaluated the water quality to protect the water life. Abbas and Hassan [9] found that the CWQI was provided poor the water quality in Diwanyiah River based on the ninth variables. Majeed [10] investigated the CWQI of water quality in Bani-Hassan River, branch of Euphrates, Alhindya Barrage, Iraq. They found that the CWQI was 75 to 79 which is categorized as fair water quality. Madhloom and Al-Ansari [11] used Geographic Information System (GIS) integrated with WQI to evaluate the water quality of The Diyala River, within Baghdad City, for drinking use from January to December of 2016. They measured TDS, TH, SO_4^{-2}, DO, and BOD_5 and found that these parameters were higher than the permissible limits specified by Iraqi standards. Several other recent studies were also performed CWQI around the worldwide [12]; [13].

Recent study by Hommadi and Dahir [14] found that the reduction in water level in upstream of Alhindya Barrage, Euphrates River, Iraq, caused an increase in sediment of shallow water river section. This may be influence in the water quality of upstream of Alhindya Barrage. Preceding studies have not investigated the water quality upstream of Alhindya Barrage, Euphrates River. The aim of this study was to investigate the water quality upstream of Alhindya Barrage, Euphrates River, using Canadian Water Quality Index (CWQI). The following parameters was tested and compared in CWQI in order to investigate the water quality for drinking usage: Electric Conductivity (EC), Total Hardness (TH), pH, Total Dissolved Solids (TDS), Calcium (Ca), Magnesium (Mg), Sodium (Na), Chloride (Cl^{-1}), Sulfate (SO_4^{-2}), and Nitrate (NO_3).

2. Study Area, Experimental Work, and Methodology

The tested parameters conducted on upstream of Alhindya Barrage, Euphrates River, Alhindiya Township, Babylon Governorate, Iraq. The study area located in 44̊43' 42 N and 44̊16' 8.0'' E as shown in Figure 1. This project belongs to State Commissions for Dam and Reservoir, Alhindiya Township, Babylon Governorate, Iraq.

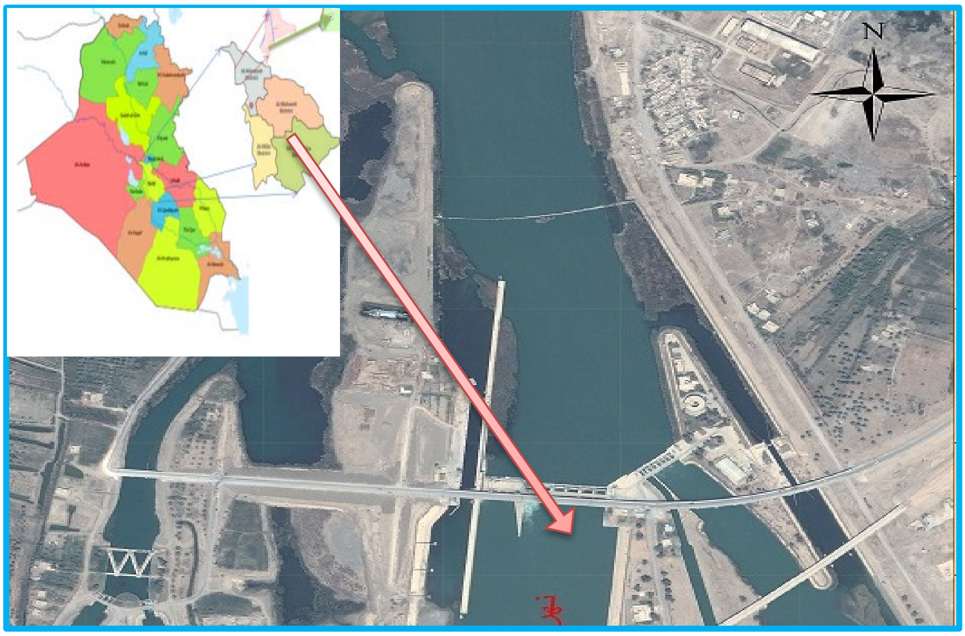

Figure 1. Location of study area Alhindya Barrage, Euphrates River, Babylon Governorate, Iraq.

According to data availability, the data was acquired in years of 2008 and 2009. The parameters of Water Temperature, Electric Conductivity (EC), Total Hardness (TH), pH, Total Dissolved Solids (TDS), Calcium (Ca^{+1}), Magnesium (Mg^{+1}), Sodium (Na^{+1}), Chloride (Cl^{-1}), Sulfate (SO_4^{-2}), and Nitrate (NO_3), were tested in the laboratory of Alhindya Barrage.
The Water Temperature was measured by Mercury Thermometer (Hanna Company). The temperature was acquired each five minute. The pH (measuring of acidity and alkalinity) was measured using pH meter. The pH meter is a SUP-pH6.0 Model with 4 to 20 mA analog signal, RS-485 digital signal, and ability to measure pH of 0 to 14 at temperature of 0 to 100 C°. The device is used for industrial processes and water treatment processes pH control. Atomic Absorption Instrument was used to measure Ca^{+1}, Na^{+1}, Cl^{-1}, SO_4^{-2}, and NO_3. They are five element components of Atomic Absorption Instrument which are; light source, absorption cell, monochromator, detector, and display to the reading of the results. The EC, Turbidity, and TDS were measured using portable digital (type CG857, YSI incorporated 650 MDS device) (Figure 2). This portable digital device contains digital monitor which was able to test and read the results after taking the water sample. The TDS was determine from TDS = 0.64 *EC. The Total Hardness (TH) was measured using method of Lind [15] by adding 25 milliliter of sample into 50 milliliter of mitigation distilled water. The Calcium was tested using Lind [15] methodology. Accordingly, the Magnesium was determined by followed the American Public Health Association [16] using the following equation:

$$\text{Magnesium in (mg/l)} = 0.243 * [\text{TH (as } CaCO_3/l) - \text{Calcium (as } CaCO_3/l)] \quad (1)$$

The results of water samples were recorded daily and then they were incorporated in Microsoft Excel Software to be analyzed.
The flowrate is quantity of water transport from upstream to downstream of the river or stream and measuring in m^3/s. The subsection of cross-section area of river and corresponding velocity section were used to measure the flowrate in the upstream of Alhindya Barrage. The Acoustic Doppler Current Device (ADCP) was utilized to measure velocity section as shown in Figure 3. The flow velocity was determined by measuring the velocity at 0.8d and 0.2d, where d is the water depth. For shallow depth, the velocity was measured at 0.6d. The flowrate was measured by multiply velocity of each section by the corresponding area.

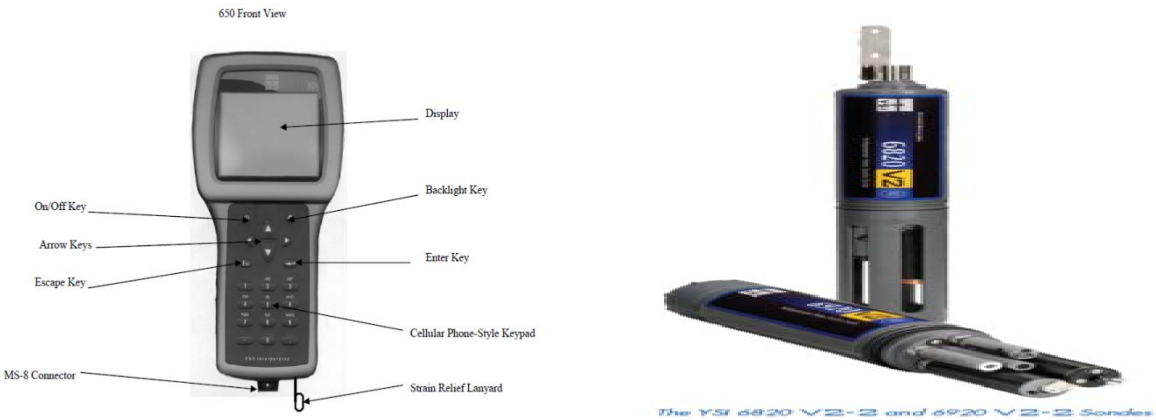

Figure 2. The portable digital of YSI incorporated 650 MDS device to measure Electrical Conductivity (EC), Turbidity, and Total Dissolved Solids (TDS).

Figure 3. The Acoustic Doppler Current Device (ADCP) to measure velocity section at upstream of Alhindya Barrage.

a) b)

Figure 4. a) Stuff gauge setup, and b) Radar Level Recorder setup.

There are automatic calculating devices was used in upstream and downstream of Alhindya Barrage to calculate the water level. The stuff gauges was also setup in upstream and downstream of Alhindya Barrage to ensure identical reading of water levels. The Radar Level Recorder (SUTRON instrument) was also recorded water level and sent the required information via Satellite to National Center. These instruments were setup in three stations. Two stations were installed in upstream and downstream of Alhindya Barrage, Euphrates River, and the third station was setup on Alhila River (Figure 4).
The Canadian Water Quality Index (CWQI) theory is based on the British Columbia Ministry of Environment formula which is modified by Alberta Environment. The CWQI included three variables elements: the scope F_1, which is the number of variables not meeting the water quality objectives, the

frequency, F_2, which is the number of tests of the objectives are not meeting the water quality objectives, and the amplitude F_3, which is the amount that the objectives are not meeting the water quality. The CWQI obtains a value between zero as polluted water quality and 100 as excellent water quality. The formula of estimating F_1, F_2, and F_3 are expressed as follows [17]:

$$F_1 = (\frac{\text{Number of failed variables}}{\text{Total number of variables}}) * 100 \quad (2)$$

$$F_2 = (\frac{\text{Number of failed tests}}{\text{Total number of tests}}) * 100 \quad (3)$$

$$F_3 = (\frac{NSE}{0.01\, NSE + 0.01}) * 100 \quad (4)$$

$$NSE = (\frac{\sum_{i=1}^{n} excuration\ i}{\text{Number of tests}}) \quad (5a)$$

$$excuration\ i = \left(\frac{\text{Faild test value } i}{\text{Objective } j}\right) - 1 \quad (5b)$$

$$excuration\ i = \left(\frac{\text{Objective } j}{\text{Faild test value } i}\right) - 1 \quad (5c)$$

where, *NSE* is the normalized sum of excursions, *n* is total number of variables, and *i* and *j* are an iteration. Accordingly, the CWQI is expressed as:

$$\text{CWQI} = 100 - (\frac{(\text{F1}^2+\text{F2}^2+\text{F3}^2)^{1/2}}{1.732}) \quad (6)$$

Table 1 reported the CWQI standard values according to Canadian Council of Ministers of the Environmental [17] to evaluate the water quality.

Table 1. The CWQI standard values according to Canadian Council of Ministers of the Environmental [17].

Rank	CWQI values
Excellent	95-100
Good	80-94
Fair	65-79
Marginal	45-64
Poor	0-44

The measured flowrates for 2008 and 2009 were statistically examined using the analysis of variance (ANOVA) technique within SigmaPlot 12.5 Software. The descriptive statistics for measured flowrates of 2008 and 2009 was reported the mean, standard deviation, standard error, maximum, minimum, 25% percentile, and 75% percentile. The paired t-test method for pairwise comparison was suggested by the Software. The paired t-test revealed a significant difference compared to ANOVA with a significance level of P-value less than 0.05 [18]; [19]; [20]; [21]; [22].

3. Results and Discussions

Table 2 shows the measured parameters of pH, Total Dissolved Solids (TDS), Calcium (Ca), Magnesium (Mg), Sodium (Na), Chloride (Cl^{-1}), Electric Conductivity (EC), Nitrate (NO_3), Sulfate (SO_4^{-2}), and Total Hardness (TH) from June of 2008 to December of 2008. It is clear from Table 2 that all measured parameters were within the Iraqi standard, excluded the measured Sulfate in June, 2008 and December, 2008. The values of SO_4^{-2} were 499 and 420 ppm for June and December of 2008, respectively, which were higher than the Iraqi standards of 400 ppm. These values should be checked by CWQI.

Table 2. The measured parameters of pH, Total Dissolved Solids (TDS), Calcium (Ca), Magnesium (Mg), Sodium (Na), Chloride (Cl^{-1}), Electric Conductivity (EC), Nitrate (NO_3), Sulfate (SO_4^{-2}), and Total Hardness (TH) from June of 2008 to December of 2008.

Date	pH	TDS, ppm	Ca, ppm	Mg, ppm	Na, ppm	Cl^{-1}, ppm	EC, mg/l	NO_3, ppm	SO_4^{-2}, ppm	TH, ppm

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June	8.10	842	12.9	46.5	NA*	101	1133	NA*	*499*^	223
July	7.70	812	0.5	44.6	NA*	117	1169	NA*	278	184
August	7.84	844	7.0	48.7	NA*	117	1155	NA*	257	182
September	7.85	772	10.4	10.4	150.5	117	1125	0.35	266	188
October	8.13	819	7.1	49.3	90.3	120	1150	0.83	325	210
November	8.14	994	9.3	58.5	106.5	132	1262	0.75	313	250
December	8.15	996	26.9	72.7	165.5	174	1430	1.35	*420*^	365
Iraqi Standards	6.5-8.5	1000	150	100	200	350	1563	50	400	500

*Not available.
^The italic number represents the measured parameter is higher than the standard.

Table 3. The measured parameters of pH, Total Dissolved Solids (TDS), Calcium (Ca), Magnesium (Mg), Sodium (Na), Chloride (Cl^{-1}), Electric Conductivity (EC), Nitrate (NO_3), Sulfate (SO_4^{-2}), and Total Hardness (TH) from January of 2009 to December of 2009.

Date	pH	TDS, ppm	Ca, ppm	Mg, ppm	Na, ppm	Cl^{-1}, ppm	EC, mg/l	NO_3, ppm	SO_4^{-2}, ppm	TH, ppm
January	8.05	900	22.4	68.3	134	152	1404.5	1.15	340	336
February	7.95	918	13.8	59.6	123	147	1319.5	1.25	313	279
March	7.95	894	14.5	63.1	122	334	1303.5	0.80	334	295
April	7.97	867	8.3	49.7	103	142	1178.5	0.90	234	210
May	8.03	*1024*^	145.3	54.6	114	155	1405.0	0.25	372	*587*^
June	7.89	*1200*^	147.3	48.8	93	153	1375.0	1.50	*439*^	*569*^
July	7.55	*1156*^	150.0	65.6	131	165	*1570.0*^	2.50	*431*^	*624*^
August	7.79	*1146*^	*176.0*^	50.3	121	138	1519.5	2.40	*447*^	*647*^
September	7.96	*1122*^	*156.0*^	65.9	NA*	145	*1593.0*^	0.05	*456*^	*662*^
October	7.56	632	115.0	40.6	NA*	159	*1603.0*^	0.60	*426*^	456
November	7.90	*1048*^	113.3	57.3	NA*	144	1426.0	1.03	342	*519*^
December	7.90	*1002*^	147.0	62.5	NA*	138	1318.5	0.70	365	*625*^
Iraqi Standards	6.5-8.5	1000	150	100	200	350	1563	50	400	500

*Not available.
^The italic number represents the measured parameter is higher than the standard.

Table 3 shows the measured parameters of pH, TDS, Ca, Mg, Na, Cl^{-1}, EC, NO_3, SO_4^{-2}, and TH from January of 2009 to December of 2009. It is clear from Table 3 that most of measured parameters that have values more than Iraqi standards which were measured during May to September of 2009. These parameters are TDS, Ca, EC, SO_4^{-2}, and TH. Even in November and December of 2009, some parameters were higher than the Iraqi standards such as TDS and TH. These values should be checked by CWQI in order to investigate the water quality for drinking purpose.

Table 4 shows the scope F_1, which is the number of variables that are not meeting the water quality objectives, the frequency, F_2, which is the number of tests of the objectives that are not meeting the water quality objectives, the amplitude F_3, which is the amount that the objectives are not meeting the water quality, and Canadian Water Quality Index (CWQI) for years of 2008 and 2009. Based on the results of F_1, F_2, and F_3, the CWQI for 2008 and 2009 were 94, which is represented good water quality, and 69, which is represented fair water quality for drinking purpose, respectively. The reduction in flowrates from 2008 to 2009 plays significant role in the values of measured parameters as discussed in the next paragraph.

Table 4. The values of F_1, F_2, F_3, and Canadian Water Quality Index (CWQI) for years 2008 and 2009 that proposed in this study.

Year	F_1	F_2	F_3	CWQI	Description
2008	10	3.13	0.46	94	Good
2009	50	20.69	2.46	69	Fair

The monthly flowrates in upstream of Alhindiya Barrage for years of 2008 and 2009 is shown in Figure 5a. Figure 5b reports the flowrates versus corresponding water depth in upstream of Alhindiya Barrage. Note that the high flowrates from June through September is due to that the most of flowrates were released from the planning reservoir storage and not from actual flowrate of Euphrates River. This was to cover the needed requirements for drinking, aquiculture, and industrial during shortage time (summer season). The analysis of variance (ANOVA) technique using descriptive statistics reported the mean, standard deviation, standard error, maximum, minimum, 25% percentile, and 75% percentile of 415.92 m^3/s, 88.28, 25.48, 586.00 m^3/s, 283.00 m^3/s, 344.75, and 487.25 for flowrates of 2008 and 274.83 m^3/s, 48.38, 13.97, 370 m^3/s, 213, 231.25, and 311.25 for flowrates of 2009, respectively. The pairwise multiple comparisons using paired t-test indicated that there is a statistically significant difference between measured flowrates for 2008 and 2009 with P-value of less than 0.001. There is a strong relationship between the measured flowrate and the CWQI. Figure 6 shows the reduction of discharge influence on water quality and increasing concentration of elements. As flowrate decreased in 2009 in comparison of 2008, the CWQI decreased too. This impact of water quality is influence on human health negatively. Future studies are needed to investigate the CWQI for recent years in upstream of Alhindiya Barrage and any other sites especially in south of Iraq.

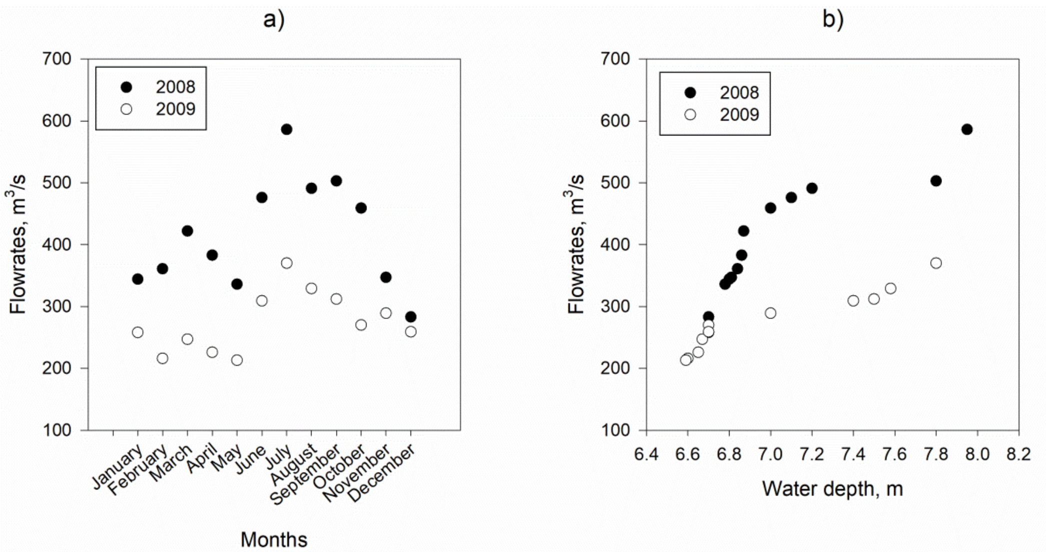

Figure 5. a) Monthly flowrates in upstream of Alhindiya Barrage for years of 2008 and 2009, b) Flowrates and water depth in upstream of Alhindiya Barrage for years of 2008 and 2009.

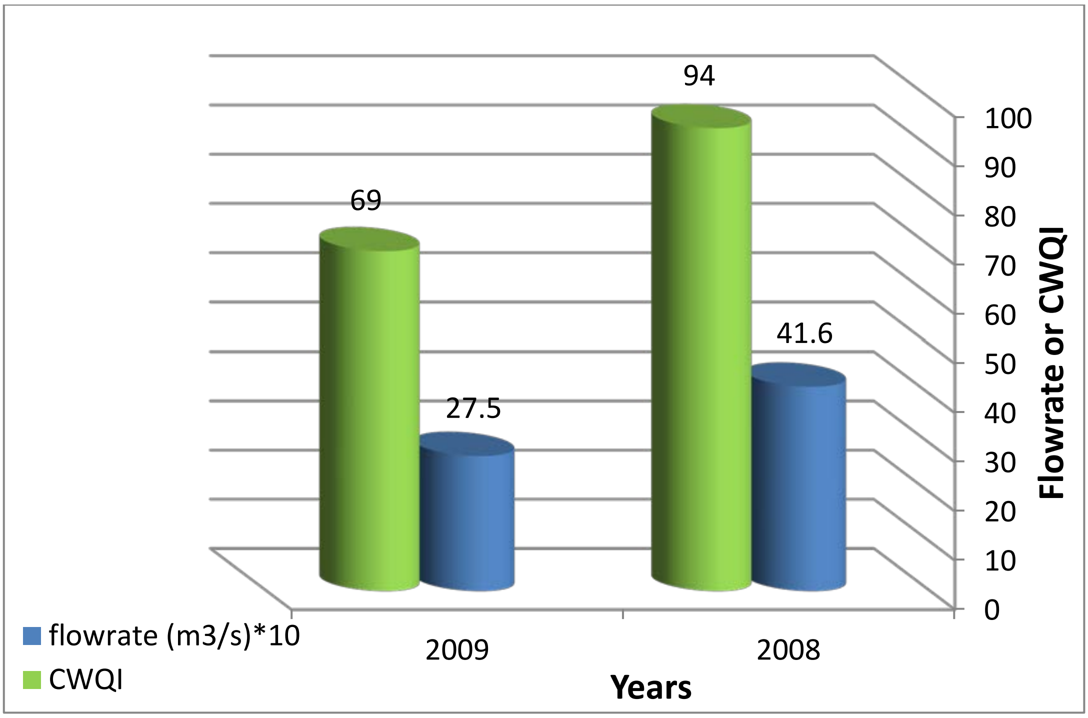

Figure 6. The relationship between the mean of measured flowrates and the CWQI for 2008 and 2009.

4. Conclusions

Global warming phenomenon is a major reason for dry seasons and rainfall intensity in Iraq. Additionally, dams on Euphrates and Tigris Rivers that built in neighboring countries (Turkey and Iran) that cutoff most of flow to Iraq is another reason for low flowrate in these main rivers. The reduction of flowrate influenced on water quality. Many researches were performed to estimate the water quality index of surface water and ground water to avoid the water pollution. The aim of this study was to investigate the water quality for drinking purpose at upstream of Alhindya Barrage, Euphrates River, using Canadian Water Quality Index (CWQI). The results showed that the CWQI for 2008 and 2009 were 94, which is represented good water quality, and 69, which is represented fair water quality for drinking purpose, respectively. Statistical analysis were performed on measured flowrates and indicated that there is a statistically significant difference between measured flowrates for 2008 and 2009. Strong relationship between the measured flowrate and the CWQI was reported. The results from this research indicated that human health was negatively influenced by water quality. Future studies are needed to investigate the CWQI for recent years in upstream of Alhindiya Barrage and any other sites especially in south of Iraq.

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