Assessment of Water Quality of Shatt Al-Basrah Canal using Water Pollution Index

Ayman A. Hassan[1], Ammar S. Dawood[2], Nassrin J. AL-Mansori[3]

[1,2]*Civil Engineering Department, College of Engineering, University of Basrah, Iraq*
[3]*Environmental Engineering Department, Collage of Engineering, University of Babylon, Iraq*

Abstract

This study evaluates the water quality for the Canal of Shatt Al-Basrah, located in Basrah province, Iraq. The Shatt Al-Basrah Canal used to connect the waterway from Al-Hammar marshes in the north of Basrah province, to Khor Al-Zubair port in the south of the province. Nine physicochemical water quality parameters have been measured and analyzed for calculating the water pollution index (WPI) in the Canal. These parameters, which were used in developing the WPI, included: Potential of Hydrogen (pH), Nitrate (NO_3^-), Calcium (Ca^{2+}), Total Alkalinity (TA.), Electrical Conductivity (EC), Sodium (Na^+), Total Dissolved Solids (TDS), Sulfate (SO_4^{2-}), Phosphate (PO_4^{3-}), Dissolved Oxygen (DO), Total Hardness (TH), Chloride (Cl^-), Magnesium (Mg^{2+}), and Potassium (K^+). The aim of this paper is to analyze and assess the water pollution of the Shatt Al-Basrah Canal in the year 2014, making use of the WPI method. The annual WPI mean value during the study period was more than the safe value; therefore, the water quality of the Canal ranged from impure (type V) to the heavily impure (type VI) and hence definitely regarded as unsuitable for drinking uses. Consequently, there is a need that is immediate to take some measures to stop the pollution and enhance the water quality of the Canalas a component that is integral tothe environment in Basrah province. In Basrahprovince, the disposal of wastewater in the Shatt Al-Basrah Canal is big maintenance difficulty of the Canal water quality.

Keywords: Pollution index, Water quality, Physico-chemical parameters, Shatt Al-Basrah, Water Canal, Iraq.

1. Introduction

The quality of surface water decided by some natural processes, such as precipitation, soil erosion, and atmospheric conditions. The other non-natural processes, which influence the surface water quality related to human activities such as urbanization, industrial and agricultural activities, as well as the demand on the exploitation of water resources (Carpenter et al. 1998; Jarvie et al. 1998).The term water quality used to characterize the physicochemical properties of water, commonly with regard to its suitability for a purpose that is particular.

Water is necessary for sustaining the full life on the planet. Therefore, people must increase the good water supplied to communities satisfactorily. Nonetheless, the safety of water is the important issue need to be assess. Since supplying reliable water and ingesting that is safe is an important problem, evaluation of drinking water quality is necessary in order to guarantee safe water to supply it to the community. Therefore, specific and vital parameters of water quality are required to be monitored so that it is easy to determine its evaluation.

Modern society is contributing, through its commercial, agricultural activities, not just to change global environmental trends, but also, more straight, to local degradation that is environmental. The management of water resource is an issue that is universal, especially affects populations surviving in areas where extreme agricultural and industrial activities occurred, as this could impact the quality and quantity of surface water/groundwater. Monitoring is an actual means of regular testing of certain quality parameters figured out international as

well as national based guidelines and limitations. Consequently, the monitoring process and compared the results with the standards, is a tool that is important to decide, whether or not drinking water is safe.

The problem of pollution for surface water happens to be listed among the many problems that tend to be severe in developing countries. In the developing world, a lot of rivers in the urban areas are the endpoint of effluents that discharged from some local industries. The main effects on public health reduce agriculture production, and water resources degradations are the wastewater discharges from industrial plants and urban runoff.

The assessment criteria associated with the surface water status using the physicochemical quality factors reasonably reveal existing pollution of the surface water. Extensive assessment of pollution has to assess a more substantial number of pollutants such as the microbiological contaminants as well as water. When any water quality parameter surpasses the restrict values of the desired ideal condition, the ecosystem strategy demonstrably suggests the require to take monitoring that is continuous, so as to prevent the pollution.

Following the event of severe drought experienced in the last years, it was decided to assess waters of the Canal of Shatt Al-Basrah as an alternative source of water supply for the city of Basrah. An attention that is special must be provided with to the assessment of the Shatt Al-Basrah water quality and contamination problems, as their intended purpose that the Canal is one of the most effective artificial water resources in Basrah.

As an important to know the water resources quality, this paper aims to determine and assess the pollution in the Shatt Al-Basrah Canal by calculating a water pollution index (WPI) based on different physicochemical parameters of water quality. The

Canal's assessment was subject to the data obtained from three water measuring stations on the Shatt Al-BasrahCanal in the study location for 2014. The results of this work should suggest if the real water quality refers to the needed water quality of the Canalaccording to the WHO specifications. The other purpose of this study is to monitor and manage the water quality parameters in the Canal in a one-year period.

2. Materials and Methods

2.1. Study area

The Canal of Shatt Al-Basrah is located in Basrah province, south of Iraq, and next to Zubair district. The Shatt Al-Basrah Canal is 38 km long. In 1983, the Canal is constructed. The latitude and the longitude locations of the Canal are ranged E 47º 00ˈ to E 47º 60ˈand N 30º 20ˈ to N 30º 60ˈrespectively. No activities which can be anthropogenic been reported along the Canal banks. The water Canal source isAl-Hammar march in the north of the Canal, passing near Zubair district, and then it discharges to Khor Al-Zubair Canal. The Canal of Shatt Al-Basrah is the second longest, after the Shatt Al-Arab River, and the first water richest Canal in Basrah. Figure 1 shows the map of the study area in which the Zubair district is shown.
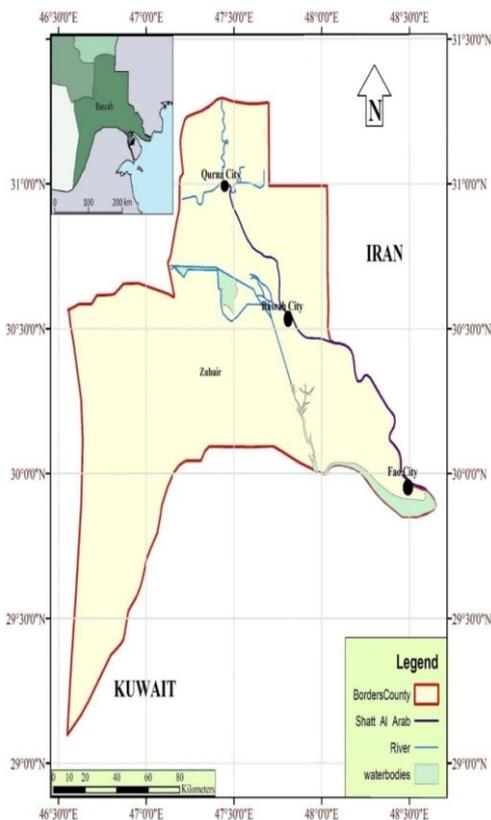

Fig. 1: Basrah geographic map showing Zubair district (Dawood et al. 2018a)

2.2. Sampling Measures and Analyses

The aims of the current work are to identify whether the water quality of the Shatt Al-Basrah Canal exceeds water quality standards, and also to measure the status of water quality of the Canal. To perform this work, monthly water samples were obtained from 3water stations along the Canal as source water and had been monitored with regards to specific water quality parameters throughout the period from January 2014 to December 2014.

The water samples were collected for the analysis of the physicochemical parameters was performed at the sampling stations and then was transported to the Laboratory where the appropriate procedures were conducted to complete the tests. To calculate the WPI for the Shatt Al-Basrah Canal, the following physicochemical parameters was used, Potential of Hydrogen (pH), Nitrate (NO_3^{-1}), Calcium (Ca^{+2}), Total Alkalinity (TA.), Electrical Conductivity (EC), Sodium ($Na+^1$), Total Dissolved Solids (TDS), Sulfate ($SO4^{-2}$), Phosphate (PO_4^{-3}), Dissolved Oxygen (DO), Total Hardness (TH), Chloride (Cl^{-1}), Magnesium ($Mg+^2$), and Potassium ($K+^1$). Analytical methods were applied to analyze each parameter followed the procedures and techniques suggested by standard methods (APHA, 1998). Some parameters were tested at the same time as sampling stations making use of previously calibrated devices, such as pH, and concentrations of electrical conductivity and total dissolved solids and dissolved oxygen as well as temperature. The allocation map of water samples in the study area is presented in Figure 2.
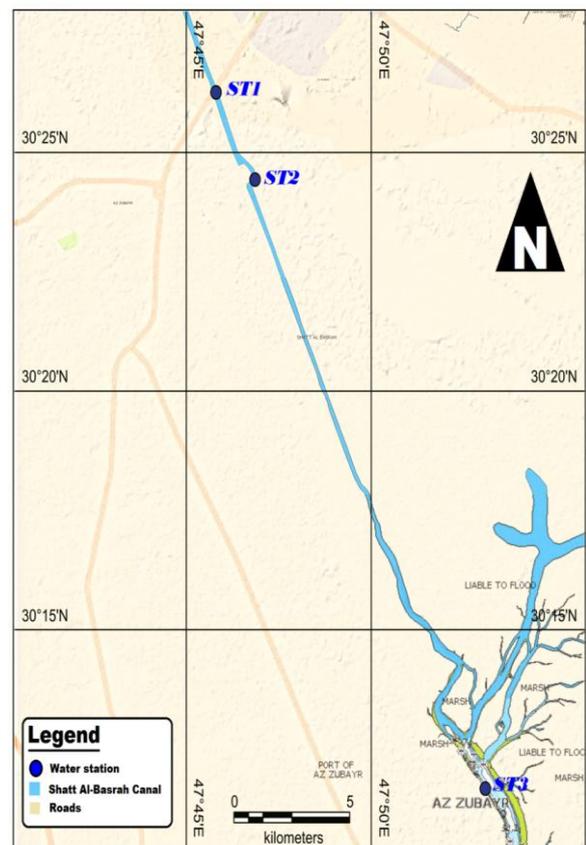

Fig. 2: Location map of sampling stations in the study area

2.3. Data analysis

Descriptive statistics for the water quality parameters used in this study were performed by utilizing SPSS software version 20 (Wagner 2012). The summary for descriptive-statistics details of the water samples, including mean, minimum, maximum, range, and standard deviation, are shown in Table1 for the study location.

Table 1: Descriptive statistics values for water samples in the study location

Parameter	Minimum	Maximum	Mean	Range	Std. Dev.	CV
pH	7.8	8.5	8.13	0.7	0.181	2.232
DO	2.26	9.84	7.27	7.58	1.480	20.353
PO_4	0.15	97.86	4.23	97.7095	17.485	413.239

NO₃	5.63	105.80	13.82	100.17	16.274	117.786
Ca	268	920	606.51	652	223.383	36.831
Mg	329	1927	907.51	1598	456.969	50.354
TH	2234.5	10192	5288.60	7957.5	2399.696	45.375
K	20.75	2800	218.19	2779.25	501.814	229.988
Na	2200	15350	6172.41	13150	3933.486	63.727
SO₄	1000	3500	1888.51	2500	634.645	33.606
Cl	2195	17005	6707.44	14810	4181.119	62.335
TDS	7373	37468	16678.10	30095	8470.724	50.790
EC	5426.5	50550	22484.07	45123.5	11627.843	51.716
TA	161	16519.5	638.22	16358.5	2722.531	426.580

2.4. Water Quality Standards

The criteria of drinking water are established in an effort to supply water quality at a quality that is certain to the community continuously. The water quality parameters need to be monitored and the limit values determined have been updated since the health effects of chemical and biological compounds existing in the waters are understood more clearly with the obtaining and enhancement of the available data on the compounds (Artiola 2004).

Each of WHO guidelines and Iraqi national drinking water Standards are definitely the most generally acceptable for drinking water standards in international and national based, respectively. The international and national standards for some water quality parameters are listed in Table 2, respectively. Water quality parameters listed in these national and international guidelines (Gray 2008; I.Q.S.2001)are introduced in Table 2.

Table 2: Drinking Water Quality Parameters based on WHO and Iraqi standards (Gray 2008; I.Q.S. 2001)

Parameter		The maximum standard for drinking water	
	Measurement unit	WHO Standard	Iraqi Standard
pH	-	8.5	8.5
DO	mg/L	5	5
NO₃	mg/L	50	50
Ca	mg/L	300	50
Mg	mg/L	20	50
TH	mg/L	500	500
Na	mg/L	200	200
SO₄	mg/L	250	250
Cl	mg/L	250	250
TDS	mg/L	1000	1000
TA	mg/L	250	-

2.5. Calculation of WPI

The method of WPI is regarded as an easy indicator to show the watershed pollution. It is usually used as an effective tool for assessing the management of water quality. It offers an application that is wide it's utilized as a signal of the quality for rivers (Filatov et al. 2005), that is why it has been frequently used by various authors around the world.

WPI connects the physical and the chemical parameters into an index, that makes that index feasible to compare different water quality, as its basic function used to search for the presence of pollutants in water.

The method of calculation for WPI is proposed by (Filatov et al. 2005) and express in the following equation:

$$WPI = \frac{1}{n} \sum_{i=1}^{n} \frac{A_i}{T_i} \quad - - - - - - - - - - - - - - - - (1)$$

Where A_i is the average parameter value, T_i is the allowable values (based on standards) of the parameter and n is the total number of the studied parameters.

The standard values, for all used drinking water parameters, are listed in Table 2.

Predicated on the acquired WPI values, the WPI has been categorized into six groups (Lyulko et al. 2001); the water quality is rated very pure, pure, moderately, polluted, impure and heavily impure when the value of the WPI lies between <0.3, 0.3-1.0,1.0–2.0, 2.0–4.0,4.0–6.0, and >6.0, respectively (Table 3).

Table 3: Water quality category in accordance with the WPI values

Type	Water properties	WPI value
I	Very pure	< 0.3
II	Pure	0.3-1.0
III	Moderately polluted	1.0-2.0
IV	Polluted	2.0-4.0
V	Impure	4.0-6.0
VI	Heavily impure	> 6.0

2.6. Correlation Analysis

In the studies of water quality, the correlation analysis for any two or more variables which are randomly selected is the determination of the relationship that is statistical significance between them. The strength of the relationship between any random variables (two or more), may be identified through the calculation of the correlation coefficient (R). Generally, the value of R varies from -1 to 1. At the R values, in the analysis, closer to zero, implies a weak correlation, but at R values close to -1, indicates a negative strong correlation between these selected random variables. However, at R values close to 1, shows a strong positive correlation between these selected random variables.

3. Results and Discussion

From the results of the analysis for the physicochemical parameters (Table 1), pH was noticed to differ among months and locations with a range from 7.8 (at ST1) to 8.5 (at ST1), the lowest value was recorded in July and the highest in February, it is noticed that pH values within the guidelines (6.5 – 8.5), hence, the pH of the study location shows that the water was slightly alkaline, and similar results were found as reported by Dawood et al. (2018b).

The highest DO content value of 9.84 mg/L was recorded in February at ST1 and the lowest of 2.26 mg/L recorded in August at ST1. The DO content value, as suggested by Iraqi and WHO standards, must not exceed a value of 5 mg/L. The minimum PO₄ content in the water samples was recorded in April at ST2, while the maximum was recorded in September at ST1. There is no limit recommended by Iraqi and WHO standards for allowable PO₄ content in drinking water.

The values of NO₃ content were found in the range of 5.63-105.79 mg/L, lowest NO3 was observed in January that was within the permissible limit (at ST3) and the highest value was recorded in November (at ST3) that was commonly more than the standards revealing the bad status of the Canal. The high NO₃ concentration recorded in the study location was higher than what was earlier reported by (Dawood et al. 2018b)for their study, which includes the area of Shatt Al-Arab River.

The lowest Ca content value of 268 mg/L was recorded in April at ST1 and the highest value of 920 mg/L recorded in September at ST3. There is a big difference in the threshold values between the WHO standard (< 300ppm) and Iraqi Standard (<50 ppm). For the Iraqi standard, all the water samples are not suitable for drinking, but according to WHO standard, some of them are not suitable for drinking. The highest Mg content value of 1927 mg/L was recorded in October at ST3 and the lowest value of 329 mg/L was recorded in May at ST1. All the water samples in the study location were exceeded standard limits.

Total hardness values lie in the range 2234.5 mg/L (recorded in February at ST2) to 10192.0 mg/L (recorded in October at ST3), indicating the bad status of water, not within the standard guidelines.

The maximum K content in the water samples was recorded in September at ST1, while the minimum was recorded in April at the same water station. There is no limit recommended by Iraqi and WHO standards for allowable K content in drinking water. However, all recorded values were high.

The values of Na content were ranged from 2200 to 15350 mg/l with the lowest value recorded in March at ST1, and highest value recorded in September at ST3, all the range of Na values was exceeded the permissible limits.

The major anions such as Cl and SO_4, have recorded content exceeded the permissible limits, as suggested by the Iraqi and WHO standards, in all the study period and at all water stations.

For TDS and EC contents in water samples, it was observed that all their concentrations were not within the acceptable limits based on Iraqi and WHO standards at all water stations within the study period and signifying high mineral content. In the downstream (ST3), the EC and TDS concentrations are noticed to increase because of the anthropogenic activities and the work's activities Khor Al-Zubair port. The TDS is originated from natural sources such as agricultural runoff and sewage. The high values of TDS in the study location were higher than that which was beforehand reported by (Dawood et al. 2018b) in a nearby study area. The effect of soil erosion and the geology of the area are two important factors that increase some parameter measures, such as TH, EC, and TDS. These parameters that influenced by the factors mentioned above were used as an indicator of inorganic pollution (Turner & Rabalais 2003).

The pollutants discharged to the scheme of water resource from industrial effluents, agricultural runoff, domestic wastewater discharges, and other sources, most of which potentially without treatment, could possibly have together short and long terms considerable impacts on the water quality (Singh et al. 2007). This impact is a common rehearse for people residing across the water catchments to release their human excrete as well as the home-based waste into rivers (Jain 2009, Best et al. 1997).

The WPI demonstrates the integrating water parameters, in an arithmetical method, to assess the physicochemical and environmental status of surface water. Considering the physical and chemical parameters, the WPI offers an easier evaluation process for pollution in water.

The WPI, for the Canal of Shatt Al-Basrah, was calculated by the application of equation 1 and depending on the monthly field measurements of the eleven or ten parameters in Table 2 based on WHO or Iraqi standards, respectively.

According to the WPI classification in Table 3, the results show the various water quality at different stations and months (Figures 3 and 4), in which the highest values (heavily impure type) of WPI in the last station are due to industrial and domestic discharge from the Khor Al-Zubair port. The WPI values slowly enhanced from the upstream of the Canal.
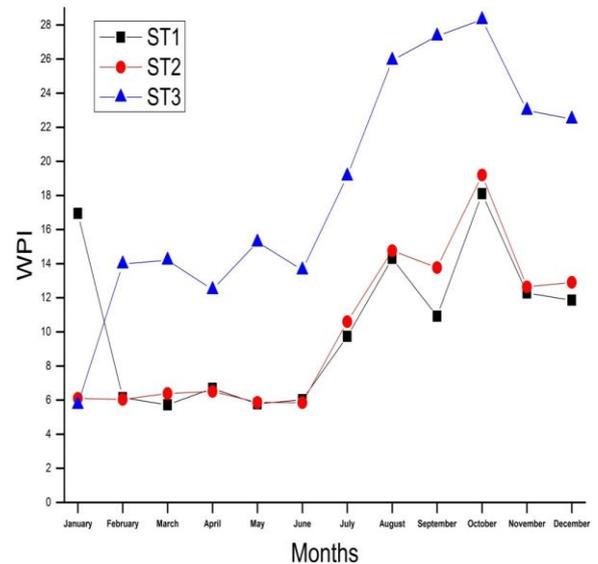

Fig. 3: WPI values for Shatt Al-Basrah Canal based on WHO standard

The WQI values of the of the Canal are given in (Table 4; Figures 3 and 4). It can be observed that the WPI ranges from 5.71 to 28.31 with a mean value of 12.58, which reflects its unsuitability for drinking according to WHO standard. Furthermore, WPI values for the same stations are ranged from 5.54 to 26.70 with a mean value of 12.29 based on the Iraqi standard. Figure 5, shows the annual WPI for the water station in the study location.
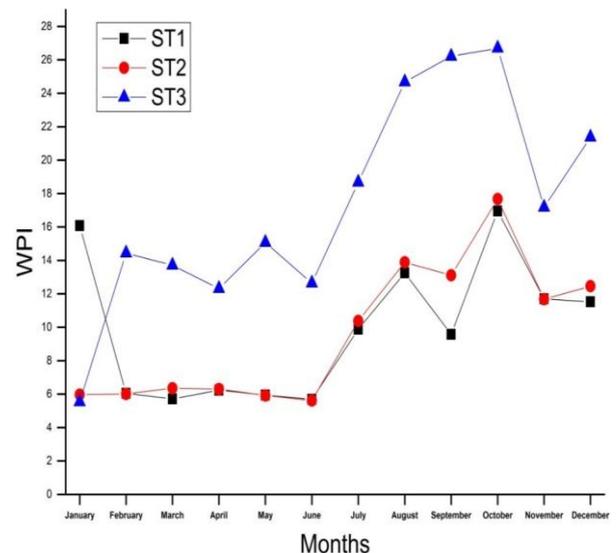

Fig. 4: WPI values for Shatt Al-Basrah Canal based on Iraqi standard

Table 4: WPI values at Shatt Al-Basrah Canal in the study sites

| Months	WPI: Based on WHO standard			WPI: Based on the Iraqi standard		
	ST1	ST2	ST3	ST1	ST2	ST3
January	16.94	6.11	5.74	16.08	5.97	5.54
February	6.14	6.03	13.98	6.05	6.01	14.44
March	5.72	6.38	14.21	5.71	6.35	13.71
April	6.68	6.51	12.48	6.23	6.30	12.32
May	5.78	5.86	15.26	5.94	5.92	15.07
June	6.02	5.85	13.63	5.68	5.62	12.64
July	9.74	10.60	19.14	9.88	10.38	18.68
August	14.31	14.76	25.93	13.26	13.89	24.67
September	10.92	13.77	27.35	9.58	13.11	26.21
October	18.10	19.19	28.31	16.95	17.67	26.70
November	12.28	12.64	22.99	11.69	11.68	17.18
December	11.86	12.90	22.48	11.53	12.45	21.37
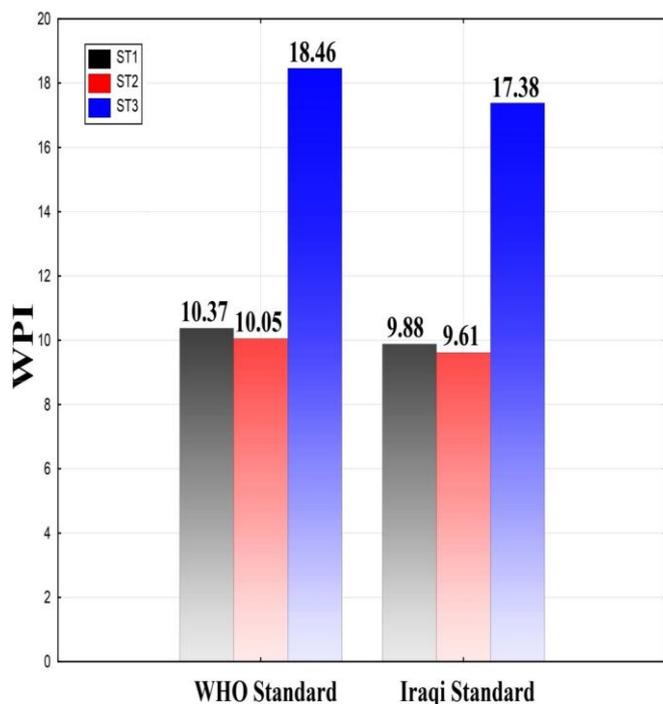
Fig. 5: The annual WPI values for Shatt Al-Basrah Canal

The values of the WPI for Shatt Al-Basrah Canal revealed an impure water type of 13.89 % of the data and heavily's impure water type of 86.11 % of the data, showing that the water body is not suitable for drinking according to WHO standards. But, the WPI values that based on Iraqi standard, have various percentages for the water type, as follows 19.44 % of the data showing an impure water type and the rest of the data (81.56 %) revealing the heavily's an impure water type. Here again, the water body is not suitable for drinking, according to Iraqi standards. These increases in pollution. These raises in pollution are an issue that is major for the local people using the Canal's water if they use Canal' water for drinking and all other activities.

There are different factors noticed to contribute on deteriorating of water quality of the Shatt Al-Basrah Canal, most of it is anthropogenic activities such domestic use of water, pretreatment, agriculture, and industry. The impact of these anthropogenic activities on water quality of the Canal is increasing trend of parametric values during the last decade. The increasing trend included raised anion concentration, high concentrations in each of EC, TDS, Mg and decreased trend in DO concentration on the time period recommending that the domestic and industrial wastewater as well as the agriculture water runoff, had been combining into the Canal.

The coefficients of correlation amongst the selected water samples presented a high and strong relationship. Table 5 shows the correlation matrix for the data (water samples). It was observed that there is a high correlation ($R>0.9$) that were seen between the following parameters: (Na with each of Cl and TDS), (Cl with each of EC and TDS), and (NO_3 with TA). Table 5, additionally shows a strong relationship ($R>0.8$) between the following parameters: (PO_4 and K), (TH with each of Na, Cl, TDS, and EC), and (Mg with each of Cl, TDS, and EC). Finally, there are moderate relationships (Table 5) appears in Mg with each of SO_4 and Na, and between Ca with each of Cl and Na.

Table 5: Coefficients Correlation for water samples in the study location

Parameter	pH	DO	PO4	NO_3	Ca	Mg	TH	K	Na	SO_4	Cl	TDS	EC	TA
pH	1.00													
DO	0.50	1.00												
PO_4	-0.10	-0.10	1.00											
NO_3	-0.22	-0.02	-0.05	1.00										
Ca	-0.60	-0.31	-0.05	0.08	1.00									
Mg	-0.60	-0.22	0.09	0.10	0.83	1.00								
TH	-0.60	-0.20	-0.02	0.13	0.89	0.98	1.00							
K	-0.16	-0.07	0.86	0.27	-0.01	0.20	0.09	1.00						
Na	-0.66	0.01	-0.07	0.30	0.58	0.79	0.80	0.10	1.00					
SO_4	-0.16	-0.25	0.34	0.01	0.49	0.53	0.47	0.43	0.14	1.00				
Cl	-0.66	0.00	-0.03	0.34	0.59	0.81	0.82	0.17	0.98	0.17	1.00			
TDS	-0.66	-0.05	-0.03	0.12	0.68	0.89	0.89	0.10	0.96	0.28	0.96	1.00		
EC	-0.68	-0.08	0.03	0.20	0.67	0.88	0.88	0.18	0.96	0.31	0.97	0.99	1.00	
TA	-0.13	0.05	-0.04	0.97	-0.09	-0.05	-0.03	0.30	0.22	-0.08	0.26	0.03	0.11	1

4. Conclusions

The WPI was an essential tool utilized to assess the water quality of the studied Canal. Pollution's level and the aquatic ecosystem variability are affected by the level of human activity that showed the quality of any watercourses truthfully. The results of the identified WPI show actuality for the ten important parameters that were used in the computation strategy utilized in this study. This study shows variations in the noticed environmental categorization of three monitoring stations along the Shatt Al-Basrah Canal and can plainly be explained by distinctions in methodological techniques. The results from this research, are a significant part for environmental protection. Furthermore, it regards as a basis for further water monitoring and assessment. The environmental assessment of the eco¬logical status of the Canal involves the method of comparison and analysis of the assessed values of the single water quality parameters with standard values to identify the sort of Canal' water. Most of the water quality parameters in the study area exceed the permissible limits and hence the pollution of water increased. This evaluation study, using WPI assessment, applied as a function of different physicochemical parameters of the environmental status and shows that the water pollution in the Shatt Al-Basrah Canal, based on the calculated WPI was ranged from impure type to heavily impure. The research discovered that the level of Canal's pollution is rising due to the discharge of agricultural activities, dumping of solid waste, and sewage effluents into the canal. The water quality category, according to the calculated WPI agrees with the results of the environmental state of the Canal. Finally, the results indicate that particular WPI could possibly be effectively used in the water quality as a good assessment tool.

5. Suggestion

The following suggestion can be obtained from the study area:
- Protecting the water resources by encouraged practices on bi-product recovery and waste recycling.

- The effluents of industries wastewater at one place can be received, treated, and disposed to assist in abatement of pollution.
- Installing wastewater treatment facilities in the industrial area by pollution control measures, and maintain the previously installed.
-Controlling the use of fertilizer and pesticides in agricultural runoff by education understanding it by people.
- Making use of the management of effective solid waste by preventing pollutants access into surface and groundwater sources existent in the project area.

References

[1] Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, 8(3), 559-568.

[2] Jarvie, H. P., Whitton, B. A., & Neal, C. (1998). Nitrogen and phosphorus in east coast British rivers: speciation, sources and biological significance. Science of the Total Environment, 210-211, 79-109.

[3] Dawood, A. S, Jabbar .T., Gatea, M. H., & Al-ameemi H. J. (2018a). A study of groundwater characteristics by using of groundwater quality index and pollution index in Zubair district, Basra province, Iraq. Journal of applied engineering sciences, 8(21), 19-26.

[4] APHA A. (1998). Standard methods for the examination of water and wastewater, American Public Health Association. Inc., Washington. DC.

[5] Wagner III, W. E. (2012). Using IBM® SPSS® statistics for research methods and social science statistics. Sage Publications.

[6] Artiola, J. F. (2004). Monitoring Surface Waters, Environmental Monitoring and Characterization, 141-161.

[7] Gray, N. F. (2008). Drinking water quality: problems and solutions. Cambridge University Press, 2nd edition, 48-50.

[8] Drinking-Water Standard, I. Q. S. (2001). 417. Central Organization for Quality Control and Standardization, Council of Ministers, Republic of Iraq.

[9] Filatov, N., Pozdnyakov, D., Johannessen, O., Pettersson, L., & Bobylev, L. (2005). White Sea: its marine environment and ecosystem dynamics influenced by global change. UK: Springer and Praxis Publishing.

[10] Lyulko, I., Ambalova, T., & Vasiljeva, T. (2001). To integrated water quality assessment in Latvia. Nunspeet, Netherlands, In MTM (Moni'toring Tailor-Made.) HI, Proceedings of International Workshop on Information for Sustainable Water Management 449-452.

[11] Dawood, A. S., Akesh, A. A., & Khudier, A. S. (2018b). Study of Surface Water Quality and Trends Assessment at Shatt Al-Arab River in Basrah Province. Journal of Kerbala University, 16(1), 215-231.

[12] Turner, R. E., & Rabalais, N. N. (2003). Linking landscape and water quality in the Mississippi River basin for 200 years. AIBS Bulletin, 53(6), 563-572.

[13] Singh, L. B., P. N. Pandey, B. Mahto, & R. K. Singh. (2007). River pollution.

[14] Jain, A. K. (2009). River pollution. APH Publication, New Delhi, India.

[15] Best, G., Bogacka, T., & Niemirycz, E. (1997). International river water quality: pollution and restoration. CRC Press.