ASSESSING AND MAPPING WATER QUALITY (CASE STUDY: WESTERN DELTA -EGYPT)

A.A. Agrama[1] and E. A. El-Sayed[2]

[1] *Ass. Prof., Environment & Climate changes Research Institute, National Water Research Center, El-Qanater El-Khairiya, Egypt. Postal Code:13621/5, E-mail:asmaaagrama_new2012@yahoo.com*
[2] *Researcher,Drainage Research Institute, National Water Research Center, El-Qanater El-Khairiya, Egypt.Postal Code:13621/5, E-mail:ehab7878@hotmail.com*

ABSTRACT

In terms of the importance of investigating the water quality in Egypt, this research was initiated in order to evaluate the surface water quality in the Western Delta Region by using Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) based on Egyptian guidelines of law 48/1982. The water quality of El-Nubaria Canal-the main surface water resource for the horizontal expansion projects in Western Delta-, El Mahmoudia; El Hager; El Nassr; El Khandak; and Abo Diab Canals was investigated. The Geographic Information System (GIS) was used for mapping the WQI variations in different canals. The results of the index average for different sites location at each canal showed that the water quality in the studied canals ranked as marginal for all canals. This is attributed to the fact of mixing low quality water of agricultural drains with canals fresh water in the study area. It was thus recommended that water use in the western delta should be restricted to its quality or to improve the water quality by increasing the fresh water discharge or reducing water mixing ratio with drains.

Keywords: WQI, Canals, Western Delta, Egypt.

1 INTRODUCTION

There are many-water related challenges facing Egypt. The limited amounts of rainfall make the country dependent mainly on water from the Nile River. The Nile water is of high quality as the river reaches Cairo. Deterioration in water quality occurs when the Nile bifurcates into Damietta and Rosetta Branches due to the disposal of the municipal and industrial effluents and agricultural drainage with decreasing flows, (World Bank, 2005). Nevertheless, the majority of Egypt population is concentrated in the Nile Valley and Delta which caused significant stress on the Nile River water. In order to relieve the pressure on the Nile Valley and Delta, the government has embarked on an ambitious program to increase the inhabited area in Egypt by means of horizontal expansion projects in the desert. Such new projects increase the demand of water. Moreover, pressure on the water resources due to population growth and the related developments have resulted in water pollution, (AWF, 2007). During the last few decades, the Egyptian Ministry of Water Resources and Irrigation (MWRI) has adopted different strategies aimed at increasing the use of groundwater and agricultural drainage water especially for new land reclamation projects. The amount of annually reused drainage water is expected to be 9.0 BCM/year by the year 2017, (DRI, 2007). One of these horizontal expansion projects is in the Western Nile Delta Region which is an area of high development potential depends on groundwater. However, with the rapid development over the past few years, there has been an excessive exploitation of the groundwater. Groundwater is now being quickly depleted and its quality is deteriorated. To resolve this problem, the Government has been reviewing options to replace groundwater with surface water for irrigation system, (PPIAF, 2005).

For this reason, the present research was initiated with the objective of evaluating the surface water quality in the Western Delta Region. This paper deals with one of the very important objectives of the ecosystem initiatives for the Western Delta Project through assessment the water quality in its main canals. The objective of this study describes the application of the CCME-WQI to monitor the changes in water quality at 19 sites in six Western Delta Canals, El-Nubaria; El-Mahmoudia; El-Hager; El-Nassr; El-Khandak; and Abo Diab Canals. This was achieved via investigation phases. These phases are represented in this paper under the following headlines:

- Executing site visits and describing the study area
- Determining the water index
- Investigating the water quality in the delta region using CCME-WQI
- Mapping the water quality in the delta region using GIS
- Analyzing and representing the results

2 EXECUTING SITE VISITS AND DESCRIBING STUDY AREA

West Delta region was chosen to be investigated, as a case study. Several site visits were executed to the study area during which photos were captured, observations were documented and measurements were undertaken. Based on the site visits the study area could be described as follows:

El-Nubaria Canal is the major surface water source for the horizontal expansion projects in the West Delta Region. It is mainly fed by fresh water from El-Rayah El-Nassery and El-Rayah El-Beheiry. It serves a total area of 373,800 hectare (ha), (El-Gammal and Ali, 2008).

El-Mahmodia Canal takes fresh water from Rosetta Branch at km 194.200 with actual served area of 130,200 ha (AboKila, 2012).

El-Hager Canal feed from El-Nubaria Canal at km 9.960 with served area of 93100 feddans.

El-Nasr Canal is located at Km 57.500 on El-Nubaria Canal with served area of 38919 feddans.

3 DETERMINING THE WATER INDEX

The National Water Research Center (NWRC) within MWRI is charged of water quality monitoring for the purpose of fulfilling MWRI's responsibility in providing water of suitable quality to all users. NWRC maintains a national monitoring network, testing laboratory and database for conducting its responsibilities related to water quality management. Three institutes of NWRC play key roles in NWRCs efforts. Drainage Research Institute (DRI) was one of these institutes. In West Delta, DRI monitors 39 points on drains and 7 on canals, (APRP, 2002).The Canadian Council of Ministries of the Environment (CCME) Water quality Index (WQI) facilitates the evaluation of surface water quality for protection of aquatic life with specific guidelines. Calculations of the index are based on Scope (F1); frequency (F2) and the amplitude (F3). Sampling protocol requires at least four parameters, sampled at least four times and no maximum parameters has been set. The resultant index can be referred to a standard table which constitutes numerical values ranging between 0 and 100 with a rating of excellent, good, fair, marginal and poor. Several authors applied this index. LUMB et al., (2006) used the index to monitor the water quality in Mackenzie-Great Bear sub-basin, Canadian. Radwan and El-Sadek, (2008) used this index in assessment of water quality in irrigation and drainage canals in Upper Egypt. Furthermore, Khan et al., (2008) studied the suitability of the Nile River water for various uses by using this index. Donia and Farag, (2010) applied this index at drinking water abstraction in El-Nubaria Canal. The data represented in this paper for Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) calculation was collected on monthly basis, along one water year (i.e. August 2010 to July 2011). The 17 water quality parameters used in CCME-WQI calculation are Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrate (NO_3), Ammonia (NH_4), Total Phosphorus (TP), Cadmium (Cd), Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn), Lead (Pb), Nickel (Ni), Boron (B), Sulphate (SO_4), the power of hydrogen (pH), Total Dissolved Solid (TDS) and Dissolved Oxygen (DO). The water quality parameters data for Western Delta Canals, six canals (i.e. El-Hager, El-Khandak, El-Mahmoudia, El-Nasr, Abo Diab, and El-Nubaria) were obtained from the data base system of the water quality monitoring program for Drainage Research Institute and are represented on "Fig. 1" and "Table 1".

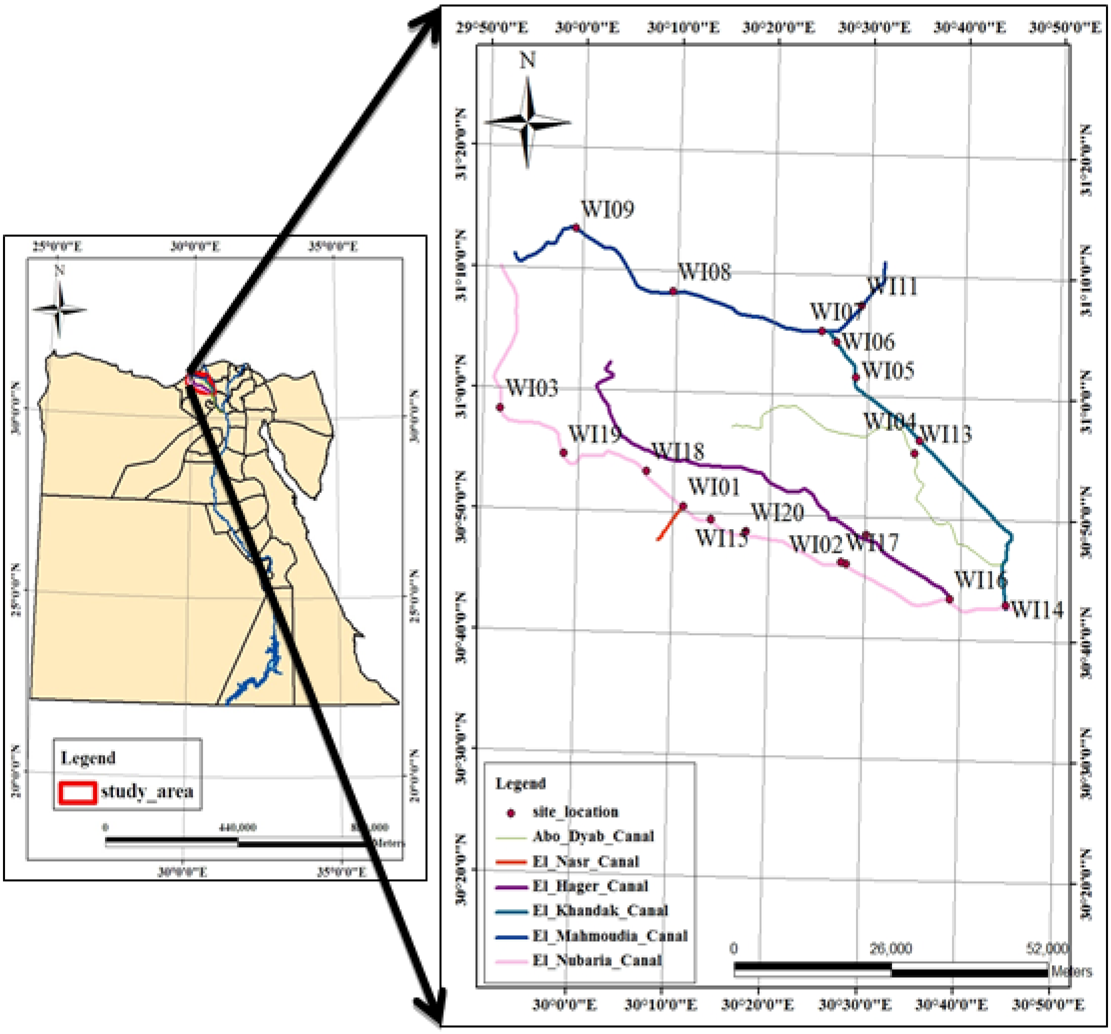

Fig. 1: Study Area, Sites and Canals

Table 1: Description for Sites Location

No.	Canal Name	Site Code	Description
1	El Nassr canal	WI01	Intake of El-Nasr Canal
2	El Nubaria canal	WI02	El-Nubaria Canal upstream of El-Boustan Reuse Pump Station (P.S.)
3		WI03	Intake of Mariut Canal from El-Nubaria Canal.
4	El Khandak canal	WI04	El-Khandak Canal downstream Etay El-Barud P.S.
5		WI05	El-Khandak Canal upstream of the Damanhur drinking water intake
6		WI06	El-Khandak Canal downstream of

No.	Canal Name	Site Code	Description
			Damanhur city
7	El Mahmoudia canal	WI07	El-Mahmoudia Canal downstream of the junction with El-Khandak Canal
8		WI08	El-Mahmoudia Canal upstream of the Kafr Dawwar drinking water intake
9		WI09	El-Mahmoudia Canal upstream of Alexandria drinking water intake
10		WI11	El-Mahmoudia Canal upstream of Edko Irr. P.S.
11	El Hager canal	WI12	El-Hagar Canal upstream of Dillingat Reuse P.S.
12	Abo Diab Canal	WI13	Abo -Diab Canal downstream of El-Khandak El- Gharbi P.S.
13	El Nubaria canal	WI14	El-Nubaria Canal intake
14		WI15	El-Nubaria Canal at the intake of El-Boustan Canal
15		WI16	El-Nubaria Canal downstream Dillingat Ext. P.S.
16		WI17	El-Nubaria Canal downstream of El-Boustan Reuse P.S.
17		WI18	El-Nubaria Canal at km 66.0
18		WI19	El-Nubaria Canal at km 81.5
19		WI20	El-Nubaria Canal upstream of El-Omoum Reuse P.S.

4 INVESTIGATING THE WATER QUALITY IN THE DELTA REGION USING CCME-WQI

The water quality was investigated. The guidelines of parameters used in the WQI calculations are presented in “Table 2”. These guidelines are according to Egyptian Ministry of Water Resources and irrigation “law 48/1982”, for protection of the Nile River and Waterways from Pollution (i.e. decree No. 49 in the amended executive regulations of the law by Minister Decision No. 92/2013).

Table 2: Water Quality Parameters and their Guidelines

No.	Parameter (units)	Guideline Decree No. 49, law 48/1982 amended in 2013
1	BOD (mg/l)	6
2	COD (mg/l)	10
3	NO_3 (mg/l)	2
4	NH_4 (mg/l)	0.5
5	TP (mg/l)	2
6	Cd (mg/l)	0.001
7	Cu (mg/l)	0.01
8	Fe (mg/l)	0.5
9	Mn (mg/l)	0.2
10	Zn (mg/l)	0.01
11	Pb (mg/l)	0.01
12	Ni (mg/l)	0.02
13	B (mg/l)	0.5
14	SO_4 (mg/l)	200
15	pH	6.5-8.5
16	TDS(mg/l)	500
17	DO (mg/l)	6

The WQI is an attempt to represent overall quality of water collected from water body. It is considered a tool for simplifying the reporting of water quality data. WQI numerically summarizes the information from multiple water quality parameters into a single value. The single value can be used to compare data from several sites. On the other hand WQI is defined as rating reflecting the composite effects of a number of parameters on the overall water quality.

The CCME-WQI, (CCME, 2001) was used in the calculation after the following equation:

$$CWQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right)$$

The factor of 1.732 arises because each of the three individual index factors can reach 100. This means that the vector length can reach a maximum of 173.2 as shown below:

$$\sqrt{100^2 + 100^2 + 100^2} = \sqrt{30000} = 173.2$$

The index comprises of three factors:

Factor 1 (F1-Scope) assesses the extent of water quality guideline non-compliance over the time period of interest, which means the number of parameters whose objective limits are not met "failed variables". It has been adopted directly from the British Columbia Water Quality Index. Then F1 (Scope) represents the percentage of variables that do not meet their objectives "threshold limits" at least once during the time period under consideration, relative to the total number of variables measured:

$$F_1 = \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \right) \times 100$$

Factor 2 (F_2-Frequency) represents the frequency (i.e. how many occasions the tested or observed value was off the acceptable limits) with which the objectives are not met, which represents the percentage of individual tests that do not meet the objectives "failed tests". The formulation of this factor is drawn directly from the British Columbia Water Quality Index:

$$F_2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} \right) \times 100$$

Factor 3 (F_3-Amplitude) represents the amount by which failed test values does not meet their objectives. F_3 is calculated in three steps.

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an "excursion" and is expressed as follows, when the test value must not exceed the objective:

$$excursion_i = \left(\frac{Failed\ Test\ Value_i}{Objective_j} \right) - 1$$

For the cases in which the test value must not fall below the objective:

$$excursion_i = \left(\frac{Objective_j}{Failed\ Test\ Value_i} \right) - 1$$

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions, or nse, is calculated as:

$$nse = \left(\frac{\sum_{i=1}^{n} excursion_i}{number\ of\ tests} \right)$$

F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$F_3 = \left(\frac{nse}{0.01 nse + 0.01} \right)$$

Depending upon the water quality index, the quality of the water is ranked by relating it to one of the following categories as in "Table 3".

Table 3: CCME-WQI categories

CCME-WQI Value	Rating	Remarks
95 - 100	Excellent	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.
80 – 94	Good	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
65 – 79	Fair	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
45 – 64	Marginal	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
0.0 – 44	Poor	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

5 MAPPING THE WATER QUALITY IN THE DELTA REGION USING GIS

GIS database are often large and complex collections of geographic shape files features with their corresponding attribute tables. In this study GIS database is developed to illustrate the water quality for specified sites location at six Western Delta Canals in Western Delta Region. Base map is created by added layers of polyline shape files for studying six canals on Arc Map to help in identifying the sites location on these studied canals. Actual collected data such coordinates for each site location by using GPS system has been created on the map as a point shape file by using Arc Catalog. This point shape file is added as a sites location layer on the base map. In the attribute table of the sites location layer, CCME-WQI values and rank is added in two fields. Then according to categories classification for the values and rank of the index the WQI map was created.

6 ANALYZING AND REPRESENTING THE RESULTS

Data was obtained, analyzed and represented. From which, it was clear that, the irrigation canals in Western Delta are mainly used for irrigation purposes and also for purposes of drinking such as water treatment plants on El-Nubaria and El-Mahmodia canals. In order to satisfy the water demands of the Western Delta irrigation improvement project, fresh water is abstracted for the Western Delta Project mainly from Rosetta Branch. The pumping stations on Rosetta Branch were constructed to supply El-Rayah El-Nasery and El-Rayah El-Behery. These intakes from Rosetta Branch are located downstream the outfall of El-Rahawy drain and thus their water is expected to negatively impact the water quality of El-Nubaria Canal, which is fed partly by El-Rayah El-Nasery Canal and partly by El-Rayah El-Beheiry (Donia and Farag, 2005). This is not only the source of deterioration of water quality in the Western Delta Canals, but also the water that is discharged directly from different drains to Western Delta Canals, as El-Nasr-3, El-Umoum, Tharwat, Abu-Almatamir, Edko and Zarkon drains. So the surface water quality in the Western Delta Region must be monitoring to management this area in a good manner. The WQI according to law 48/1982 varied from site to site in the studied canals according to the specific effect of the pollutants to the index calculation. This variation is considered according mainly to BOD and COD and sometimes to NO_3, NH_4, SO_4, B, DO, TDS, and some heavy metals. The average water quality index (AWQI) in each canal was calculated. "Fig. 2" shows the spatial variations of the AWQI for the different studying canals. For the considered canals, the lowest and the highest AWQI are recorded at El-Nasr and El-El-Khandak Canals respectively. AWQI values indicated that water quality for overall canals are marginal (i.e. AWQI ranged between 50.2 and 58.58).

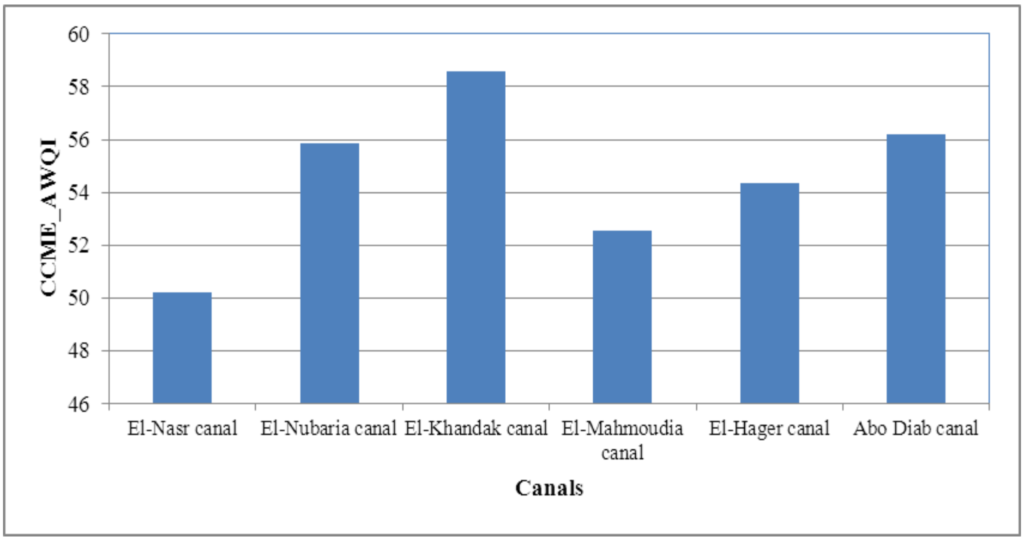

Fig. 2: CCME-AWQI for Different Canals

It was found that the highest WQI value recorded at El-Nubaria Canal Downstream of El-Boustan Reuse P.S. at site (WI17) and the lowest value was found at El-Mahmoudia Canal, upstream of Kafr El-Dawwar drinking water intake (WI08), "Fig. 3". It is noticed that the WQI varies from each site to the other due to the changes in drainage water quality and quantity that are reused into the canals. Furthermore, the marginal rank for WQI at sites (WI05, WI08, and WI09), upstream of drinking water plants intakes, indicated that an intensive treatment must be implemented for these drinking water plants. The quality levels of each site are presented on water quality map. This map is visualized by using GIS software to draw sites classification based on the WQI values and the rating in the attributed table to show the spatial variation for each sites at the studied canals, "Fig. 4". It was Obvious that, WQI of all sites ranked as marginal (WQI values ranged between 48.19 and 64.83). This means that their water quality are frequently threatened or impaired; conditions often depart from natural or desirable levels. These conditions illustrated the negative effect of the official and non-official reused of drainage water discharged into such canals. No good or excellent water quality levels were recorded along studied Western Delta Canals. This deterioration in water quality levels is attributed to the pollution of Rosetta Branch and low quality of drainage water that was discharged into Western Delta Canals as well as the agricultural activities in the studied Regions. Detailed study of the considered sites in Western Delta canals was carried out. Excursion values which present the comparison of the parameters concentrations with the standard (law 84/1982) were calculated and presented in "Table 4". The results displayed that the reduction in the WQI levels is due to the increase in the organic matters as illustrated in parameters of organic pollution indicators DO, BOD and COD. This indicated the presence of domestic pollution in such canals. As well as the deterioration in WQI levels is attributed also to the presence of nutrients (NO_3), NH_4, B, and TDS where these pollutants are attributed to agricultural activities. In addition, the presence of heavy metals (Cu, Fe, Mn, Zn, Cd) in the water pointed out that the industrial activates affected this water and appears in this area of study. So these pollutants in the study area was may be due to the official reuse of agricultural drainage water in the considered area. As well as non-official reuse of drainage water is considered as another source of pollution affected on the canals deterioration. The deterioration in water quality in the study area is also due to the pollution considered in fresh water as a result of polluted Rosetta Branch from different sources of pollution (domestic, agricultural, and industrial pollution). Rosetta branch at kafr-Ezzyat city in El-Gharbia governorate received considerable amounts of untreated industrial effluents, (Abd El-Hamid, 1992).

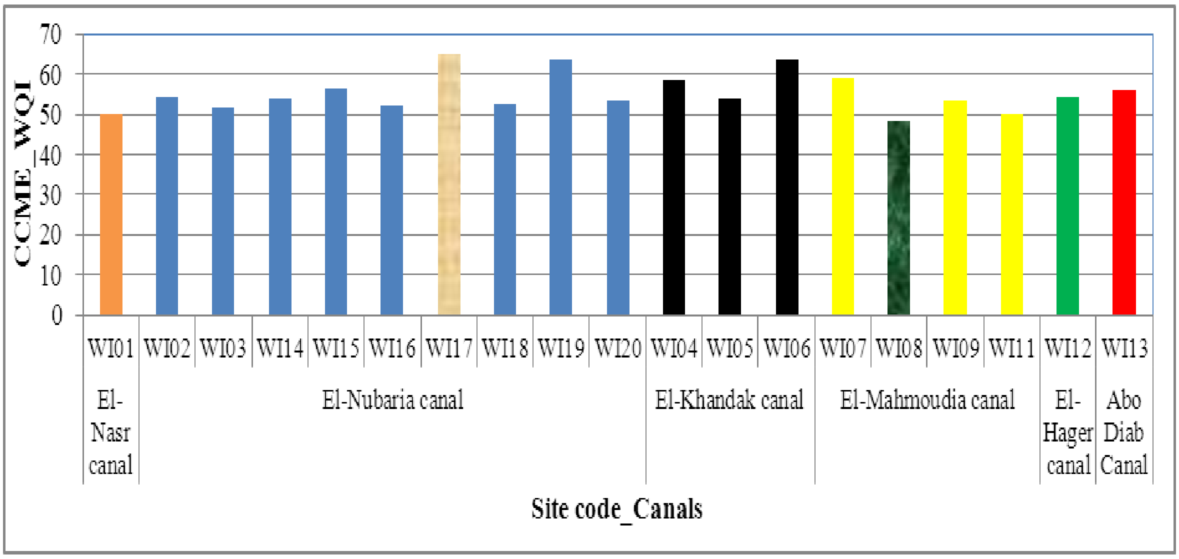

Fig. 3: CCME-WQI at Different Sites in Canals

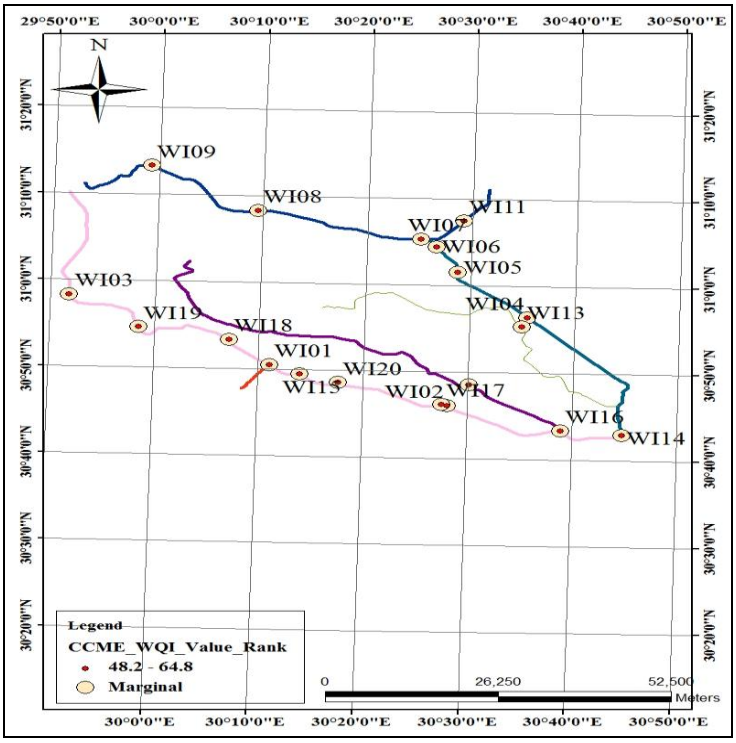

Fig. 4: CCME-WQI Map (Values and Rank) for Sites in Studying Canals

Table 4: Calculated values of CCME-WQI in Western Delta Canals

Canal Name	Site Code	Total No. of Var.	No. of Failed Var.	Total No. of Tests	No. of Failed Tests	F_1	F_2	Sum of Exc.	nse	F_3	CWQI	Rank
El-Nasr canal	WI01	17	11	176	68	64.71	38.64	127.16	0.72	41.95	50.20	Marginal
El-Nubaria canal	WI02	17	10	187	64	58.82	34.22	125.31	0.67	40.12	54.39	Marginal
	WI03	17	9	204	87	52.94	42.65	196.67	0.96	49.09	51.59	Marginal
El-Khandak canal	WI04	17	8	204	63	47.06	30.88	166.13	0.81	44.88	58.43	Marginal
	WI05	17	9	204	72	52.94	35.29	191.49	0.94	48.42	53.84	Marginal
	WI06	17	8	204	62	47.06	30.39	84.81	0.42	29.37	63.48	Marginal
El-Mahmoudia canal	WI07	17	9	204	73	52.94	35.78	93.06	0.46	31.33	58.91	Marginal
	WI08	17	11	203	63	64.71	31.03	236.97	1.17	53.86	48.19	Marginal
	WI09	17	10	204	45	58.82	22.06	212.71	1.04	51.05	53.26	Marginal
	WI11	17	11	204	90	64.71	44.12	123.43	0.61	37.70	49.82	Marginal
El-Hager canal	WI12	17	10	170	58	58.82	34.12	114.70	0.67	40.29	54.36	Marginal
Abo Diab Canal	WI13	17	10	204	69	58.82	33.82	105.12	0.52	34.01	56.18	Marginal
El-Nubaria canal	WI14	17	10	204	58	58.82	28.43	176.43	0.86	46.38	53.74	Marginal
	WI15	17	10	204	64	58.82	31.37	111.85	0.55	35.41	56.42	Marginal
	WI16	17	10	204	83	58.82	40.69	149.74	0.73	42.33	52.01	Marginal
	WI17	17	7	170	45	41.18	26.47	96.71	0.57	36.26	64.83	Marginal
	WI18	17	11	187	64	64.71	34.22	111.18	0.59	37.29	52.57	Marginal
	WI19	17	8	187	50	47.06	26.74	87.54	0.47	31.89	63.73	Marginal
	WI20	17	9	187	53	52.94	28.34	218.75	1.17	53.91	53.41	Marginal

7 CONCLUSIONS AND RECOMMENDATIONS

The results of this study proved that:

The water quality at the study area in the Western Delta Canals is impacted by high concentration of BOD, COD, DO, NO_3, NH_4, TDS, B, SO_4, Fe, Cu, Cd, Mn, Pb, Zn due to the presence of different sources of pollution. This can be attributed to the official and non-official reuse of agricultural drainage water used in feeding the studying canals.

The CCME-WQI index was calculated depending on the standard of Egyptian law 48/1982 for Western Delta Canals. CCME-WQI calculations were done on monthly basis along one water year (August; 2010 to July; 2011). From these calculations, the water quality classified as marginal quality level at the studied canals. This deterioration is most probably due to the accumulation of industrial effluents, domestic and agricultural discharges into the drains that flow directly to Western Delta Canals. The fresh water from Rosetta Branch is considered also as another source of pollution because this branch received different sources of pollution.

In general the water quality in the studying sites is considered as marginal; water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

The generated results made a good contribution in the view of the official and non-official reuse of drainage water as well as the Rosetta Branch water.

The results of this study might assist the decision makers in the pollution control in the Western Delta Regions where the CCME-WQI gives an effective over view about the study area which are required intensified monitoring activities.

Moreover, this study demonstrated that using CCME-WQI to evaluate water quality does identify the specific problematic variables/parameters that may be contributing towards lowering the CCME-WQI values and categories. This information can be of great value for water users (public), planners, policy makers, and scientists reporting on the state of the environment.

As a result it was recommended that optimizing utilizations of water in the Western Delta should be restricted according to its quality or the water quality should be improved by increasing the discharge of fresh water with good quality, or reducing the water mixing ratio with bad quality drains through improving the drains quality before feeding the canals.

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