Application of Multi Criteria Analysis Technique in Surface Water Quality Management

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Abstract: The population growth, economic development, with the consequent anthropogenic activities in Egypt and global climate change pose to reduce the quality trends of surface water resources. The limited amounts of rainfall make the country dependent mainly on the Nile River. The management of river water quality is a major environmental challenge. Cairo, sits on the River Nile south of the Mediterranean Sea, just upstream of the point where the river widens into the Delta. Cairo has an average reach length along the river about 50 km (from Km 900 to km 950 Referenced to Aswan High Dam). This research study area covers Cairo governorate along the River Nile, bounded by El Saff town at Km 877.00 from the South and El Kanater town at Km 953.00 from the North. This area is of particular importance in the study of surface water quality because; industrial and municipal wastes, agricultural and run-off from developing areas were mixing with river flow and surrounding water body thereby deteriorating the water quality. This study mainly aims to develop a framework based on Multi Criteria Analysis (MCA) for management water quality upstream Cairo drinking plants and control the pollution sources. The collected data were utilized in three phases of analysis. In the first phase water quality indices (WQIs) were calculated using Canadian Water Quality Index (CWQI). In the second phase, mathematical model (MIKE11 model) developed by Danish Hydraulic Institute (DHI), Denmark) was formulated to simulate WQ parameter. This model was calibrated and used to simulate different scenarios to improve study reach water quality. In the third phase, an integrated evaluation framework is developed using analytical hierarchy process of MCA that takes four indicators into account; technical, environmental, economical and socio-community for evaluation and ranking various water quality management scenarios. The developed MCA framework shows that there is significant value of such framework in providing information and input for different decision-making levels. MCA results for different scenarios showed that the water quality management scenario focusing on treatment of DWPs sludge is the most convenient scenario.
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1. Introduction

Water quality management has been identified as one of the elements of sustainable development, which aim to achieve sustainable use of our water resources by protecting and enhancing their quality while maintaining economic and social development. Water quality management involves the identification and assessment of point and non-point source pollutants and their sources, and then determining the best management practices to control those pollutants to improve water quality status.

Given the importance of water for the socio-economic development of the country, the government of Egypt is committed to take all necessary means and measures to manage and develop the water resources of the country in a comprehensive and equitable manner. Accordingly, the Ministry of Water Resources and Irrigation has recently launched a National Water Resources Plan for Egypt (NWRP). The latter is a comprehensive document which describes how Egypt will safeguard its water resources in the future, both with respect to quantity and quality, and how it will use these resources in the best way from a socio-economic and environmental point of view (NWRP, 2010).

Furthermore, to confront the prevailing water scarcity, Egypt has endorsed several policies to achieve both integration and decentralization of water management to the lowest possible level. Ministry of Water Resource and Irrigation is implementing the Strategy of Water Resources Management 2050 to fulfill the later objectives including the establishment of water user associations, the transfer towards integrated water management districts, and matching irrigation demands systems (MWRI, 2010).

The MIKE 11 model, developed by the Danish Hydraulics Institute (DHI) in the early seventies, has been used worldwide since 1979 for predicting in-stream concentrations. The model has been efficiently used for water quality evaluation in the South Asian Subcontinent where Kazmi and Hansen (1997) have applied it for Yamuna River in India and Kamal et al. (1999) for Buriganga River in Bangladesh. This model has also been applied by various researchers in other continents of the world.

Multi Criteria Analysis (MCA) is a process of integrated assessment of projects, alternatives or options for ranking or selecting, priority setting among the finite set of projects, alternatives or options. MCA is a structured approach to determine overall preference among alternatives, where the alternatives accomplish several objectives. The advantage of the MCA processes is that it enables an integrated assessment of subjective and objective information with stakeholders' values in a single framework.

Different MCA or Multi-Criteria Decision Making (MCDM) methods have been widely used in the area of environmental resources planning and management. Recico et al. (1999) developed a system for water evaluation and monitoring that was applied to an aquifer in Spain. Raju et al. (2000) used MCDM analysis for a case study of an irrigation area to rank different alternatives using economic, environmental and social factors as criteria. Of all the MCDM tools, Analytical Hierarchy Process (AHP) is being used widely because of the nature of the problem and the structure of the relevant criteria (Karamouz et al., 2002).

2. Material and Methods

2.1 Study Area

Cairo, sits on the River Nile about 160 kilometers south of the Mediterranean Sea, just upstream of the point where the river widens into the Delta. Cairo has an area of 353 km^2 with an average reach length along the river about 50 km (from Km 900 to km 950 Referenced to Aswan High Dam). The study area covers Cairo governorate along the River Nile, extended to El Saff town at Km 877.00 from the South and El Kanater town at Km 953.00 from the North, (Figure 1).

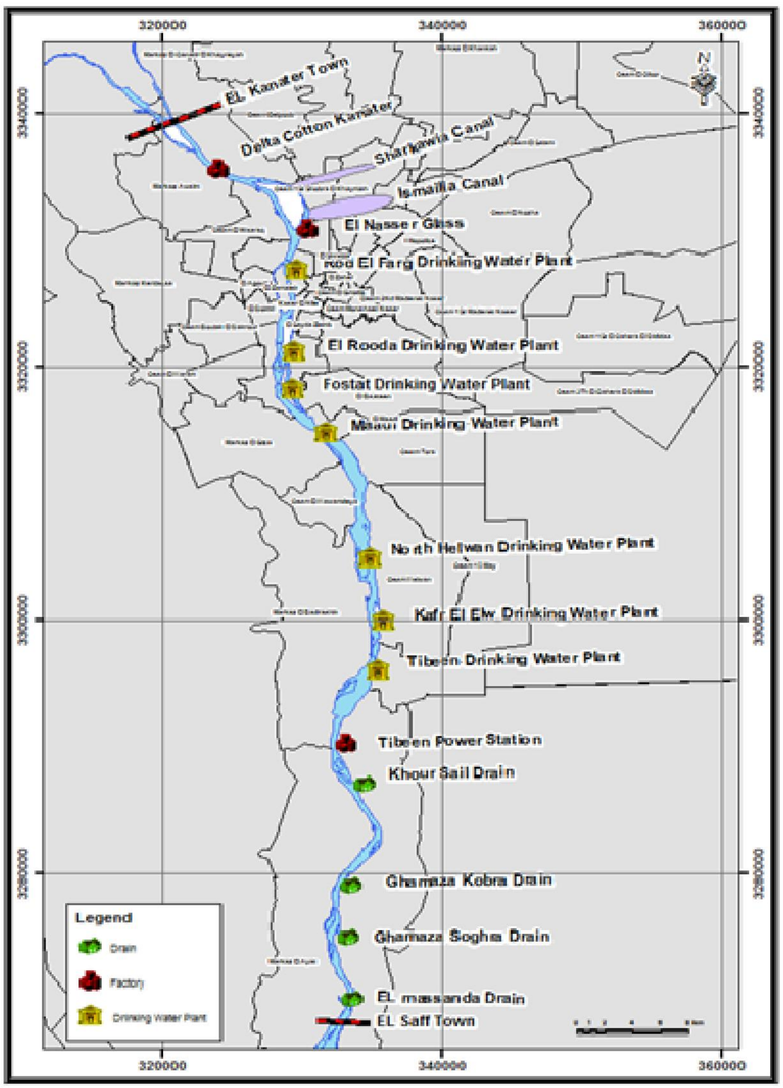


Figure (1) Study area layout

2.2 Sampling Sites

Surface Water samples were collected from various sampling locations of rivers, canal, drains and industrial pollution sources of study area. The measured data include 48 locations including 4 locations for drains, 3 locations for industrial pollution sources and 7 locations for waste water from drinking water plants sludge disposal. The collection and various chemical analysis for water quality parameter is done at Cairo Drinking water Company Central Laboratory. Figure (2) illustrates sample sites.

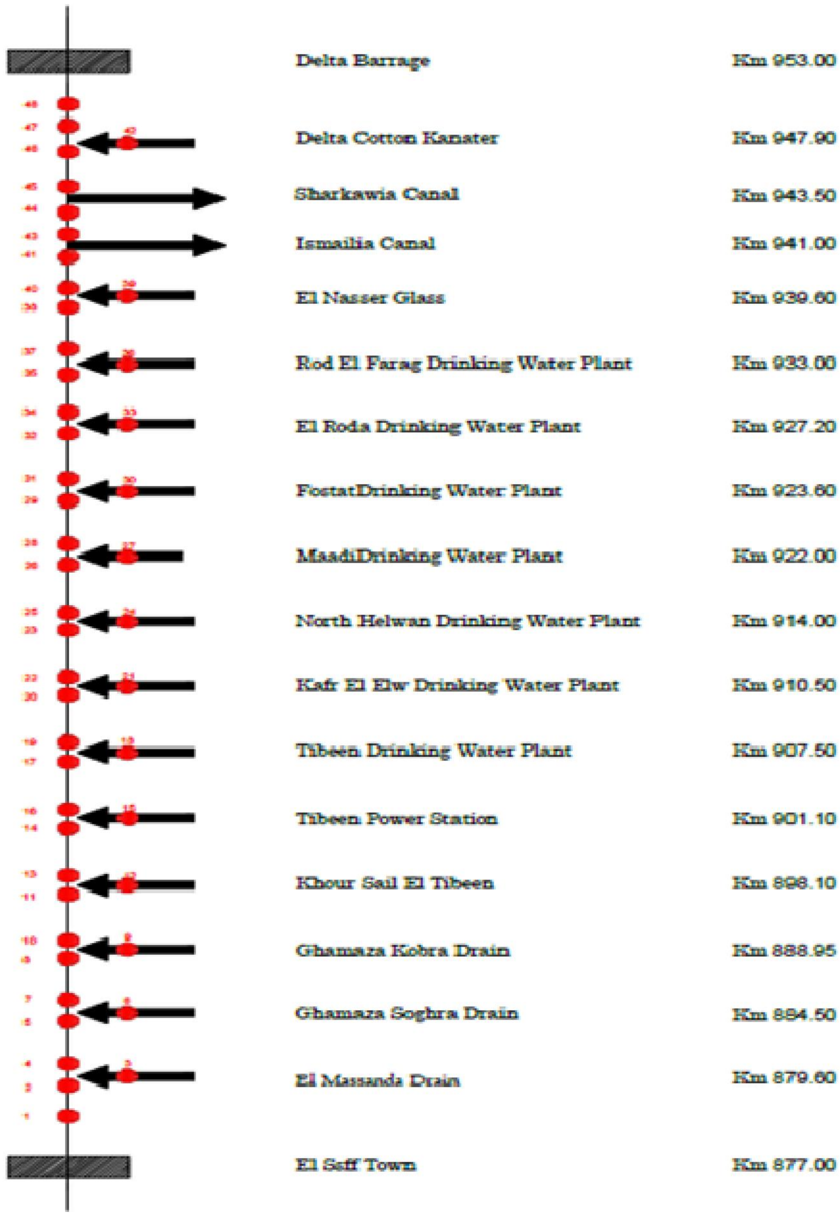


Figure (2) Sample Locations

2.3 Sampling Analysis

Samples were collected in polythene bottles and analyzed for various water quality parameters as per standard procedures given in APHA, Standard Methods, 1992. These samples were tested for pH, Dissolved Oxygen (DO), Total Dissolved Salts (TDS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Fecal Coliform (FC), Iron, Nitrates and Ammonia. The samples measured and analysis had done in the central lab of Cairo drinking water company. Three consecutive water quality parameters data sets for years 2012, 2013 and 2014 were assessed and grouped to satisfy model calibration, run and validation requirements.

2.4 Calculation of Water Quality Index (CCME – WQI)

The observed values of samples were compared with standard values recommended by Egyptian drinking water quality standards (objectives), Law 48/1982 with its ministerial and decree 92/2013 regarding the protection of the River Nile and waterways from pollution. For fecal coliform, as there exists no Egyptian standard for it, the used objective was previously determined by WHO (1989) as a guideline for use of water for unrestricted irrigation (1000/MPNml). The methodology of WQI determination is based on Calculations of the index based on scope (F1): number of parameters that exceed the water quality guidelines; frequency (F2): number of times that the guide lines are not respected and the amplitude (F3): the difference between non-complaint measurement and the corresponding guidelines, (Rita et al., 2011). Based on the above WQI values, the water quality is rated as excellent, good, fair, marginal and poor for human consumption shown in Table (1).

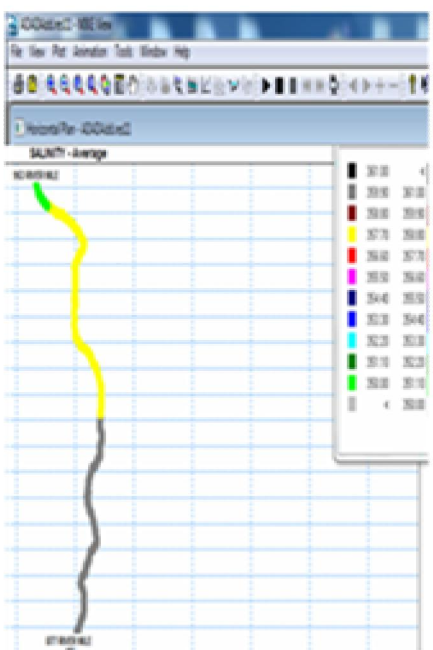
Table (1) Water Quality Index Rating Classification

Rank	WQI Value	Description
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels; these index values can only be obtained if all measurements are within objectives virtually all of the time.
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

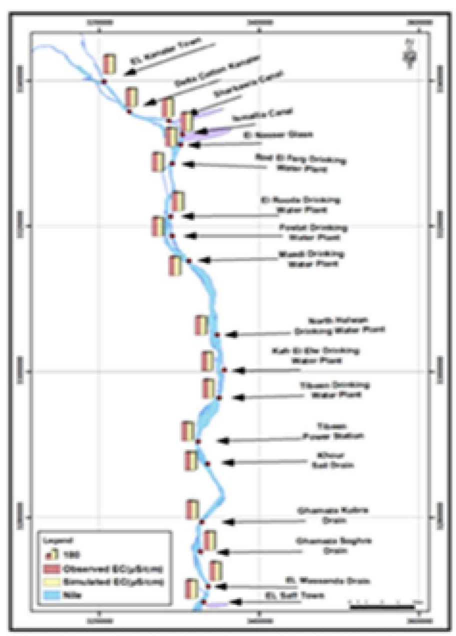
Source: Canadian Council of Ministers of the Environment (CCME), WQI (2005)

2.5 MIKE 11 Calibrations

MIKE11 model was calibrated using water quality data set collected during 2012. Salinity was chosen for calibration process because it is considered a conservative material and it is an excellent water mass tracer. Figure(3) shows the comparison between observed and simulated represented in GIS map for Electric Conductivity (EC) in µS/cm units at various locations of study area.



Figures (3) Simulated Salinity,2012



Figures (4) Simulated and Observed Salinity, 2012

2.6 Running of MIKE 11

After calibration of MIKE11 model, the model was successfully executed as described in last sections. The input dataset used for this model run is water quality data for year 2013. The Hydraulic Dynamic Module (HD), Advection-Dispersion Module (AD) and Ecological Laboratory Module (ECO Lab) were used for the Purpose of simulation in this research. In MIKE 11 environment some of the models that can be selected are dependent on other modules in a simulation and it is therefore required to have more modules selected (e.g., Selection of ECO Lab, which will form the basis of the water quality simulation selects AD-model and HD model also). Therefore for performing the water quality model, HD model and AD model were run. Water Quality modeling takes place through the ECO Lab model entry where DO, BOD, COD and FC as water quality parameters were selected from the ECO Lab templates.

2.7 Water Quality Management Scenarios

Water quality management scenarios are simulated using 2013 WQ data set and the pre-calibrated model as a base condition. The main objective of this simulation is to propose alternative solution to improve the water quality of the study reach; however five scenarios using Mike11 HD, AD and EcoLab modules are designated as explained in Table (2).

Table (2) Management Scenarios Description

Scenario	Description
Base Condition	Pre-Simulated model with 2013water quality dataset.
Scenario (1)	Treatment of four polluted drains (El Massanda, Ghamaza Soghra, Ghamaza Kobra and Khour Sail drains) using wetland technique in order to reduce pollution loads from these drains.
Scenario (2)	Stopping the sludge disposal effluent from the treatment processes of seven DWPs (Tibeen, Kafr El Elw, North Helwan, Maadi, Fostat, El Roda and Rod El Farag) and applying sludge treatment alternative.
Scenario (3)	Twenty percent increase in study reach discharge over the maximum discharge in low demand period in order to dilute the effect of pollution concentrations.
Scenario (4)	Increase the drains discharge by twenty percent.
Scenario (5)	Combination of scenario (1), scenario (2) and scenario (3).
Scenario (6)	Treatment of four polluted drains by construction wastewater treatment plants to reduce pollution loads from these drains.
Scenario (7)	Combination of scenario (1), scenario (2) and scenario (6).

2.8 MCA Framework

MCDA identifies multiple criteria against which the study area water quality management scenarios can be evaluated and then compared to each other. MCA technique mainly based on ranking for prioritizing the alternatives through technical, economical environmental and socio-cultural criteria (Belton, 2002), Figure (5) shows the main MCA Criteria and Indicators.

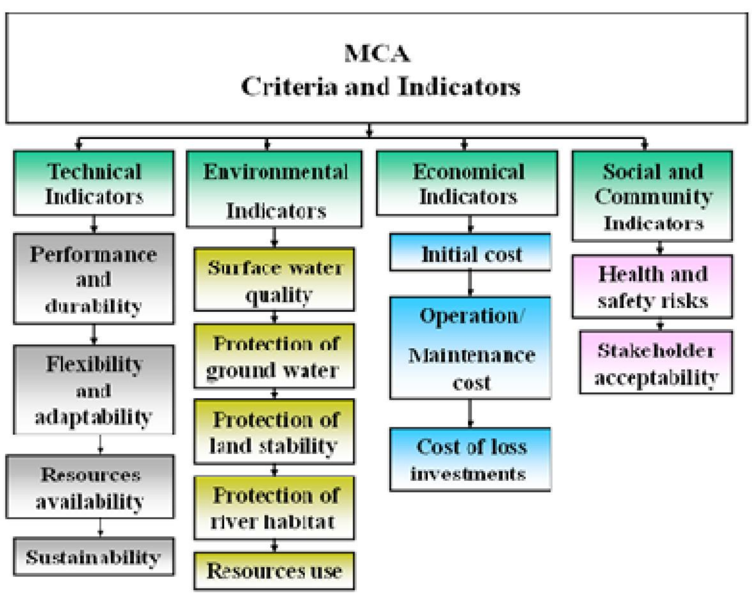


Figure (5) MCDA Main Criteria and Indicators

2.8.1 MCA Formation

The following methodological steps were followed to construct MCA, Howard (1991):-

- Determine available management scenarios "Discrete decision options" which usually will be ranked or scored.
- Choose evaluation criteria. The criteria are used to measure the performance of decision options. They should be non-redundant and relevant to the decision making objectives. Redundant criteria are typically highly correlated and measure the same underlying factor.
- Obtain performance measures for the evaluation. These values be sourced from expert judgments and other environmental models.
- Weight the criteria based on the degree of importance of each adaptation option.
- Rank or score the options. At this stage the weights are combined with the performance measures to attain an overall performance rank or score for each decision option.
- Prioritization of options based on the final weighted scores per option which calculated according to the equation:-

$$Value(x) = \sum_{i=1}^{n} W_i(x) \times C_i(x)$$

Where:-
Value (x) = Final value for alternative x
Wi (x) = Weight of criterion i for alternative x
Ci(x) = Score of criterion i for alternative x

3. Analysis and Results

3.1 WQI Results

Table(3) illustrates the study area spatial variation of mean annual water quality parameters along the study reach, WQI according to Law (48)/1982 guidelines with its ministerial decree 92/2013 regarding the protection of the River Nile and waterways from pollution.

Table (3) spatial variation of water quality parameters and WQI

Sample No.	Location	pH	DO	TDS (mg/l)	BOD (mg/l)	COD (mg/l)	F.C. CFU	Iron (mg/l)	Nitrate (mg/l)	Ammonia (mg/l)	WQI Value	WQI Rank
1	After El Saff Town	7.77 ±.0.04	7.41 ±0.44	285.66 ±43.31	3.48 ±0.51	17.89 ±0.40	1365 ±110	0.20 ±0.03	0.41 ±0.06	0.22 ±0.03	94.81	Good
2	Before Massanda Drain	7.75 ±0.04	7.46 ±0.31	288.69 ±15.10	3.52 ±0.12	17.92 ±0.57	1375 ±136	0.22 ±0.04	0.46 ±0.33	0.23 ±0.03	95.39	Excellent
3	After Massanda Drain	7.86 ±0.13	7.39 ±0.18	310.32 ±12.83	3.53 ±0.51	18.11 ±0.51	1383 ±69	0.24 ±0.04	0.53 ±0.27	0.34 ±0.04	91.39	Good
4	Before Ghamaza Soghra Drain	7.88 ±0.10	7.43 ±0.11	301.99 ±22.17	3.49 ±0.25	17.95 ±0.16	1372 ±127	0.23 ±0.04	0.5 ±0.29	0.22 ±0.02	95.73	Excellent
5	After Ghamaza Soghra Drain	7.86 ±0.14	7.42 ±0.16	312.83 ±0.71	3.56 ±0.30	18.19 ±0.42	1389 ±235	0.31 ±0.07	0.56 ±0.28	0.31 ±0.02	94.27	Good
6	Before Ghamaza Kobra Drain	8.00 ±0.08	7.47 ±0.50	289.59 ±29.52	3.5 ±0.33	17.96 ±0.71	1375 ±94	0.29 ±0.03	0.43 ±0.24	0.22 ±0.04	94.17	Good
7	After Ghamaza Kobra Drain	7.98 ±0.19	7.43 ±0.18	312.84 ±36.15	3.55 ±0.45	18.22 ±0.57	1389 ±162	0.31 ±0.08	0.46 ±0.37	0.29 ±0.03	92.17	Good
8	Before Khour Sail El Tibeen	8.01 ±0.29	7.48 ±0.09	290.16 ±41.30	3.51 ±0.19	17.95 ±0.50	1372 ±88	0.28 ±0.05	0.39 ±.23	0.20 ±0.04	94.93	Good
9	After Khour Sail El Tibeen	7.81 ±0.25	7.39 ±0.24	309.55 ±33.53	3.54 ±0.24	18.09 ±0.48	1389 ±55	0.31 ±0.05	0.38 ±0.38	0.32 ±0.03	90.90	Good
10	Before Tibeen Power Station	7.88 ±0.17	7.37 ±0.13	281.17 ±23.36	3.53 ±0.13	17.94 ±0.24	1370 ±116	0.28 ±0.05	0.33 ±0.43	0.21 ±0.04	94.55	Good
11	After Tibeen Power Station	7.76 ±0.18	7.29 ±0.14	302.57 ±18.29	3.49 ±0.15	18.09 ±0.42	1385 ±124	0.31 ±0.07	0.31 ±0.13	0.30 ±0.05	93.14	Good
12	Before Iron and Steel Factory	7.55 ±0.13	7.38 ±0.14	300.73 ±18.35	3.53 ±0.18	18.00 ±0.36	1386 ±130	0.30 ±0.09	0.32 ±0.17	0.31 ±0.07	94.52	Good
13	After Iron and Steel Factory	7.54 ±0.18	7.25 ±0.16	303.69 ±14.44	3.55 ±0.15	18.11 ±0.25	1392 ±201	0.39 ±0.17	0.39 ±0.13	0.34 ±0.16	90.21	Good
14	Before Tibeen Drinking Water Plant	8.03 ±0.10	7.35 ±0.10	280.72 ±15.66	3.58 ±0.08	17.89 ±0.28	1380 ±111	0.28 ±0.04	0.26 ±0.04	0.22 ±0.02	95.20	Excellent
15	After Tibeen Drinking Water Plant	7.98 ±0.43	7.26 ±0.18	302.42 ±5.81	3.59 ±0.24	18.00 ±0.26	1391 ±111	0.3 ±0.07	0.30 ±0.06	0.25 ±0.04	92.01	Good
16	Before Kafr El Elw Drinking Water Plant	8.05 ±0.20	7.25 ±0.15	285.94 ±24.11	3.58 ±0.40	17.86 ±0.40	1387 ±152	0.31 ±0.05	0.25 ±0.05	0.24 ±0.03	94.15	Good
17	After Kafr El Elw Drinking Water Plant	8.11 ±0.17	7.23 ±0.09	291.73 ±16.93	3.59 ±0.12	17.91 ±0.30	1391 ±135	0.34 ±0.06	0.25 ±0.05	0.30 ±0.03	92.93	Good
18	Before North Helwan Drinking Water Plant	8.12 ±0.19	7.19 ±0.06	273.68 ±23.94	3.56 ±0.18	17.84 ±0.25	1390 ±83	0.33 ±0.06	0.23 ±0.04	0.23 ±0.06	94.68	Good
19	After North Helwan Drinking Water Plant	7.8 ±0.24	7.17 ±0.21	300.13 ±21.81	3.58 ±0.08	17.90 ±0.09	1395 ±172	0.30 ±0.04	0.25 ±0.07	0.26 ±0.07	92.61	Good

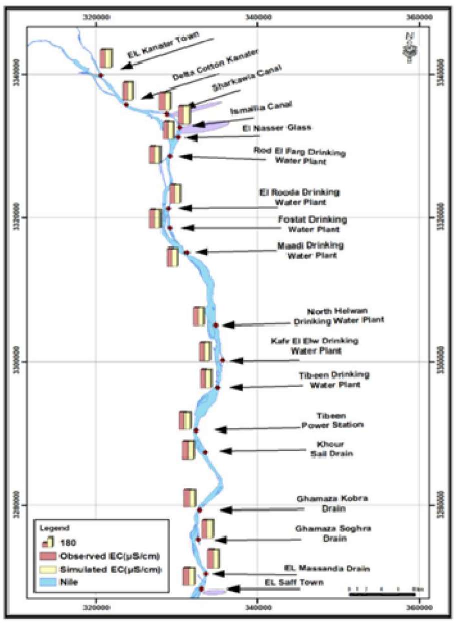
Table (3) (Continued) spatial variation of mean annual water quality parameters and WQI

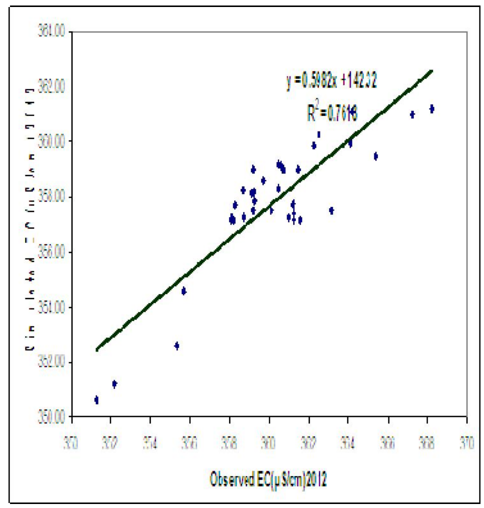
Sample No.	Location	pH	DO	TDS	BOD	COD	F.C.	Iron	Nitrate	Ammonia	WQI	WQI Rank
20	Before Hawamdia Chemical	8.10 ±0.12	7.22 ±0.12	302.45 ±23.68	3.56 ±0.21	17.84 ±0.21	1386 ±78	0.3 ±0.07	0.23 ±.0.06	0.22 ±0.05	95.01	Excellent
21	After Hawamdia Chemical	7.89 ±0.21	7.17 ±0.24	311.75 ±26.16	3.60 ±031	17.96 ±0.61	1395 ±110	0.34 ±0.06	0.4 ±0.45	0.35 ±0.10	91.04	Good
22	Before Maadi Drinking Water Plant	7.87 ±0.25	7.19 ±0.16	268.38 ±16.86	3.60 ±0.30	17.84 ±0.39	1399 ±126	0.3 ±0.09	0.36 ±0.25	0.25 ±0.09	97.36	Excellent
23	After Maadi Drinking Water Plant	7.88 ±0.29	7.15 ±0.15	284.25 ±19.37	3.56 ±0.23	17.93 ±0.60	1399 ±161	0.35 ±0.04	0.39 ±0.30	0.27 ±0.08	92.71	Good
24	Before Fostat Drinking Water Plant	8.15 ±0.29	7.24 ±0.09	268.75 ±14.99	3.58 ±0.14	17.85 ±0.24	1389 ±91	0.32 ±0.05	0.46 ±0.11	0.22 ±0.04	93.66	Good
25	After Fostat Drinking Water Plant	7.9 ±0.18	7.18 ±0.09	294.23 ±23.98	3.61 ±0.16	17.90 ±0.15	1398 ±170	0.36 ±0.07	0.37 ±0.53	0.27 ±0.03	92.35	Good
26	Before El Roda Drinking Water Plant	8.12 ±0.11	7.23 ±0.18	277.53 ±24.47	3.58 ±0.33	17.83 ±0.22	1388 ±86	0.34 ±0.09	0.28 ±0.16	0.23 ±0.03	94.70	Good
27	After El Roda Drinking Water Plant	7.77 ±0.18	7.17 ±0.13	307.76 ±28.37	3.59 ±0.16	18.09 ±0.44	1399 ±164	0.35 ±0.06	0.32 ±0.18	0.27 ±0.05	93.18	Good
28	Before Rod El Farag Drinking Water Plant	8.27 ±0.08	7.26 ±0.07	272.87 ±25.67	3.56 ±0.13	17.85 ±0.13	1384 ±84	0.33 ±0.06	0.28 ±0.09	0.25 ±0.04	95.50	Excellent
29	After Rod El Farag Drinking Water Plant	7.99 ±0.11	7.17 ±0.09	311.27 ±24.20	3.6 ±0.16	18.00 ±0.40	1399 ±196	0.34 ±0.05	0.34 ±0.14	0.27 ±0.02	92.40	Good
30	Before El Nasser Glass	8.05 ±0.15	7.15 ±0.33	286.35 ±24.53	3.57 ±0.28	17.87 ±0.10	1385 ±128	0.35 ±0.07	0.25 ±0.11	0.23 ±0.02	93.53	Good
31	After El Nasser Glass	7.91 ±0.18	7.14 ±6.06	306.41 ±47.79	3.60 ±0.31	17.91 ±0.34	1399 ±183	0.38 ±0.09	0.43 ±0.05	0.35 ±0.10	92.28	Good
32	Before Ismailia Canal	8.02 ±0.15	7.16 ±0.27	288.05 ±28.64	3.56 ±0.27	17.86 ±0.28	1389 ±96	0.38 ±0.02	0.33 ±0.06	0.22 ±0.05	92.97	Good
33	After Ismailia Canal	8.03 ±0.13	7.13 ±0.13	261.06 ±31.53	3.60 ±0.21	17.91 ±0.52	1399 ±151	0.31 ±0.05	0.29 ±0.05	0.24 ±0.04	91.52	Good
34	Before Sharkawia Canal	8.01 ±0.16	7.15 ±0.08	279.16 ±16.33	3.56 ±0.26	17.84 ±0.42	1392 ±132	0.33 ±0.06	0.3 ±0.07	0.26 ±0.03	91.77	Good
35	After Sharkawia Canal	8.00 ±0.13	7.15 ±0.24	271.37 ±16.47	3.6 ±0.25	17.95 ±0.45	1399 ±154	0.35 ±0.07	0.32 ±0.05	0.24 ±0.06	96.26	Excellent
36	Before Delta Cotton Kanater	7.93 ±0.13	7.14 ±0.09	274.69 ±15.63	3.57 ±0.20	17.81 ±0.37	1388 ±125	0.34 ±0.09	0.3 ±0.04	0.26 ±0.03	90.80	Good
37	After Delta Cotton Kanater	8.01 ±0.06	7.15 ±0.10	278.62 ±20.55	3.57 ±0.21	17.94 ±0.46	1389 ±208	0.36 ±0.06	0.24 ±0.07	0.22 ±0.05	90.17	Good
38	Before EL Kanater Town	7.87 ±0.09	7.13 ±0.07	264.6 ±14.98	3.56 ±0.34	18.00 ±0.20	1395 ±128	0.37 ±0.05	0.25 ±0.03	0.21 ±0.04	90.52	Good

From Table (5-1), it can be noted that:-

- The mean annual study area pH values range from 7.75±0.13 to 8.27±0.17. These values are within the permissible limits (6.5-8.5) of law 48/1982 and its ministerial decree 92/2013.
- The mean annual study area DO values vary from 7.13±0.15 to 7.48±0.21 mg/l. These values are within the permissible limits (minimum permissible 6mg/l) of law 48/1982 and its ministerial decree 92/2013. The relative decrease of dissolved oxygen concentrations in some locations may be related to pollutants discharge's which contain high amount of organic matter.
- The mean annual study area TDS concentrations varied from 261±33 to 314±24 mg/l. These values are within the permissible limits (maximum permissible 500 mg/l) of law 48/1982 and its ministerial decree 92/2013.
- The mean annual organic substances concentrations represented by the biological oxygen demand (BOD) for the study area varied from 3.49±26 to 3.61±34 mg/l). These mean values are within the permissible limits (maximum 6 mg/l) of law 48/1982.
- The study area's COD values showed slight and steady increase from South to North. The mean annual COD concentrations vary from 17.81±0.19 to 18.22±0.23 mg/l. These mean values violate the permissible limits (maximum 10 mg/l) of law 48/1982. This increase may be due to the discharge of industrial effluents and other wastes into the Nile by some factories.
- Because of Law 48/1982 did not specify a standard value for fecal coliform (FC) counts for the ambient water quality of the Nile River. Therefore, the value given by the WHO (1989) as a guideline for use of water for unrestricted irrigation (1000/MPNml) has been taken as a guide for the evaluation of the water quality in this study. The mean annual F.C. values for the study area vary from 1370±15 to 1399±22 FCU. The high mean values of FC may be related to the domestic wastewater discharge into the River Nile.
- The mean annual Iron concentrations for the study area vary from 0.22±0.09 to 0.39±0.06 mg/l. These values are within the permissible limits (maximum permissible 1mg/l) of law 48/1982 and its ministerial decree 92/213.

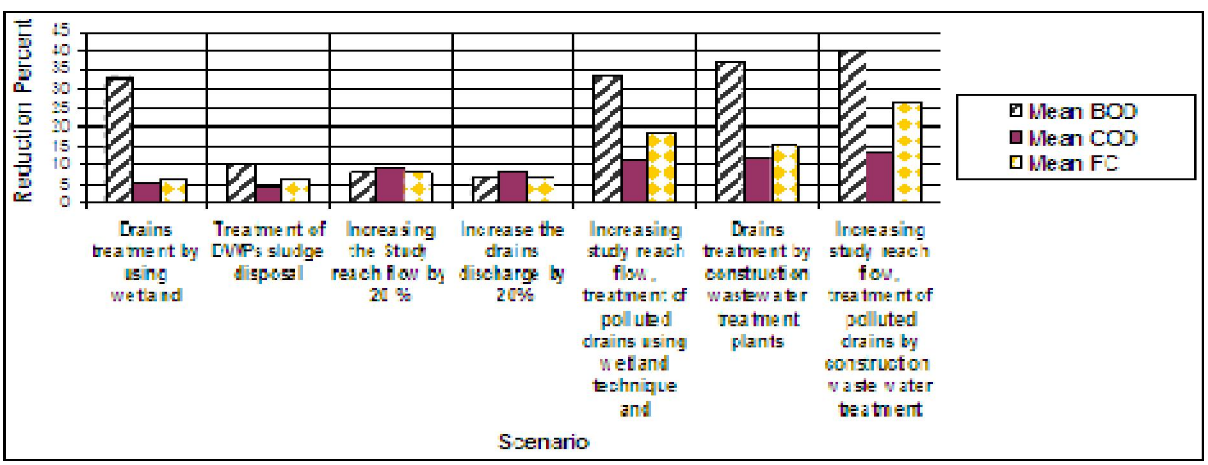
- The mean annual Ammonia concentrations for the study area vary from 0.20±0.03 to 0.37±0.08 mg/l. These values were within the permissible limits (maximum permissible 0.50 mg/l) of law 48/1982 and its ministerial decree92/213.
- The mean annual Nitrate concentrations for the study area varied from 0.23±0.05 to 0.56±0.03 mg/l. These mean values were within the permissible limits (maximum permissible 2.00 mg/l) of law 48/1982 and its ministerial decree 92/213.
- Generally, WQI for the study reach can be categorized into two types “Good water” and “excellent water". The mean annual WQI values for the study area are ranged from 90.12±1.53 to 97.36±2.09. A relative decreasing of River Nile water quality status expressed by WQI after pollution sources locations.





A B

Figures (7a and b) Observed and Simulated Mean Annual EC(µS/cm), 2012



Figure(8) Water quality improvement upstream Cairo drinking water plants under various management scenarios

3.2 Study Area Water Quality Modeling

In this part water quality model MIKE11 was adopted to simulate the water quality status. This model was calibrated and validated to simulate different scenarios for improving water quality problems in the study area. In this study, three years datasets are used to simulate River Nile at Cairo reach in MIKE11 model.

The model was run and analysis based on this output datasets.

5.2.1 Model Calibration

Figures (7a) and (7b) and show the comparison between observed and simulated profiles EC (µS/cm) at various locations of study area

Table (4) Water Quality Management Scenarios Results

DWP			Tibeen	Kafr El Elw	North Helwan	Maadi	Fostat	El Roda	Rod El Farag	Mean Reduction Percent
Scenario (1)	Reduction Percent	BOD	34.46	33.90	33.43	33.20	32.29	32.01	31.07	32.77
		COD	5.89	5.39	5.17	5.34	5.39	5.40	5.17	5.39
		FC	6.13	6.30	6.49	6.58	6.66	6.30	6.45	6.42
Scenario (2)	Reduction Percent	BOD	11.02	10.45	9.92	9.60	10.76	9.07	8.76	9.94
		COD	5.10	4.88	4.77	4.55	4.60	4.33	4.27	4.64
		FC	6.42	6.88	6.93	6.72	6.51	6.30	6.16	6.56
Scenario (3)	Reduction Percent	BOD	8.76	8.19	7.65	8.19	7.37	8.22	8.47	8.12
		COD	10.20	9.60	9.04	9.22	9.10	10.12	8.99	9.47
		FC	7.88	7.25	8.66	7.38	8.10	8.48	8.56	8.04
Scenario (4)	Reduction Percent	BOD	8.19	7.34	6.52	6.50	6.52	6.80	6.21	6.87
		COD	8.69	8.70	8.37	8.09	8.14	7.93	7.92	8.26
		FC	6.13	7.03	7.15	7.16	7.02	6.88	6.60	6.85
Scenario (5)	Reduction Percent	BOD	34.46	33.62	33.99	33.62	32.29	32.58	32.20	32.25
		COD	11.38	11.17	11.17	10.96	10.78	11.02	11.01	11.07
		FC	18.60	19.06	19.21	18.94	18.67	18.41	18.42	18.76
Scenario (6)	Reduction Percent	BOD	38.14	37.57	36.54	37.01	36.54	36.83	36.44	37.01
		COD	11.94	11.90	11.68	11.80	11.90	11.64	11.57	11.87
		FC	15.03	15.43	15.60	15.40	15.48	15.36	15.08	15.34
Scenario (7)	Reduction Percent	BOD	40.68	39.55	39.09	39.55	39.66	40.23	40.68	39.72
		COD	13.62	13.58	13.36	13.43	13.48	13.21	13.20	13.41
		FC	25.60	26.16	26.28	26.10	26.41	26.45	26.18	26.17

From previous results of management scenarios, it is clear that the behavior of the river upstream Cairo drinking water plants response to varying in water quality conditions. From the absolute view point of water quality improvement only, scenarios(5),(6) and (7) appear the most significant impact.

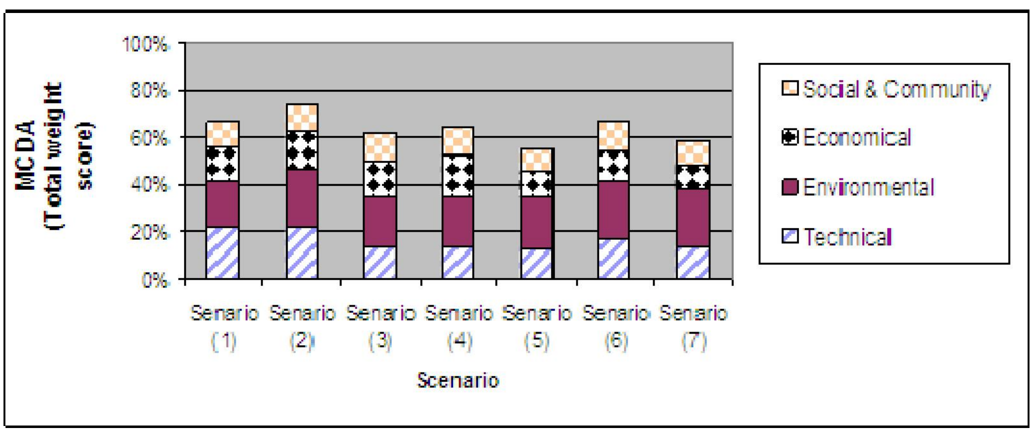


Figure (9) MCA Total Weight Scores

3.2 Management Scenarios Results

Table(4) and Figure(8) illustrate the output of water quality management scenarios upstream Cairo drinking water plants along the study reach compared with the base condition of pre-calibrated model.

3.3 MCA Results

Table (5) provides a semi-quantitative (but nevertheless still subjective) according to MCA evaluation approach. MCA scoring system is based on the procedure developed by the US Environmental Protection Agency (Heaney et al., 1997) which scores all positive aspects of each system type from 1 (lowest) up to 5 (highest having the most desirable conditions). All parameters were weighted equally (weighting factor =6%) with the exception of the four criteria relating to the Sustainability, Resource use, Cost of loss investments and Health- safety risks. These four criteria were allocated a weighting factor of 10% each. The scores and group rankings are based on information and data gathered from the international literature (Linkov (2006), Burgman, M. (2005), Goodwin & Wright, 2009; Lai et al., 2008) and also on personal experience. Figure(16) shows MCA total weight score for different scenarios.

Table (5) MCA for Management Scenarios Evaluation

Primary Criteria and Indicators		Weight	Scenario (1)		Scenario (2)		Scenario (3)		Scenario (4)		Scenario (5)		Scenario (6)		Scenario (7)	
			Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Technical Criteria	Performance and durability	6%	4	0.24	4	0.24	4	0.24	4	0.24	4	0.24	4	0.24	4	0.24
	Flexibility and adaptability	6%	4	0.24	4	0.24	4	0.24	4	0.24	3	0.18	4	0.24	3	0.18
	Resources availability	6%	4	0.24	4	0.24	2	0.12	2	0.12	2	0.12	3	0.18	3	0.12
	Sustainability	6%	4	0.40	4	0.40	1	0.10	1	0.10	1	0.10	2	0.10	1	0.10
Technical criteria total weight			22%		22%		14%		14%		13%		17%		14%	
Environmental Criteria	Surface water quality	6%	2	0.12	2	0.12	2	0.12	2	0.12	4	0.24	5	0.30	5	0.30
	Protection of ground water	6%	3	0.18	4	0.24	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
	Protection of land stability	6%	3	0.18	4	0.24	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
	Protection of river habitat	6%	3	0.18	4	0.24	4	0.24	4	0.24	3	0.18	4	0.24	4	0.24
	Resources use	10%	3	0.30	4	0.40	3	0.30	3	0.30	3	0.30	3	0.30	3	0.30
Environmental criteria total weight			19%		25%		20%		20%		22%		24%		24%	
Economical Criteria	Initial Cost	6%	3	0.18	4	0.24	5	0.30	5	0.30	3	0.18	2	0.12	2	0.12
	Operation/ Maintenance cost	6%	4	0.24	4	0.24	5	0.30	5	0.30	3	0.18	4	0.24	3	0.18
	Cost of loss investments	10%	3	0.30	3	0.30	2	0.20	3	0.30	2	0.20	3	0.30	2	0.20
Economical criteria total weight			14%		16%		16%		18%		11%		13%		10%	
Social and Community Criteria	Health and safety risks	10%	3	0.30	3	0.40	4	0.40	4	0.40	3	0.30	4	0.40	3	0.30
	Stakeholders acceptability	6%	4	0.24	4	0.24	3	0.18	3	0.18	3	0.18	4	0.24	4	0..24
Social & Community criteria total weight			11%		11%		12%		12%		10%		13%		11%	
Management scenario total weight score			66.80%		73.60%		62.00%		64.00%		55.20%		67.20%		58.80%	

It can be noted from MDA illustrated in table (5) and figures (9) that:-

- MCA total weight score for various management scenario were found 73.60%, 67.20%, 66.8%, 64.00%, 62.00%, 58.80%, and 55.20% for scenarios (2), (6), (1), (4), (3), (7) and (5) respectively.
- Scenario(2) for DWPs sludge treatment has the highest overall weight score, total technical and environmental weight scores. However, this scenario can be represent the most convenient scenario for study area water quality management.
- Scenario(1) for treatment of study area drains by using wetland technique has a relatively high technical criteria weight but a relatively low social & community criteria weight due to effect of stakeholders acceptability,Health and safety risks sub criteria evaluation.
- Scenarios (4), (3) and (2) respectively have the highest economical criteria total weights.
- Scenarios based on increasing Nile discharge at low flow month such as scenarios(3), (5) and (7) have a relatively low technical criteria total weight due to their sustainability sub criteria inverse effect on compliance with current water management strategy.
- Scenario (6) for treatment drain discharge by construction wastewater treatment plants has a relatively high technical weight but a relatively low economical weight.

4. Conclusions

The following conclusions were derived based on the results of the study:-

- The CCME-WQI index was calculated depending on the standard of Egyptian law 48/1982. CCME-WQI calculations were done on monthly basis along one year (from January; 2013 to December; 2013). From these calculations, the water quality classified from good to excellent quality level at the studied reach. However, the WQI study on this reach shows that the water can be used for different purposes.
- The results of various water quality parameters proved that the water quality at the study area is impacted by a relatively high concentration of COD and FC due to the presence of different sources of pollution. This deterioration is most probably due to the accumulation of industrial effluents, domestic and agricultural discharges directly into the river. Therefore this study might assist the decision makers in the pollution control upstream Cairo drinking water plants where the CCME-WQI gives an effective over view about the study area which is required intensified monitoring activities.
- The hydraulic and water quality parameters upstream Cairo drinking water plants could be successfully simulated using MIKE11 model by using three years data sets (2012, 2013 and 2014). The main objective of this simulation is to test and evaluate the different scenarios for improving the water quality of study reach.
- MCA tools could help in deciding what criteria can be used to judge and determine the relative importance of each of the management scenarios, and to compare the scores to identify the best convent scenario.
- The advantages of using MCA techniques over other less structured decision-making methods are numerous: MCA provides a clear and transparent methodology for making decisions and also provides a formal way for combining information from disparate sources. These qualities make decisions made through MCA more defensible than decisions made through less structured methods.
- Moreover, this study information can introduce a great value for water users (public), planners, policy makers, and scientists reporting on the state of the environment.

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