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Impact assessment of desalination plants on Kuwait Bay using GIS/water quality index analysis

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ABSTRACT

Desalination plants are located along the Kuwait Bay which receives the hypersaline brine effluent discharged from such plants. Kuwait Bay is a semi-enclosed water body that suffers from various pollution loads. The bay covers an area of 735 km^2 and has 130 km coastline. It is a unique ecosystem in Kuwait's territorial waters. This study presents a new approach, which integrates the water quality index with the GIS technology, to assess the impact of desalination plants on Kuwait Bay. The water quality of the bay was determined by a number of parameters. The water quality index was used to translate a set of a large number of variables to a single value describing the water quality to be used in the management of the bay's water, as communicated to policy makers, service personnel, and the public. In this study, the World Health Organization maximum permissible limit values and Kuwait Environment Public Authority water quality standards were used to compare with the results of GIS analysis. The water quality index was consistently higher than 75 in the winter season and higher than 100 in the summer season, showing that the Kuwait Bay is suffering from a very poor to unsuitable water quality all over the year due to the discharge of desalination plants brines and other polluted effluents. GIS mapping was used to indicate the most affected areas in the bay. For a rehabilitation plan, new locations for the outfalls are proposed based on GIS mapping.

Keywords: Brine discharge; Desalination plants; GIS; Water quality index

1. Introduction

Kuwait suffers from fresh water scarcity, therefore, desalination of seawater withdrawn from the Arabian Gulf became an essential part of the water resource management system for supply of fresh water to satisfy a growing demand for potable water. Intakes of such plants as well as outfalls of their brine effluents are distributed along the Kuwait Bay. The bay is located at the upper northwest section of the Arabian Gulf. It is a semi-enclosed water body that suffers from increasing pollution loads. The bay covers an area of 735 km^2 and has 130 km coastline. It is a unique ecosystem in Kuwait's territorial waters.

In addition to brine water, the bay receives discharges from power plants, treated and partially treated wastewater effluents, and storm waters through 32 discharge outfalls. Water quality degradation is caused by the discharge of such wastes which threaten the marine environment and is becoming a serious problem today causing fish kills, in spite of endless efforts to control it. In the Arab countries, in general, and in the Arabian Gulf countries, in particular, marine pollution has recently received much attention since it adversely affects not only the fisheries but also the water supply since these countries depend primarily on seawater desalination as a source for fresh water (Hamoda, 2004).

Perhaps, the Arabian Gulf is the most affected marine environment in the Middle East, where almost all countries along the gulf shore discharge polluted effluents into the gulf waters. In this regard, the State of Kuwait discharges various polluted effluents into the Kuwait Bay. Six large desalination plants located along the bay extract large volumes of seawater and discharge hyper-saline brine back into

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the marine environment. It is stated that desalination plants have strong potential to detrimentally impact the environmental, physicochemical, and ecological attributes of receiving marine environments (Al-Ghadban et al., 2002; Miri and Chouikhi, 2005; Mauguin and Corsin, 2005; Naser, 2015). A comprehensive review of the impact of brine discharge in sea water was conducted by Roberts et al. (2010) who concluded that there is a widespread belief and recognition that discharge of desalination plants brine adversely affects water quality of the sea and poses a potentially serious threat to marine ecosystems. According to Tomlin (1990), the GIS technology could be used in mapping the water quality but such an approach was not applied to the Kuwait Bay.

This study presents a new approach, which integrates the water quality with the GIS technology, to assess the impact of desalination plants and the discharge of wastewaters on pollution of Kuwait Bay.

2. Methodology

Kuwait Environmental Public Authority (KEPA) provided the data of 12 monitoring stations and 15 buoys stations which are located in Kuwait Bay (Fig. 1). Such data were collected during the period from the year 2014 to the year 2017. The data were analyzed to determine the water quality index (WQI) and the weighted arithmetic water quality index method was used to classify the water quality according to the degree of purity by using commonly measured water quality parameters such as salinity, nitrates, phosphates, DO, TSS, and total coliforms.

2.1. Water quality index calculation

The collected data (Table 1) of total dissolved oxygen, ammonia, nitrate, nitrite, total coliform bacteria, phosphate, pH, total suspended solids, and salinity from the 11 monitoring stations were used to calculate the water quality index. In this study, the weighted arithmetic method was used to calculate the water quality index following the approach of Garcia et al. (2014).

2.2. Weighted arithmetic water quality index method

Weighted arithmetic water quality index method classified the water quality according to the degree of purity by using the most commonly measured water quality variables.

The calculation of WQI was performed using the following equation:

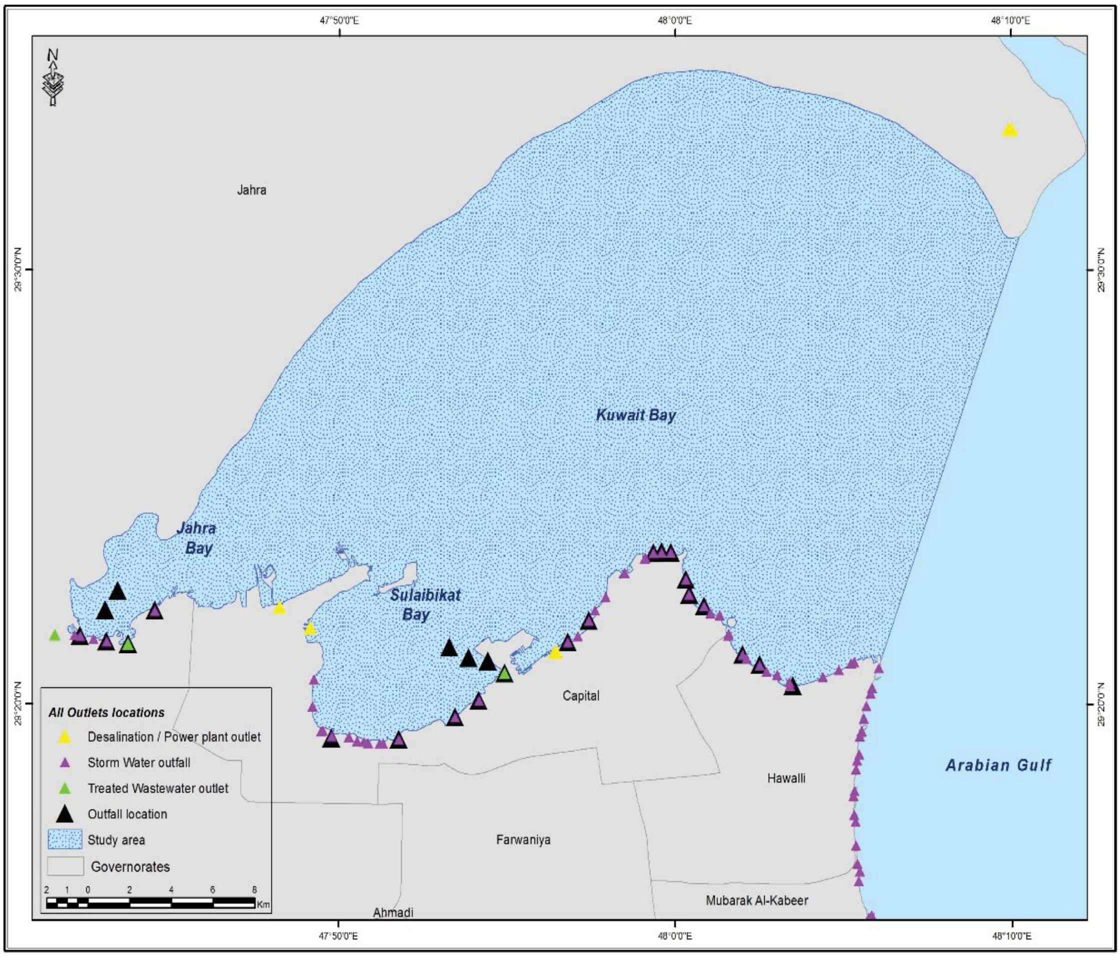

Fig. 1. Outfalls along Kuwait Bay.

Table 1
Water quality parameters from monitoring stations

Location ID	Station	Ammonia	DO	pH	Nitrate	Nitrite	Phosphate	Total coliform	TSS	Salinity
Z00	Al-Beda'a	141.22	6.05	7.91		2.735	16.85	0	18,500	36.31
Z02	Al-Doha	143.15	3.52	8.68	4.85	3.62	28.125	40	14,400	42.15
Z08	Al-Fintas	119.98	6.24	7.95		3.45	23.58	0	9,600	36.54
Z09	Al-Mangaf	130.61	6.75	7.97		2.75	26.98	0	10,700	36.63
Z07	Al-Messila	120.68	7.95	7.93		3.935	19.44	0	11,200	36.21
Z04	Al-Shuwaikh	127.52	3.37	8.61	3.84	4.42	17.165	100	23,600	41.71
Z01	Medayrah (Jal Az-Zour)	131.17	3.19	8.57	3.13	3.23	18.96	10	20,120	41.81
Z10	Mina Abdulla	127.82	6.07	7.94		3.905	23.73	0	11,600	36.55
Z05	Ras Ajuzah	131.94	5.79	7.9		3.68	25.75	0	15,400	38.15
Z06	Ras Al-Ard	149.065	5.11	7.87		7.155	22.98	0	15,100	37.57
Z03	Ras Ushayrij	201.295	3.12	8.57	3.51	4.54	30.905	20	16,000	42

$$\text{WQI} = \frac{\sum Q_i W_i}{\sum W_i} \quad (1)$$

The quality rating scale (Q_i) for each parameter is calculated by using this expression:

$$Q_i = 100\left[\frac{(V_i - V_0)}{S_i - V_0}\right] \quad (2)$$

where,

V_i = measured concentration of ith parameter in the analyzed water
V_0 = the ideal value of this parameter in pure water
V_0 = 0 (except pH = 7.0 and DO = 14.6 mg/L)
S_i = recommended standard value of ith parameter

The unit weight (W_i) for each water quality parameter is calculated by using the following formula:

$$W_i = \frac{K}{S_i} \quad (3)$$

where,
K = proportionality constant and can also be calculated by using the following equation:

$$K = \frac{1}{\sum \frac{1}{S_i}} \quad (4)$$

3. Results and discussion

Tables 2 and 3 show the WQI for stationary and buoyant stations, respectively, based on data obtained from KEPA. The values of WQI were all high (above 75) indicating that the water quality is poor. Meanwhile, Fig. 2 presents variations in WQI between different stations in the years 2014 and 2015. Such variations were consistent and indicate that

Table 2
Water quality index for the 12 monitoring stations year 2014 and 2015

Buoys station number	WQI_Jan_2017	WQI_June_2017
St-01	83.81	117.24
St-02	82.40	117.87
St-03	81.82	109.17
St-04	84.03	118.17
St-05	82.76	120.89
St-06	81.80	121.11
St-07	79.57	118.17
St-08	90.98	120.14
St-09	88.76	121.97
St-10	87.52	122.06
St-11	97.26	122.70
St-12	88.11	119.04
St-13	95.98	127.70
St-14	90.69	121.99
St-15	83.81	117.24

Table 3
Water quality index for the 15 Buoys monitoring station for year January and June 2017

Name	WQI_Sep_2014	WQI_May_2015
Al-Beda'a	78.0771	86.76192
Medayrah (Jal Az-Zour)	105.8206	85.61359
Al-Doha	107.6095	77.29153
Ras Ushayrij	111.8248	81.68797
Al-Shuwaikh	105.4712	79.75187
Ras Ajuzah	79.78159	94.37651
Ras Al-Ard	84.43719	88.17478
Al-Messila	67.26932	83.72505
Al-Fintas	77.07395	85.87413
Al-Mangaf	75.46737	83.87686
Mina Abdulla	78.41669	82.68312

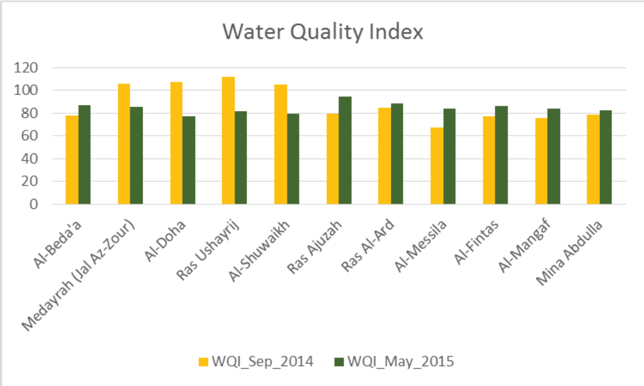

Fig. 2. Comparison between water quality index year 2014 and year 2015.

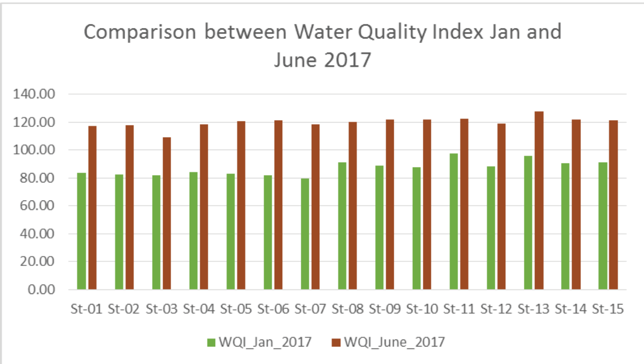

Fig. 3. Comparison between water quality index January and June 2017 based on 15 buoys stations.

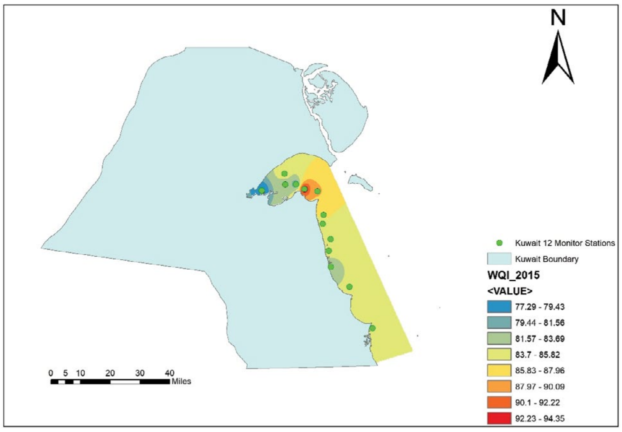

Fig. 4. Spatial distribution for water quality index year 2014 based on 13 monitoring stations.

the water quality was poor in all locations across the bay. Fig. 3 displays seasonal variations in WQI based on WQI obtained in January and June 2017. This figure clearly shows that WQI in summer (June 2017) is higher than in winter (January 2017) showing that the water quality is even worse in the summer season.

Based on values calculated in Table 2, the inverse distance weighting interpolation generated the spatial distribution

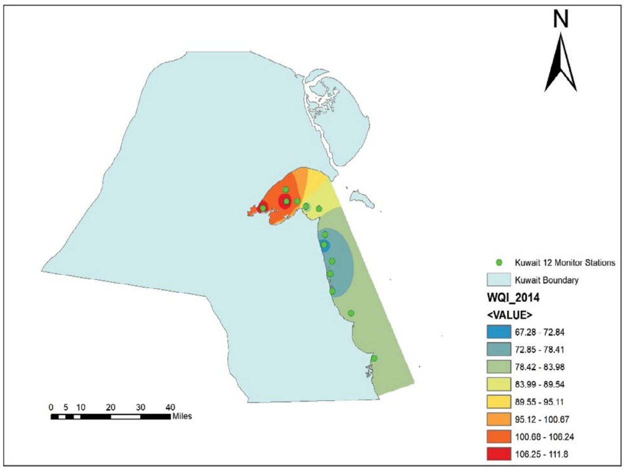

Fig. 5. Spatial distribution for Water quality index year 2015 based on 13 monitor stations.

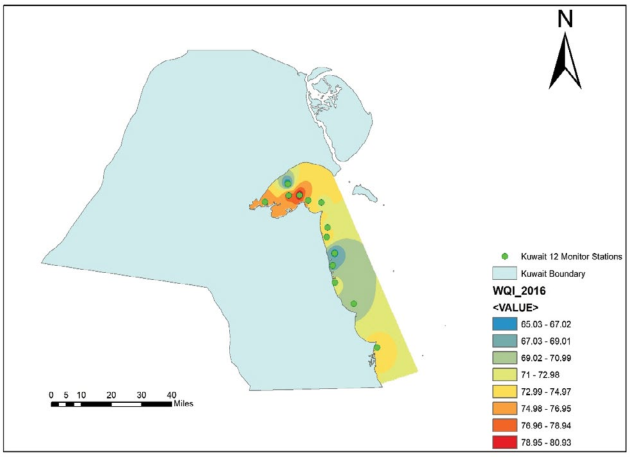

Fig. 6. Spatial distribution for Water quality index year 2016 based on 12 monitor stations.

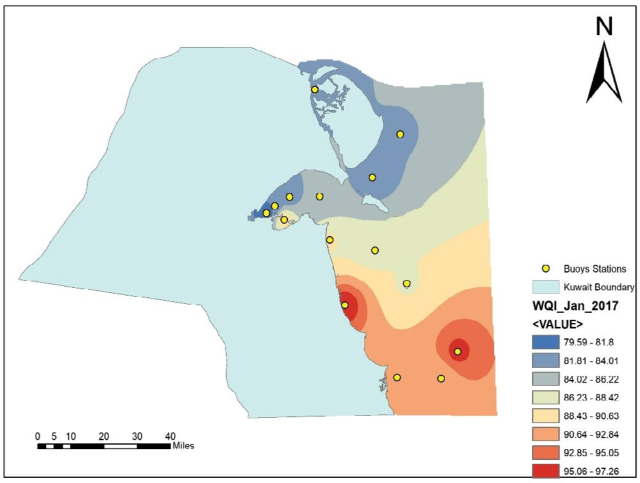

Fig. 7. Spatial distribution for Water quality index year January 2017 based on 15 Buoys monitor stations.

Table 4
Water quality rating as per weight arithmetic water quality index nethod

WQI value	Status	Grading	Possible usage
0–25	Excellent water quality	A	Drinking, irrigation and industrial
26–50	Good water quality	B	Domestic, irrigation and industrial
51–75	Fair water quality	C	Irrigation and industrial
76–100	Poor water quality	D	Irrigation
101–150	Unsuitable for drinking purpose	E	Restricted use for irrigation
Above 150	Unfit for drinking	F	Proper treatment required before use

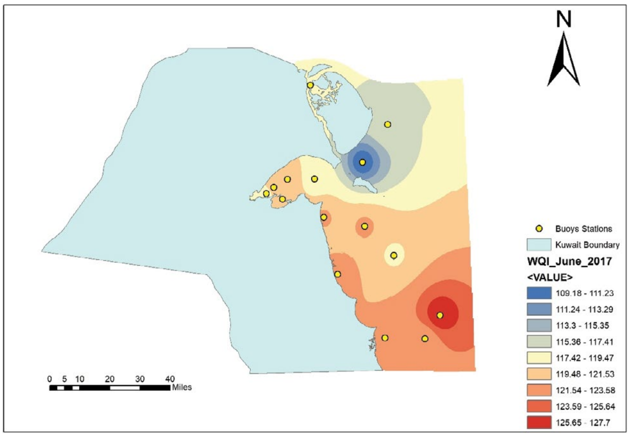

Fig. 8. Spatial distribution for Water quality index year June 2017 based on 15 Buoys monitor stations.

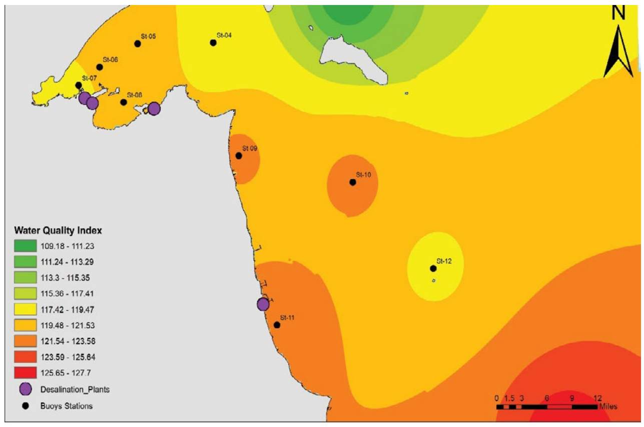

Fig. 9. Water quality index near desalination plants showing a score higher than 100 (June 2017).

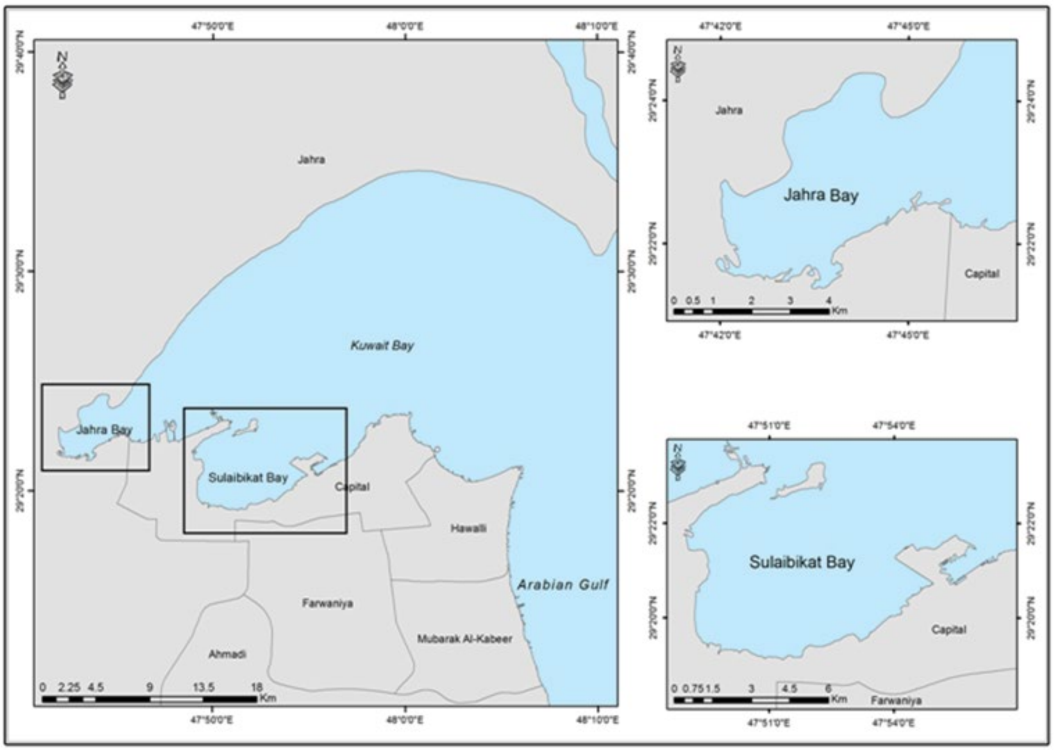

Fig. 10. Highly risk zones in Kuwait Bay.

map of water quality index as shown in Fig. 4 for year 2014; Fig. 5 for year 2015; Fig. 6 for year 2016; Fig. 7 for January 2017; and Fig. 8 for June 2017.

For the years 2014, 2015, and 2016, the readings of 12 monitoring stations were used while for year 2017 15 buoys stations were used for WQI calculation. The rating of water quality according to this WQI was determined according to the weighted arithmetic water quality index method and the results are presented in Table 4.

Fig. 9 shows the buoys station 7, station 8, and station 11 near the desalination plants with WQI higher than 100. Fig. 10 illustrates the risk zones in Kuwait bay according to WQI scores.

4. Conclusions

- The WQI scores show very poor to unsuitable quality of water samples in almost all the outfalls sampling sites and desalination plants along the bay, suggesting that a rehabilitation plan should consider relocation of many of the existing outfalls.
- Use of GIS mapping proved to be a useful technique in identifying the most affected areas in the Bay.
- The Sulaibikhat Bay and Jahra Bay locations of effluent discharge outfalls are badly sited and their adverse impact on the WQI was clearly identified. For a rehabilitation plan, new locations for the outfalls are proposed based on GIS mapping.
- Desalination plants need to stop discharging the brines or treat the brine before discharging it into the sea since the score of WQI is above 100 in the summer season and status of the water is unsuitable according to the WHO criteria.

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