Application of Water Quality Index to Assess the Environmental Quality of Kuwait Bay

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***Abstract*—**This paper employs widely used Water Quality Index (WQI), which synthesizes biological and physiochemical parameters into one single number that can be straightforwardly understood by decision makers and public. The used WQI was formulated based on Delphi technique, which take into account the expert opinions. Water quality data obtained from six sampling sites throughout of Kuwait Bay between 2009 and 2011. According to the WQI, the water quality at most of the sites was within an environmentally satisfactory condition during summer, but the WQI dropped during the winter, emphasizing seasonal effects on water quality. Of the samples collected during 2009, 39.1% were classified as excellent; however, this percentage sharply decreased to 1.5% in 2010, most likely due to the breakdown of the Mishref sewage pumping station in late 2009. Since this is unprecedented attempt to apply WQI on Kuwait Bay, the used WQI proved to be a highly effective tool to assess the water quality of Kuwait Bay in simple way, and its use is strongly recommended.

***Keywords*—**Environmental assessment, Kuwait Bay, Wastewater, water quality index, monitoring network.

I. Introduction

AMONG several important ecosystems in the Arabian Gulf region, Kuwait Bay is considered the most unique. It is highly productive and characterized by several natural settings, such as large shallows and extensive tidal flats, as well as slow water circulation that make it an appropriate habitat for various species (Al-Sarawi et al., 1985; Hasegawa et al., 2004; Barth and Khan, 2008). Kuwait Bay is encountering considerable challenges on global, regional, and local scales that threaten its water quality as well as the ecosystem in general. A greater-than-predicted increase in the Sea Surface Temperature (SST), a significant consequence of climate change, has negatively affected the quality of Kuwait Bay's ecosystem (Al-Rashidi et al., 2009). Moreover, more than 29% of Kuwaiti wetlands are estimated to be affected if the sea level rises by 5 meters due to climate change (Dasgupta et al., 2007).

On a regional scale, the Shatt Al-Arab River plays a significant role in variability of water quality in Kuwait Bay. The nutrient-rich and turbid water discharged from this river increases the input of nutrients such as nitrate (NO_3) and phosphorus (PO_4) as well as suspended sediments and multiple pollutants into Kuwait Bay (Al-Ghadban and El-Sammak, 2005; Khan, 2008; Al-Yamani, 2008). Locally, various point sources of pollution exist along the southern coast of Kuwait Bay, including desalination and power plants, sea harbors, emergency outfalls, and recreational and industrial activities. The discharges from these anthropogenic activities could adversely influence the ecosystem of Kuwait Bay. For example, concentrations of trace metals in mullet fishes reared in Kuwait Bay were higher than in mullets reared in other areas of Kuwait's coastal waters (Bu-Olayan et al., 2008). Additionally, the cooling and process water used in desalination and power plants contributes 22% of the total water pollution, and discharged sewage from outfalls contributes 43% (Al-Ghadban et al., 2002). In late 2009, Kuwait's marine environment suffered negatively when the Mishref sewage pumping station broke. A huge amount of raw wastewater was discharged directly into the seawater without treatment. The water quality in Kuwait Bay was spatially classified into two distinct patterns, one on the eastern side, and the other on the western side of the Bay. The patterns were different in terms of the quantity and type of anthropogenic activities. Despite the existence of a water monitoring system in Kuwait Bay, the number and spatial distribution of monitoring stations need to be revised to adequately monitor Kuwait Bay (Al-Mutairi et al., 2014).

One of the complicated issues in environmental management is communicating the condition of the environment to decision-makers and the public. This issue was partially solved by synthesizing and indexing several water quality parameters into a single number, a Water Quality Index (WQI). The advantages of using a WQI become clear when comparing and assessing the status of water quality within certain ecosystems or among different geographical areas (Kannan, 1991; Pradhan et al., 2001). WQIs are commonly used to assess whether water quality is suitable and healthy for different purposes and to communicate that information to others (Sadiq et al., 2010). Abassi and Abassi (2010) discussed the benefits of WQIs in detail. Four essential and common steps are used to develop a WQI: selecting parameters, transforming the parameters into dimensionless and unitless values, weighting each parameter, and aggregating the sub-index for each parameter to arrive at the final score.

Horton (1965) developed one of the earliest WQIs, including 10 common water quality parameters. Numerous scientists followed Horton, developing their own WQIs. Ott (1978) and Abbasi and Abbasi (2010) reviewed the most frequently used WQIs and described the formulae and

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procedures used to develop each index. Among the frequently used indices is that developed by Brown et al. (1970). They selected water quality parameters using the Delphi technique (Kumar and Alappat, 2009). The index includes nine parameters selected based on experts' answers to three questionnaires. The first questionnaire asked experts to list up to 35 index and rank parameters according to their significance. In the second questionnaire, nine parameters were added by developers, and the experts were then asked to select no more than 15 parameters that they considered to be most important for inclusion in a WQI. The results of the first and second questionnaires were combined to review the experts' individual judgments and obtain a greater convergence of opinions (Ott, 1978). The responses to the first two questionnaires enabled Brown et al. (1970) to identify the following nine parameters for inclusion in their WQI: dissolved oxygen, fecal coliform, pH, 5-day biochemical demand, nitrate, phosphates, temperature, turbidity and total suspended solids.

In the last questionnaire, the experts were asked to draw a rating curve for each parameter included in the index on blank graphs. The level of water quality ranging from 0 to 100 was indicated on the y-axis of each graph, and the increasing level of the particular parameter was indicated on the x-axis. Brown et al. (1970) then averaged all of the curves to produce a single line for each parameter. The rating curves (sub-index graphs) are presented in detail by Ott (1978) and Mitchell and Stapp (2000). Brown et al. (1970) used a statistical analysis to assign weight to each parameter, where the sum of the weights is equal to one. The aggregation method used to develop this index is referred to as a weighted arithmetic method. WQI developers suggest that water quality results can be reported using descriptor words corresponding to a particular range of WQI values.

Brown's WQI is a public index that ignores the type of water consumption (Ott, 1978; Salim et al. 2009); thus, it can be used in different types of bodies of water. For example, Riza and Singh (2010) used Brown's WQI to assess the water quality of the river water in the Angul district of Orissa in India and found it helpful in assessing spatial and temporal changes and classifying the water quality of the river. Likewise, Rajankar et al. (2009) used Brown's WQI to classify water quality from different groundwater sources in different seasons as poor, fair, medium, good, or excellent and concluded that groundwater beneath urban areas is more polluted than that in other areas. Grupta et al. (2003) demonstrated that a weighted arithmetic WQI such as Brown's gives similar results as weighted multiplicative and unweighted arithmetic and multiplicative WQIs. Moreover, the water quality of seawater in Thailand is regularly monitored and assessed using Brown's WQI principles (PCD, 2006). In earlier efforts to develop a WQI for Chesapeake Bay, McErlean and Reed (1979) recommended and used Brown's index.

Despite the presence of a water-quality monitoring system in Kuwait Bay and existence of a large amount of water quality data, a WQI has not been used to quantify the environmental condition of Kuwait's marine quality. The environmental policies regarding water quality has not been properly enforced because the complex nature of water quality data has made it difficult to communicate environmental condition to decision-makers and the public. This research represents the first application of a WQI to assess water quality in Kuwait's marine environment. Therefore, the research aim is to qualitatively and quantitatively assess the water quality of Kuwait Bay using the WQI developed by Brown et al. (1970).

II. Materials and Methods

A. Study Area

Kuwait Bay (Figure 1) is a semi-enclosed shallow body of water extending approximately 35 km inland. It is an ellipsis-shaped bay at the northwestern edge of Kuwait's territorial waters and covers roughly 750 Km^2 (Al-Ghadban, 2004). The maximum depth of water in Kuwait Bay is 20 m, and the mean depth is 5 m (Al-Yamani et al., 2004). The water currents of Kuwait Bay are driven by both the tides and prevailing wind year around. The maximum tides in Kuwait Bay reach to 4 m during neap tide, and the peak velocity is approximately 0.5 m/s. Due to the bay's shallowness, the water column is well mixed (Al-Yamani et al., 2004). The waters of Kuwait Bay require over one year to be completely renewed (Rakha et al., 2010).

B. Data Source

Water quality data obtained from six monitoring stations covering the Kuwait Bay for period from 2009 and 2011. These dates were purposely chosen to examine the potential impacts of the breakdown of a wastewater treatment plant in late 2009. Water samples were collected from the water surface (<30 cm) three times per week and averages each water quality parameter into a single representative value for each month. The water quality data include six parameters: pH, turbidity, Total Suspended Solids (TSS), dissolved oxygen, nitrate (NO_3), and phosphorus (PO_4). A Hydrolab multi-parameters field instrument was used to determine the pH. The turbidity and concentrations of TSS, dissolved oxygen, NO_3, and PO_4 were measured according to MOOPAM (1999) in KEPA laboratory.

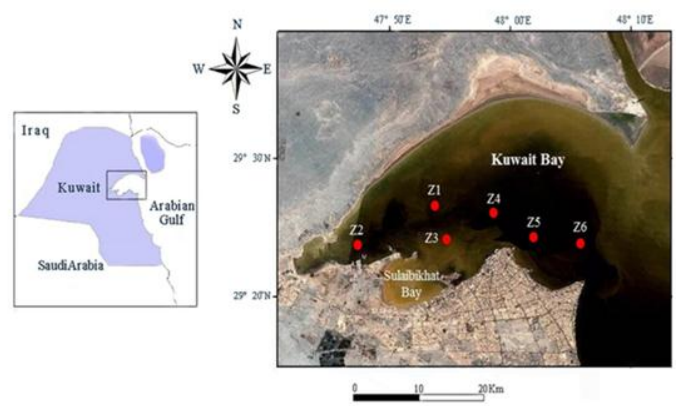

Fig. 1. Monitoring stations in Kuwait Bay

C. Calculation of WQI

The Kuwait Bay water quality was assessed using Brown's weighted arithmetic index. Each individual water quality parameter was transformed into a unitless sub-index (Qi) value using Q-value the charts described by Ott (1978). Next, the sub-index for each parameter was multiplied by its weight (Wi), as shown in Table 1. The mathematical expression used to calculate the overall WQI is given by equation (1):

$$WOI = \sum_{i=1}^{6} WiQi \tag{1}$$

To convert the numerical values of the WQI into an easily understood format, word descriptors associated with a specific range of WQI values were used, as illustrated in Table 2. Although the WQI is designed to include nine parameters, it can still be calculated if data for some parameters are missing (Srivastava and Kumar, 2013). In our study, the parameters excluded from the WQI were fecal coliform because it is not regulated as an environmental indicator for Kuwait Bay seawater, biochemical chemical demand due to missing values, and changes in the seawater temperature due to the complications of defining a reference point. The weights of the missing parameters in the WQI were distributed to other parameters based on the weight of each parameter in the index.

TABLE I
WEIGHTS OF WATER QUALITY PARAMETERS

Parameters	Weight	Weight after remove missing parameters
Dissolved Oxygen	0.17	0.27
Fecal coliform	0.16	--
pH	0.11	0.17
Biochemical Oxygen Demand	0.11	--
Temperature change	0.1	--
Total phosphate	0.1	0.16
Nitrates	0.1	0.16
Turbidity	0.08	0.13
Total suspended solids	0.07	0.11

TABLE II
DESCRIPTOR WORDS OF WQI

Descriptor word	Range
Excellent	90-100
Good	70-90
Medium	50-70
Bad	25-50
Very bad	0-25

III. RESULTS AND DISCUSSIONS

Based on WQI values, the majority of seawater samples (57.8%) were classified as good in 2009, whereas the excellent and medium represented 39.1% and 3.1% of total seawater samples, respectively (Fig. 2). During 2010, only 1.5% of total seawater samples were considered excellent, most likely due to the Mishref station breakdown in late 2009. The water quality recovered, with 37.7% of the total seawater samples collected during 2011 considered excellent. The changes in the WQI over time for each station are shown in Fig. 3. The WQIs of seawater collected at station Z01 ranged from 67 to 95. The lowest WQI found at this station corresponded to a medium level recorded in May 2011, whereas the highest value, recorded in June 2011, was considered excellent. The water quality varied remarkably during 2011, most possibly due to irregular discharges from emergency outfall. Slight seasonal effects were noticed within the WQI values. The highest WQI value of seawater samples taken at station Z02, 94, was recorded during August 2009 and June 2011. The lowest WQI, 69, was found in February 2009.

Contrary to previous mentioned stations, the WQI of seawater monitored at station Z03 showed clear seasonal variations during 2010 and 2011. The lowest WQI value, 70, corresponded to samples collected in February 2009, whereas the highest WQI value, 95, was recorded in June 2011. The water quality at this station is influenced from most significant stressor in Kuwait Bay, the discharge from emergency outfalls and is responsible for the sharp decline in the WQI at station Z03. For example, the WQI dropped from 92 in January 2009 to 70 in February 2009 and from 91 in February 2011 to 72 in March 2011. The highest WQI value at station Z04 was 94, recorded during August 2009 and June 2011, whereas the lowest WQI value of 69 was recorded in February 2009.

The highest WQI recorded at station Z05 was 96 in June 2011, and the lowest WQI was 70, recorded in February 2009. The occurrence of seasonal variations could not be investigated due to missing data. Lastly, the highest WQI recorded at station Z06 was 94 and occurred in January 2009, April 2009, and October 2010. Generally, the WQI gradually decreased from January to July 2010 at station Z06. In contrast to other stations, the WQI values recorded at station Z06 were higher in winter than in summer. The WQI values of samples taken at station Z06 were among the highest in Kuwait, with a mean WQI of 87.2. This station is situated away from the heavily developed coast, at the entrance of the Bay where the water of the Bay mixes with the water from the Arabian Gulf (Al-Yamani et al., 2004).

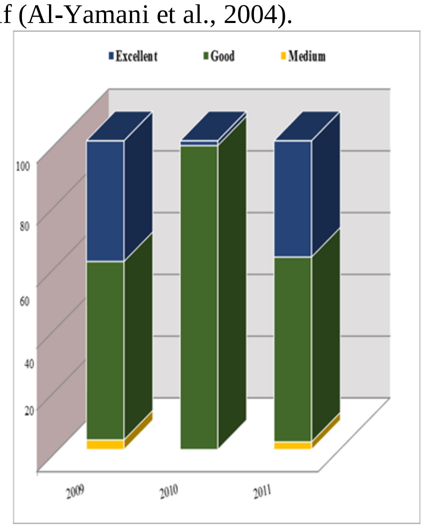

Fig. 2 Qualitative changes in WQI over years

Generally, the WQI values fluctuated from station to station and from month to month at individual stations. With the exception of station Z06, the WQI values were higher during summer than in winter, emphasizing seasonal effects. The discharge of raw sewage or partially treated sewage due to the overload of the Mishref station prior to its breakdown might explain the drop in the WQI at all of the stations during February 2009. Furthermore, the Mishref station breakdown in August 2009 had obvious influences on the WQI values at most stations.

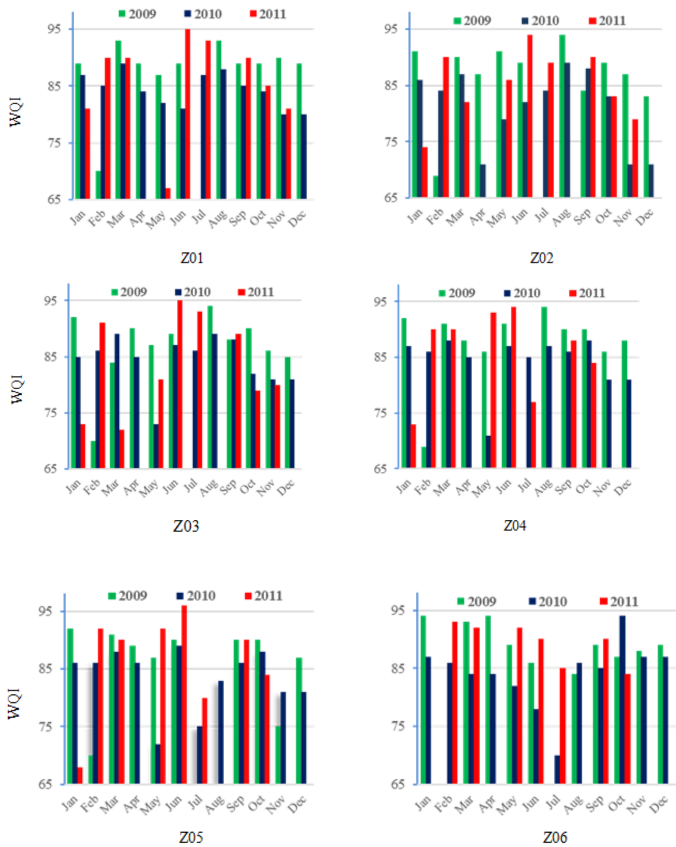

Fig. 3 Changes in WQI over time at each station

IV. Recommendations and Conclusions

The complexity of water quality data is principle obstacle to understanding and evaluating the environmental situations for any ecosystems. Accordingly, several environmental indices were developed in different fields to communicate environmental status of certain ecosystem to fill the gap between scientific data and people. The application of WQI in waters of Kuwait Bay indicates effectiveness and simplicity of the index without losing significant information. The water quality at the monitoring stations on Kuwait Bay was easily compared and assessed using the WQI described in this paper.

Furthermore, using WQI detect the impacts of anthropogenic activities on water quality of Kuwait Bay such as effects from the breakdown of Mishref sewage pumping station in late 2009. Using this method to monitor, assess, and report water quality allows decision makers and the public to easily understand the condition of the water quality in Kuwait Bay and promotes environmental awareness in the society. Due to its simplicity and effectiveness, our present research recommends using WQI used in this research to communicate and assess the water quality of Kuwait Bay.

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