GEOSPATIAL ANALYIS FOR THE POTENTIAL IMPACTS OF OUTFALLS DISCHARGE ON KUWAIT BAY

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ABSTRACT

The GIS technology is used in this study to analyze the water quality and determine the extent of pollution in Kuwait Bay using the collected data in 2014 during winter and summer months. The analysis included five water quality parameters namely ammonia, nitrate, phosphate, TOC and chlorophyll concentration. The IDW interpolation method proved to be helpful for better mapping of water quality. Seasonal variations in concentrations of all water quality parameters were observed in this study. Temperature plays an important role in such variations since the temperature of Kuwait bay reached an average value of 31.85ºC in July, while it reached an average of 14.22ºC in January. For both seasons, the bays' water is highly polluted according to KEPA standards, while summer months being more critical than winter months. The dissolved oxygen concentration in summer reached 4.0 mg/l while in winter is 6.8 mg/l. The used technique proved to be very illustrative in determining spatial distribution and mapping of water quality parameters.

Key Words: Effluent discharge, geographic information system (GIS), inverse distance weighting (IDW), spatial distribution, water quality parameters

INTRODUCTION

With the rapid economic and social development in recent decades, point source pollution to the marine environment from power plants, desalination plants, municipalities and industries adversely affects the marine water quality. 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 polluted effluents into the Kuwait Bay. Desalination plants along the bay extract large volumes of seawater and discharge hyper-saline brine back into 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 (Miri and Chouikhi, 2005; Maugin 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 desalination plants pose a potentially serious threat to marine ecosystems. In addition to brine water, the bay receives discharges from power plants, treated and partially-treated wastewater effluents, and storm waters.

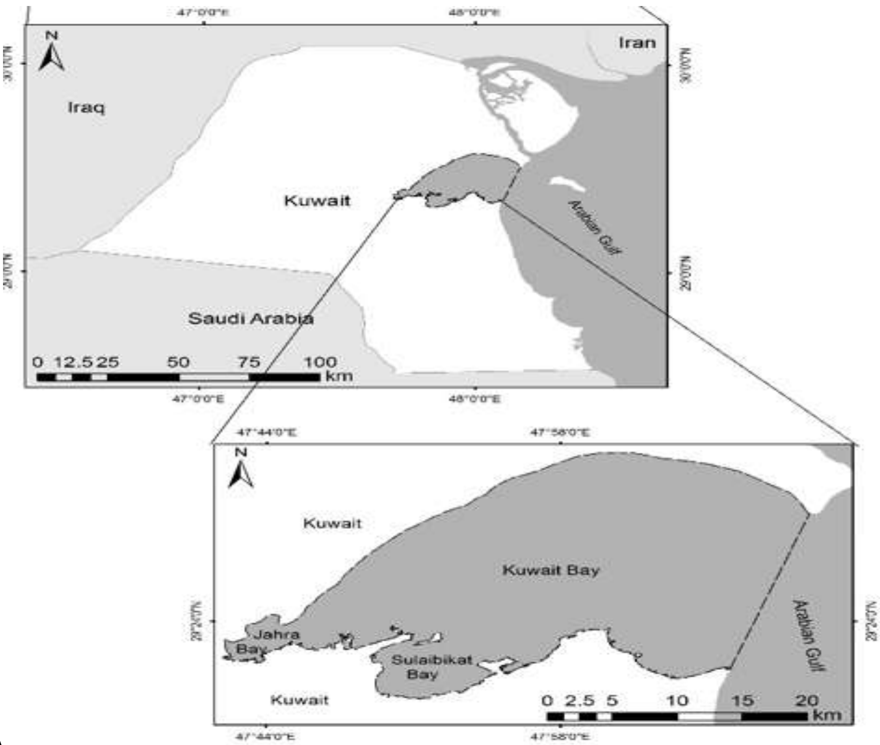
Geospatial Technology is the technology related to the collection or processing of data that is associated with location. **There are different types of Geospatial technologies such as:**

Remote Sensing (RS), Geographic Information Systems (GIS) and Global Positioning System (GPS)

Geographic information systems (GISs) are widely used in the fields of environmental science and related disciplines. GIS is a mapping, monitoring, measuring, management and modeling tool. Familiarity with this burgeoning technology may be a prerequisite for success in our efforts to sustain the environment. GIS is rapidly changing the ways that engineering planning, design, and management of water resources are conducted (Johnson, 2009). Advances in data-collection technologies using microprocessor-based data-collection platforms and remote sensing provide new ways of characterizing the water environment and our built facilities. Spatial databases containing attribute data and imagery over time provide reliable and standardized archival and retrieval functions and they allow sharing of data across the Internet. GIS analysis functions and linked mathematical models provide extensive capabilities to examine alternative plans and designs. Map-oriented visualizations in color, three-dimensional, and animation formats help communicate complex information to a wide range of participants (Johnson, 2009). Therefore, this study used GIS to assess the impact of effluent discharge from outfalls into the Kuwait Bay to determine the changes in water quality parameters in the bay comparing winter and summer conditions in recent years.

STUDY AREA

Kuwait Bay (Fig. 1) is a semi-enclosed shallow water body extending approximately 35 km inland. It is an ellipsis-shaped bay at the northwestern edge of Kuwait's territorial waters and covers roughly 750 Km2 (Al-Ghadban, 2004). The mean water depth of Kuwait Bay is 5 m, and the maximum depth reaches 20 m at the entrance to the Bay (Al-Yamani *et al.*, 2004). Kuwait's marine environment is a unique ecosystem in Kuwait's territorial waters and is characterized by a variety of habitats and wildlife and that is clearly manifested in the northern part of Kuwait's waters. It is also considered as one of the most prominent features of Kuwait's marine environment. It is a highly productive ecosystem, which also provides various services including provisioning, regulatory, supporting and cultural services. Kuwait's waters, particularly the Kuwait Bay, are rich in a diversity of species that had supplied about 40% to 50% of the country's food demand (Al-Yamani *et al*. (2004).



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Fig(1): Kuwait Bay study area.

Based on textural characteristics of its sediments, Kuwait Bay is divided into two energy zones. The first one is a low-energy zone that includes most of the Bay, with primarily mud sediment. The second zone is a moderate-energy zone restricted to the southern offshore area with primarily sand and sandy deposits (Khalaf *et al*., 1982). The maximum current speed was recorded at approximately 1 m/s at the Bay's entrance, with the currents slowing towards the western portion of the Bay to < 40 cm/s (Al-Yamani *et al*., 2004). During the last few decades, Kuwait's marine environment experienced adverse incidents on a regional and local scale threatening the quality of water and the ecosystem in general. One of the local stressors is a steady growth in Kuwait's population, effectively doubling in 30 years. Due to the extensive aridity of the land and the lack of agricultural resources, most of population has been forced to concentrate in the coastal zone, particularly the southern coast of Kuwait Bay (Al-Ghadban *et al*., 2002). To meet the population's needs, many governmental and private sector facilities, such as desalination plants, power plants, recreational facilities, hospitals and other urban and industrial facilities, have been constructed along Kuwait Bay's coast. Most of these facilities discharge their effluent directly into the Bay causing severe burdens on the Bay's ecosystem. Kuwait's Bay encompasses two small bays, namely Sulaibikhat bay and Jahra. Both are semi-closed and shallow area. There are thirty-two outfalls discharging polluted waters in the Kuwait's Bay which include eight outfalls in Sulaibikhat Bay and seven outfalls in the Jahra Bay (Fig. 2).

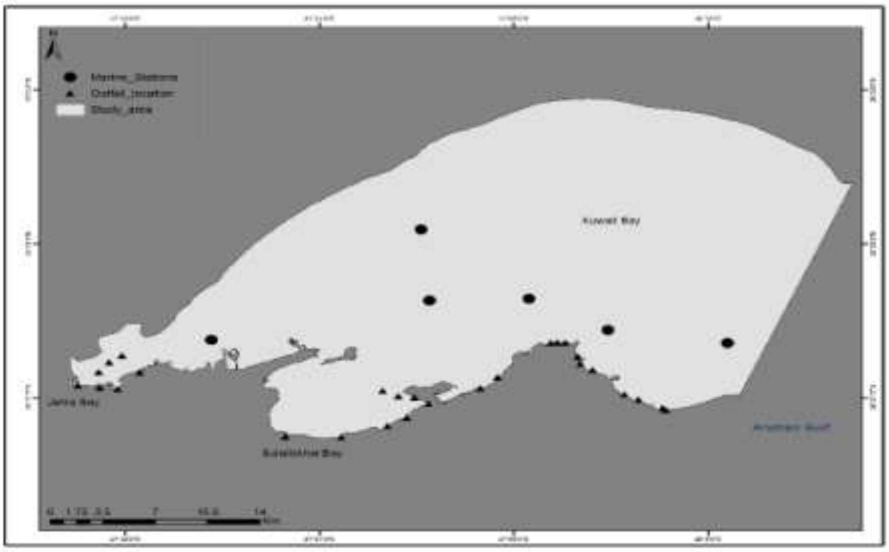

Fig. (2): Outfalls locations and monitoring stations established by Kuwait Environment Public Authority (KEPA)

MARIALS AND METHODS

1. **Data Collection:** Water quality data were obtained from the Ministry of Public Works for thirty-two outfalls along Kuwait Bay for the year 2014. Besides that, the marine water monitoring system of Kuwait Environment Public Authority (KEPA) includes 13 floating stations throughout the territorial waters of Kuwait, only six of which are in Kuwait Bay and were used in this study in year 2014. These data collected from different sources were used to prepare the Geodatabase for all water quality parameters measured from January to December over the period 1996 to 2017.

The Geodatabase design classified into three steps as follows:

- Conceptual database design
- Logical database design, it included entity types, data attributes and relationships between entities
- Physical database design to create the internal database schema

The geodatabase consisted of the spatial data sets and the Attribute data sets (Fig.3). The Geodatabase as obtained, were used to assess the impact of progressive discharge of polluted effluents.

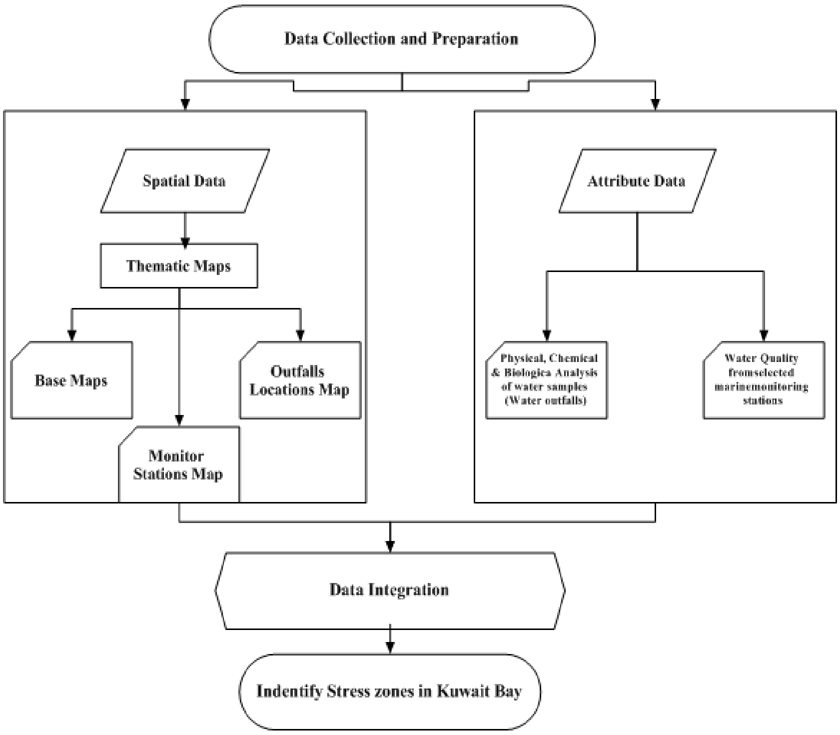

Fig. (3): Flowchart to identify the stressed zones

Water quality data included five parameters: Ammonia, Nitrate (NO_3^-), phosphates (PO_4^{-3}), Chlorophyll-a, and Total Organic Carbon (TOC) since the Outfalls were sampled for these parameters.These parameters are of three types bio-indicator (Chlorophyll-a), inorganic indicator (Ammonia, Nitrates and phosphates) and organic indicator Total organic carbon. The procedures to measure concentrations of these parameters are those specified by ROPME (1999).

2. **Geospatial Technology:** In this study, the Geographic information system (GIS) was used to represent the spatial distribution of the marine parameters that associated with the discharge of outfalls and raster maps were created. The capabilities of GIS in manipulation and analysis of spatial information make GIS an indispensable vector and raster-based solution for assessing environmental problems. Moreover, maps as a presentation tools, are used for communication of the information obtained because the analysis in GIS, add another dimension to this technology for being so popular. The sampling locations were captured as latitude / longitude data in Degree, Minutes, Seconds (DMS) format. The data was converted to decimal degrees (Longed and LatDD) for all the sampling locations. The sampling parameters at each outfall are stored in Excel file, and exported to personal geodatabase that works with ArcMap.
3. **Interpolation:** Generation of spatial distribution maps of various water parameters have been created by run interpolation spatial analysis using ArcGIS 10.4.1 software. The Spatial Analyst Tool in the ArcGIS software was employed for interpretation of data. The spatial distribution of the water quality parameters was achieved by interpolation using inverse

distance weighting (IDW) method (Weighted Moving Average technique) (Huchhe *et al*., 2016), where:

Value of z (x) is the water quality at unsampled location estimated from all known values of z at all n points.

The formula $z(x) = \sum_{i=1}^{n} w_i z_i$

$$weights\ usually\ added\ up\ to\ 1 \quad , \qquad \sum_{i=1}^{n} w_i = 1$$

Where: zi = the measured value at the ith location

wi = weight value for the measured value

z(x) = the predicated value

In (IDW), the weights are based on the distance from each of the known points (i) to the point we are trying to estimate (x). In (IDW), we consider the inverse distance as shown below:

$$w_i = \frac{\frac{1}{d_{ix}}}{\sum_{i=1}^{n} \frac{1}{d_{ix}}}$$

The results were stored as Raster files upon analysis. IDW is deterministic interpolation method because it is based on specific mathematical formula that determines the smoothness of resulting surface. Geospatial analysis for five water quality parameters was applied for the assessment of outfalls discharge impact in Kuwait Bay.

RESULTS AND DISCUSSION

The spatial pattern of each water quality parameter studied is shown below for winter and summer seasons. It is to be noted that based on climatic conditions in Kuwait, there are two distinct seasons which are the winter which extends from October to January and summer which extends from May to September. The months of February to April are termed “spring” although temperatures in these months vary in a wide range between typical winter and summer temperatures. The variation in water temperature from January to December in Kuwait Bay is shown in Figure 4.

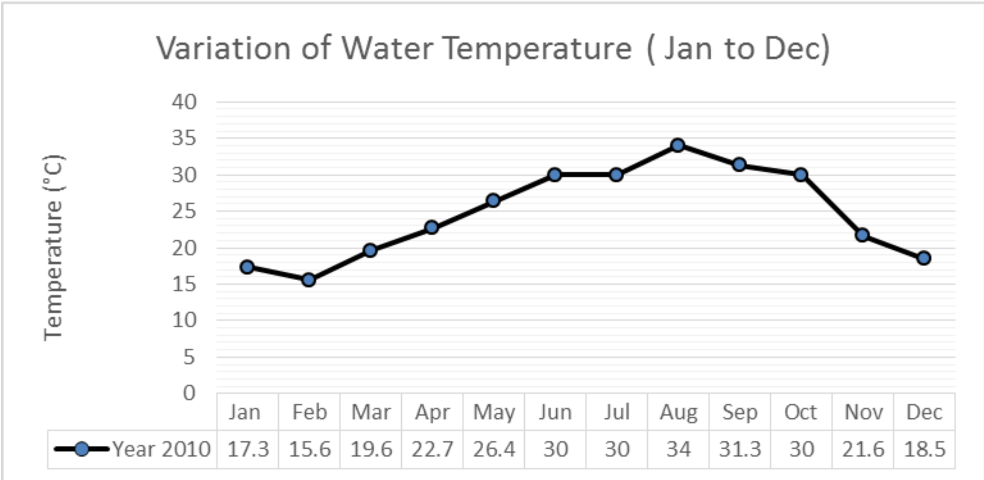

Fig. (4): Water Temperature variation over a 12 month from Jan to Dec

The spatial distributions for the studied parameters are as follows:

1- **Phosphates:** High concentrations of phosphorus and nitrogen in the water cause algae to grow more rapidly than the ecosystems can tolerate. Significant increases in algae concentrations adversely affect water quality, food resources and habitats, and may, in case of extended dark periods, decrease the oxygen that is essential for fish and other aquatic life to survive. In winter season the spatial distribution of phosphate in Sulaibikhat Bay range from 1.41-6.35 mg/l, while during the summer season the spatial distribution of phosphate in Sulaibikhat Bay range from 2.62-15.76 mg/l, as shown in Fig.5. In both seasons winter and summer, the phosphate concentration in Sulaibikhat Bay exceeds the KEPA standard value which is 0.0337 mg/l.

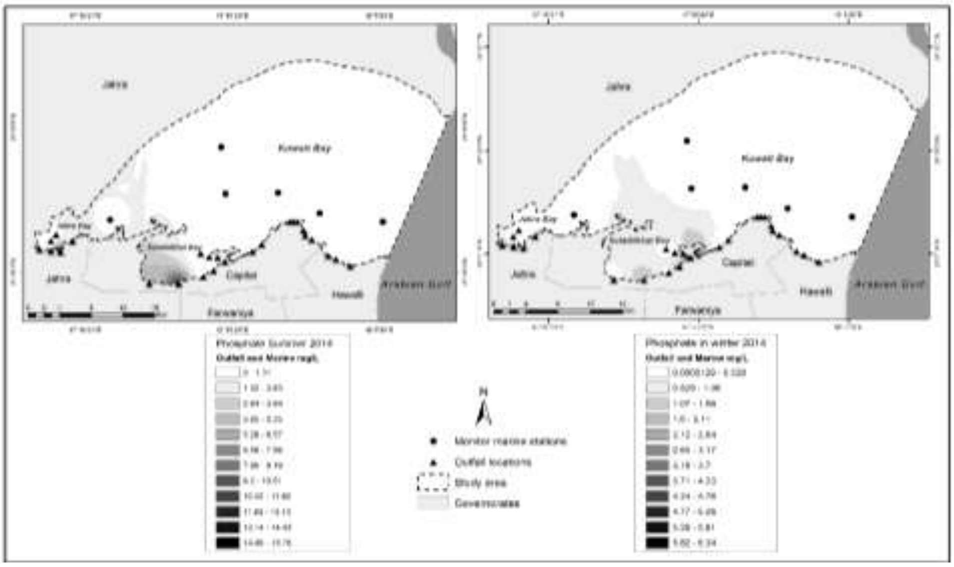

Fig. (5): Spatial distribution of Phosphate in Kuwait Bay during winter and Summer

2- Ammonia: Ammonia (NH3) is one of the most important pollutants because it is relatively common in many effluents but can be toxic, causing lower reproduction and growth, or death in aquatic life. It comes from domestic, industrial and / or agricultural pollution, primarily from fertilizers, organic matter or fecal matter. Ammonia is a nutrient which exists as NH3 in the un-ionized state and NH4+ in the ionized form, it is measured analytically in water as total ammonia.

The nutrient containing nitrogen preferred for plant growth is ammonia which can be oxidized to nitrite (NO2-) and nitrate (NO3-) by bacteria in presence of oxygen, and then used by plants. Nitrate and ammonia are the most common forms of nitrogen in marine systems. Nitrate prevails in uncontaminated waters. Nitrogen can be an important factor to control algal growth when other nutrients, such as phosphate, are plentiful. If phosphate is not abundant it may limit algal growth rather than nitrogen.

The spatial distribution of Ammonia in Sulaibikhat Bay ranges from 2.55-22.82 mg/l during the winter season, while it ranges from 3.42-13.63 mg/l during the summer season as presented in Fig. 5. Sulaibikhat Traditional Café outfall has the highest concentration of ammonia during summer and winter, see Fig. 6.

Ammonia concentration in Sulaibikhat Bay exceeds the KEPA standard value which is 0.06 mg/l.

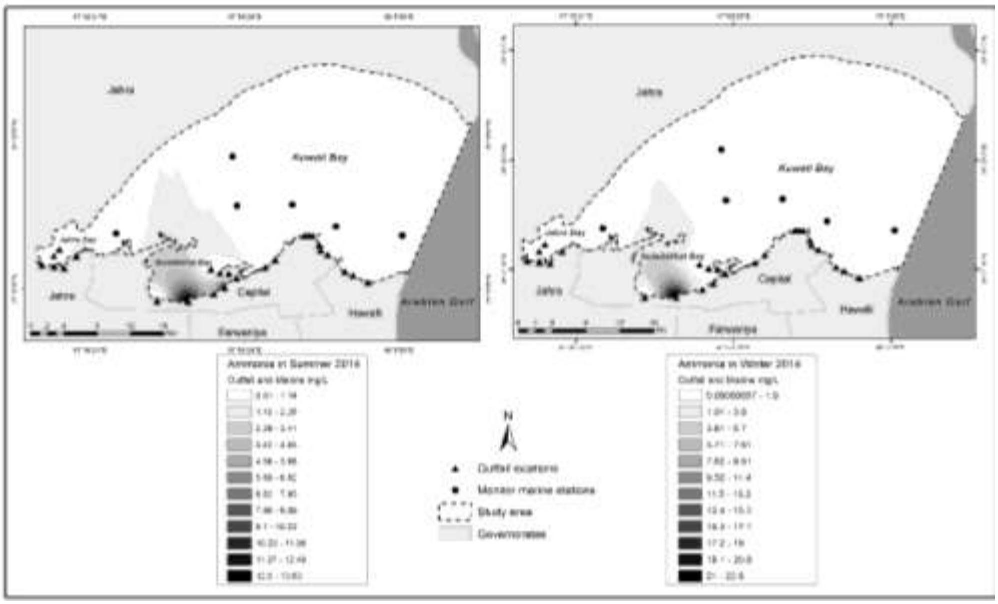

Fig. (6): Spatial Distribution Ammonia in Kuwait for both summer and winter.

3- **Nitrates:** Nitrate is one form of dissolved nitrogen that occurs naturally in soil and water. Some human activities that introduce nitrates into water are fertilizing, runoff from animal feedlots, leaky septic tanks, industrial wastes and domestic wastewater treatment effluents. Nitrate can also be formed in water bodies through the oxidation of other forms of nitrogen, including nitrite, ammonia, and organic nitrogen compounds such as amino acids. Nitrates are highly soluble, meaning that they easily dissolve in water. Any high level of nitrate in water is a nutrient source for growth of algae. The spatial distribution of Ammonia in Sulaibikhat Bay ranges from 0.41-1.19 mg/L during the winter season, while the spatial distribution of Ammonia in Sulaibikhat Bay ranges from 0.48-1.78 mg/l during the summer season, as displayed in Fig. 7.

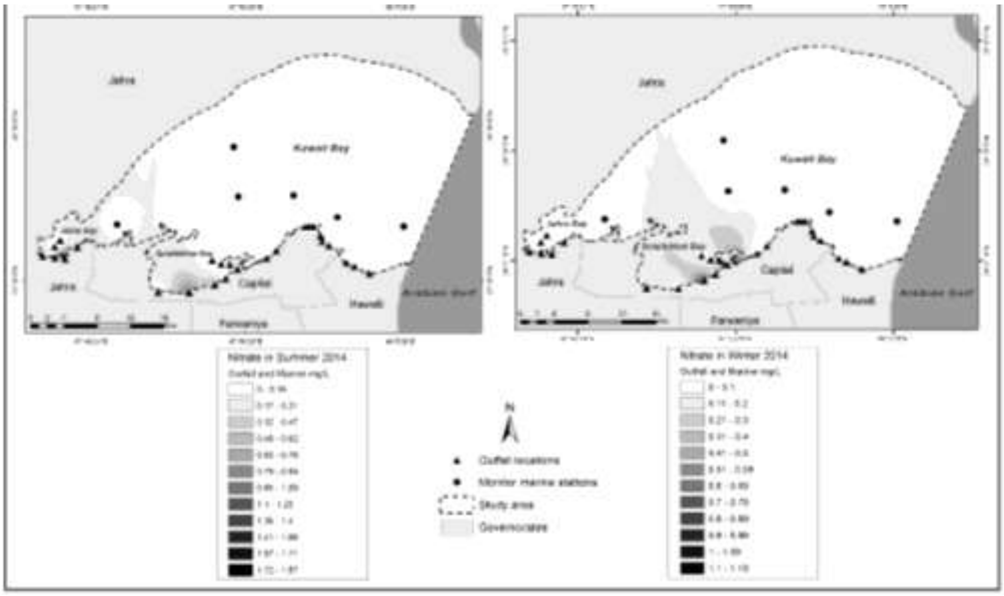

Fig. (7): Spatial distribution of Nitrate in Kuwait Bay during summer and winter.

Nitrate concentration in Sulaibikhat Bay exceeds the KEPA Ambient Seawater Quality Criteria standard value which is 0.0947 mg/l, in winter and summer.

4- **Chlorophyll-a:** Chlorophyll- a, is an indicator of the number of algae growing in a water body. It can be used to classify the alimental condition of a water body. Chlorophyll-a allows plants (including algae) to use sunlight to convert simple molecules into organic compounds. Chlorophyll-a, is the predominant type of chlorophyll found in green plants and algae.

Although algae are a natural part of freshwater ecosystems, high algae biomass concentration (is measured as concentration of chlorophyll a to show the quality condition of degraded water) can cause visual problems such as green layers and can bad odors, and result in decreased levels of dissolved oxygen.

In winter season Chlorophyll-a concentration in Jahra Bay ranges from 13.62-17.48 mg/m3, while in summer season Chlorophyll-a concentration in Sulaibikhat Bay ranges from 42.78-72.92 mg/m3, as presented in Fig. 8.

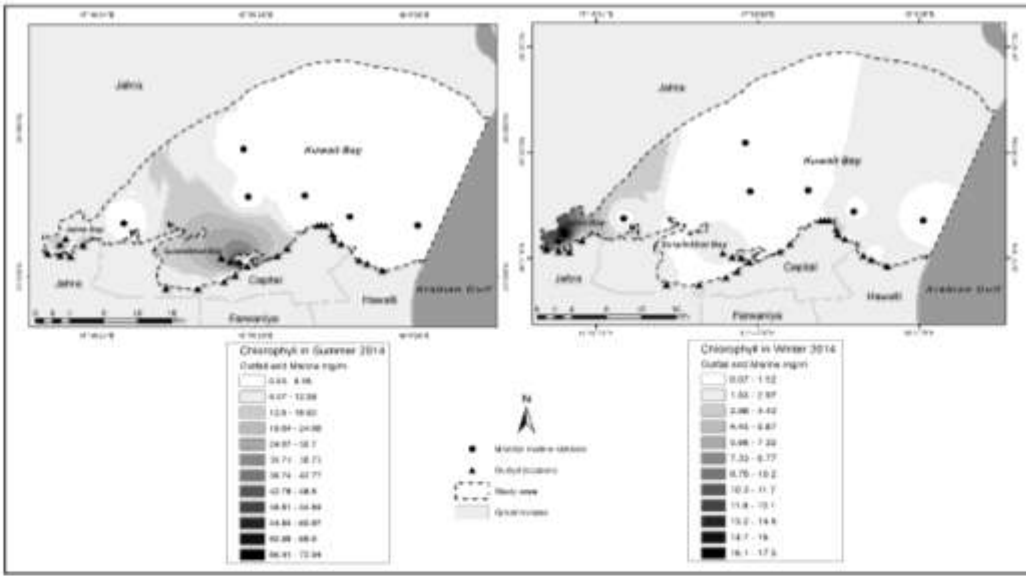

Fig. (8): Spatial distribution of chlorophyll-a in Kuwait Bay during summer and winter seasons.

5- Total Organic Carbon (TOC): Total organic carbon (TOC) is widely used for wastewater monitoring, design, modeling and plant operational analysis. Knowing the amount of organic carbon in a water body is an indicator of presence of the organic matter. The larger the organic content, the more the increase in the growth of microorganisms which contribute to the depletion of oxygen in a water body. The source of this organic material could be wastewater treatment plants discharging partially-treated or untreated (surplus) sewage into a water body.

TOC concentration in Sulaibikhat Bay ranges from 10.07-27.88 mg/L during winter season (see Fig. 8). This is high knowing that the BOD/TOC ratio of domestic sewage is about 4, which shows that this is equivalent to about 50 mg/L of BOD. However, KEPA water quality criteria does not provide a specific value for TOC. During summer season TOC concentration in Sulaibikhat Bay ranges from 10.7-38.42 mg/L (see Fig. 9). This is high since it is on the average equivalent to a BOD of 70 mg/L.

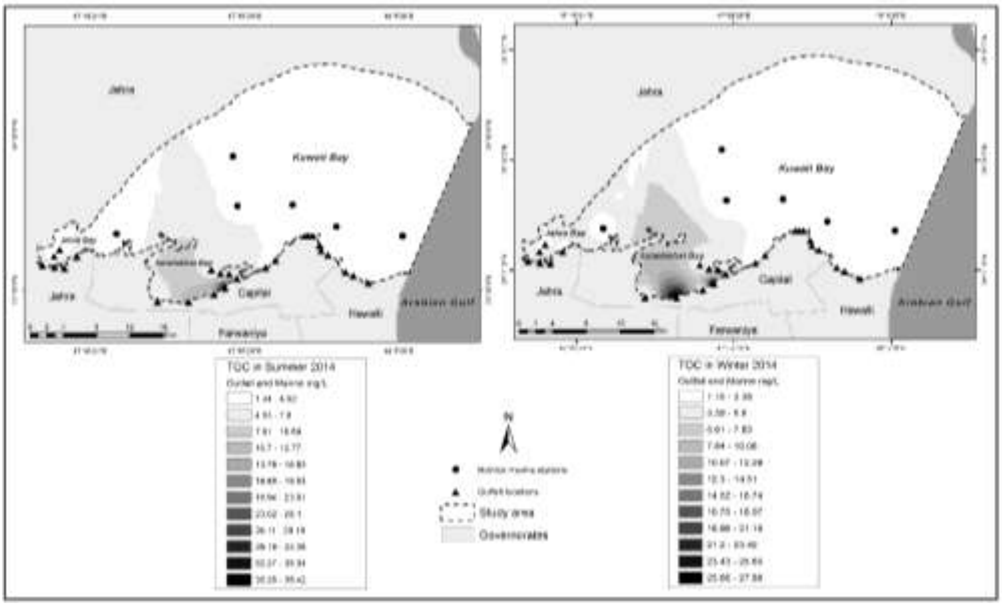

Fig. (9): Spatial distribution of chlorophyll-a in Kuwait Bay during summer and winter seasons.

It is clear from the above discussion that concentrations of various pollutants were higher in the summer season than in the winter season, presumably due to high temperatures, decreased dissolved oxygen levels, and lower currents in the Bay waters during the summer season (Table 1). Dissolved oxygen levels during winter are shown is Table 2. Temperature plays a great role in such seasonal variations since in Kuwait the temperature of water in the bay reached an average value of 31.85°C (in July 2014), while during January it reached an average value of 14.22°C (in January 2014). (See Fig 9). The stress zones of Kuwait bay are shown in figure 11.

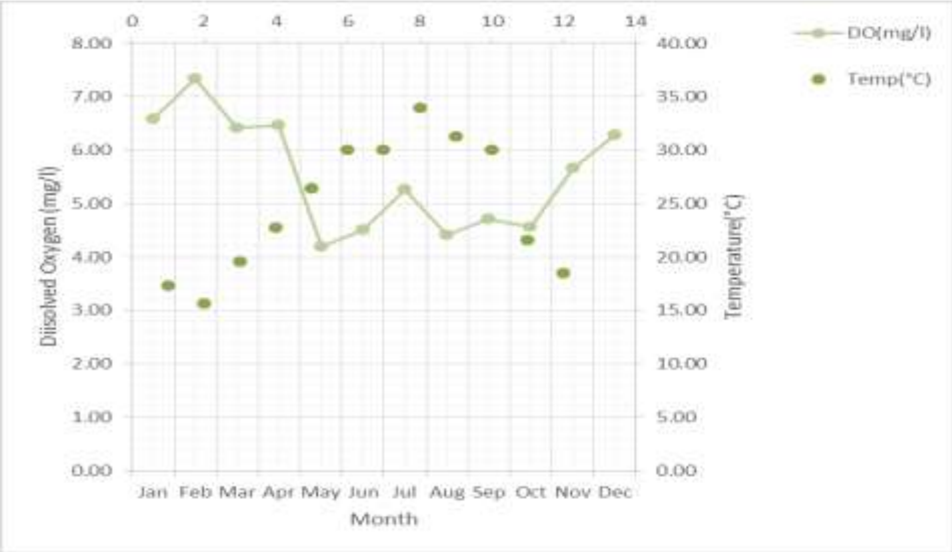

Fig. (10): Dissolved oxygen and Temperature variation in Kuwait Bay over the period from Jan to Dec.

Table (1): Temperature, Dissolved oxygen and Current speed in summer

Monitor Stations Summer 2014	Temperature(°C)	DO (mg/l)	Current Speed (cm/s)
Medayrah (Z01)	32.34	3.19	0.21
Al-Doha - (Z02)	32.61	3.52	0.147
Ras Ushayrij - (Z03)	32.95	3.12	0.147
Al-Shuwaikh - (Z04)	33.22	3.37	0.287
Ras Ajuzah - (Z05)	29.9	5.79	0.279
Ras Al-Ard - (Z06	30.09	5.11	0.273

Table (2): Temperature, Dissolved oxygen and Current speed in winter

Monitor Stations Winter 2014	Temperature(°C)	DO (mg/l)	Current Speed (cm/s)
Medayrah (Z01)	13.41	6.84	0.302
Al-Doha - (Z02)	13.74	6.62	0.314
Ras Ushayrij - (Z03)	13.64	6.53	0.431
Al-Shuwaikh - (Z04)	14	6.56	0.285
Ras Ajuzah - (Z05)	13.68	7.15	0.378
Ras Al-Ard - (Z06	14.11	6.9	0.355

Table (3): Summary of studied water quality parameter properties

Parameter	High Summer concentration at Temperature 31.85°C	Low Winter Concentration at Temperature 14.22°C	Standard Value/KEPA
Location	Sulaibikhat Bay	Sulaibikhat Bay	
Phosphate	2.62-15.76 mg/l	1.41-6.35 mg/l	0.0337 mg/l
Nitrate	0.48-1.87 mg/l	0.41-1.19 mg/l	0.0947 mg/l
Ammonia	3.42-13.63 mg/l	2.55-22.82 mg/l	0.06 mg/l
TOC	10.7-38.42 mg/l	10.07-27.88 mg/l	_
Location	Sulaibikhat Bay	Jahra Bay	
Chlorophyll-a	42.78-72.92 mg/m3	13.62-17.48 mg/m3	_

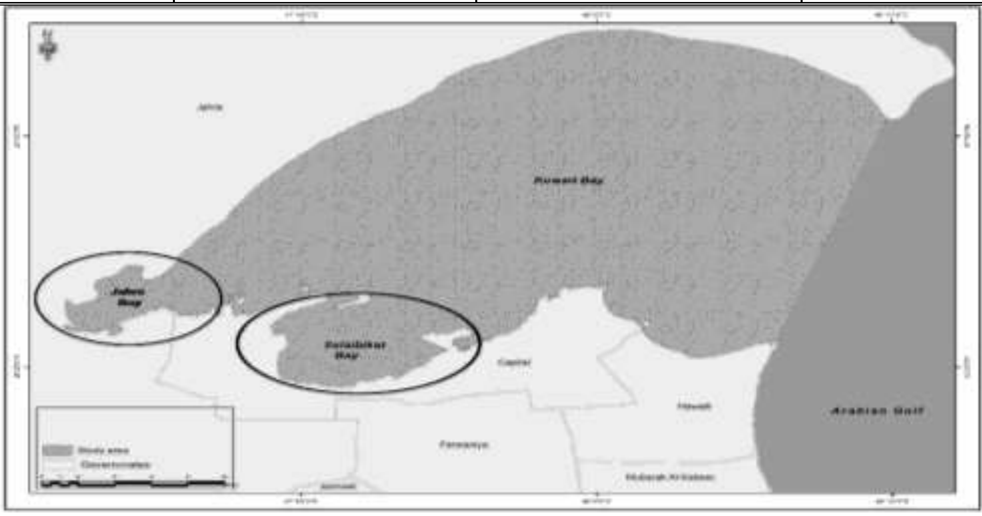

Fig. (11): Spatial distribution of stress zones in Kuwait Bay

CONCLUSIONS AND RECOMMENDATIONS

This study developed a database for the management of pollution in Kuwait Bay as an example of semi-enclosed seawaters. The results of this investigation indicated that the Kuwait Bay especially, Sulaibikhat Bay and Jahra sectors, were polluted to levels exceeding the standards set by Kuwait Environment Public Authority (KEPA). The study has shown that using IDW interpolation method helps for better mapping of water quality. There were distinct seasonal variations in concentrations of all water quality parameters considered in this study. Temperature played a great role in such variations since in Kuwait the temperature of water in the bay reached an average value of 31.85°C (in July 2014), and had an average value of 14.22° C (in January 2014). For both seasons, the bays' water was highly polluted according to KEPA standards with summer months being critical than winter months.

The following is a list of recommendations can be made after this study:

Recommended further studies

1) Both the discharged effluents and the water body must be monitored for organic matter levels.
2) A further study using hydrodynamic model and water quality model can simulate the outfalls to find the carrying capacity of Kuwait Bay.
3) A further study for Sulaibikhat bay is recommended to determine its carrying capacity since it has other types of outlets such as desalination and storm water outlets on a semi-closed sea.

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التحليل المكاني للتأثيرات المحتملة لصرف مياه المجارير علي خليج الكويت

[٥]

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المستخلص

حللت هذه الدراسة جودة المياه باستخدام نظام المعلومات الجغرافية والبيانات التي تم جمعها من خليج الكويت في عام ٢٠١٤ خلال أشهر الشتاء والصيف، لتحديد مدي التلوث في الخليج مقارنة ظروف الشتاء والصيف . شمل التحليل خمس معايير لجودة المياه وهي الامونيا، النترات، الفوسفات، toc أثبتت طريقة الاستقراء IDW إنها تساعد في رسم خرائط أفضل لجودة المياه. وقد لوحظت التغيرات الموسمية في تركيزات جميع معايير جودة المياه في هذه الدراسة . تلعب درجة الحرارة دوراً كبيراً في مثل هذه الاختلافات، حيث وصلت درجة حرارة المياه في الخليج الي ٣١,٨٥٠ درجة مئوية في شهر يوليو، بينما وصلت في شهر يناير الي متوسط قيمة ١٤,٢٢٠ درجة مئوية في كلا الموسمين، تكون مياه الخلجان ملوثة بشكل كبير وفقاً لمعايير KEPA حيث تكون أشهر الصيف أكثر حرجاً من أشهر الشتاء. أثبتت التقنية المستخدمة إنها كانت توضيحية للغاية في تحديد التوزيع المكاني ورسم خرائط لمقاييس جودة المياه .

الكلمات الاستدلالية: تصريف النفايات السائلة، نظم المعلومات الجغرافية (GIS)، الترجيح العكسي عن بعد (IDW)، التوزيع المكاني، معاملات نوعية المياه .