Effect of Physical and Human Factors on Temporal and Spatial Variations of Dissolved Oxygen in Kuwait Bay

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Abstract—**The primary aim of this research is to obtain a better understanding of (a) temporal and spatial variations of dissolved oxygen in Kuwait Bay and (b) the physical and human factors involved in controlling these variations. For this purpose, we performed various statistical and field investigations to analyse and interpret the main factors, which included temperature, salinity and power stations. Data obtained from the Environment Public Authority, the Ministry of Electricity and Water, and field-work were analysed statistically to determine whether a relationship between dissolved oxygen and other factors exists and which factors have a significant effect on dissolved oxygen. The results revealed varying degrees of dissolved oxygen, temperature and salinity in Kuwait Bay throughout the year, whereas spatial variations were less noticeable. Conversely, power stations increase production during summer months; the Western Doha Station recorded its highest production and the Alshuwaikh its lowest. Based on an analysis of the relationship between dissolved oxygen and other factors, only temperature among the physical factors has an inverse relationship, while dissolved oxygen is controlled positively by the distance from power stations.**

Index Terms—**dissolved oxygen, water temperature, salinity, Kuwait Bay, power and desalination plants**

I. INTRODUCTION

Dissolved oxygen (DO) refers to oxygen gas that is dissolved in water. Oxygen enters water through the photosynthesis of aquatic biota and by transfer of oxygen across the air-water interface. Also, wind and waves can significantly enhance the gas transfer rate and increase the dissolved oxygen concentration in a body of water [1]. Oxygen concentrations are much higher in air, about 21%, than in water, at less than 1%. Where the air and water meet, this tremendous difference in concentration causes oxygen molecules in the air to dissolve into water.

Dissolved oxygen in aquatic systems is essential to the survival and growth of many aquatic organisms; it is used as an indicator of the health of surface water. For examples, lakes could not support life without oxygen. All organisms in a lake need oxygen for respiration, from fish to insects to microscopic zooplankton. During respiration, organisms consume oxygen and give off carbon dioxide. If faced with low dissolved oxygen, many fish species will migrate to more tolerable regions, dramatically altering the local fish community structure [2].

While absorbing food molecules to obtain energy for growth and maintenance [3]. Coastal waters typically require a minimum of 4.0 mg/l and do better with 5.0 of oxygen, which provides for optimum ecosystem function and highest carrying capacity. Low oxygen concentrations can cause damage in critical life stages of aquatic animals, including in larval invertebrates and fish eggs. The ideal dissolved oxygen level for fish is between 7 mg/l and 9 mg/l; most fish cannot survive at levels below 3 mg/l of dissolved oxygen. The index of water pollution is the decrease of oxygen level measured by dissolved oxygen levels [4].

Dissolved oxygen concentrations are influenced by salinity, temperature, conductivity, atmospheric exchange, barometric pressure, currents, upwelling tides, biological processes, respiration and photosynthesis [5]. The amount of dissolved oxygen in saturated water will be greater in cooler waters than in warmer waters. For this reason, fish usually reside at the bottom of these waters during the summer months because the water is cooler and has more dissolved oxygen, whereas the surface water is warmer and more saturated with oxygen. The amount of dissolved oxygen also decreases as salinity increases [6]. In addition, many human factors affect the amount of dissolved oxygen, such as treatment plants and power and desalination plants, which routinely discharge heated waste-water into natural waters, leading to low dissolved oxygen concentrations [7]. Dissolved oxygen decreases if sewage and other waste (e.g. from food processing) with high biological oxygen demand (BOD) are discharged into the sea [8].

This paper examines study the temporal and spatial variations of the physical (dissolved oxygen, temperature and salinity) and human (power and desalination plants) variables and the relationship between these variables and dissolved oxygen in Kuwait Bay.

II. MATERIALS AND METHODS

The data set used for the statistical analysis comprises ten years (2000-2009) of monthly measurements of dissolved oxygen, temperature and salinity that the

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Environment Public Authority of Kuwait (EPA) collected at six monitoring stations in Kuwait Bay (Fig. 1).

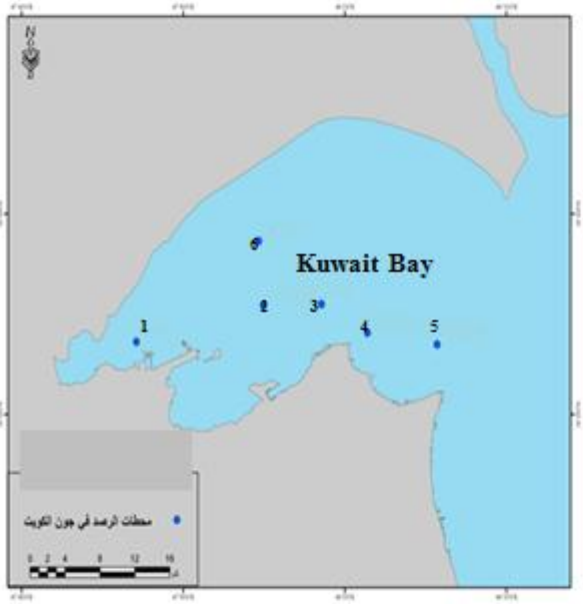


Figure 1. Monitoring stations of the Public Authority for the Environment in Kuwait Bay.

Also, the monthly production figures for power and desalination plants came from the Water and Electricity Ministry from 2000-2009 (Fig. 2).

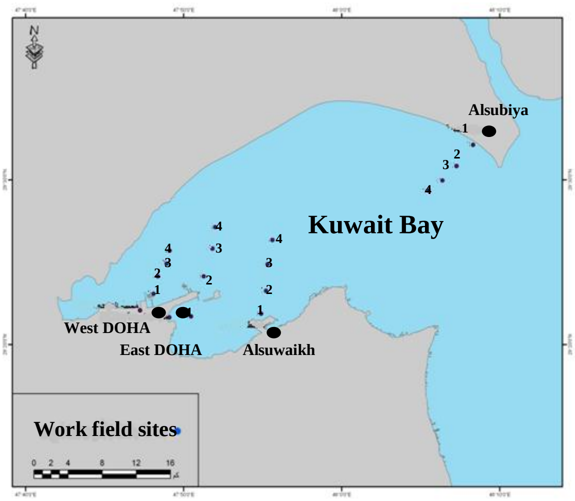


Figure 2. Field work monitoring sites

In addition, we conducted field-work to examine the spatial impact of power and desalination plants located on the coast of Kuwait Bay. We measured dissolved oxygen levels, along with temperature and salinity, at 16 sites in January 2013. The samples were measured on the upper strata of surface water (0-1 m depth). Our boat was equipped with a winch, an electric generator, a global positioning system (GPS) and a depth finder. Dissolved oxygen, temperature and salinity were calculated using the Hana digital potable instrument (Fig. 3).

Statistical analyses were calculated using Microsoft Excel on the above parameters, the mean, the standard deviation and the correlation coefficient.

Figure 3. Shows Hana device

III. Results

A. *Physical Variables*

Table I shows the range, mean and standard deviation of dissolved oxygen in Kuwait Bay from 2000-2009. Dissolved oxygen ranged from 5.80 mg/l in July to 8.53 mg/l in January for the surface water. Also, one can see the differences in dissolved oxygen concentration between summer and winter. Dissolved oxygen concentrations ranged from 5.80 mg/l-6.44 mg/l during summer months (from May-October), while the dissolved oxygen mean ranged from 6.66 mg/l-8.53 mg/l during the winter months (from November-April). The highest spatial variability was in April (SD=0.45 mg/l), while the lowest occurred in October (SD=0.17 mg/l).

TABLE I. Range, Mean and Standard Deviation for Dissolved Oxygen Surface in Kuwait Bay from 2000-2009

Month	Range	Mean ± SD
January	8.06-8.78	8.53-0.26
February	7.22-8.33	7.5-0.37
March	7.11-7.68	7.42-0.19
April	6.62-7.98	7.13-0.45
May	5.74-6.91	6.04-0.39
June	6.04-6.84	6.44-0.25
July	5.47-6.19	5.80-0.25
August	5.55-6.42	6.03-0.30
September	5.72-6.99	6.34-0.39
October	5.80-6.34	6.0-0.17
November	5.97-7.20	6.66-0.38
December	7.63-8.38	8.03-0.22

The mean temperature of surface water, presented in Table II, ranged from 13.6℃-31.9℃. The lowest monthly mean temperature in Kuwait Bay occurred in January, whereas the highest occurred in August. The annual mean temperature was 23.5℃ with an annual range of 18.3℃. The highest spatial variability of temperature was in November (SD=0.70 ℃), while the lowest was observed in February (SD=0.08 ℃).

TABLE II. RANGE, MEAN AND STANDARD DEVIATION OF SURFACE TEMPERATURE IN KUWAIT BAY FROM 2000-2009

Month	Range	Mean ± SD
January	13.4-14.0	13.6-0.19
February	14.6-14.8	14.7-0.08
March	17.6-18.5	17.9-0.3
April	21.4-22.8	22.0-0.49
May	25.7-27.2	26.4-0.54
June	28.3-29.4	28.9-0.34
July	30.2-30.7	30.4-0.20
August	31.5-32.3	31.9-0.33
September	29.1-30.2	29.7-0.37
October	27.6-28.2	27.8-0.22
November	21.7-23.6	22.7-0.70
December	16.5-17.4	16.8-0.33

Spatial and temporal variations of the mean salinity concentration of the surface water are presented in Table III. Salinity values ranged from 39.2‰ (April and May) to 42.9‰ (December). Also, one can see low rates of salinity in March, April and May. Spatially, the highest variability was seen in August (SD=1.53‰), while the lowest occurred in February (SD=0.28‰).

TABLE III. RANGE, MEAN AND STANDARD DEVIATION FOR SALINITY SURFACE IN KUWAIT BAY FROM 2000-2009

Month	Range	Mean ±SD
January	40.2-41.4	40.9-0.41
February	39.8-40.7	40.3-0.28
March	39.3-40.6	39.9-0.36
April	38.5-39.9	39.2-0.41
May	38.8-40.0	39.2-0.40
June	40.1-41.2	40.6-0.33
July	40.2-41.5	40.7-0.40
August	37.2-41.5	40.4-1.53
September	41.1-42.4	41.8-0.39
October	41.9-43.2	42.5-0.36
November	42.2-43.1	42.9-1.14
December	41.5-42.8	42.3-0.41

B. Human Variable

Spatial and temporal variations of the mean production of power and desalination plants are presented in Fig. 4. The mean production of power and desalination plants increased from May to October (summer months) and decreased from November to April (winter months). The lowest monthly mean production of power and desalination plants occurred in February, whereas the highest was recorded in July and August. Spatially, the West Doha plant recorded the highest production, while the Shwaikh plant recorded the lowest.

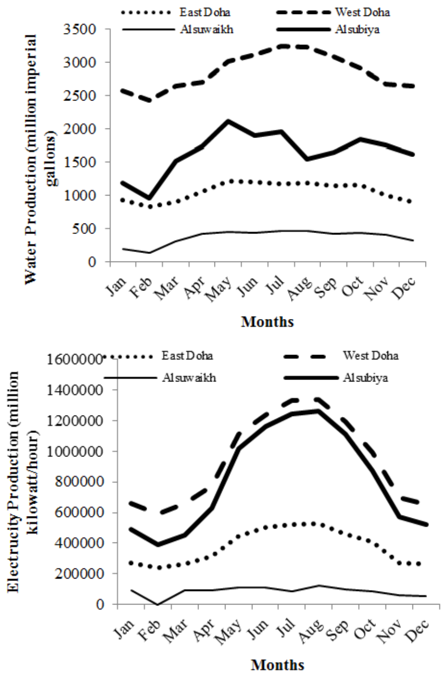
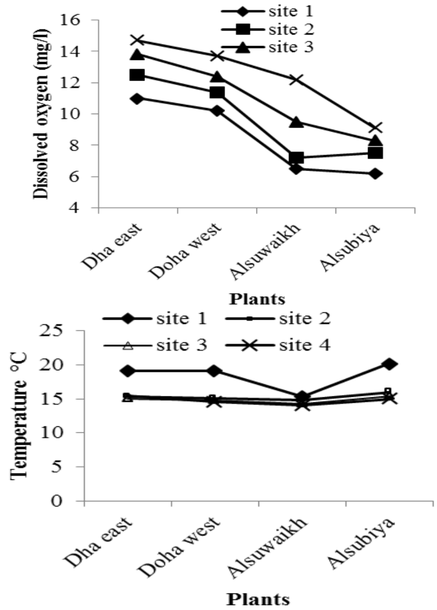


Figure 4. Production of power and desalination plants in Kuwait.

Fig. 5 shows the physical variables of seawater near the power and desalination plants in Kuwait Bay. Dissolved oxygen on the surface water ranged from 6.5mg/l-14.7mg/l. Site 1 recorded the lowest concentrations, which ranged from 6.5mg/l-11mg/l, while site 4 had the highest concentrations, from 9mg/l-14.7mg/l.

The surface water showed temperatures ranging between 15 ℃-20 ℃. The highest temperature was found at site 1, while the lowest was seen at site 4.

The surface water salinity ranged from 35‰-40‰. The highest recorded salinity values were at site 1, ranging from 35‰-37‰, while the lowest were seen at site 4, ranging from 36‰-40‰.



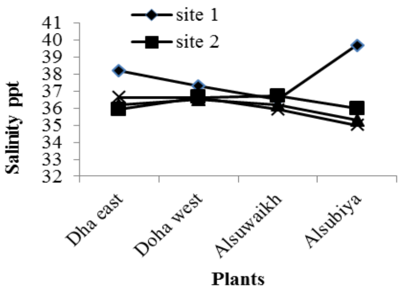


Figure 5. Dissolved oxygen, temperature and salinity rates near the power and desalination plants

IV. Discussion

In Kuwait Bay, the temperature and dissolved oxygen vary significantly between winter and summer, whereas no significant spatial variation is apparent. The temporal variation of temperature was greatly influenced by the seasonal variation of solar intensity and air temperature [9]. However, the rates of salinity at the study sites indicated that the minimum values of salinity in Kuwait Bay that were recorded from March through May might be attributed to the remaining spring flood reaching the north Arabian Gulf through the Shatt Al-Arab River: the spatial and temporal distributions of Kuwait seawater characteristics, such as salinity, are clearly associated with the Shatt Al-Arab discharge [10].

Conversely, the power and desalination plants' production increased in the summer months, while their production fell considerably during the winter months; in the warmermonths, people use more electricity for air conditioning and consume more water.

A. Influence of Physical Variables on Dissolved Oxygen

We used Pearson's coefficient to study the relationship between dissolved oxygen and the physical variables, and found a negative correlation between the dissolved oxygen concentration and the temperature (correlation confession = -0.47). The concentration of dissolved oxygen in surface water in Kuwait Bay is controlled by temperature. It is clear from this relationship that dissolved oxygen increase in winter, when the temperature is low; conversely, the dissolved oxygen concentration is low in the summer when the water temperature is high.

Temperature affects the amount of dissolved oxygen because aquatic organisms have an optimal temperature range for their metabolism. Warmer water also promotes higher metabolism and respiration rates, leading to increased consumption of dissolved oxygen [11].

Additionally, the Pearson's coefficient shows a weak positive correlation between dissolved oxygen and salinity (correlation confession = 0.11). The statistical significance correlation was very low, which can be attributed to numerous environmental variables that affect dissolved oxygen in the field.

B. Impact of Power and Desalination Plants on Dissolved Oxygen

It is evident from the results that power and desalination plants have an adverse effect on dissolved oxygen, temperature and salinity. Additionally, when we moved away from plants, the dissolved oxygen concentration increased from 6.5mg/l-12.2mg/l (Alsuwaikh plant) to 10.2mg/l-13.7mg/l (West Doha plant), to 11mg/l-14.7mg/l (East Doha plant) and 6.2mg/l-9.1mg/l (Alsubiya plant). It is clear from the results that the amount of dissolved oxygen decreased, thereby increasing the temperature and salinity values near the plants.

The water temperature of the power and desalination plants' effluents will be high and will increase the seawater temperature. In the summer, the ambient seawater temperature in Kuwait Bay was about 32 ℃ on average, and the power and desalination plants caused an increase in the temperature level in the vicinity by about 7 ℃ to 8 ℃ above the ambient condit [12]. Desalination processes also produce large quantities of brine water. However, a high concentration of salt is discharged into the sea through the desalination plants' outfall, which leads to an increased level of salinity in the sea. As result, all these factors lead to a decreased concentration of dissolved oxygen in Kuwait Bay.

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