A GIS-based Spatiotemporal Study of the Variability of Water Quality Parameters in the Dubai Creek

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Abstract

High concentrations of nutrients canincrease algal growth in coastal marine systems. The growth of harmful algal blooms (HAB's) has become common in UAE, especially in late 2008 and early 2009 when a huge HAB event devastated the coasts of the whole country and a significant portion of Arabian Gulf. Nutrient enrichment in Dubai coast has been one of the primary environmental concerns for eutrophication. Increased algal growth normally leads to oxygen depletion by bacteria to decompose the dead algal cells in the bottom leading to low-oxygen water. Such situation normally leads to the killing of different types of fish; lowering the biotic diversity. Dubai Creek, a saltwater lake connected to the coast of Dubai has similar characteristics as the coast and suffers from similar water quality concerns. The paper presents the outcomes of a comprehensive study of the spatiotemporal variability of major water quality parameters in the creek. In-situ water quality data from 10 monitoring stations along the Dubai creek have been used in the study. The results showed unique trends of spatiotemporal variability of chlorophyll-a and nutrients over the creek in the period of study. This result was attributed to the increasing anthropogenic activity in Dubai due to the rapid urban development, shallow water depth in the creek, poor flushing and irregular circulations and wave patterns in the area.

Keywords: Algal Growth, Spatiotemporal Analysis, and Water Quality

Introduction

Dubai has rapidly developed in the past decade to be a major centre of attraction. However, these developments have resulted in significant impacts on the environment (Al-Azab et al., 2005). The Dubai Creek, a 14 kilometer stretch of a salt water body, is situated at the heart of the urban development and divides the city into two areas; Deira and Bur Dubai. The creek is mainly used for transportation, trade and recreation. Urbanization and population growth have taken its toll on the creek especially that it is a poorly flushed water body (Abu-Hilal et al., 1995; Hassan et al., 1995). One major source of the creek's water quality degradation is the treated sewage discharge from Al-Aweer Sewage Treatment Plant (Ismail, 1992; Saunders et al., 2007). Moreover, the number of ships and boats using the creek has increased rapidly in the past years as the city of Dubai has expanded as a center of trade. Likewise, the landscape areas on the banks of the creek started to play adverse role on the water quality when fertilizers get washed out by runoffs. Additionally, the stagnant water condition at the bottom of the creek along with the poor flushing of the entire water body can contribute to the pollution of the creek (El-Sammak, 2001; Howari and El-Saiy, 2008)). Dubai Municipality collects water quality data at ten monitoring stations, at one meter below the water level. The stations are approximately parted by equal distance intervals. Figure 1 shows the locations of these monitoring stations along the creek (Ali, et al., 2013).

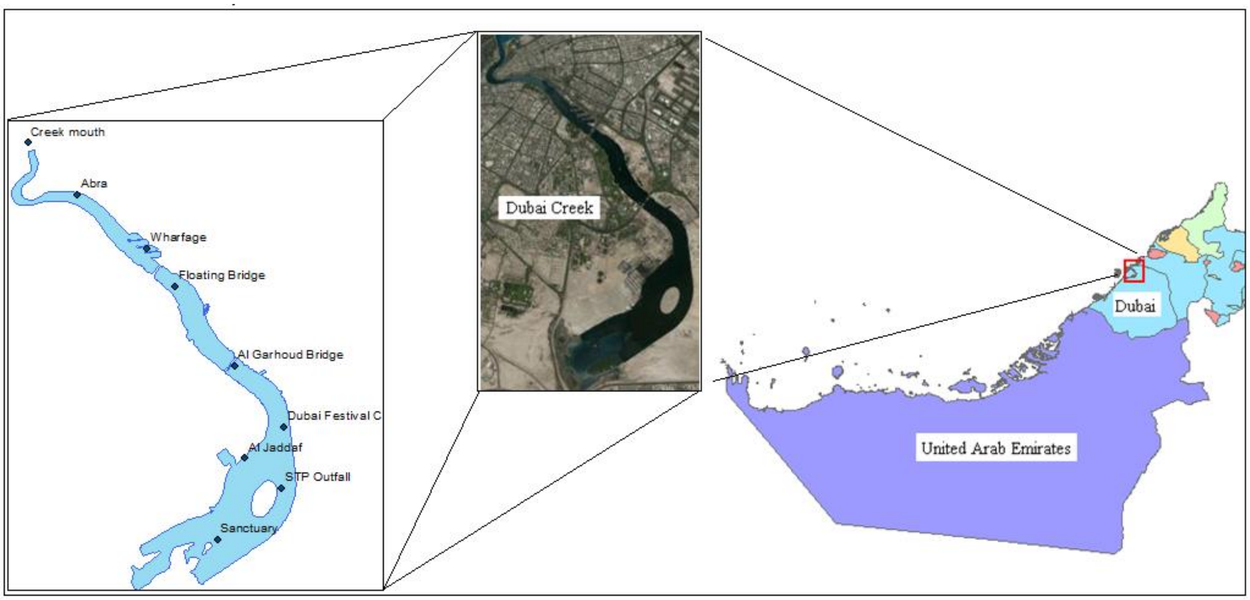

Figure 1. The locations of the monitoring stations along the Dubai Creek

The current situation has created significant concern, especially after the devastating algal bloom (red-tide) event of 2008, which caused catastrophic fish kills in the creek and the whole costal area of Dubai. The emirates wildlife society believed pollution, high temperatures, eutrophication and algal blooms were the major causes of the death of fish in 2008 (Landais, 2008).

High concentrations of nutrients; mainly nitrogen and phosphorus compounds can lead to eutrophication; the process of accelerated growth of algae and other forms of plants. Another indication of eutrophication in addition to the evident excessive algal growth in the water body is the decrease of dissolved oxygen in water, a condition commonly known as hypoxia (Johansson, 1997). Eutrophication results in disturbance of the balance of aquatic life by decreasing the diversity of species and increasing plant biomass. This condition normally increases turbidity of the water column and therefore increases the potential for sedimentation.

The objective of this study was to develop a spatiotemporal model to analyse pollution scenarios of Dubai Creek. In this study, Geographic Information Systems (GIS) based single and multivariate analyses were carried out to data of five water quality parameters recorded at the ten monitoring stations from 2010 to 2013.

Materials and Methods

The water quality data obtained from the Dubai Municipality includes measurements of pH, Turbidity, Chlorophyll-a, Nitrate, Total Nitrogen, Dissolved Oxygen and Phosphate. Temporally, the data was categorized into four quarters for both of 2012 and 2013. For creating the GIS Model, initially a base map was created with the focus on the area of study. Then, the polygon tool was used to create a polygon which represented the water body of the creek. Furthermore, the monitoring stations were projected onto Dubai Local Transverse Mercator (DLTM) coordinate system. Finally, the desired water quality gradients were produced using the Kriging interpolation tool. The interpolation was performed for each single parameter on quarterly basis. Although there were several interpolation methods (e.g. Inverse Distance Weighted (IDW), natural neighbour, Spline, etc.), the Kriging method was preferred because of its proven higher precision. (Mabit and Bernanrd, 2007; Ali, 2004). A recent study aimed at monitoring groundwater activity and evaluated the effects of GIS interpolation on the accuracy of the spatial representation of such data. In the study, water level and chloride concentration data were used for three interpolation methods; IDW, Spline and Kriging. Results showed that amongst these three methods, Kriging was the most robust and is hence an optimum choice for generating surface maps in GIS (Ali, 2004).

Results and Discussion

The results obtained in GIS over the creek in the first quarter of 2012 showed low chlorophyll-a concentrations except at around the Wharfage and the Floating bridge station which have values of 40.8 and 51.2 μg/L respectively (Figure 2). The second quarter showed an increase in the concentrations from the Floating bridge station to the bottom of the creek in ranging from 57.5 μg/L to 92.58 μg/L. These numbers indicated an algal bloom event in this region. As expected, the concentrations dropped in the next quarter to a maximum of 41.38 μg/L. This decrease continued until the last quarter of 2012 and the 1st quarter of the following year. However, the second quarter of 2013 showed a notable rise in chlorophyll-a levels; ranging from 128.4 μg/L to 192.64 μg/L. This was an indication of a second algal bloom event which occurred within the period of two years. The 3rd quarter witnessed a drop from 192.64 μg/L to 6 μg/L at the creek's mouth.

Total nitrogen in water is essential for aquatic plant and animal life and an excess of it is an indicator of pollution. Optimum total nitrogen values were between 0.5 mg N/L and 1.0 mg N/L. By analysing the 2012 water quality data, total nitrogen levels were high in the 1st and last quarter around the middle and lagoon parts of the creek. These areas had values as high as 15 mg N/L; indicating pollution. In 2013, the high levels of total nitrogen indicate the migration of pollution towards the lagoon segment of the creek (Figure 3).

The optimum range for phosphate was 0.05 mg P/L to 0.1 mg P/L. Algae consumes it as food; hence it is one of the major reasons for eutrophication (Hochanadel, 2010). The results obtained via the GIS model illustrate that the phosphate levels exist within the optimum range, in both time periods, at the mouth of the creek and the coast (Figure 4). However, higher levels of phosphate (more than 0.1 mg P/L) was observed at the center and at the end of the creek in the 1st quarter of 2012 (0.5 mg P/L) and 4th quarter of 2012 (0.67 mg P/L), 1st quarter of 2013 (0.8 mg P/L).

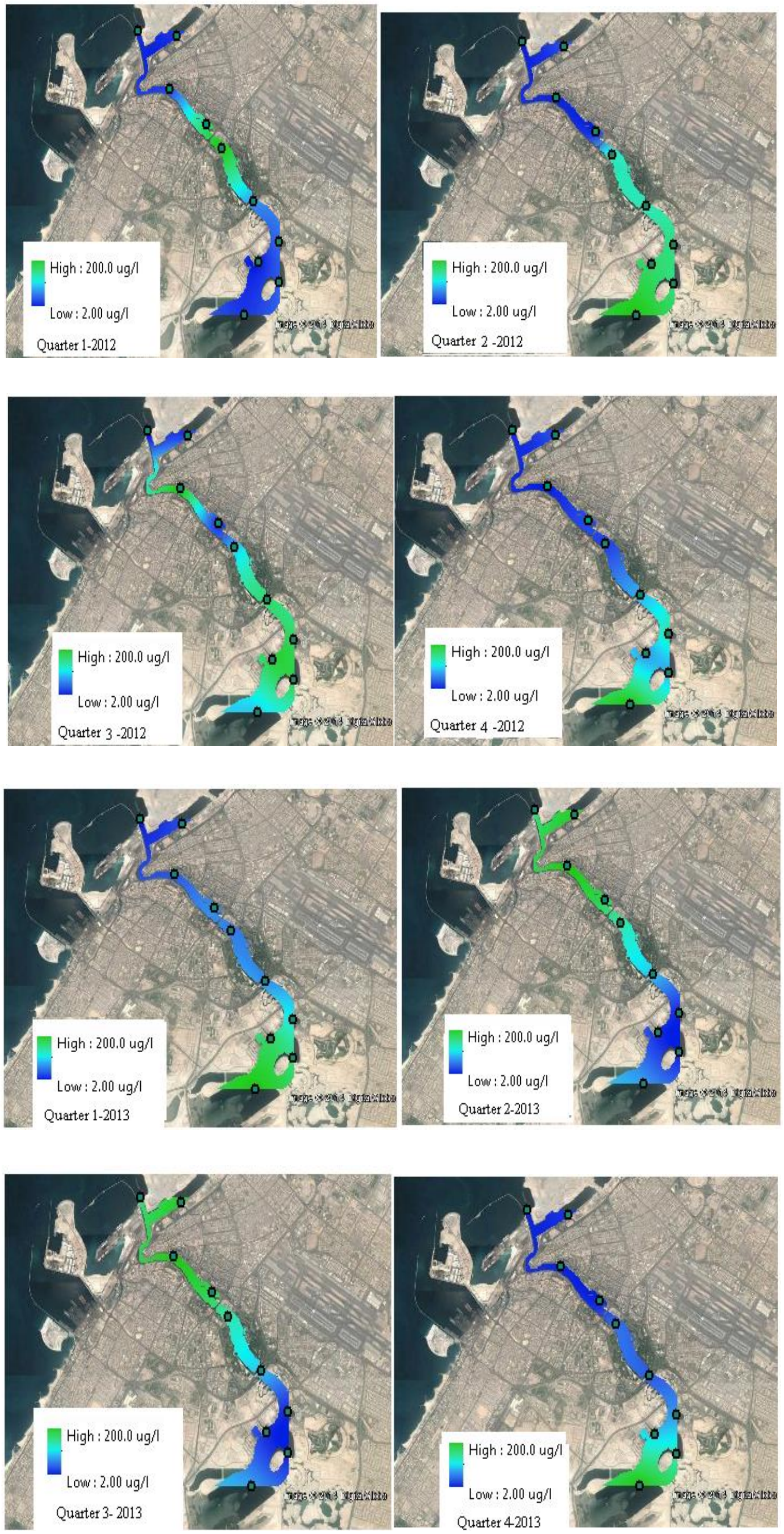

Figure 2. Maps of chlorophyll-a concentrations in 2012 & 2013

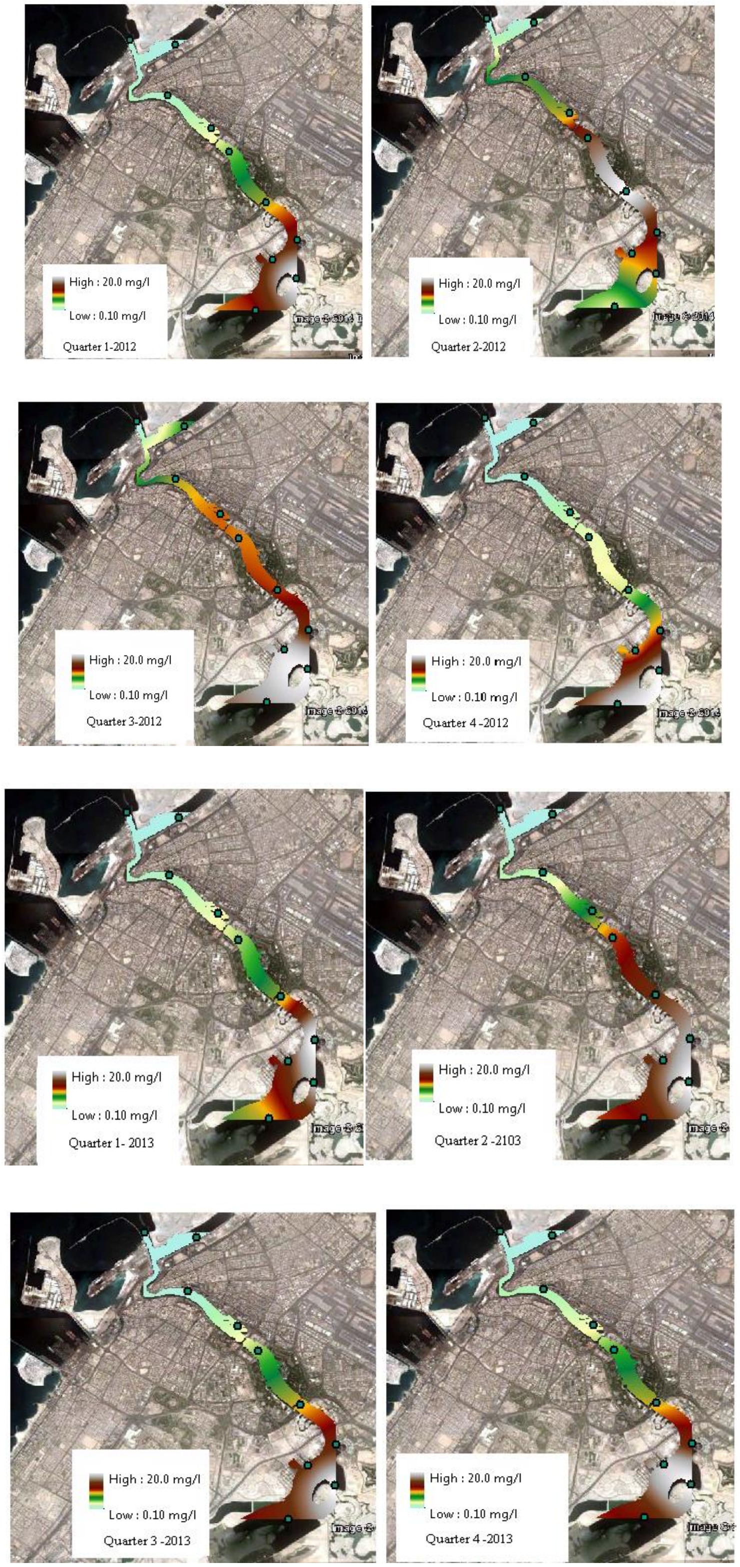

Figure 3. Maps of total nitrogen concentrations in 2012 & 2013

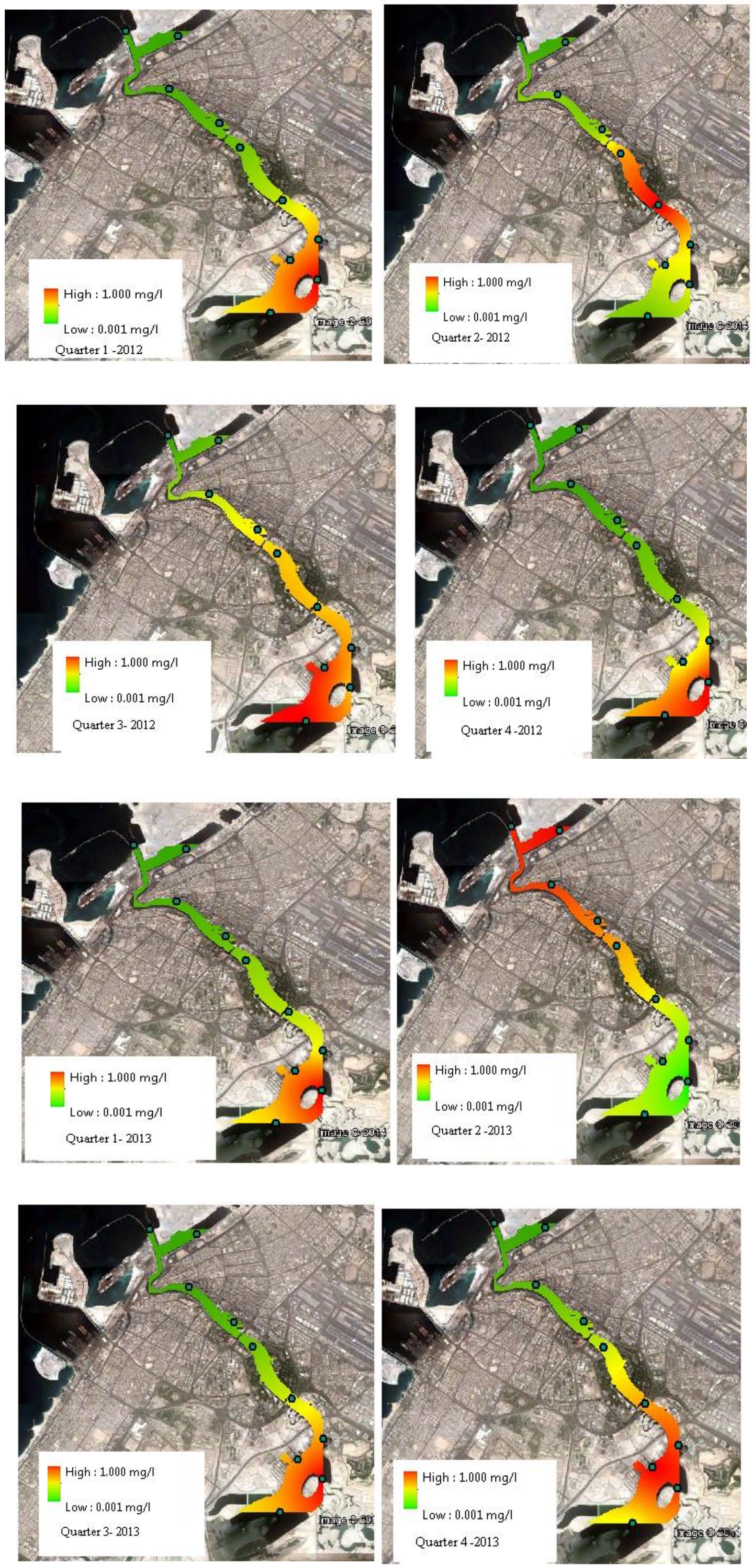

Figure 4. Maps of phosphate concentrations in 2012 & 2013

To understand the temporal variation of the major nutrients with chlorophyll-a, multivariate plots have been created for all of the ten monitoring stations in order to illustrate the variation patterns of the concentrations of nitrate, total nitrogen, and phosphate with chlorophyll-a. Since most of the concerns of water quality were around the middle and lower half of the creek, the analysis was focused on selected sampling stations.

At Floating bridge station, it is clear that nitrate was the main nutrient that triggered the increase in algal growth (Figure 5). The sudden increase in the amount of nitrate led to an accelerated algal growth in the 2nd quarter of 2013 once again. The results from Al-Garhoud station illustrated an evident algal increase with increase in nitrate and total nitrogen concentrations (Figure 6). It was noteworthy to mention that nutrients concentrations at this station and the remaining four stations between this location and the lagoon part of the creek were higher than the concentrations recorded at the stations from this location to the mouth of the creek. Possible reasons for this pattern could be the location of the effluent from Al Aweer Sewage Plant at the lagoon part of the creek in addition to expected nutrients-rich surface runoffs from the landscapes at the two sides of the creek. Moreover, the amount of leisure and transport ships that set dock at this area was significantly higher than other locations. At the Festival city station, a pattern was observed at the beginning of 2012 when nitrate and total nitrogen concentration were high and led to an increased algal growth in the 2nd quarter of 2012 (Figure 7). However, the increase in nutrients in the 4th quarter of 2012 and the 1st quarter of 2013 have not resulted in a significant increase in the chlorophyll levels.

The same pattern at Festival city station was observed at Jadaf station, which is a repetitive cycle of increase in amount of limiting nutrients which consequently resulted in an increase in chlorophyll-a concentrations (Figure 8). The cycle occurred twice over the two-year period. It is interesting that the concentrations recorded at this station are higher than previous stations and the pollution pattern occurred twice over the two-year period. This is an indication that this area was prone to excessive pollution. The results of the STP outfall station showed significant increase in the amount of limiting nutrients at around the middle of 2012, which is probably a consequence of the ongoing pollution in this area (Figure 9). The results from Sanctuary station which is situated at the utmost bottom of the creek in the lagoon part of the creek are interesting (Figure 10). A decrease in limiting nutrients caused a drop in algae population as expected. Moreover, due to pollution, a massive increase in the amount of limiting nutrients was observed resulting in a late algal increase at about middle of 2013. As expected, a decrease in nutrients has occurred due to the high consumption of nutrients by algae.

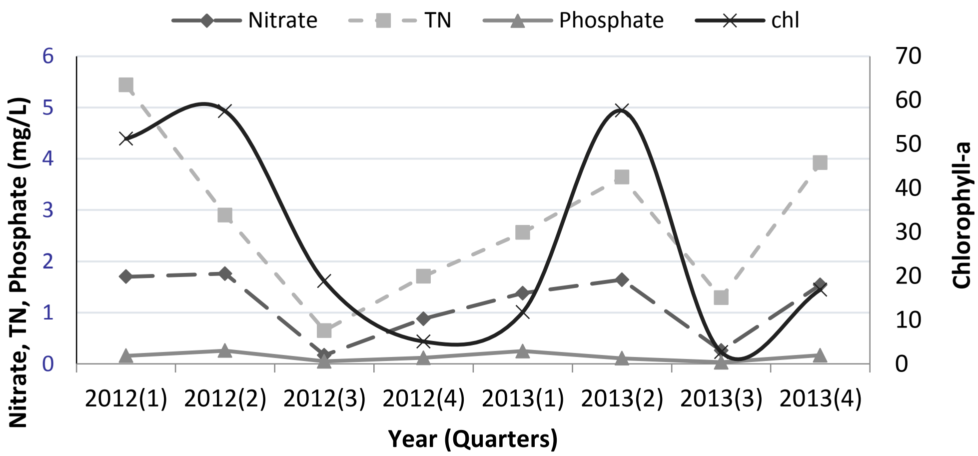

Figure 5. Floating Bridge (scale: Nitrate (x10) and Phosphate (x10))

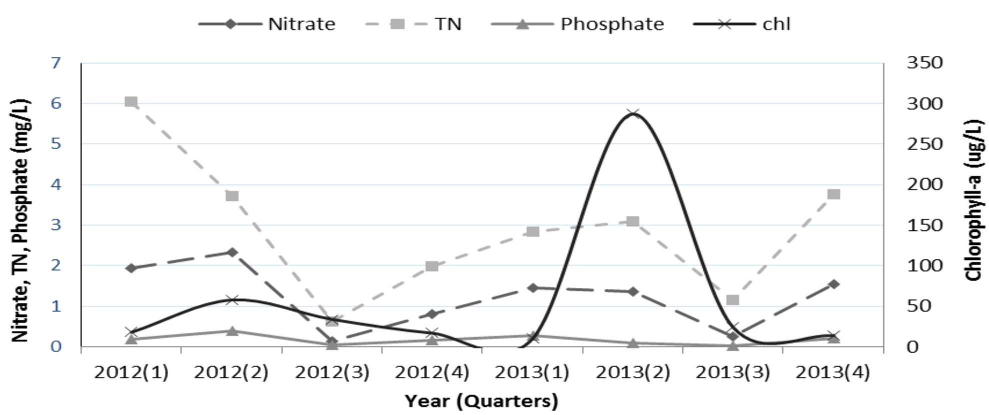

Figure 6. Al-Garhoud Bridge Station (scale: Nitrate (x10) and Phosphate (x10))

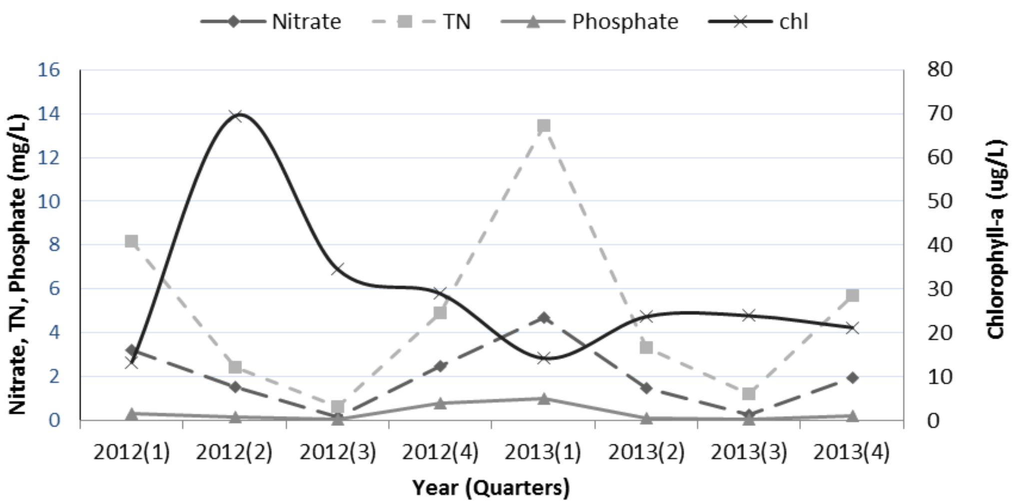

Figure 7. Dubai festival City Station (scale: Nitrate (x10) and Phosphate (x10))

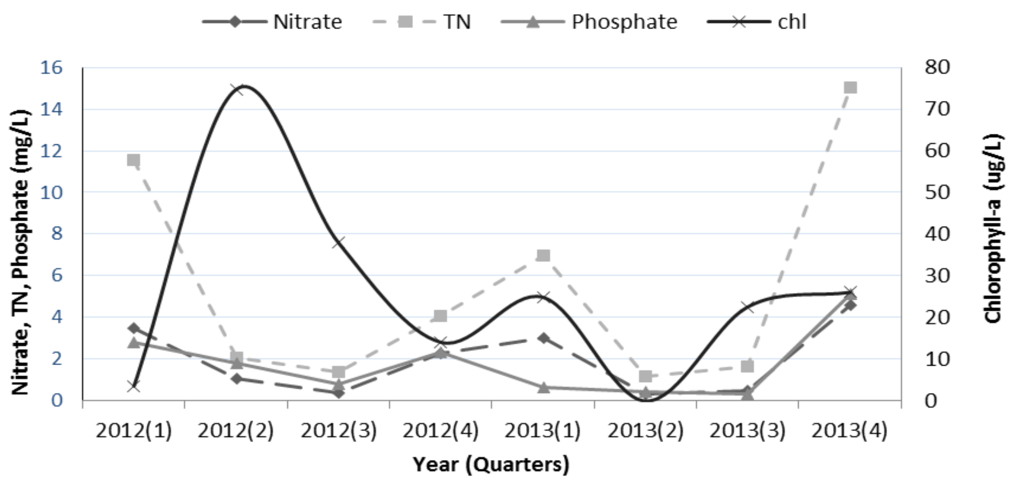

Figure 8. Jadaf Station (scale: Nitrate (x10) and Phosphate (x10))

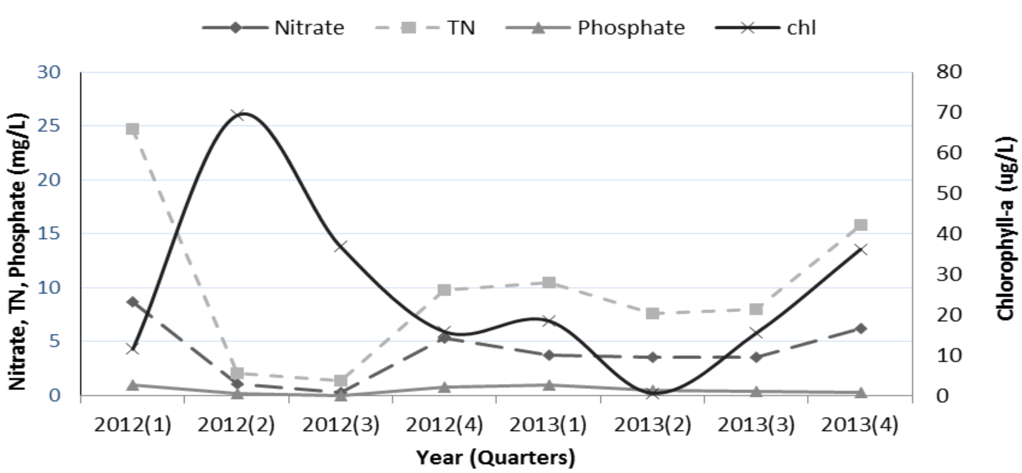

Figure 9. STP Station

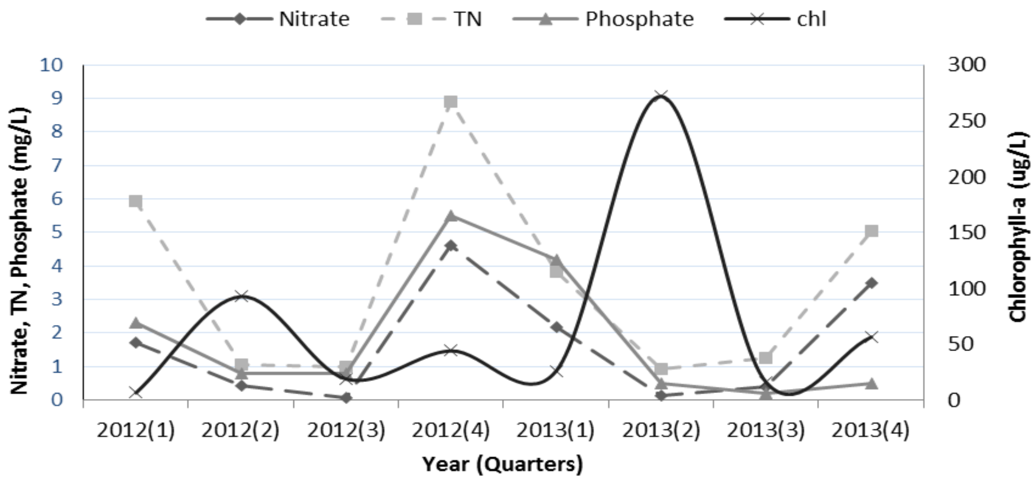

Figure 10. Sanctuary Station (scale: Nitrate (x10) and Phosphate (x10))

Conclusion

The pollution pattern observed was in agreement with the anticipated pattern. Nitrate, phosphate, and total nitrogen have increased due to pollution, which in turn accelerated algal growth in the creek. As a result of the increased algal growth, dissolved oxygen levels decreased. Spatially, it is evident that pollution occurs at the center and makes its way, while increasing in value, towards the lagoon part of the creek. Possible reasons for this pattern were the location of the effluent from Al Aweer Sewage Plant at the lagoon part of the creek characterized with poor flushing in addition to expected nutrients-rich surface runoffs from the landscapes at the two sides of the creek. Consequently, the part of the creek from the coast to the center was characterized with better water quality compared to the part from the center to the lagoon or bottom of the creek. In this study, the correlations between levels of chlorophyll-a and phosphate, nitrate, and total nitrogen were evident. Based on this study, a pollution control plan is much needed in order to reduce the levels of nutrients in the creek. This includes the control of the nitrate and phosphate concentration in the discharge from Al Aweer Sewage Plant as well as the control of the non-point source pollution source; specifically the nutrients-rich surface runoffs from the landscapes at the two sides of the creek.

References

Abu-Hilal AH, Adam AB, Banat IM, Hassan ES (1994). Sanitary conditions in three creeks in Dubai, Sharjah and Ajman Emirates on the Arabian Gulf (UAE). *Environmental Monitoring Assessment 32*(1): 21- 36. doi: 10.1007/BF00548149.

Al-Azab M., El-Shorbagy W, Al-Ghais S.. (2005) *Oil Pollution and its Environmental Impact in the Persian Gulf Region.* [Google books version]. Retrieved from http://books.google.com/

Ali, T., Mortula, M., and Atabay, S. (2013). Study of Water Quality in Dubai Creek using DubaiSat-1 Multispectral Imagery. International Conference on Geo-Informatics in Resource Management and Sustainable Ecosystem (GRMSE2013), Wuhan, China. *Communications in Computer and Information Science (CCIS),* Vol. 398, pp. 200-210.

Ali TA (2004). On the Selection of Appropriate Interpolation Method for Creating Coastal Terrain Models from LiDAR Data, the American Congress on Surveying and Mapping (ACSM) Conference 2004, Nashville TN, U.S.A., April 16-21.

El-Sammak A (2001). Heavy metal pollution in bottom sediment, Dubai, united Arab Emirates. *Bulletin of Environmental Contamination and Toxicology*. *26*(2): 296-303. doi: 10.1007 /S001280124.

Fahid K.J. Rabah,Said M. Ghabayen,Ali A. Salha (2011) Effect of GIS Interpolation Techniques on the Accuracy of the Spatial Representation of Groundwater Monitoring Data in Gaza Strip. *Journal of Environmental Science and Technology 4*(6), 579-489. doi: 103923/jest.2011.579.589

Hassan ES, Banat IM, Abu-Hilal AH (1995). Post-gulf war nutrients and microbial assessment for coastal waters of Dubai, Sharjah, and Ajman Emirates (UAE). *Environment International*, *21*(1): 23-32. doi: 10.1016/0160-4120(94)00036-7.

Howari F. M, El-Saiy A.K (2008). Characterization of Recent Sediments between Abu Dhabi and Dubai Coasts, United Arab Emirates, with Multiple Analytical Techniques. Journal of Coastal Research 24(2A): 74-82 doi 10.2112/05-0627.1

Ismail NS (1992). Macrobenthic invertebrates near sewer outlets in Dubai creek, Arabian Gulf. *Marine Pollution Bulletin 24*(2): 77–81. doi: 10.1016/0025-326X(92)90733-M

Johansson B (1997). Behavioral response to gradually declining oxygen concentration by Baltic Sea macrobenthic crustaceans. *Marine Biology 129*(1), pp. 71-78. doi: 10.1007/S002270050147.

Landais E. Dead Fish Floating Along Dubai Creek (2008, July 9), *Gulfnews.* Retrieved from http://gulfnews.com

Mabit L., and Bernard C. (2007) Assessment of spatial distribution of fallout radionuclides through geostatistics concept. *Journal of Environmental Radioactivity 97* (2-3) 206-219. doi:10.1016/j.jenvrad.2007.05.008

Saunders J, Al Zahed KhM, Paterson D (2007). The impact of organic pollution on the macrobenthic fauna of Dubai creek (UAE), *Marine Pollution Bulletin 54*(11): 1715-1723. doi: 10.1016/Jarpolbul.207.07.002.