

# GEOSPATIAL ANALYSIS OF THE RED-TIDE OVER THE ARABIAN GULF

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## Abstract

The characterization of the of harmful algal blooms (HABs), commonly called red-tide, in terms of location, time of occurrence, and concentration is required to manage the desalination plants over the Arabian Gulf. Several field campaigns have been undertaken over the Arabian Gulf by different organizations such as Regional Organization for the Protection of the Marine Environment (ROPME) and Environment Agency of Abu Dhabi (EAD) to collect the water temperature and chlorophyll samples. In this paper, a geospatial analysis is considered in order to map the distribution of chlorophyll in the Arabian Gulf using the kriging estimators. These maps will allow the identification of the areas mostly affected by the red-tide, periods of occurrences and their concentrations. The cross comparison between chlorophyll and dust concentration obtained from MODIS satellite and some coastal AERONET stations will be considered to clarify the dependency between them since dust contain nutrients which nurture the HABs.

Keywords: Red-tide, chlorophyll, GIS, Arabian Gulf.

## 1 INTRODUCTION

Harmful Algal Blooms (HABs), commonly called red tide, occur frequently in the Arabian Gulf, mainly during winter seasons (2000-2001; 2006, 2008-2009) [1]. This phenomenon transforms the water colour to red, green and brown due to the dense batches of the HABS formed in oceans. These HABs may cause death and or poison the fish and birds which affect the food cycle, affect human health by irritating the eyes and the respiratory systems, damage the filtration and the membrane systems of the desalination plants which are the main source of fresh water in this arid region, and affect the recreational activities in the affected areas [1].

Several sampling efforts of phytoplankton blooms have been undertaken in the Arabian Gulf by different organizations such as Regional Organization for the Protection of the Marine Environment (ROPME) in Kuwait, Environment Agency of Abu Dhabi (EAD), Marine Resource Research Centre (MRRC) in United Arab Emirates and Marine Science & Fisheries Centre (MSFC) in Oman. Thirty eight types of phytoplankton blooms were identified as source of red tide in the region (Diatoms, *Dinophysis caudata*, *D. miles*, *Prorocentrum minimum*, *P.compressum*, *Ceratium furca*, and *Pyrodinium bahamense*) [2]. The parameters used to characterize and quantify these phytoplankton blooms are: chlorophyll, which is an indicator of phytoplankton growth, water temperature, and oxygen level. These three parameters were measured in those field campaigns. The available in situ measurements were limited in time and space because the study area is wide and has complicated physical properties (high temperature and salinity, shallow nature, limited freshwater inflow, high evaporation rates[3][4][5][2]) and variable biological properties (high algae bloom biodiversity[4][6]).

The aim of this paper is to up-scale at large the scale the chlorophyll and water temperature measurements sampled at local scale during ROPME (2006) and EAD (2010-2011) field campaigns over the Arabian Gulf and Abu Dhabi coastal areas, respectively. Maps of the estimated chlorophyll values at any location in the Arabian Gulf were derived from the local measurements using the kriging estimators. These maps will be used to identify the areas mostly affected by the red-tide, periods of occurrences and their concentrations.

## 2 MATERILS AND METHODS

### 2.1 Study Sites

Two study sites are explored in this paper:

The first study site is the whole Arabian Gulf basin which is located between latitude  $24^{\circ}\text{N}$  and  $30^{\circ}\text{N}$  and longitude  $48^{\circ}\text{E}$  and  $57^{\circ}\text{E}$  [5][2][7] (Fig.1a). This basin is surrounded by 7 countries: Saudi Arabia, United Arab Emirates, Qatar, Kuwait, Bahrain, Oman and Iran. The width of the Arabian Gulf varies between 75 to 370 km and the length of is around 990 km [7]. The southern region of it is shallow, however, it becomes deeper towards the Northern region of the Gulf [5]. The Arabian Gulf is connected to Oman Gulf and the Arabian Sea by the strait of Hurmuz which is considered as a very significant water way in the area [7]. There are two major flows in the Arabian Gulf, the first one is the inflow towards the northern Iranian region from the strait of Hurmuz and the second one flows by the density difference force southwards against the other flow which leads to salinity rise in the southern region of the Gulf [2].

The second study site is the eastern coastal area of Abu Dhabi (United Arab Emirates) which is located between latitudes  $24.2.5^{\circ}$  and  $24.8^{\circ}\text{N}$  and Longitude  $54.2^{\circ}$  and  $54.8^{\circ}\text{E}$ . The coastal line of Abu Dhabi is not smooth while it includes several small shoals, islands, protected lagoons, and channels. Most of the inner part of the coast is a salt crusted desert which is called Sabkha (Fig. 1b) [8].

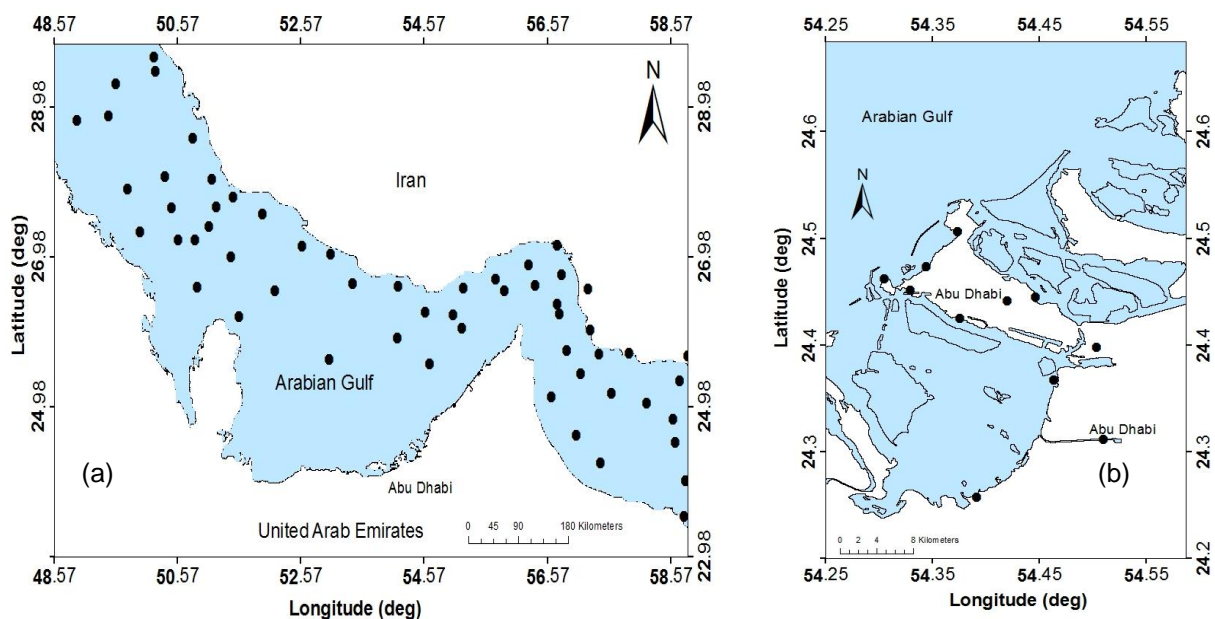


Fig. 1. Study Site 1: a) Arabian Gulf, b) Abu Dhabi.

### 2.2 In situ Data

In situ data were collected from two different organizations: ROPME and EAD.

#### 2.2.1 ROPME data

ROPME field measurements were performed during winter 2006 from February 3<sup>rd</sup> to March 9<sup>th</sup> [9]. Chlorophyll concentrations were measured at three depths (Surface, and few centimetres deeper) over 63 stations spread uniformly over the Gulf of Oman and the Arabian Gulf (Fig.1a). Two methods were used to measure chlorophyll concentrations during the campaign (Lab and CTD methods). By comparing the measurements of these two methods, it can be figured out that the samples measured using the lab method shows higher chlorophyll concentrations than using the CTD method (Table 1). CTD method underestimates the real chlorophyll concentrations, so only chlorophyll lab measurements were considered in this paper. The minimum recorded surface chlorophyll

concentration measured in the lab was  $0.4 \text{ mg m}^{-3}$ , and the maximum recorded value was around  $9.54 \text{ mg m}^{-3}$ .

Table 1. Statistical Analysis of surface chlorophyll measurements of winter ROPME 2006 cruise [9].

Measuring Method	Chl a lab. ( $\text{mg m}^{-3}$ )	Chl a CTD ( $\text{mg m}^{-3}$ )
Average	2.54	1.07
STD	2.16	1.25
Min.	0.09	0
Max.	9.45	6.5

### 2.2.2 EAD data

EAD has started collecting monthly measurements of Chlorophyll, oxygen and temperature since 2010 at different stations in the coastal line of Abu Dhabi. The sampling was regular varying between 11 stations in 2010 and 20 stations in 2011.

Monthly averaged chlorophyll concentration of 2010 and 2011 were considered for this study (Fig 2). Overall, chlorophyll concentrations fluctuated over the two years with no clear seasonal trend. This fluctuation might be explained by the human activities and high turbidity. The highest chlorophyll concentrations were measured at Mussafah East and Mussafah Industrial channels stations. These stations show high chlorophyll concentrations values for all months because of the dumped wastewater and waste from the surrounding industrial areas. The chlorophyll concentration was high as well in Al Salamiyah channel during August.

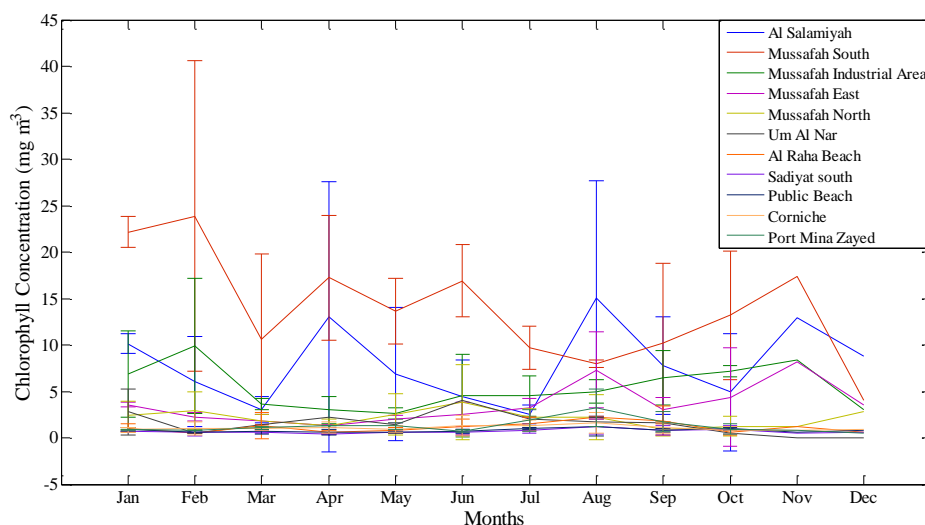


Fig. 2. EAD average chlorophyll measurements of the 11 stations.

The time schedule of all the in situ measurements used for this study is summarized in Table 2.

Table 2. In situ data used in this study.

Organization	Location	Period	Sampling location	Number of Stations	Parameters
ROPME	Kuwait	2006: Feb-Mar	Arabian Gulf	63	Chlorophyll
EAD	Abu Dhabi	2010-2011: Monthly	Abu Dhabi	20	Chlorophyll Temperature

## 2.3 Geospatial analysis - Kriging estimators

The chlorophyll and water temperature are geophysical parameters characterized by high spatial variability [9]. In geostatistics, each of these parameters is considered as a regionalized variable  $z(s)$  defined as a realization of a bi-dimensional random function  $Z(s)$ . The data  $z(s_i)$  represent the measured values of the chlorophyll (or water temperature) at a given position ( $s_i$ ) in the geographic site  $S$ . However, to determine an unbiased estimation at locations of interest (or block) using measured values, it is important to consider the following factors: 1) the number of samples, 2) the quality of the measurements at each location, 3) the positions of the samples evenly spaced and sampled with better coverage, and 4) the distance between the samples and the locations of interest (or block). Based on several researches undertaken in different fields (environmental science, hydrology, hydrogeology, agriculture and even fisheries) where the time component and the spatial variability are important, *Kriging* seems to be the best linear unbiased estimation method which takes into account all these factors using a probabilistic approach and minimising the estimated variance [10]. Two types of Kriging estimators exist:

- *Ordinary Kriging (OK)*

It is used when the mean value ( $m$ ) of the variable is constant in local neighbourhood of each estimation point. It is the widely used type of kriging. Its system of equations was primarily derived for the variables satisfying the stationary case and was extended to intrinsic variables.

- *Simple Kriging (SK)*

It is used when the mean value ( $m$ ) of the variable is constant and known over the entire study area. In such case, the SK can be used without constraint as in the case of the OK. Moreover its variance is generally smaller than that of the OK.

## 3 RESULTS AND DISCUSSION

The kriging tool of GIS was used to map the chlorophyll concentration over both study sites.

The obtained spatial distribution of surface chlorophyll concentration of ROPME data is presented in Fig.3. As shown on this figure, the chlorophyll concentration ranged between 0.25 and 8.75 mg/m<sup>3</sup>. Five areas were identified to have high chlorophyll concentrations. The first area is located in Oman Gulf, in the north and south near Kalba and Fujairah [11]. The high blooming events in that area were known to be caused by monsoon activities as reported by Gulf News [12]. The second and third areas of high chlorophyll concentration are located near the Strait of Hormuz and UAE coastline because of the inflow of the phytoplankton from Oman Gulf to the inner sea area passing through the Strait of Hormuz which has high water velocity. The fourth area is observed near Iran onshore and it is due to Shatt Al Arab discharge of highly contaminated water. This last one is an upwelling boundary current that carries the nutrients and phosphates consumed by the phytoplankton concentrated in this area. The fifth area is located near Kuwait coastline and Al Basra city in Iraq. This area is located next to the discharge point of Shatt Al Arab as well increasing the possibility of blooming activities.

The spatial distribution of surface chlorophyll concentrations and temperatures of EAD data are carried out for all months. Figures 4 and 5 show the distributions of January (winter) and July (summer), respectively. Overall, these results prove that the coastal line of Abu Dhabi is more likely to have high chlorophyll concentrations. This may be caused by the high turbidity observed over the area; however, chlorophyll concentrations seem to be high in winter than in summer. While the highest winter concentration of chlorophyll reached 17.23 mg/m<sup>3</sup>, summer concentrations doesn't exceed 4 mg/m<sup>3</sup> in most of the location. In both months, high chlorophyll concentrations were observed near Mussafah industrial area. These high values are most likely linked to the discharge of the wastewater treatment plant and the industrial waste that is discarded in this location. These both factors contribute directly to the increase of phytoplankton productivity. Similar event was reported in this region in 2003 where high concentrations of blooms and large amounts of died fish were recorded during that period [13]. The correlation between chlorophyll concentration and temperature can be observed by comparing Figures 4 and 5. As shown in these figures, the chlorophyll concentration and water temperature are inversely correlated. This correlation was demonstrated by several previous studies that relate the formation and spreading of blooms to the cold eddy associated with nutrients and poor oxygen water [14].

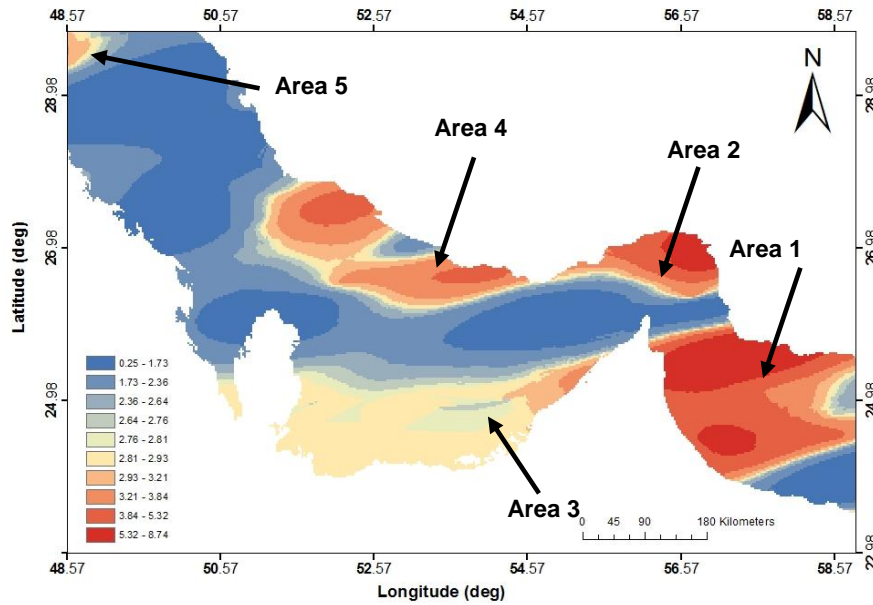


Fig. 3. Spatial distribution of the average chlorophyll concentration ( $\text{mg m}^{-3}$ ) in the water column for Winter 2006.

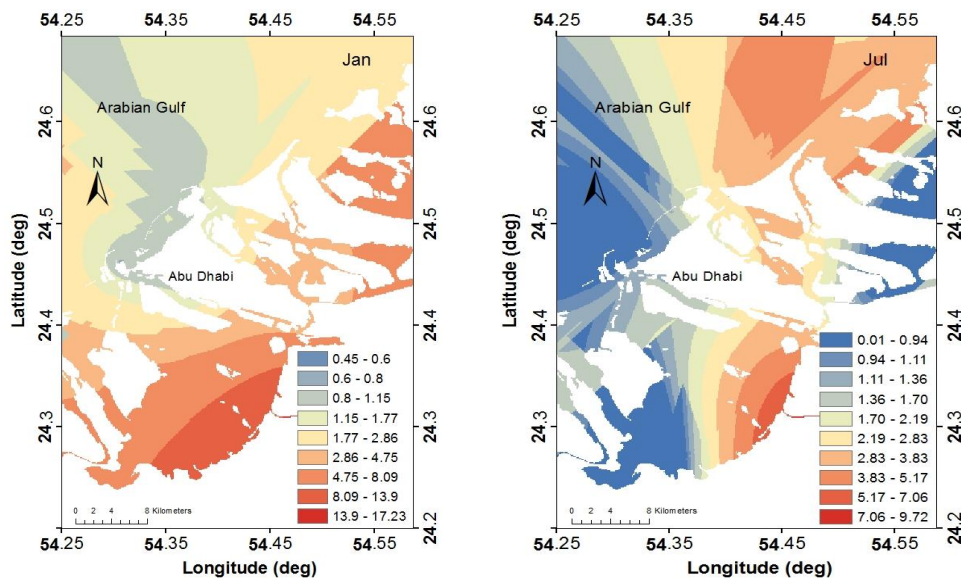


Fig. 4 . Spatial distribution of the average chlorophyll concentration ( $\text{mg m}^{-3}$ ) in Abu Dhabi coastal areas.

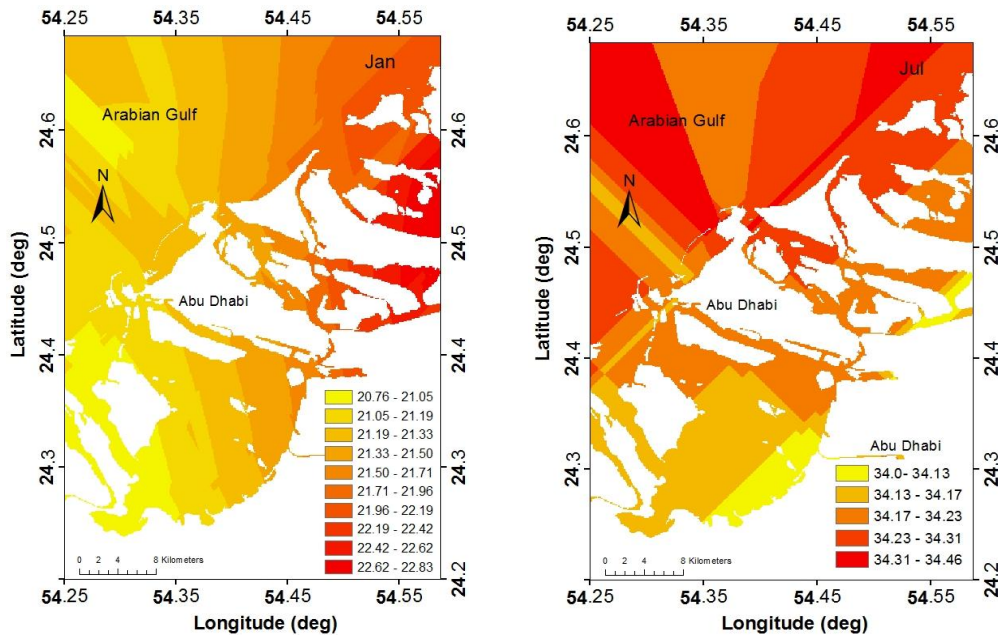


Fig. 5 . Spatial distribution of the average temperature ( $^{\circ}\text{C}$ ) in Abu Dhabi coastal areas.

## CONCLUSIONS

The characterization and the understanding the dynamic of the harmful algal blooms (HABs) in the Arabian Gulf is necessary to protect the intake of desalination plants and to preserve a healthy aquatic life. This characterization can be explored by using the available geospatial tool. Chlorophyll and temperature collected over two areas (Arabian Gulf and Abu Dhabi) were used to map the chlorophyll concentrations in the Arabian Gulf. Kriging method was helpful in performing the spatial distribution, analyzing the pattern of chlorophyll and predicting the chlorophyll in the unobserved locations.

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