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Analysis of the spatio-temporal variability of seawater quality in the southeastern Arabian Gulf

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ABSTRACT

In this study, seawater quality measurements, including salinity, sea surface temperature (SST), chlorophyll-a (Chl-*a*), Secchi disk depth (SDD), pH, and dissolved oxygen (DO), were made from June 2013 to November 2014 at 52 stations in the southeastern Arabian Gulf. Significant variability was noticed for all collected parameters. Salinity showed a decreasing trend, and Chl-*a*, DO, pH, and SDD demonstrated increasing trends from shallow onshore stations to deep offshore ones, which could be attributed to variations of ocean circulation and meteorological conditions from onshore to offshore waters, and the likely effects of desalination plants along the coast. Salinity and temperature were high in summer and low in winter while Chl-*a*, SDD, pH, and DO indicated an opposite trend. The CTD profiles showed vertically well-mixed structures. Qualitative analysis of phytoplankton showed a high diversity of species without anomalous species found except in Ras Al Khaimah stations where diatoms were the dominating ones.

1. Introduction

The Arabian Gulf (AG) is located in an arid region in the Middle East and is a marginal and semi-enclosed sea off the Indian Ocean (Price, 1993). The AG widest section spans over 340 km between the coasts of the United Arab Emirates (UAE) and Iran. Its bathymetry is relatively shallow with an average depth of 36 m. It is asymmetric along its axis with a deeper zone close to the Iranian coast and a broad and shallower shelf off the UAE coast (Elhakeem et al., 2015). It is surrounded by Saudi Arabia, Kuwait, Iraq, Iran, Oman, UAE, Qatar, and Bahrain. It is very essential for countries surrounding it. The scarcity of fresh water resources in the region due to the prevailing arid climate leads to substantial reliance on desalination for potable water supply. For example, 90% of the domestic and industrial water supply in the UAE is from desalination (Elshorbagy and Elhakeem, 2012). However, marine pollutions, such as oil spills and algal blooms, have been frequently reported in the AG (Al-Shehhi et al., 2014; Foster et al., 2011; Glibert et al., 2002; Heil et al., 2001; Moradi and Kabiri, 2012; Richlen et al., 2010; Subba Rao and Al-Yamani, 1998; Zhao and Ghedira, 2014; Zhao et al., 2014; Zhao et al., 2015a, 2015b). In addition, the fast development of coastal cities and the alteration of coastlines augment the vulnerability of the AG. Therefore, it is essential to study the spatial and temporal variability of seawater quality in the AG as a first step towards developing a full understanding of harmful algal bloom (HAB) occurrences and behaviors and other disturbances that may impact marine ecosystems.

The characterization of seawater quality in the AG can rely on one or a combination of the following three sources, namely, *in situ* observations, modeling techniques, and satellite remote sensing imagery. The latter can only provide information on seawater conditions during cloud-free and clear-atmosphere observations which are not met frequently over the AG given the abundant dust sources around it (Zhao et al., 2015b). In addition, the high evaporation rate in the AG raises water vapor contents in the atmosphere and reduces the number of valid sea surface observations from space. Also, satellite data provide integrated information on the surface and near-surface layers but not the full vertical profile. Modeling techniques are computationally demanding and require an extensive amount of *in situ* observations and ancillary data for their initialization and verification. The limited number of reliable field campaigns and the scarcity of *in situ* data in the study area reduced the potential of numerical models for the characterization of seawater in the AG. Recently, Al-Azhar et al. (2016) used the dataset from a field campaign in 1992 by Reynolds (1993) to verify their model. So, additional field sampling is very important to develop a full understanding of seawater quality and its variability in the AG. Such effort serves the use of satellite imagery and numerical modeling as well by providing needed ground truth observations for the verification of developed products.

Studies related to *in situ* seawater quality monitoring (SWQM) have been conducted in different parts of the AG. Al-Mutairi et al. (2014) assessed the spatial and temporal variations of water quality between 2009 and 2011 from six stations in the Kuwait Bay. Shriadah and Al-Ghais (1999) studied the hydrographic conditions and nutrient levels from October 1993 to September 1994 at 24 stations in the UAE waters. Moradi and Kabiri (2012) reported the variations of

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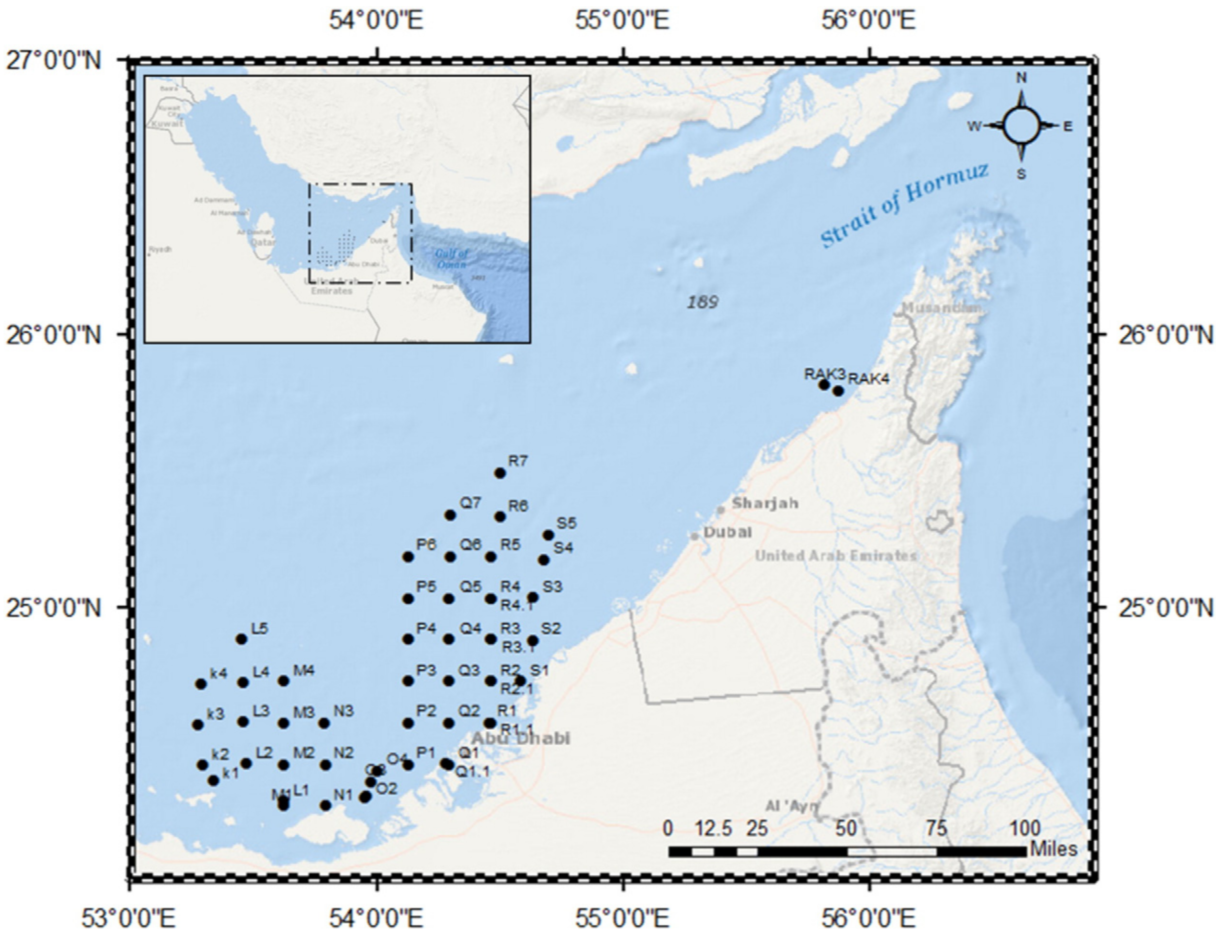

Fig. 1. Map showing the sampling sites off Abu Dhabi (AD) and Ras Al-Khaimah (RAK). The inset figure shows the Arabian Gulf with the study area outlined with a black box. Stations R1.1, R2.2, R3.1, R4.1 and Q1 are the same as stations R1, R2, R3, R4, and Q1.1 respectively. But the two tracks were investigated at different years. Refer to Table 1 for details.

chlorophyll-a (Chl-*a*) concentration during a HAB event in the Strait of Hormuz in 2008. Research experiments collecting sea currents and water quality parameters have also been conducted in the AG region (Reynolds, 1993; Pous et al., 2004). Local and regional authorities and organizations such as Regional Organization for the Protection of the Marine Environment (ROPME) (ROPME, 2010) and Environmental Agency–Abu Dhabi (EAD) (EAD, 2015) contributed to the effort of seawater sampling and characterization. However, studies covering physical, chemical, and biological conditions in the AG are scarce.

The AG is known as one of the most productive water bodies in the world, thanks to its high phytoplankton diversity (Al-Muzaini and Jacob, 1996; Poonian, 2003; Subba Rao and Al-Yamani, 1998). It is a unique environment with a distinct biotope, listed in the 49 Large Marine Ecosystems (LMEs) (Sherman, 1993). The phytoplankton communities inhabit one of the harshest marine environments with high salinity and high fluctuations in seawater temperature. Although historical studies have been performed with respect to phytoplankton community in the AG (Al-Kaisi, 1976; Hamza, 2006; Rajan and Al-Abdessalaam, 2008)

Table 1

Summary descriptive for sampling dates, transects, number of stations, and minimum and maximum values of meteorological data (air temperature, and wind speed), and physical–chemical parameters recorded during the study period, within 10 cm from the surface, at each transect. The numbers in bold represent the maximum and minimum for different parameters. ND denotes no data. B denotes bottom, which means that the water bottom is shallow and no measurements were made.

Date	Transect	Number of stations	Air temperature (°C)		Wind speed (m s^{-1})		DO (mg L^{-1})		pH		SST (°C)		Salinity (psu)		SDD (m)		Chl-*a* (mg m^{-3})	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
26/06/2013	O	4	32	36	3.8	5	6.52	7.01	**7.64**	7.91	31.70	33.20	42.00	**44.70**	6	7.5	0.21	0.46
27/06/2013	N	3	35.9	41	0.65	2.3	6.21	7.02	7.77	7.91	32.00	**34.90**	41.50	44.4	5	10.5	0.21	0.29
07/07/2013	M	4	34	37	2.15	**5.5**	6.11	6.79	7.79	7.92	32.80	34.00	41.30	42.70	ND	ND	0.17	0.71
01/10/2013	P	6	30.4	37.6	0.04	3.02	6.25	7.06	ND	ND	31.79	33.29	39.80	42.76	ND	ND	0.23	1.46
08/10/2013	Q	7	32	40	0.43	3.75	5.60	7.51	7.81	**8.34**	31.00	34.50	39.38	43.00	B	11.5	0.53	3.29
07/11/2013	R	7	27	30	1	4	6.50	6.93	8.07	8.16	28.40	31.00	39.92	42.21	B	12	0.60	1.69
06/03/2014	S	5	**21.7**	24.5	1.7	3.6	7.69	**8.03**	8.10	8.15	**21.70**	23.60	39.69	41.95	B	**16**	0.23	0.43
09/04/2014	L	5	28.7	36.5	**0**	2.2	5.56	7.61	8.01	8.14	26.90	27.80	40.92	42.53	6	13.3	**0.08**	0.84
13/05/2014	K	4	33.7	37.4	0.04	2.68	**5.33**	7.30	8.05	8.21	31.50	34.00	40.02	42.99	5.8	8.7	0.45	0.60
26/05/2014	Qx	1	**41.8**		4.45		6.13		8.08		32.80		42.08		5.4		0.78	
11/11/2014	Rx	4	28.5	29.87	1.81	2.7	6.78	7.07	8.22	8.25	25.00	28.63	40.51	41.50	B	6.6	1.01	1.62
19/11/2014	RAK	2	28	28.46	1.36	1.89	7.03	7.18	8.24	8.25	27.98	28.05	**38.54**	38.83	**4.9**		2.15	**3.90**