# *Developing satellite-based tool for water turbidity mapping in the Arabian Gulf: Abu Dhabi case study*


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***Abstract—*** *Water turbidity is a crucial water quality indicator, which describes how light attenuates through the water column. However, there were limited localized studies in the Arabian Gulf and satellite-based tools have not been adapted to local dusty climate. In this study, in situ measurements were collected to validate existing ocean color algorithms and develop new models for better adapting to the environmental conditions of the Abu Dhabi coast. Secchi disk depth (SDD) from February to April 2010 at 117 stations were collected, 35 of which were retained after strict data quality control. SDD varied in the range of 1.67~10.97 m. "Concurrent" MODIS derived diffuse attenuation coefficient for downwelling irradiance at 490 ($K_d$_490) was used to estimate SDD. Two models were established. Both models have shown their potential to detect water turbidity over Abu Dhabi coast. More in situ measurements are required to assess and improve the performance of the newly established models.*



***Keywords— Abu Dhabi, water turbidity, MODIS, Secchi disk depth, diffuse attenuation coefficient.***


## I. Introduction

Water turbidity measures clarity and transparency of water. In other words, it measures the degree of light scattering and absorption by suspended sediment, dissolved organic matter and other microscopic organisms such as plankton [1]. In general, turbidity is considered as an important key to evaluate coastal and estuarine water quality conditions [2]. The Arabian Gulf is surrounded by the Southwest Asian region- one of the challenging environments in the world to characterize, model, and monitor. The region is characterized by regular dust storms, high pollution levels, and complex flow patterns. Additionally, the Arabian Gulf atmosphere is highly affected by air masses from five subcontinents (Central-North Africa, Europe, Arabian Peninsula, Central Asia, and the Indian Subcontinent), and by tough micro to mesoscale flows from around the hot deserts, warm waters, and mountain ranges[3]. The Arabian Gulf is known to have very high turbidity compared to other water bodies but it has not been studied in depth to date.

The United Arab Emirates (UAE) is one of the gulf region countries with arid to semi-arid climate due to the scarcity of rain fall, high rate evaporation and limited sources of water. Underground and desalinated water are the two main sources of potable water in the UAE, with desalinated water being the main source for domestic use. In fact, the UAE is the second desalinating country in the world with 14% of the world water desalination capacity [4]. Majority of the UAE desalination plants depend on the seawater as feed water [5], as shown in Fig.1.

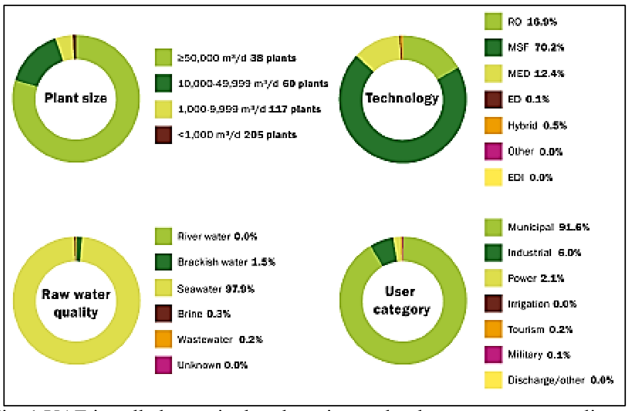


Fig. 1.UAE installed capacity by plant size, technology, raw water quality and user category produced by DesalData.com [5].

It is very essential for the UAE to keep monitoring seawater quality, since it is the main water resource in the country. The UAE is subjected to different kinds of pollution and crisis which affect water quality. Between August 2008 and September 2009, five water desalination plants in the UAE were forced to shut down, which caused 40% decreasing in water production capacity The desalination plants were disturbed because of an unexpected red tide event which started in late August 2008 in Dibba Hassan (eastern coast of the UAE) and later extended over the entire eastern coast of the UAE [6].

Another threat to the Gulf water quality is oil tankers which imposes real danger to local marine environment. About 25% of the world's oil production has passed through the Strait of Hormuz due to its strategic location. Moreover, the Arabian Gulf region (Bahrain, Iran, Iraq, Kuwait, Qatar, Saudi Arabia, and the UAE) is the major offshore oil development area in the world with 27% of the world oil production in 2000 and 65% of the world oil reserves. Several oil spill events have been reported surrounding the UAE coast, as shown in Table I [7].




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TABLE I. MAJOR OIL SPILL INCIDENTS OFFSHORE UAE

| Date | Volume of spilled oil (tons) | Oil type | Location |
|---|---|---|---|
| Mar 30 1994 | 1300-1500 | fuel | 1 mile offshore Jabal Ali |
| Jan 7 1998 | 300-900 | heavy | 7 mile NE offshore Abu Dhabi |
| Jan 14 2001 | 5000-10,000 | crude | 5 mile offshore Ajman |
| Jan 24 2001 | 16,000 | light | 9.6 mile offshore Fujairah |

Various satellite instruments, which can provide synoptic measurements, can be used to estimate water turbidity (water clarity) after proper calibration and correction. One of these instruments, namely Moderate Resolution Imaging Spectroradiometer (MODIS) instruments onboard the NASA Terra and Aqua satellites (morning pass and afternoon pass) provide daily global coverage at medium spatial resolution (250-m to 1000-m), and thus can serve as excellent candidates to map coastal water turbidity on a daily basis (providing cloud free and clear sky conditions). It is unknown how fast turbidity changes in the UAE area; therefore it is safer to choose these high-frequency instruments than others (e.g., Landsat) with lower spatial resolution. Additionally, MODIS sensor has nine optical bands calibrated for water application. These nine narrows ocean color bands cover a greater dynamic range of water-related parameters for the same given condition.

The main objective of this project is to develop satellite-based tool to produce daily assessment of water turbidity in the Arabian Gulf. To achieve this objective, two sub-objectives were defined:

- Assessing the performance of existing mapping models for Abu Dhabi coasts.
- Developing new mapping algorithms adapted to the regional climate using field measurements.

## II. MATERIALS AND METHODOLOGY

### A. Study site

The Emirate of Abu Dhabi is located on the eastern side of the Arabian Peninsula. It is confined by latitudes from 22˚40' to 25˚00' N and longitudes from 51˚00' to 56˚00' E. The interior platform of the Arabian shelf occurs in the subsurface. The fact that the Arabian Gulf is surrounded by land and exhibits extreme seasonal variations affects Abu Dhabi climate and makes it more arid and humid. Moreover, the Gulf experiences significant variations in temperature and salinity, because the narrow Strait of Hormuz inhibits the exchange of marine water into it. The nature of the coastal areas of Abu Dhabi is varying widely from dry land, Sabkha to lagoons and intensive reclamation operations, which affect the turbidity level in the water and complex the water structure. Thus they pose difficulties for scientific research [8].

### B. In situ data

*In situ* measurements were collected to validate existing ocean color algorithms and to develop new models for better adaptation to the environmental conditions of the Abu Dhabi coasts. *In situ* data of Secchi disk depth (SDD) from 117 stations over Abu Dhabi coasts were provided by Environment Agency - Abu Dhabi (EAD). The measurements were made in February, March and April 2010. All sampling stations are shown in Fig. 2.

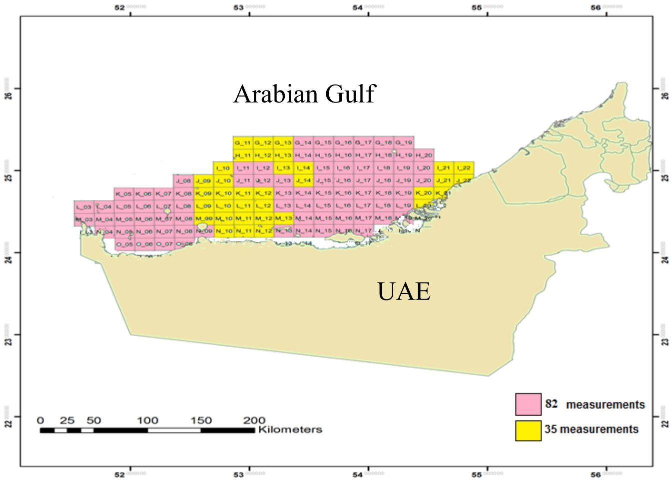


Fig. 2. 117 stations from *in situ* surveys. The stations with concurrent satellite data used in this study are annotated with the yellow color and the other stations are annotated with the pink color.

### C. Satellite imagery

MODIS Aqua and Terra level 1A data with spatial resolution of 1 km were downloaded from NASA data archive (http: //ladsweb.nascom. nasa.gov/data) via FTP and processed to level 2 products, using SeaDAS (version 6.4) software package developed by NASA with default algorithms. The flow chart of satellite data processing is shown in Fig. 3.

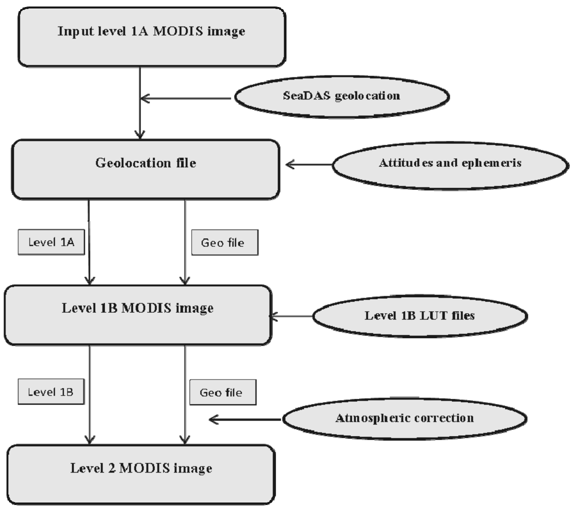


Fig. 3. Flow chart of SeaDAS image processing.

After atmospheric correction and cylindrical projection, level 2 products including diffuse attenuation coefficient for downwelling irradiance at 490 nm ($K_d$_490) from [9], [10] and [11] algorithms, fluorescence line height (FLH), reflectance at 488 nm and 547 nm, and flags, were output.

### *D. Matchup between in situ and satellite measurements*

The matchup between *in situ* and satellite measurements followed [12] and is simply described here. Satellite data with poor quality, as defined by the flags in the data products (i.e., problems due to clouds, stray light, atmospheric correction failure, high top-of-atmosphere radiance, low water-leaving radiance, large solar/viewing angles, and navigation failure), were discarded. The time interval of <±3 h, within which the satellite and *in situ* measurements were considered as "concurrent", was adopted [12]. The matchup procedure resulted in 35 pairs of *in situ* and satellite measurements.

### *E. Background for different $K_d$ algorithms*

SeaDAS, software developed by NASA, offers several algorithms to derive the $K_d$_490 for different satellite missions. The default algorithm used the relationship between ground truth $K_d$_490 and the blue-green band ratio of normalized water-leaving radiance ($nL_w$, [9]; [13]), expressed as:

$$K_d\_490 = 0.016 + 0.15645\left(\frac{nL_W(490)}{nL_W(555)}\right)^{-1.5401} \quad (1)$$

Werdell [14] updated the coefficients in Eq. (1) using a global dataset and obtained:

$$K_d\_490 = 0.1853\left(\frac{nL_W(490)}{nL_W(555)}\right)^{-1.349} \quad (2)$$

Another empirical algorithm used satellite derived chlorophyll-a concentration as an intermediate variable [15]:

$$K_d\_490 = 0.016 + 0.0773(\mathrm{chl})^{0.6715} \quad (3)$$

The above mentioned two empirical algorithms were generally designed for Case I waters, where phytoplankton dominates and other optically significant components co-vary.

However, these empirical algorithms failed for optically complex coastal waters. Lee et al. [11] developed a semi-analytical algorithm to estimate $K_d$_490 using:

$$K_d\_490 = (1 + 0.005\theta_0)a(490) + 4.18(1 - 0.52e^{-10.8a(490)})b_b(490) \quad (4)$$

where a and $b_b$ are the total absorption and backscattering of optically active constituents, and $\theta_0$ is the solar zenith angle. This algorithm works well for both oceanic and coastal waters with $K_d$_490 ranging from ~0.04 to 4 $m^{-1}$ [11].

In this paper, SDD is estimated using $K_d$_490 from the empirical Mueller algorithm [9] ($K_d$_490_mueller is hereafter used for short) and the semi-analytical algorithm [11] ($K_d$_490_lee is hereafter used for short).

## III. Results and Disscussion

Fig. 4 shows the relationship between *in situ* measured SDD and satellite derived $K_d$_490_mueller and $K_d$_490_lee. Satellite measured $K_d$_490 is generally <0.2 $m^{-1}$, which is the upper limit for the empirical algorithms [11]. *In situ* measured SDD ranged from 1.68 to 10.97 m. The best fitted relationships between SDD and satellite derived $K_d$_490 can be expressed as:

$$SDD = 15.608e^{(-9.035K_d\_490\_mueller)} \quad (5)$$

$$SDD = 39.36e^{(-16.7K_d\_490\_lee)} \quad (6)$$

Statistical analysis indicated that $R^2$ between SDD and $K_d$_490_mueller is 0.74, higher than that between SDD and $K_d$_490_lee. And RMSE is 22.25% for the former and 27.05% for the latter. It appears that the performance of the empirical algorithm is better than that of the semi-analytical algorithm. However, this does not conflict with previous studies since satellite derived $K_d$_490 used for estimation of SDD in this study is generally less than 0.2 $m^{-1}$. The semi-analytical algorithm generally presented its superiority over the empirical algorithms for $K_d$_490_lee > 0.2 $m^{-1}$ [11]. Therefore, in order to establish a region-scale algorithm to estimate SDD from satellite derived $K_d$_490, more *in situ* investigations covering different seasons and areas are desired.

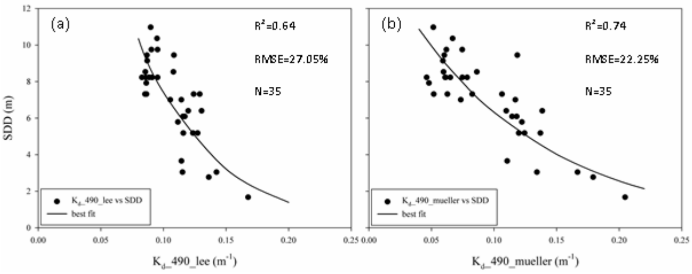


Fig. 4. Relationships between in situ measured SDD and satellite derived $K_d$_490 using the Lee (a) and Mueller (b) algorithms.

As shown in Fig. 5 and 6, two maps of SDD using Eqs. (5) and (6) are produced for the Arabian Gulf. In some coastal areas along the west coastline of Abu Dhabi, SDD estimated from Eq. (5) is misleading since it is larger than the bottom depth while SDD estimated from Eq. (6) seems to be reasonable. However, on the shelf region, e.g. to the north of Abu Dhabi, SDD from Eq. (6) is overestimated. This can be caused by shallow bottom. With proper correction algorithm, this can be avoided [16].

## IV. Conclusion

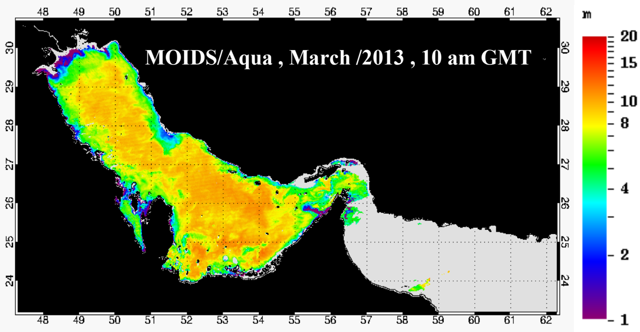


Fig. 5. SDD mapping for the Arabian Gulf using Eq. (5).

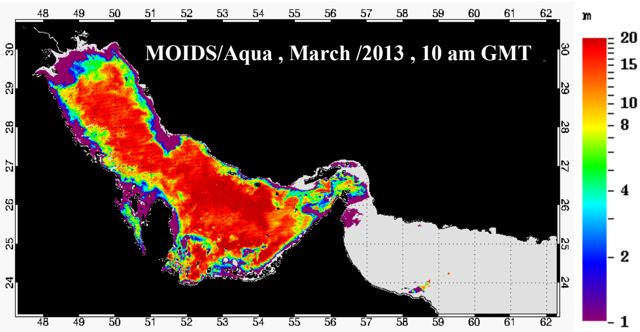


Fig. 6. SDD mapping for the Arabian Gulf using Eq. (6)

The Arabian Gulf is the source of 45% of world's desalinated water. Therefore, it is essential for the Arabian Gulf region to develop satellite based tools to monitor the water quality and, therefore, help in reducing the impact of water pollution on the operation of desalination plants. In order to improve our understanding of water quality in the Arabian Gulf, two models are established to obtain SDD from satellite derived $K_d$_490 based on one empirical algorithm and one semi-analytical algorithm, respectively. Comparisons between estimated and *in situ* measured SDD showed good performance of both models, with $R^2$ equal to 0.74 and 0.64, respectively.

Developing automated SDD mapping model will help to provide daily assessment of water turbidity over the Arabian Gulf region. However, collecting more *in situ* measurements over the Arabian Gulf is required to establish region-specific algorithms and assess their performance.

## ACKNOWLEDGMENT

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