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Long Term Investigation of SST Regime Variability and Its Relationship with Phytoplankton in the Caspian Sea Using Remotely Sensed AVHRR and SeaWiFS Data

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Abstract

Long term Sea Surface Temperature variability and its relation with, chlorophyll (chl) pigment of phytoplankton biomass were investigated using SeaWiFS (Sea-viewing Wide Field of-view Sensor) and AVHRR (Advanced Very High Resolution Radiometer) satellite imagery. SST acquired from AVHRR (1985 to 2009) showed seasonal, annual and inter-annual variability of temperature. Monthly variability chl from SeaWiFS 1985 to 2009 has also been investigated, Correlation between SST and chl was found to be 78% and significant at $P<0.05$.

Keywords: SST, Phytoplankton, AVHRR, SeaWiFS, EOF, Caspian Sea.

Uzun Periyodda Hazar Denizinin Su Yüzeyi Sıcaklığının Değişkenliği ve Değişkenliğin Fitoplanktonla İlişkisinin AVHRR ve SeaWiFS Uydularından Alınan Verilerle İncelenmesi

Özet

Bu çalışmada Hazar Denizi'nin 24 yıllık, mevsimsel su yüzeyi sıcaklığı ve bu sıcaklığın fitoplanktonla ilişkisi AVHRR (Çok Yüksek Çözümlemeli Radyometre) ve SeaWiFS (Sea-viewing Wide Field of-view Sensor) uydu verileri kullanılarak incelenmiştir. Çalışmanın en önemli sonucu fitoplankton ile su yüzeyi sıcaklığını %78 oranında korelasyon göstermesidir (P<0,05).

Anahtar Kelimeler: SST, fitoplankton, AVHRR, SeaWiFS, EOF, Hazar Denizi.

Introduction

The Caspian Sea (Figure 1) is an enclosed sea located between the 36°60′ south and 47°06′ north parallels, so there is about more than 10° differences between the south and north which cause considerable temperature difference. Southern part of the Sea has similar features to that subtropical climate zones. Northern part of the sea is not cold only due to difference in parallel; also terrestrial climate and fresh cold water input from the rivers nearby such as Volga and Ural affected temperature. Northern of the basin was feed by the rivers Volga and Ural which also carries sediments causes' low depth to be as low as 5m on average. The deepest parts of basin are the Derbent depression and the south Caspian depression with 788 m and with 1,025 m respectively (Gasımov, 1999).

The most important feature of the basin is oscillations in sea-level. This event cause important risks for the North and Northeast coast where water shallow. For a long time the level of the sea was tent to lower however mean level since 1977 started to increase, since then the level of the sea has increased about 2 m on average. This event caused some economic catastrophe as some residential (villages) areas remains under the water. Kazakhstan which has about 1,000 oil well in the shore is not usable anymore, so the oil wells leaking oil to the basin (Figure 1) (Gustafson *et al*., 1995).

Since SST and Chl have connection with studies of global changes, Caspian Sea, was studied to outline long-term SST variation along with the chl and their relation for the whole basin. Thermohaline structure and general circulation of Caspian Sea was studied by Tuzhilkin *et al*. (2005), Sea surface variability studied by Ginzburg *et al*. (2005), Natural chemistry studied by Tuzhilkin *et al*. (2005), Pollution by Korshenko

(2005), Patterns of Seasonal and Interanual Variability of Remotely Sensed Chlorophyll by Nezlin (2005), bio optical characteristics by Kopelevich *et al*. (2004). SST vs. chl studied by Hood *et al*. (1990), Robinson and Williams. (1993), Nykjaer and Van Camp (1989), Ackleson *et al.* (1988), Fox *et al*. (2005), Wang *et al*. (2006), Miles and He (2010), Ginzburg *et al*. (2002), Kopelevich *et al*. (2002), Abigail *et al*. (2008), Oğuz and Ediger (2006), Kavak and Karadoğan (2012). Among the aforementioned studies the work which was carried out by Kavak and Karadoğan (2012) for the Black Sea, has shown similar features in terms of seasonal temperature and Chl variation, except the correlation between the Chl and SST was higher than the correlation for the Black Sea.

Present work investigated long term chlorophyll pigment concentration, sea surface temperature variability using EOF and their correlation for the whole Caspian Sea.

Materials and Methods

Chl Data

SeaWiFS 8-Day Global 9-km chlorophyll images were downloaded from (http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.swf 8D.shtml) the Ocean Biology Processing Group (OBPG) by selecting the Caspian Sea). This site also gives an option to obtain 8 day averaged chl concentration of whole basin as an ascii file. So 8 day composite chl concentration of whole basin from 01/01/1998 to 01/01/2009 was downloaded as an ascii file. Monthly mean generated from 8 day averaged chl of whole basin.

The processing of SeaWiFS data for chlorophyll concentrations involves the standard four-band OC4v4 algorithm (O'Reilly, 2000) using the four available visible bands (443, 490, 510, 555 nm). Caspian Sea is a case 2 (sediment dominated waters) water, where surface color also depends on dissolved and suspended matter concentration. In this study we were unable to compare our result with in situ data since no study carried out for Caspian Sea.

SST Data

In this study we used night time (in order to remove solar heating) monthly mean a global Multi channel Sea surface Temperature (MCSST) dataset based on measurement by Advanced Very-High Resolution Radiometer on board NOAA satellites (McClain *et al*., 1985) which was available from January 1985 to December 2009. The dataset was in 16 bit HDF (Hierarchical Data Format) format and mean SST data have a temperature resolution of about 0.1°C and a spatial resolution of about 4 km. (see the

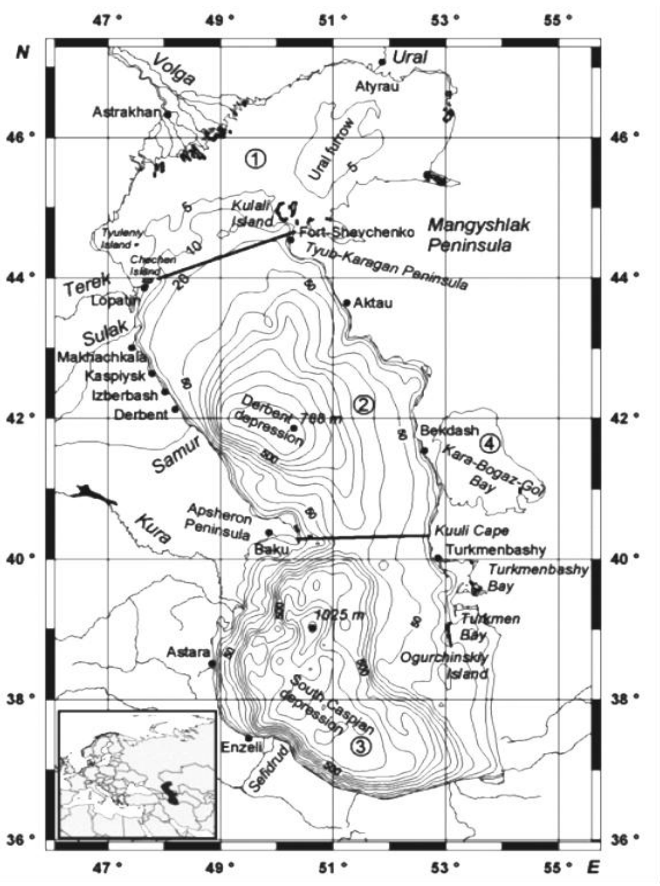


Figure 1. Geographic setting and bathymetry of the Caspian Sea.

description of AVHRR monthly Global MCSSS at: http:///podaac.jpl.nasa.gov:2031/dataset_docs/avhrr_wwww_mcsst.html).

After the extraction of Caspian Sea from global dataset, to transform digital numbers (DN) values to SST values the following equation provided by AVHRR-NOAA was applied

$$SST = DN \cdot 0.075 - 3.0$$

In the absence of quasi-synchronous MCSST and in situ data relating to the same area of the Caspian Sea, the validation of satellite-derived SSTs is impossible. In accordance with McClain *et al*. (1985), the MCSST anomalies relative to the global ship (drifter) data are as follows: biases, 0.3–0.4°C (0.1°C) and standard deviation, 0.5–0.6°C (0.5°C), with the MCSST values being lower than those of ship/drifter-based values.

To observe the dominant patterns of satellite SST variability of the Caspian Sea using an Empirical Orthogonal Function (EOF) analysis, also known as Principal Components Analysis was applied. This analysis has already been used for other regions (Kelly, 1985; Lagerloef and Bernstein, 1988; Paden *et al*., 1991; Fang and Hsieh, 1993; Gallaudet and Simpson, 1994; Hernandez-Guerra and Nykjaer, 1997). The main interest of EOF analysis is due to its capability of decomposing a data set onto orthogonal (i.e. independent) functions. The functions which contain high variance can generally be related to physical phenomena, while the functions which contain less variance are more difficult to interpret due to the orthogonality constraint and they can be considered as noise. This technique can represent the dominant patterns of residual variance found in large and complex datasets.

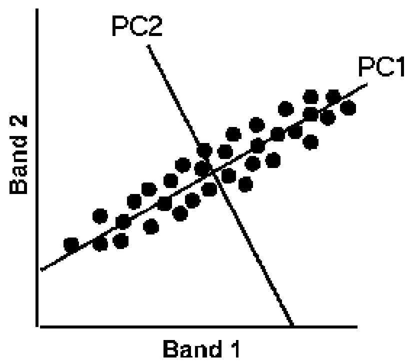


Figure 2. The principal component transform.

Figure 2 depicts the reflectance levels for set of pixels by plotting their positions in what is commonly called band space (in this case, for an image with two spectral bands). Each axis represents the reflectance in the spectral band indicated. Each image pixel can be plotted in this space by placing its location at the intersection of its reflectance level on each band. As can be noted, there is a significant amount of correlation between bands. Since the bands in Figure 2 are correlated they do not each carry independent information. Therefore, there is a good chance of being able to predict the reflectance of a pixel in one band from the reflectance in the other. Basically principal components analysis creates new axes called band axes along the lines of maximum variance within the data. Therefore once the pixels have been located by their new co-ordinate system (see Figure 2) a band axis PC1 image would contain more information than any other band axis image (Curran 1989).

Detailed information about principal component analysis may be found in some textbooks and published papers mentioned above, such as Jensen (1986) and Gallaudet and Simpson (1994).

Results and Discussions

Figure 3 shows 24 yearly averages SST from 1985-2009 of the Caspian Sea. Figure as expected, draws sine curve with small fluctuations. However

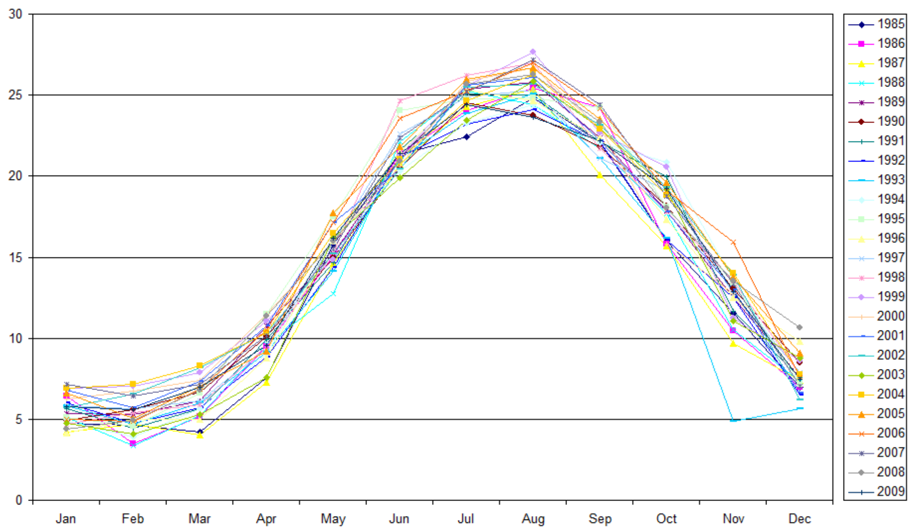


Figure 3. Sessional SST (°C)variation of the Caspian Sea from 1985 to 2009.

November 1993 is considerably off the general trend which must be investigated separately.

Figure 4 shows 24 years (Average, Minimum and Maximum) SST of the Caspian Sea, minimum temperature for November 1993 could also be observed year seasonal averaged SST. Also figure 4 shows 24 year average of SST of Caspian Sea.

Figure 5 (yearly averaged SST and linear trend line of the Caspian Sea) is extremely interesting. A clear indication of global warming and it may be discussed in this respect too.

Figure 6 shows monthly 24 year time sequence of the Caspian Sea along with 24 year averaged SST, again as seen on figure 5 a general increase of SST

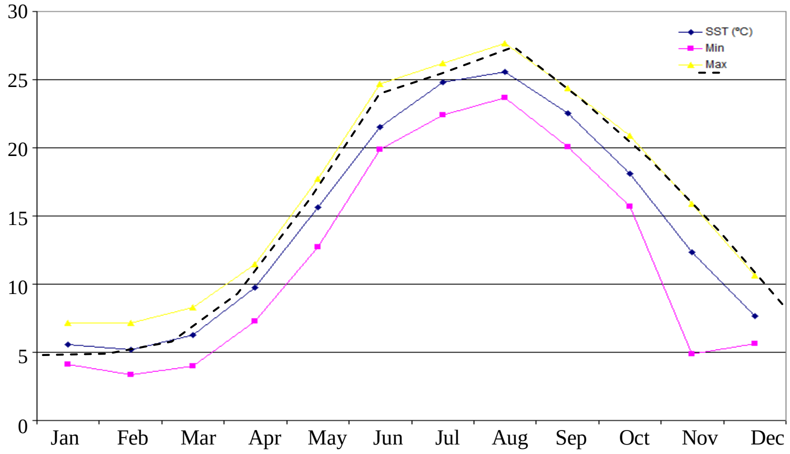


Figure 4. Average 24 seasonal cycles with Minimum and Maximum SST's of the whole basin.

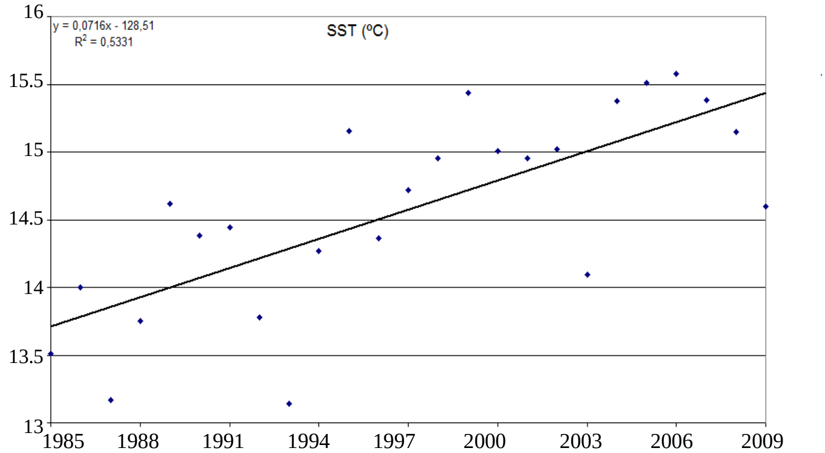


Figure 5. Yearly averaged SST and linear trend line of the Caspian Sea.

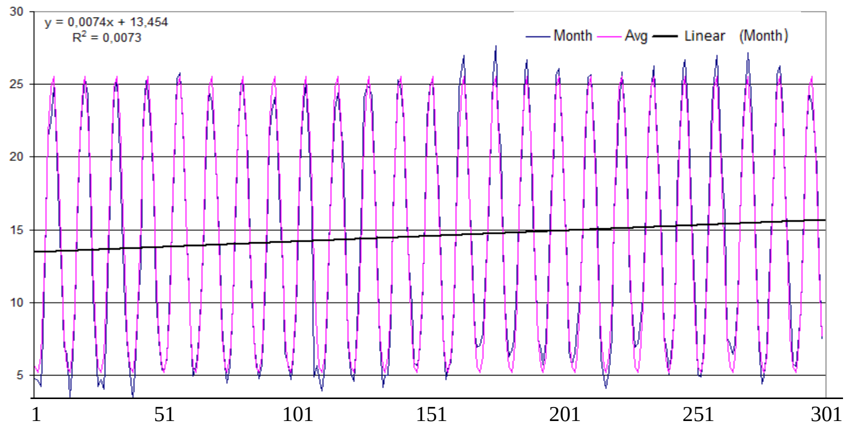


Figure 6. Seasonal and inter-annual variability of monthly mean SST (°C) averaged over the entire basin (300 images) along with trend line (1985-2009).

could be observed along with trend line seasonal and inter-annual variability.

Figure 7 shows 300 monthly averaged SST images acquired from NOAA-AVHRR from 1985 to 2009. The average of 300 images shows temperature gradient from the south to the north (high temperature to low temperature) which may be related to the climatic, bathymetric and Condition of the sea.

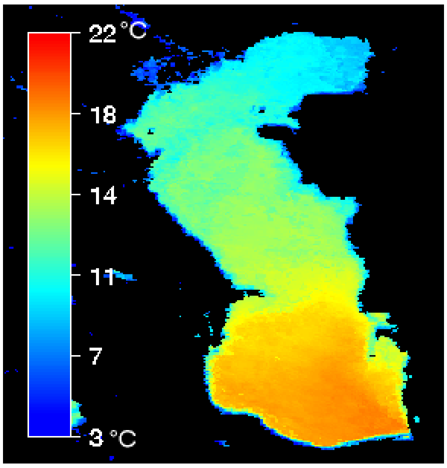


Figure 7. Average of sst temperature of the 300 images.

ERMapper (www.erdas.com) has been used to conduct PCA of SST for the Caspian Sea. The following sequence has been followed to extract PC 1, PC2 and PC3 respectively.

Dataset has been loaded into ERMapper window following equations have been entered respectively Table 1, Table 2 and Figure 8 presents a set of Eigen values with percentage of variances explained by each component extracted from ERMapper's statistics table.

As seen from Table 2 first PC contains 65%, second PC contains 7% and the third PC contains 2% of total variance. In other words three images contain 75% of total variance. The PC1, PC2, and PC3 can be seen on the Figure 9a, 9b and 9c respectively

First PC contains 65% of variation which seems to represent the general temperature of the Caspian Sea which may be seen on figure 7. Second PC contains 7% of variance seems to represent basin depressions. The third PC which contains 3% of total variance was not connected to any phenomena.

Seasonal cycle of chlorophyll concentration on Figure 10 generally located around the general average except the year of 2001 quite off the general average which may need to be investigated.

Correlation between sst and chl (Figure 11).was calculated using the same time of the years, that was

Table 1. Equations which entered to ERMapper window in order to extract principal components

Components	
SIGMA (I1..300|I? * PC_COV (,R1,I?,1))	For PC1
SIGMA (I1..300|I? * PC_COV (,R1,I?,2))	For PC2
SIGMA (I1..300|I? * PC_COV (,R1,I?,3))	For PC3

Table 2. Eigen values along with accumulated variances

Component	PC1	PC2	PC3
Eigen Value	580013,653	69202,944	19289,534
% Variance	0.65	0.07	0.02
Accumulated Variance	0.65	0.73	0.75

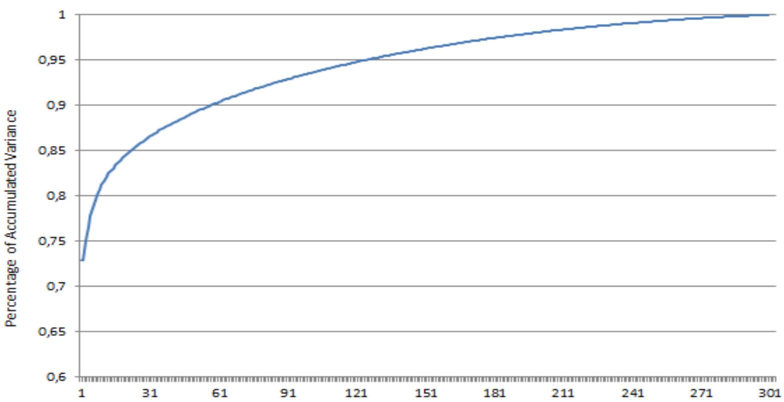


Figure 8. Accumulated variances of 300 Eigen values.

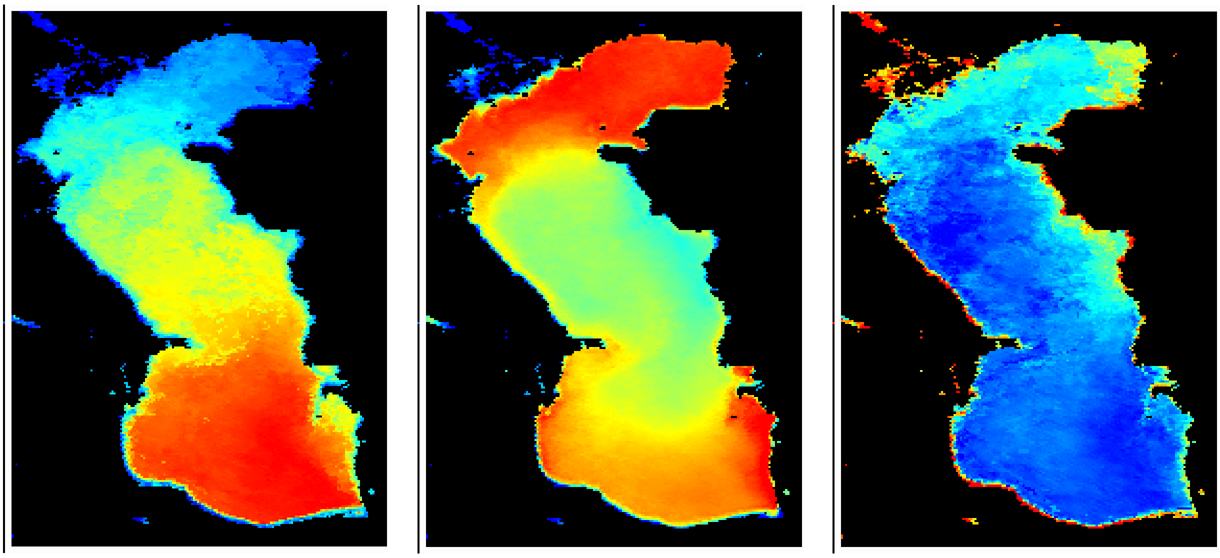


Figure 9. PC1, PC2 and PC3 of the Caspian Sea.

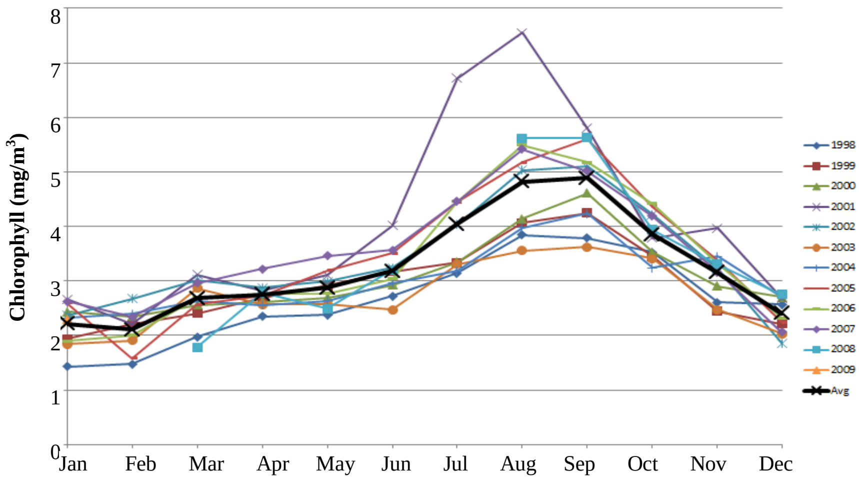


Figure 10. Superposition of seasonal cycle's monthly basin means of chlorophyll from 1998 to 2009.

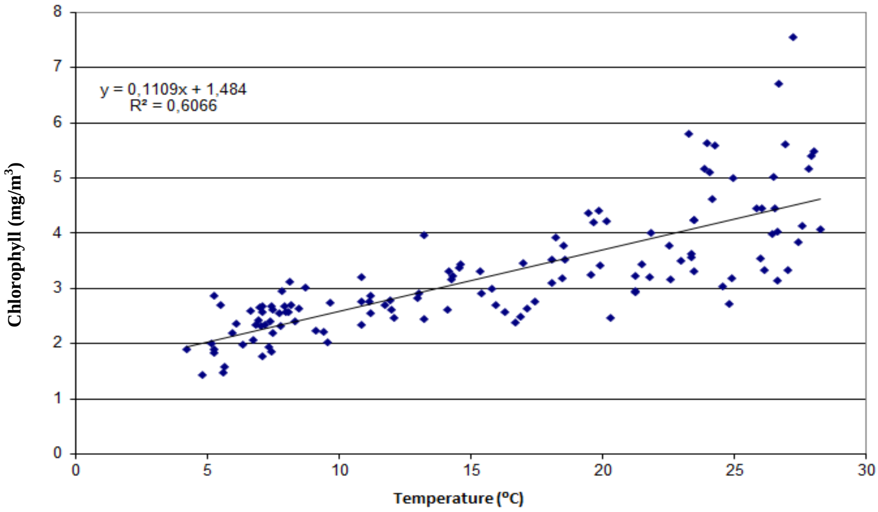


Figure 11. Cross plot of monthly averaged point's chlorophyll pigment concentration and sst of whole basin SST versus chlorophyll concentration.

available for both from1998 to 2009.

A decrease on chl from September to February and an increase from January to August on the other hand SST is minimum on February then reaches to its maximum on August. From Figure 12 we could say that chl and sst have similar trend accept March increase in chl low SST. La Violette (1994), using similar data for the North Adriatic region, have found that the highest values of chlorophyll pigment concentration occur in winter months. High chlorophyll pigment concentration in winter could be due to less-stratified (better-mixed by winter winds) water that is more likely to be rich in nutrients.

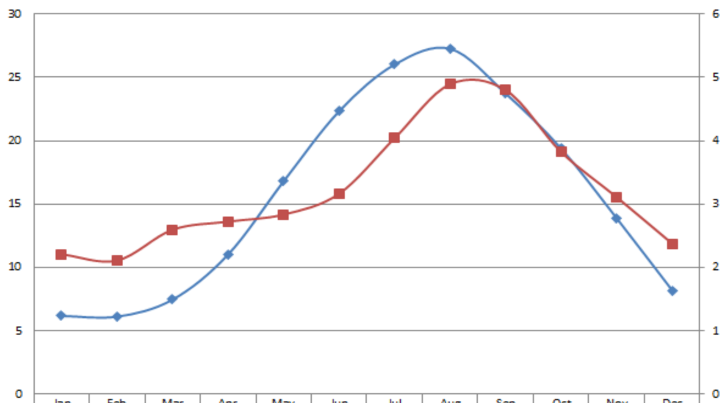
Seasonal cycles in Figure 13 along with averaged data. June July and August 2001 is quite off the general average which could be investigated separately. Years; 2005, 2006, 2007 and 2008 also have higher temperature than the general average.

As seen there is evidence of 78% correlation between chlorophyll pigment concentration and SST of the Caspian Sea. This also observed by Kavak and Karadoğan (2012) for another enclosed sea the Black Sea by 60%.

July August and September months are the best times to study Chlorophyll pigment concentration.

The results for enclosed seas have shown SST and Chl correlation. This could be attributed to strong stratification of large water bodies.

Although the present work does show correlation, as previous studies mentioned other factors must be taken into account in determining biomass growth. Such as surface flow zones substrate concentration, temperature gradients, oxygen abundance and other factors including eutrophication are important (Tran *et al*., 1993). Since there is no unique algorithm for case 1 waters (those waters which phytoplankton and their by-products play the dominant role in determining the optical properties of the water body) and case 2 waters (sediment dominated waters) as it seems to be dependent on geographic locations. Thus different waters require different algorithms (Singh. 1992). As Bowers *et al*.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SST (ºC)	6,19	6,13	7,47	11,03	16,81	22,33	26,02	27,26	23,73	19,38	13,89	8,20
Chl (mg/m3)	2,21	2,11	2,60	2,73	2,84	3,17	4,04	4,89	4,80	3,82	3,11	2,38

Figure 12. Showing monthly average chlorophyll pigment concentration and SST whole averaged data.

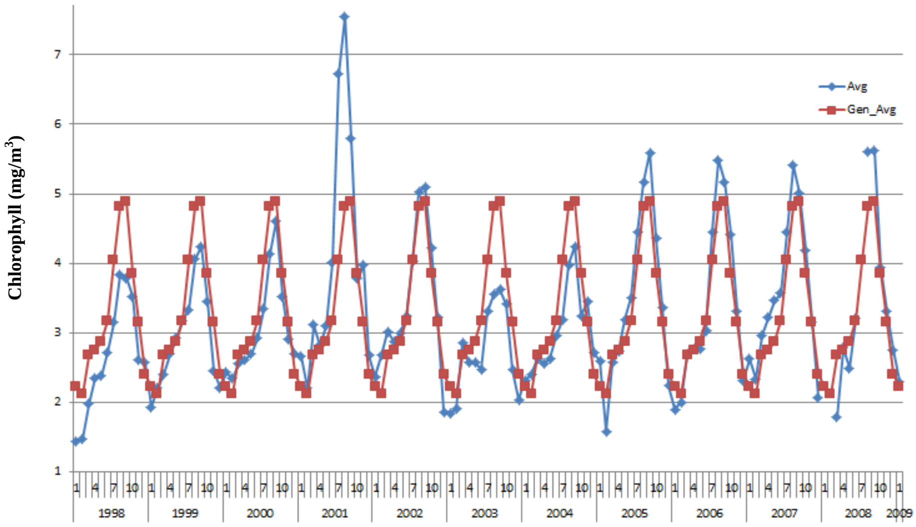


Figure 13. Seasonal and interannual variability of monthly mean Chl averaged over entire basin.

(1996) indicated, inorganic sediment concentration has to be known in order to derive chlorophyll concentration from a blue-green ratio measured by satellite to obtain more accurate results. Bowers *et al.* (1996) suggested using a three channel algorithm or the use of fluorescence or the chlorophyll absorption peak in the red.

Present work was conducted at the whole Caspian Sea using SeaWiFS and AVHRR data, with about resolution of about 1 km. However regional in situ in conjunction with high resolution satellite data such as SPOT and Landsat would show very interesting result where inflow waters are present.

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