Monitoring water quality in the coastal area of Tripoli (Lebanon) using high-resolution satellite data

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Objective

To assess water quality in Tripoli coastal area using high resolution satellite data

To provide valid data for coastal resource management

Ocean color radiometry

- For open waters: color variations depend mainly on the presence of planktonic pigments

- Many programs have been designed for monitoring the optical properties of sea water
  Some of those most widely used:

- SeaWiFs (Sea-viewing Wide Field-of-view Sensor, since 1997), pixel size 1200m

- MODIS (Moderate Resolution Imaging Spectroradiometer , since 1999 and 2002) pixel size 250m
- MERIS (Medium Resolution Imaging Spectrometer, since 20020)

- Coastal and estuarine systems: optically complex waters, with high concentrations of dissolved organic matter and suspended sediments, and by smaller geographical scales

- Landsat TM and Landsat 7 ETM+ (higher spatial resolution, 30 m)

Material and methods

The general approach of this study involved the following steps:

(1) Acquisition of water quality data from boats, near simultaneously with the Landsat 7 ETM+ scene

(2) Location of sample sites on Landsat ETM+ image

(3) Extraction of digital data from TM bands

(4) Development and verification of regression models, relating values of selected water quality parameters to the spectral data

(4) Application of models to the entire study area

(5) Production of color-coded resultant images depicting the distribution of a selected water quality parameters(chlorophyll-a, turbidity, Sechii depth, and SST)

Study area: Tripoli coastal area

Continental shelf: about 12 km

The average depth: roughly 30 m, but the bathymetry is quite variable

Sizable freshwater input from the Nahr Abou-Ali (369 Mm3/year)

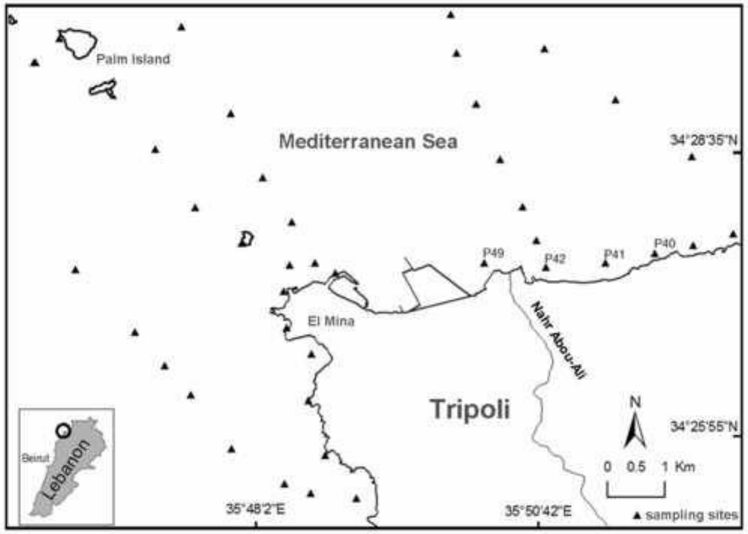
The major open dump for solid waste and wastewater discharge of Tripoli are located in the same area

CDR: A plant for primary treatment of sewage

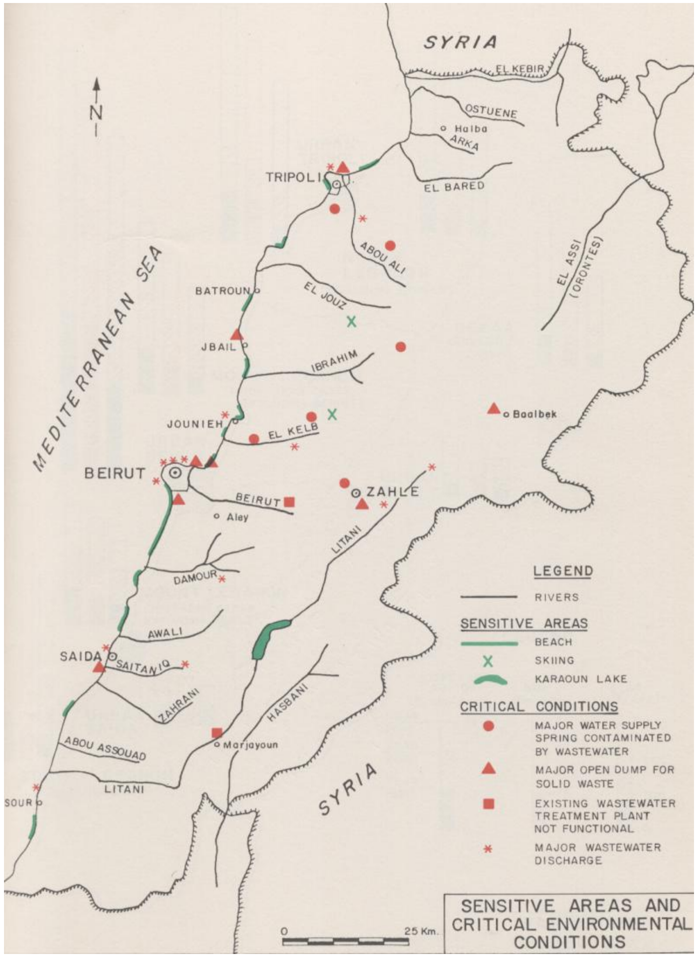
However, at present, raw domestic and industrial wastewaters, from various sewer pipelines and drainage channels, are released at sea without treatment (200 Ml/day, in the year 2000).

Due to the high nutrient input associated with this runoff, the Tripoli coastal/shelf zone plays an important role in supporting abundant marine life.

The area of Palm Island (5 km offshore): is one of the few natural reserves in Lebanon



Map of the Tripoli coastal area and sampling stations



Sensitive areas and critical environmental conditions (CDR, Master Plan for Wastewater Management, 1982)

- In Tripoli coastal area the major open dump for solid waste and the major wastewater discharge are near the mouth of Nahr Abou Ali river

Acquisition of sea truth data

- A group of 45 locations were monitored within 6 hours
- The sampling stations were selected so as to represent the full range of environmental conditions expected in the study area.
- All stations were located by GPS (Trimble Geoexplorer), accuracy of the GPS measurements being 2 m
- All water quality parameters were determined in situ
- The spreading of river discharges was seen to be eastwards along the coastline, and driven by the dominant westerly and southwesterly winds.
- Chlorophyll-a concentration was measured below the surface, at 30–50 cm depth, using a Seapoint Chlorophyll Fluorometer with a measured sensitivity of 0.001 mg m−3 and a minimum detectable level 0.02 mg m−3 of chlorophyll-a.
- In order to avoid the interference of strong sunlight with the sensor, for the measurements at less than 1 m depth, the sensor was shaded from direct sunlight by a black disk put on the sea surface over the sensor.
- Turbidity was measured below the surface, at 50–60 cm depth, using a Seapoint Turbidity Meter (Oceano Instruments)
- Secchi depth was measured with a 20 cm diameter black and white quadrate disk
- Weather conditions were optimal, with a cloudless sky.

In situ data

Table 1. Range of environmental variables measured in Tripoli coastal area (N indicates the total Number of stations used, SD the Standard Deviation)

variable	*N*	*mean*	*maximum*	*minimum*	*SD*
Chlorophyll-a (mg m^{-3})	34	0.82	3.07	0.30	0.46
Secchi disk depth (m)	36	6.16	11.00	2.00	2.50
Turbidity (FTU)	45	2.34	8.43	0.58	1.86
Temperature (°C)	47	17.95	19.93	16.76	0.87

•The mean chlorophyll-a concentration of the 34 sampling stations was 0.82 mg m^{-3}

A relatively high standard deviation (0.46 mg m−3) was recorded, underlining the pronounced spatial variability of Chlorophyll-a concentration

Higher concentrations were found along the coast

The highest concentration 3.07 mg m^{-3}, was recorded at the location of the El Baddawi sewage outfall

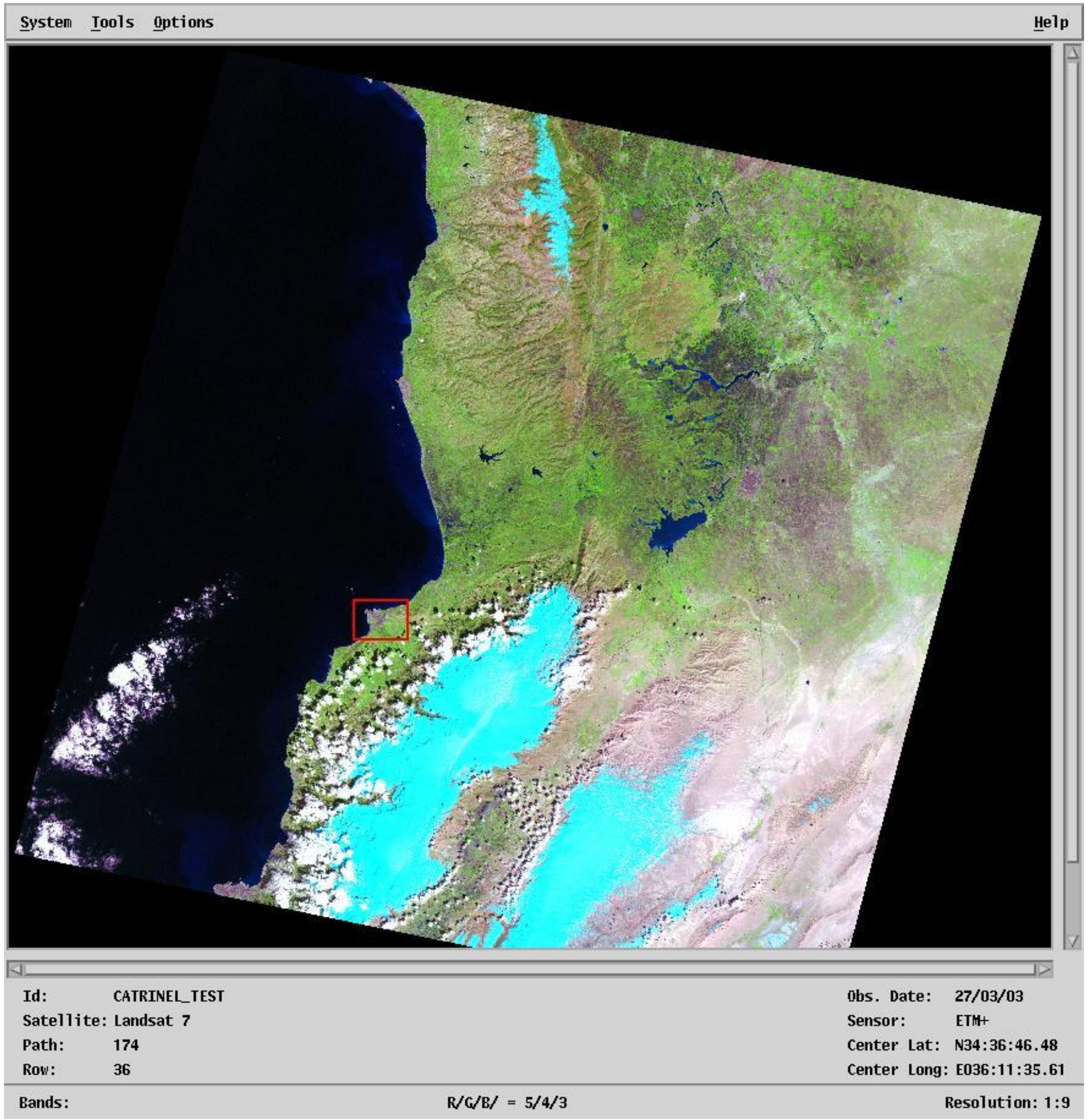
Relatively high concentrations, of 1.8 mg m−3, 1.41 mg m−3 and 1.42 mg m−3, were recorded in The area where nutrients brought in by the Nahr Abou- Ali tend to have their maximum impact

Satellite data: A Landsat 7 ETM+ image (path: 174, row: 36, date of acquisition: 27 March 2003) was used for this study. The image was acquired under clear sky and calm conditions

Table 2. Landsat 7 ETM+ bands, spectral interval and spatial resolution

ETM+ band	*name*	*spectral interval*	*Spatial resolution*
Panchromatic band		0.52- 0.90 µm	15m
Visible band B1*	ETM+ 1 (blue)	0.45 - 0.51 µm	30 m
Visible band B2*	ETM+ 2 (green)	0.525 - 0.605 µm	30 m
Visible band B3*	ETM+ 3 (red)	0.63 - 0.69 µm	30 m
NIR band	ETM+ 4	0.75 - 0.90 µm	30 m
Mid-infrared band	ETM+ 5	1.55 - 1.75 µm	30m
Mid-infrared band	ETM+ 7	2.09 - 2.35 µm	30 m
TIR band	ETM+ 6	10.40 - 12.50 µm	60m

In addition to a panchromatic band, with 15 m spatial resolution, the Landsat 7 ETM+ includes 7 spectral bands, with 30 m spatial resolution for all except band 6, which is a thermal infrared band, with 60 m spatial resolution



The entire Landsat scene(172 x 185 km).

A Precision Map Image over Tripoli coastal area

Data processing

- The Landsat ETM+ image was geometrically corrected using ERDAS Imagine 9.0

  The image was geometrically rectified to a Universal Transverse Mercator (UTM) projection using 7.5 min quadrangle topographic maps. More than 35 Ground Control Points were selected from both the image and the topographic maps.

- The Landsat ETM+ image was radiometrically corrected, pixel values were transformed to reflectance values

- The atmospheric correction was applied to by the original data supplier

- Because of possible residual errors in the remapping, and in order to take into account local uncertainties due to water dynamics, a window of 3 × 3 pixels around each pixel corresponding to a sampling station was considered for further processing. Then, the mean reflectance of the 3 × 3 window, instead of the central pixel, was extracted and used to derive empirical algorithms for water quality parameters

- The corresponding SeaWiFS derived chlorophyll-a maps were used for comparison with the available Landsat 7 ETM+ image.

- The monthly mean map From SeaWiFS (i.e. March 2003), for the Lebanese coastal area was used also for comparison with the available Landsat 7 ETM+ image

Scattering/absorption features of chlorophyll-a

- The prominent scattering/absorption features of chlorophyll-a are:
  Reflectance Maxima in the green and near-infrared and reflectance minima in the blue and in the red
- Therefore, the four bands which are mostly used to assess chlorophyll-a concentrations are the blue, green, red, and near-infrared bands
- The two bands which have the most penetration power, i.e. the blue and the green, can also be used to estimate Secchi disk depth and turbidity.

Development of regression models

- Analysis of the in situ data was carried out through statistical correlation and regression procedures.
- Logarithmically transformed chlorophyll-a, Secchi disk depth and turbidity were used as the dependent variables for the regression models, while the logarithmically transformed Landsat 7 ETM+bands were used as the independent variables
- The final selection of models was based on R^2, probability of a greater F-value for the overall model, and significance of the t-test for the regression parameters.
- A significant level of 0.05 was used for all models and regression parameters.
- The empirical algorithms in Table 3 (where B1, B2 and B3 correspond to the Landsat 7 ETM+ bands as indicated in Table 1) were found to be the best predictors of the natural log of the environmental parameters labeled chlorophyll-a, Secchi disk depth turbidity
- Water quality spatial maps were produced on the basis of the established regression models

Statistical analysis and regression models

(1a)	$Ln(CHLA) = 1.67 - 3.94\ Ln(B1) + 3.78\ Ln(B2)$	$N = 34$	$R2 = 0.723$
(1b)	$Ln(CHLA) = 6.92274 - 5.75815\ [\ Ln(B1) / Ln(B3)\ ]$	$N = 34$	$R2 = 0.719$
(2)	$Ln(SECCHI) = -7.27 + 4.84\ Ln(B1) - 2.95\ Ln(B2)$	$N = 35$	$R2 = 0.54$
(3)	$Ln(TURB) = 10.6823 - 5.6838\ Ln(B1) + 3.5418\ Ln(B2)$	$N = 45$	$R2 = 0.57$

Table 3. Predictive algorithms derived from the matching in situ and Landsat 7 ETM+ data

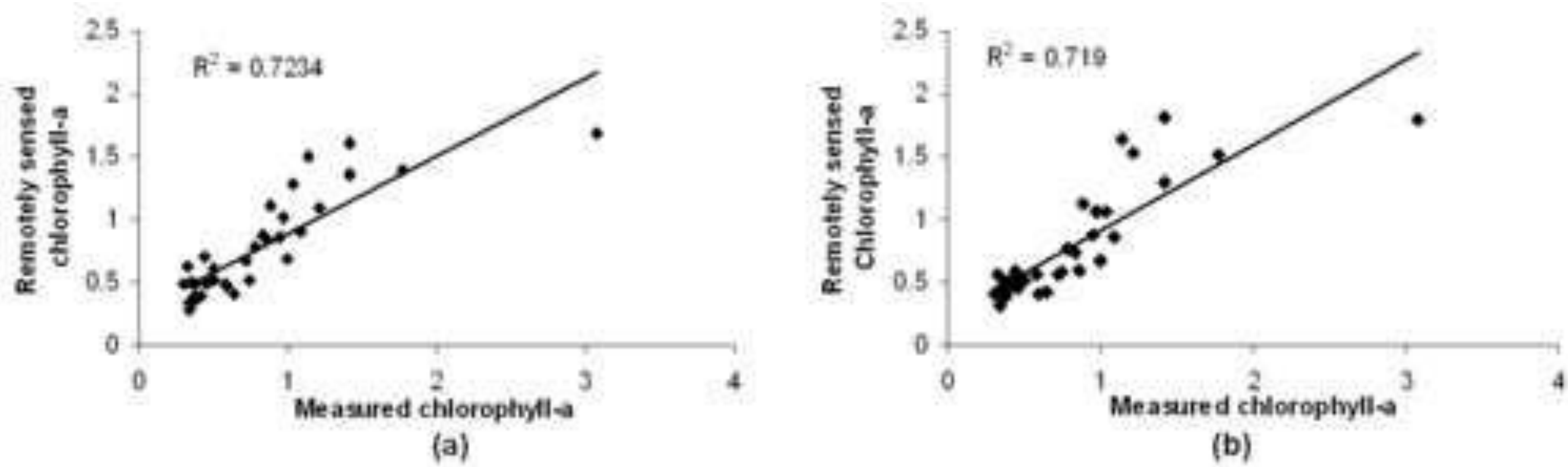


Fig. 2. Comparison between the surface chlorophyll-a concentrations derived from the predictive algorithms in Table 3, using (a) equation 1a and (b) equation 1b, and the in situ values.

The values predicted from the algorithms show a reasonable amount of scatter against the observed values. In both cases, the results appear to be statistically significant.

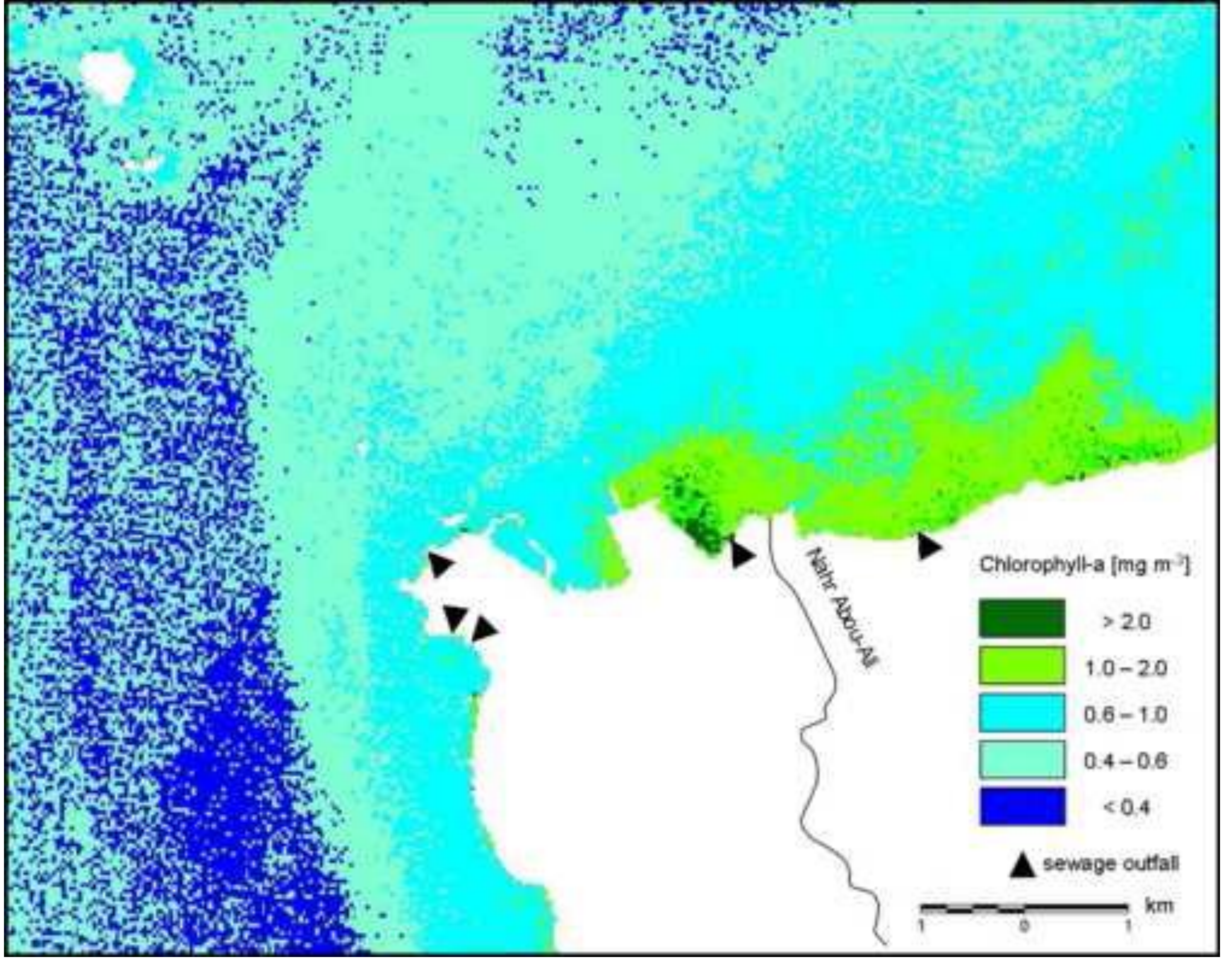


Fig. 3. Chlorophyll-a (algorithm 1a, Table 3) map of the Tripoli coastal area. From Landsat 7 ETM+ data, at 30 m resolution, 27 March 2003

a first synoptic view of chlorophyll-a for the Tripoli coastal area viable to date

The chlorophyll-a levels are above 0.6 mg m−3 for most of the coastal area considered. These values compare well with typical values (ranging between 0.5 and 1.0 mg m−3), reported for other Mediterranean near-coastal regions exposed to moderate eutrophication (UNEP-WHO, 1988)

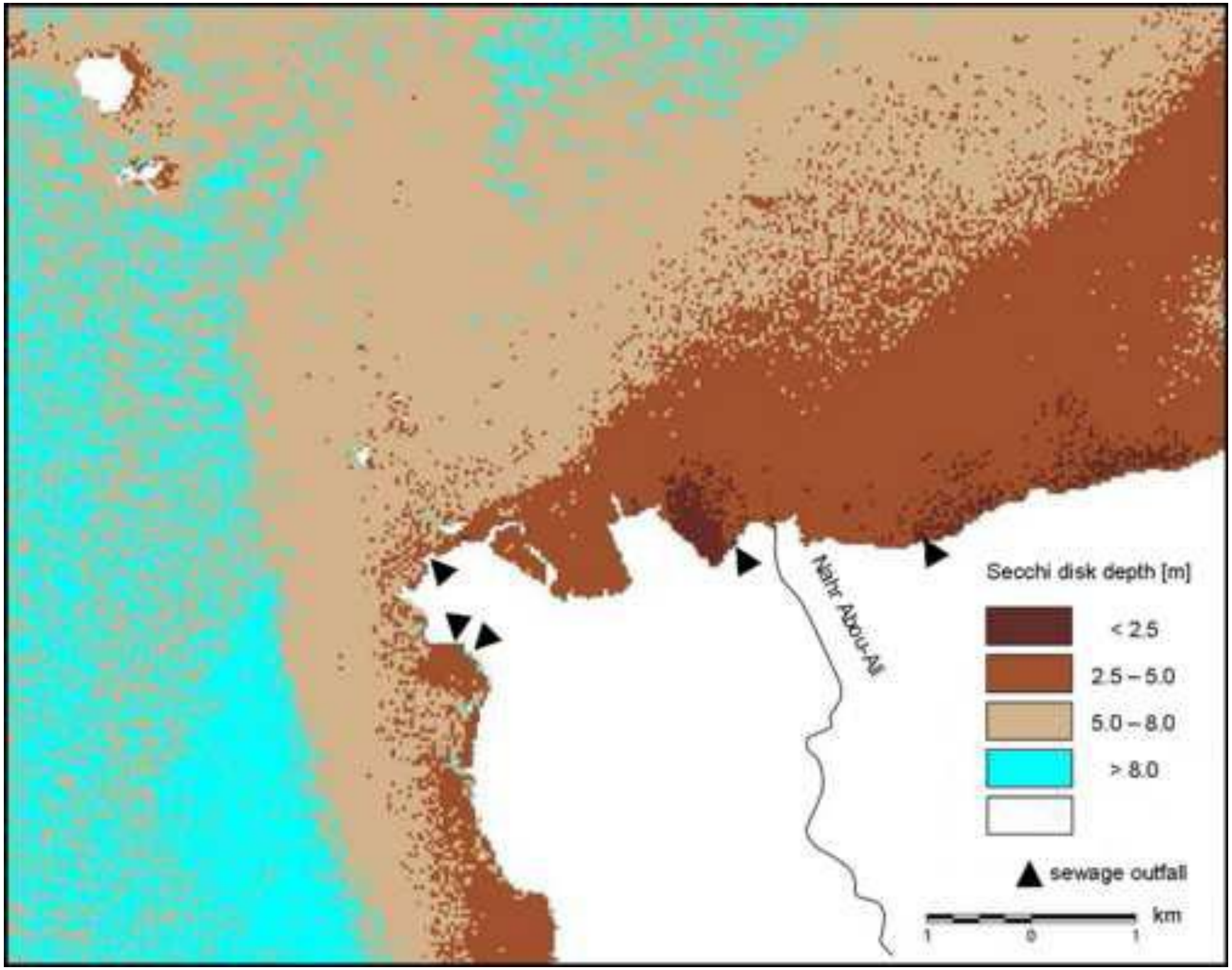


Fig. 4. Secchi disk depth (algorithm 2, Table 3) map of the Tripoli coastal area. From Landsat 7 ETM+ data, at 30 m resolution, 27 March 2003.

Hotspots along the northern coastal stretch, where water Secchi depths fall below the critical values of 2 to 3 m (UNEP-WHO, 1982), display concentrations of chlorophyll-a up to and above 2.0 mg m−3.

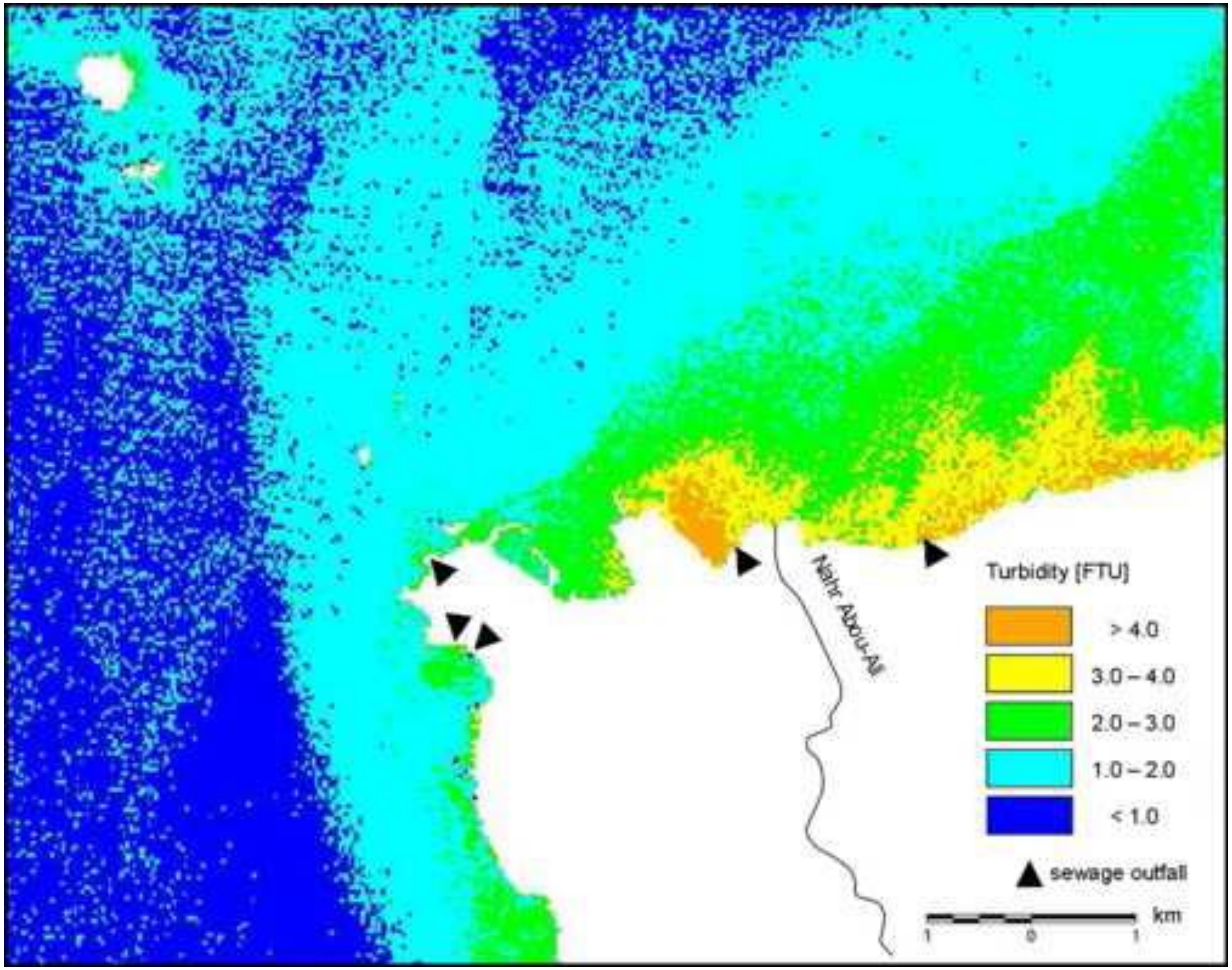


Fig. 5. Turbidity map (algorithm 3, Table 3) of the Tripoli coastal area. From Landsat 7 ETM+ data, at 30 m resolution, 27 March 2003.

Plumes of turbid waters, where transparency is low and chlorophyll-a relatively high, can be observed at several hotspots adjacent to the shoreline, in particular along the northern coastal stretch.

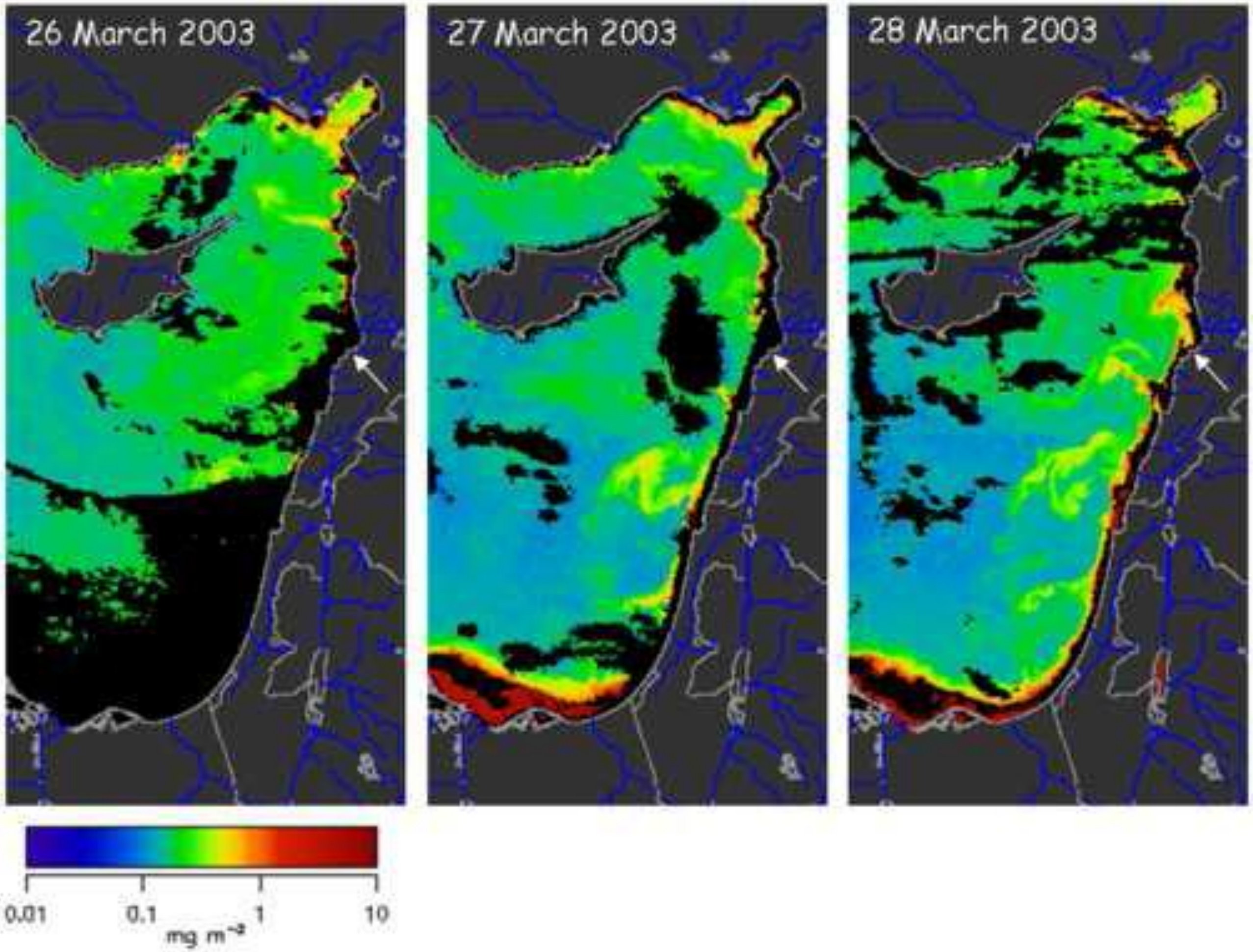


Fig. 6. Chlorophyll-a maps of the eastern Mediterranean Sea as derived from SeaWiFS data, at 2 km resolution; 26, 27 and 28 March 2003. Black pixels represent clouds. The white arrows indicate the area of Tripoli.

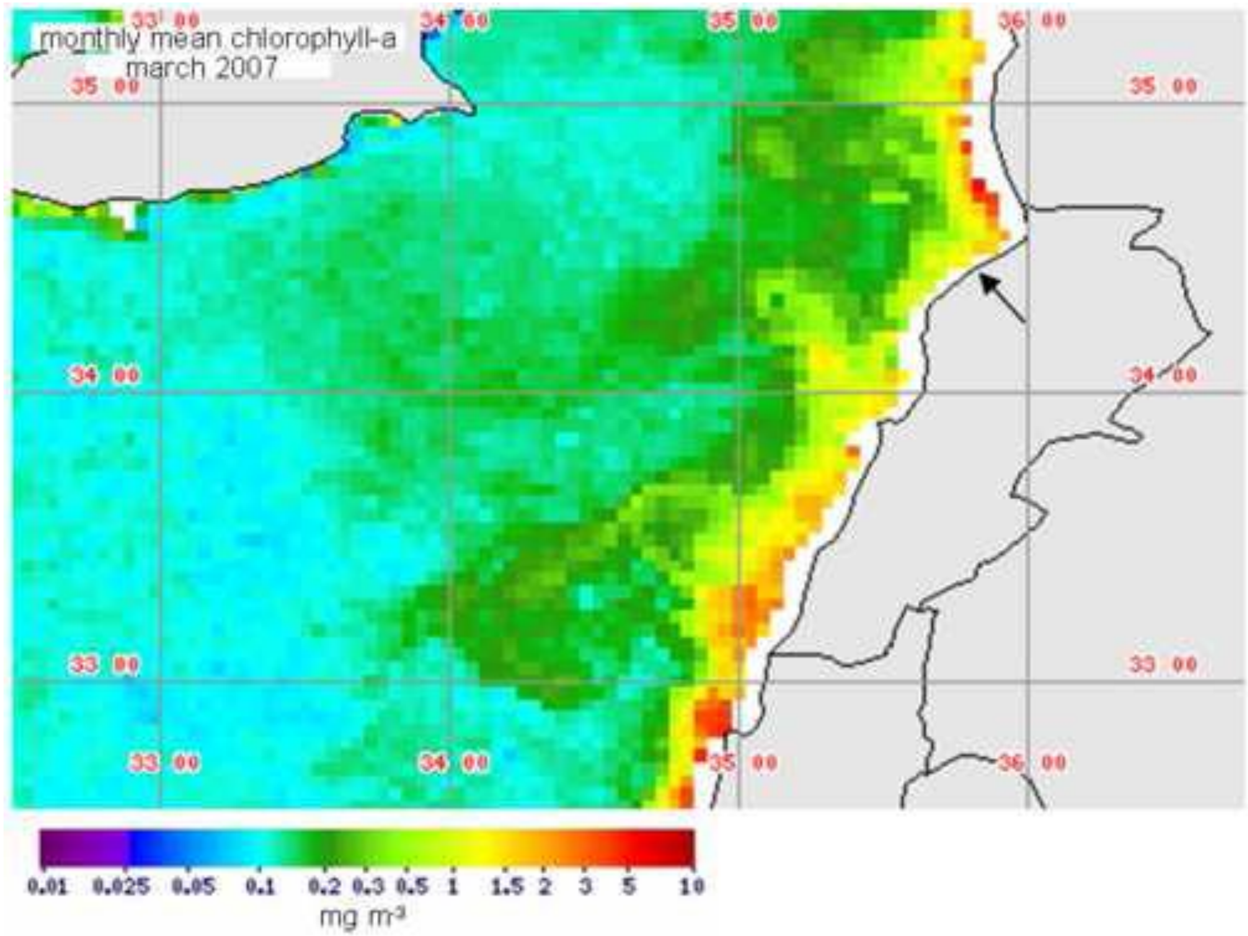


Fig. 7. Monthly mean chlorophyll-a map of Lebanese waters as derived from SeaWiFS data, at 5 km resolution; March 2003. White pixels along the coast represent areas where the processing algorithm failed systematically to derive significant chlorophyll-a values. The black arrow indicates the area of Tripoli.

Results

- The color-coded maps represent a first synoptic view of water quality parameters for the Tripoli coastal area viable to date).
- Ocean color radiometry of the coast around Tripoli indicates that this area is exposed to the risk of developing eutrophic conditions, along most of its shoreline (in particular along the northern stretch, due east of the headland of El Mina)
- Sewage outfalls, at various locations (indicated in Figs. 3–5), as well as the Nahr Abou-Ali, may be at least partly responsible for such conditions, due to their abundant release of pigmented materials (and nutrients).
- The main gradients are sloping in the offshore direction, where the surface patterns seem to be oriented toward the north-east, possibly in line with the prevailing current
- Relatively high concentrations of chlorophyll-a 1.8 mg m-3, 1.41 mg m-3 and 1,42 mg m-3, were recorded in the area where nutrients brought in by the Nahr Abou-Ali tend to have their maximum impact
- The comparison of the chlorophyll-a map with SeaWiFS data covering the entire eastern Mediterranean region shows that in both cases offshore waters present concentrations up to approximately 0.4 mg m−3 (except for a number of large-scale coastal plumes, where the concentration can be twice that value).
- Inshore waters present concentrations around or above 1.0 mg m−3

Conclusion

Ocean colour radiometry of Tripoli coastal area indicates that this area is exposed to the risk of developing eutrophic conditions, along most of its shoreline (in particular along the northern stretch, due east of the headland of El Mina). This appears to be linked to the presence of fluvial and wastewater runoff sources.

The combination of spectral and spatial resolution of the Landsat 7 ETM+ proved useful for the intended application, which generated a first set of thematic maps showing the distribution of selected water quality parameters.

The maps can be compared with large scale assessments of analogous parameters, derived from SeaWiFS data, to place the local results obtained from the Landsat 7 ETM+ into a regional perspective

This information, still to be evaluated at seasonal and interannual scales in future studies, will be used to start a national database on water quality for the Lebanese coastal environment

Reference

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Thank you for your attention