Satellite Analysis of Environmental Changes in the Golden Horn*

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ABSTRACT

This paper describes the first results of pollution evaluation in the Golden Horn, Istanbul by means of satellite techniques. The parameters studied are suspended sediments (SS), dissolved oxygen and turbidity. The Landsat MSS and TM spectral bands 2, 3 and 4 have been used and the digital data compared with the ground truth. There is reasonable correspondence between the satellite and ground truth data.

1. INTRODUCTION

The Golden Horn is an offshoot of the Bosphorus Strait that links the Black Sea with the Marmara Sea, which is eventually connected to the Mediterranean Sea. It is, therefore, one of the most important regions of the world for environmental study, since it affords investigation of air-sea interaction in two major seas of the world. Also, because of the fact that a major city *viz.*, Istanbul is situated along this strait, it would further facilitate investigation of the formation of urban heat islands. Since the Golden Horn penetrates right into the heart of Istanbul, this has been engaging the attention of researchers in this region for quite some time. During the 60s and 70s, the Golden Horn was highly polluted because of effluents from the factories as well as domestic discharges into the Horn and the Strait. Thereafter, consequent to the sustained efforts of the government in removing the industries from the urban areas, the pollution in the Horn is greatly under control.

In order to study the environmental degradation in the Horn during the past two decades, Landsat MSS and TM data have been used. Image analysis has been performed using the I^2S image processing system on Sun Sparc II workstation. The image processing techniques such as image enhancement, classification, filtering and scaling have been used. This paper has compared the extrapolated ground truth values of SS, dissolved oxygen and turbidity at different locations of the Horn with the pixel

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values obtained from satellite imageries for the years 1975 (Landsat MSS), and 1990 (Landsat TM). Unsupervised classification techniques have been applied to detect highly polluted areas by means of extrapolated ground truth as well as satellite data.

Satellite remote sensing provides an alternative means for obtaining relatively low-cost, simultaneous information on surface water conditions from the Golden Horn as well as the entire Istanbul Strait. Preliminary examination of Landsat TM data have indicated that different bands have potential for use in analysis of water quality parameters identified before. Results suggest that remote sensing from space-based platforms can provide meaningful information on water quality variability. Observations of SS, dissolved oxygen and turbidity can provide quantitative information concerning water quality conditions and can be used in various numerical schemes to characterize the trophic state of an aquatic ecosystem. *In situ* measurements of water quality characteristics tend to be limited, especially in the temporal and spatial domains, because of the costs associated with data collection and laboratory analyses. Natarajan and Kurar (1994) have given a detailed analysis of various water quality parameters in the Ömerli Lake using Landsat specral data. Kurar and Natarajan (1994) have studied the suspended sediment concentration using Landsat spectral data.

This paper presents preliminary results of water quality analysis of the Golden Horn. This work would also provide a basis for environmental regulation of the Golden Horn area, which constitutes the life-line of the entire Istanbul population, as also, greater understanding of ecology, biology and dynamics in this region. Figure 1 shows the study area.

2. RESEARCH METHODOLOGY

The research methodology for SS evaluation consists of:

* Acquisition of water quality samples using Landsat MSS and TM imageries.
* Extraction of digital numbers from the relevant spectral bands.
* Examination of color-coded images, each depicting the generic water quality distribution for different spectral bands.
* Comparison of the digital values of water quality parameters as obtained from spectral data with the extrapolated ground truth values.

Landsat MSS and TM bands 2, 3, and 4 are used for spectral investigation of water quality parameters. The minimum, maximum and average values of the water quality data have been taken from Artüz and Korkmaz (1977). These have formed the basis for the ground truth data based on linear extrapolation. The actual ground truth data at different sample sites are being collected and compiled, and further research is in progress. The study is limited by the availability of a large number of ground truth data across wide-spread locations of the Golden Horn at different times in the past. The spectral bands used are shown in Tables 1 and 2. (Here, b.w. = width of the wavelength channel; c.w. = center of wavelength channel; nm = nanometer).

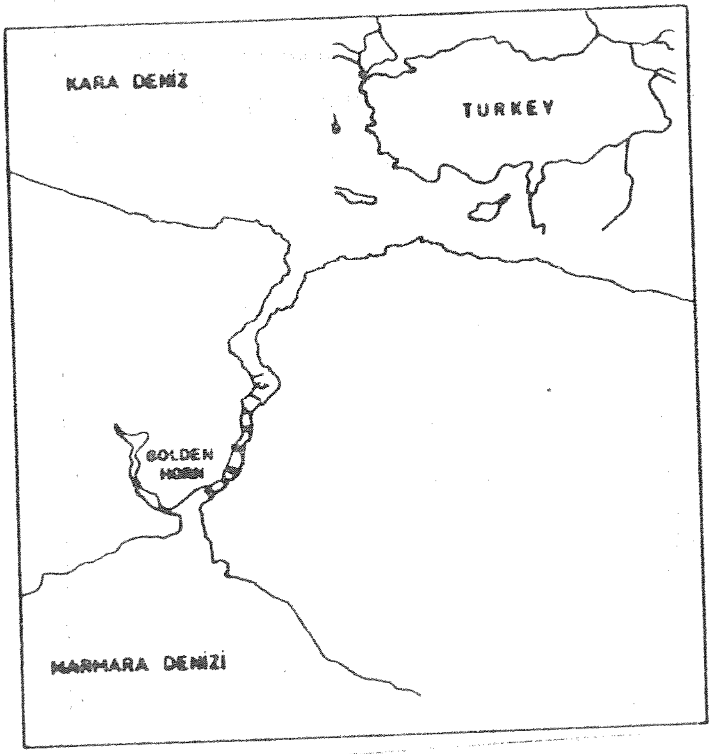

Fig. 1 (a): Location of Golden Horn

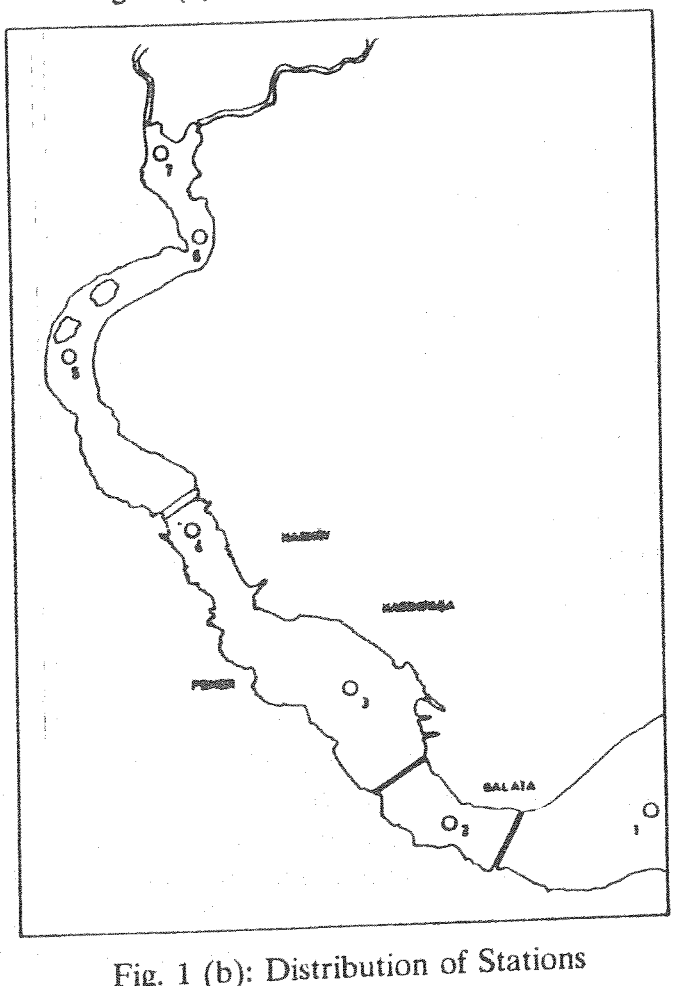

Fig. 1 (b): Distribution of Stations

Fig. 1. The Study Area

Table 1 : Details of Landsat TM Spectrum Used for the Investigation

TM Band no.	Band region	Band range (μm)	b.w. (nm)	c.w. (nm)
TM 2	green	0.52-0.60	80	560
TM 3	red	0.63-0.69	60	660
TM 4	near-infrared	0.76-0.90	140	830

Table 2 : Details of Landsat MSS Spectrum Used for the Investigation

MSS Band no.	Band region	Band range (μm)	b.w. (nm)	c.w. (nm)
MSS 2	red	0.60-0.70	100	650
MSS 3	near-infrared	0.70-0.80	100	750
MSS 4	near-infrared	0.80-1.10	300	950

3. RESULTS AND DISCUSSIONS

In order to study the water quality parameters, Landsat pixel values have been obtained for two different occasions, *viz.*, 1975 and 1990. For 1975, Landsat MSS spectral data have been studied for the bands 2, 3, and 4. For 1990, Landsat TM spectral data have been studied. The spectral data have been compared with the ground truth data for all the 7 stations along the Golden Horn. The locations of these stations have been so chosen as to represent fairly uniform spatial distribution. Table 3 summarizes the digital values of MSS as well as TM reflectances for all the 7 stations.

Preliminary analysis of the data suggests that the pixel values of MSS 3 and 4 spectral bands are in great agreement, as seen in Figure 2. The MSS 1 band however, shows some variation for stations 2, 3 and 4, though, for other stations, the data are in harmony with MSS 3 and 4 bands. The Landsat TM bands 2, 3 and 4 show overall agreement in terms of digital values, as shown in Figure 3. The ground truth values for all the stations are shown in Figure 4.

These data need to be correlated with the ground truth values, and the results will be reported separately. To facilitate this, radiance values may have to be used, rather than the pixel values. Reddy (1993) has given an account of investigating SS in Krishna Bay estuary of India, for which he resorted to radiance values, using the equation given by Robinove (1982). Previous research has also demonstrated that exoamospheric reflectance, calculated by correcting the satellite data for differences in sensor characteristics and sun elevation angle, can provide better explanation of the SS concentration; i.e., higher coefficients of determination when compared with either

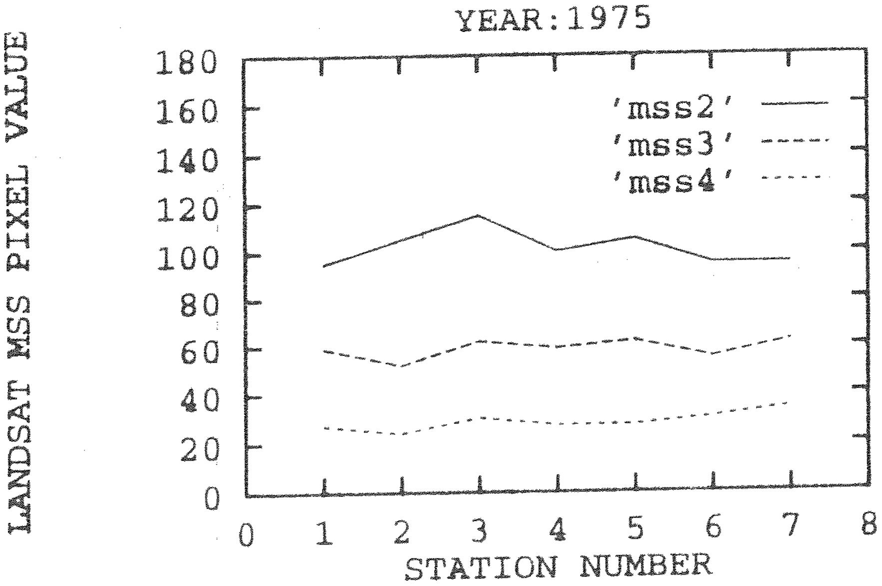

Fig. 2. Landsat MSS Pixel Values for Bands 2, 3, and 4.

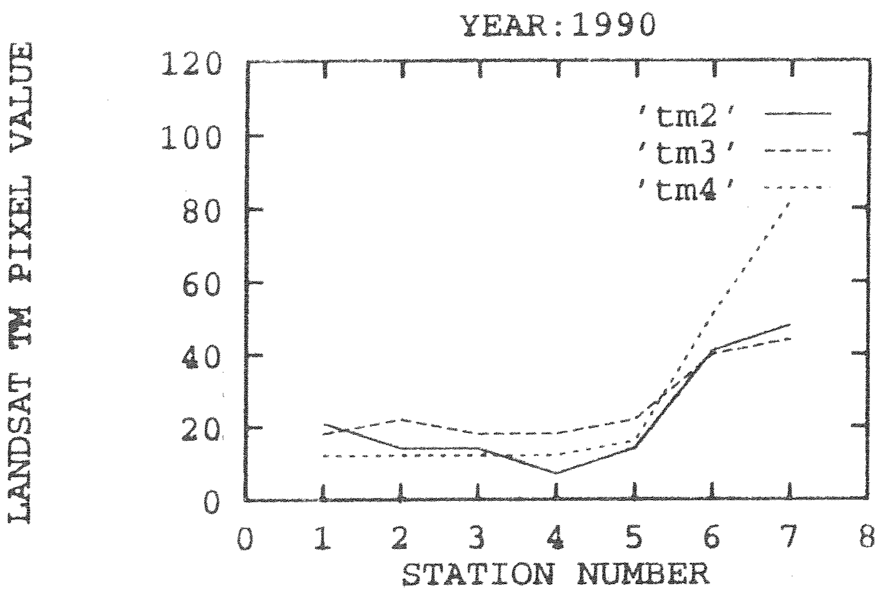

Fig. 3. Landsat TM Spectral Values for Bands 2, 3, and 4

radiance or raw digital numbers. Thus, in principle, Landsat data transformed to exoatmospheric reflectance should preferably be used in the analysis of this study. Simple linear regression techniques can be used to analyze the relationship between the water quality parameters and exoatmospheric reflectance, as suggested in previous studies, for instance, by Lyon *et al.* (1988); Ritchie *et al.* (1987); and Shih and Gervin (1980). In addition, simple linear regression has to be performed following a natural logarithmic transform of both variables. Finally, an optimized curve-fitting technique (DeCoursey and Snyder, 1969) based on the use of an exponential relationship between water quality parameters and exoatmospheric reflectance will be relevant. Theoretical considerations involving Beer's law should also be used in accordance with the procedures explained in detail by Harrington, Jr. *et al.* (1992). Here, the accent is on atmospheric path radiance attributable to Rayleigh and Mie scattering with the reflectance from clear water, considering the atmospheric path reflectance and saturation reflectance values. Though the present investigation has considered only the digital values as obtained from different Landsat spectral data, further research is in progress at Marmara Research Center on the above lines considering the exoatmospheric reflectance and radiance values as well.

Table 3. Landsat MSS (1975) and TM (1990) Spectral Data

Station no.	MSS 2	MSS 3	MSS 4	TM 2	TM 3	TM 4
1	95	59	27	21	18	12
2	105	52	24	14	18	12
3	115	62	30	14	18	12
4	100	59	27	7	18	12
5	105	62	27	14	22	16
6	95	55	30	41	40	51
7	95	62	34	48	44	82

4. LIMITATIONS OF THE STUDY

(a). A proper evaluation of water quality parameters requires reliable ground truth data. Systematic records of water quality in the temporal and spatial domains are not available in this regard, imposing serious constraints on water quality research. However, some are indeed available in isolated cases, and one has no option but to use these limited data, and extrapolate them temporally and spatially.

(b). While satellite tapes are cost-effective in relation to *in situ* measurements, Landsat tapes, by themselves are expensive from the point of view of the developing nations. Whereas, some tapes are available in Turkey, maintaining an up-to-date archive of Landsat tapes is prohibitively expensive for most of the developing nations. In such a scenario, investigation is possible only by using the available tapes, rather than the actual one appropriate for a particular situation. This procedure gives rise to inevitable inaccuracies in data collection and interpretation.

(c). Digital numbers for all the stations have been extracted for the single pixel. It will be more appropriate to extract these values from an n-pixel-block, say nine-pixel-block encompassing the center pixel corresponding to each sample site. It is necessary to carry out investigation using single-pixel values and kernel (block) averages to verify that kernels represent spectrally uniform areas. For instance, if a site is close to a rock jetty, there may be sustantial deviation between single-pixel and kernel average values.

5. ACKNOWLEDGMENT

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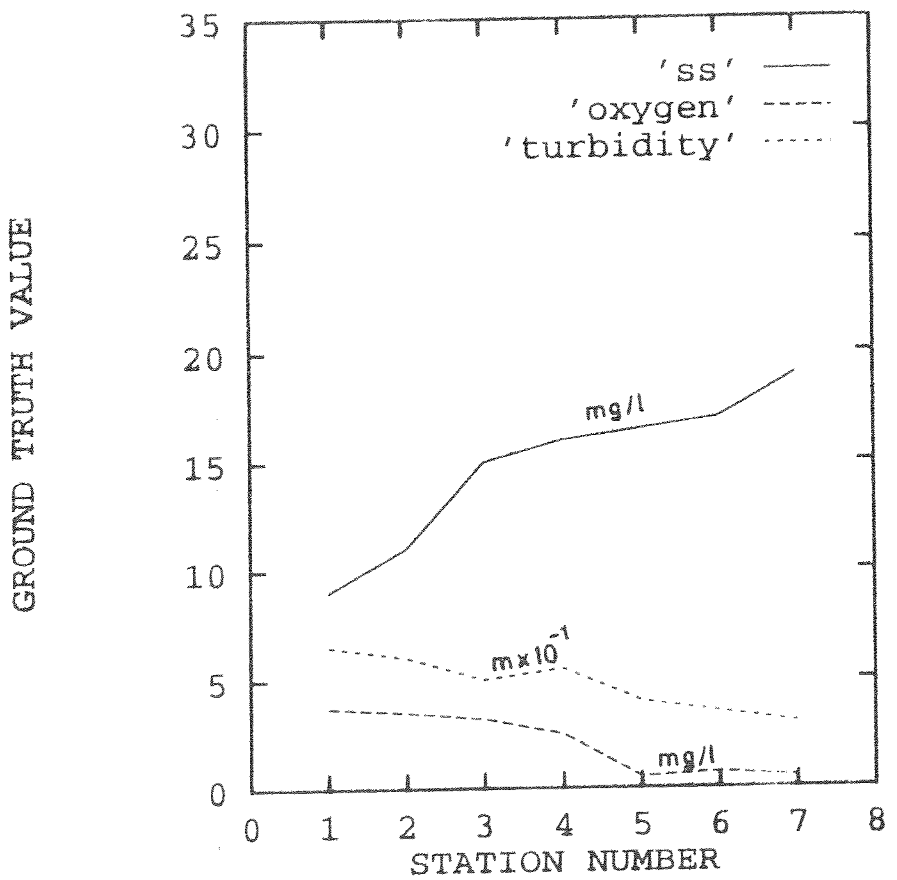

Fig. 4. Ground Truth Values for Different Stations