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MARINE POLLUTION MONITORING AT LYARI RIVER OUTFALL USING SATELLITE REMOTE SENSING

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ABSTRACT

In this study Landsat TM data was employed to ascertain the water quality of marine water at Lyari River outfall. Lyari River is a seasonal river and main sewage carrier, it is one of the sources of water pollution at Karachi port area. In the present study multiple regression algorithms were derived through multi-spectral data acquired from Landsat TM sensor and the sea truth data collected at different pre-designated sites. Water quality parameters ascertained at different locations included turbidity, total suspended solids and biochemical oxygen demand. The algorithm used was based on exo-atmospheric reflectance in different spectral bands. A window of 3x3 pixels was selected coinciding with the sea truth locations and the mean of digital numbers from these pixels were utilized to calculate volumetric radiance and reflectance. During the calculation of reflectance solar zenith angle taken from meta-data provided with the satellite image and earth to sun distance based on Julian days were used. The efficiency of models was evaluated using Karl Pearson's coefficient of correlation and maps were generated employing calibrated algorithms of water quality parameters.

Key-words: Marine pollution, Lyari river, TM sensor, Remote sensing

INTRODUCTION

The coast of Pakistan is rich in marine resources like estuaries, creeks, bays, peninsulas, islands and river outfalls. Due to this variety of physical features Pakistan is characterized with both floral and faunal diversity in coastal regions. Karachi, which is the largest city of Pakistan and also included in the mega cities of the world, is located at the coastal area of Sindh, Pakistan. The coastal zone of Karachi is extended up to 135 km that contains outfalls of two major rivers Lyari River and Malir River (Munshi *et al.*, 2004). Karachi is a hub of industrial activities and due to unavailability of specially designed sewage drains, the two Rivers are exposed to heavy pollution load of both domestic and industrial origin. Lyari River receives major portion of direct untreated sewage and industrial effluents as it passes through the urban settlements and major industrial areas (Sindh. Industrial Estate, Karachi) and finally finds its way to the sea at Machar Colony near Karachi Fisheries (Khan *et al.*, 1999).

Extremely high levels of pollutants such as solid waste, BOD (biochemical oxygen demand) and COD (chemical oxygen demand) have been reported, especially in the coastal waters and in the sea at Karachi coast (Shahzad *et al.*, 2009; Khan and Khan, 2001). Expectedly, these toxicants have perilous impact on the marine biodiversity and fish-eating birds and the related food chains. The impact of these pollutants on commercial fin-fish and shrimp fisheries are unknown, but likely to be significant (WWF, IUCN and GOP, 2000). In addition to that high levels of suspended solids reduce the light penetration into the marine ecosystem which eventually leads the marine ecosystem to hypertrophic situation. The same situation prevails with the outfall of ecosystem situated in front of Karachi fisheries, due to continuous disposal of untreated effluents from Lyari River; the area is now in hypertrophic situation (Khan and Khan, 2001).

The issues of water quality deterioration,that are of worldwide occurrence, have received increasing consideration from various countries and their governments. Thus many studies have been conducted on water quality and trophic state assessment in various parts of the globe (Brezonik *et al.*, 2005; Ritchie, 2003; Iwashita *et al.*, 2004). The marine ecosystem at Lyari river outfall has become so contaminated and fouled that it needs immediate notice from the concerned authorities to avoid further devastation of coastal ecosystem and consequently the marine food chains.

Sampling extensive areas of water bodies for quality determination using field sampling procedure is not only inefficient but also often prohibitively costly and usually not representative. Spectral radiance measurements obtained by satellite remote sensing techniques can yield synchronized data in a time efficient manner for assessing the water quality parameters of different types of water bodies (Zibordi *et al.*, 2006). Such information can be employed for the management of water quality as well as the monitoring of water pollution and the modeling of pollutant distribution in aquatic environments (Catts *et al.*, 1985).

The present investigation aims at the development of models by using satellite derived reflectance in different spectral bands to ascertain marine water quality parameters so as to determine the extent of pollution load at marine ecosystem in front of Karachi fisheries which is responsible for its degradation.

MATERIAL AND METHODS

Study area

Lyari River outfall is located at 24^0 $52^/$ $04^{//}$ Lat and 66^0 $58^/$ $23^{//}$ long, its receiving water body lies between Manora (peninsula) and Kemari Harbour and has a total area of 1.761 km^2. The water at the outfall of Lyari River is brackish in nature with salinity levels between 1.1 to 2.9 %. Due to industrial discharges via Lyari River, the estuary is now facing severe water pollution and has high levels of suspended solids, biochemical and chemical oxygen demands.

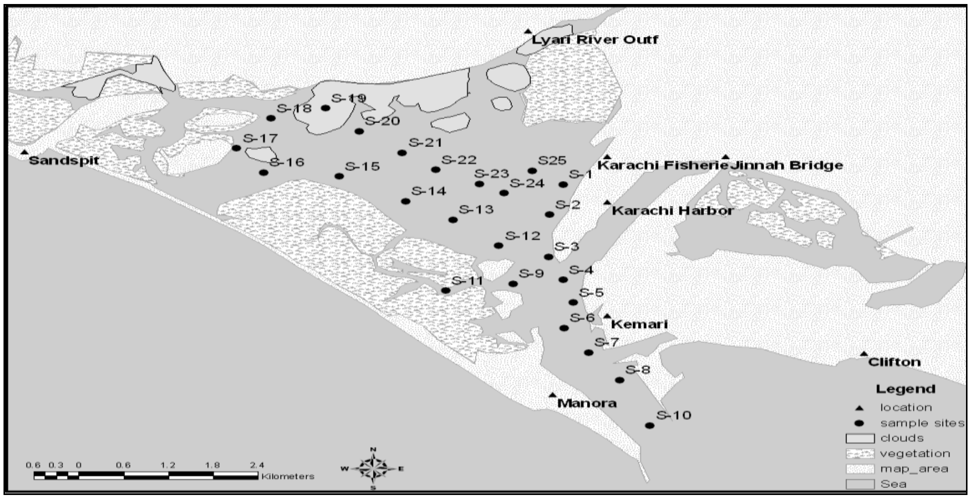

Fig. 1. Study area showing sampling sites.

In situ data

In this study, altogether 25 samples were collected at low tide from the surface layer of the water body that receives effluent from Lyari River (Fig 1) on 19 Aug, 2010 at 1.30 pm that is synchronous to the satellite acquisition time. At the time of collection, pH, turbidity and temperature were determined and subsequently samples were brought to Institute of Environmental Studies, University of Karachi for the assessment of total suspended solids and biochemical oxygen demand. BOD was determined on the day of collection of samples and for total suspended solids analysis the samples were kept at 4^0C after adding 2 ml conc. H_2SO_4/L. The methods chosen for the analysis were those outlined by APHA (1992).

1. TSS was determined by gravimetric analysis in which pre-measured volume of sample was passed through pre-weighed membrane of cellulose acetate. The membrane was then put into dry heat oven at 103-105^{o}C and then weighed. Difference in weight showed TSS level in the sample (APHA, 1992).
2. Turbidity was ascertained by using EUTEC-TN 100 turbidity meter.
3. BOD_5 was measured using 300-ml Winkler bottles. The dissolved oxygen was determined before and after incubating the sample, after appropriate dilution, at 20^{o}C for 5 days. Alkali-azide modification method was used to ascertain BOD_5 (APHA, 1992).

Satellite data and Atmospheric correction

There is spatio-temporal variation in atmospheric conditions which is because of absorption and scattering due to molecules present in the atmosphere. The atmosphere has selective scattering characteristics; that is, different wavelengths have various atmospheric influences on TM images. In this study, post monsoon Landsat TM image was utilized (Table 1).

Table 1. Image specification of Landsat TM data.

S.No	Acquisition date	No. of Bands	Spatial resolution	Scene No.	Sun Elevation
1	19 Aug, 2010	7	30m	152-43	62.3385363

To remove disturbances by the atmosphere digital numbers (DN) are converted to at-satellite radiance based on the gain (L_{max}) and bias (L_{min}) for each band (Markham and Barker, 1986), which were provided from image header file.

$$L_{\lambda sensor} = ((L_{max} - L_{min}) / Q_{calmax}) * Q_{cal} + L_{min}$$

Where,

$L_{\lambda sensor}$: Spectral radiance in W/(m^2.sr. µm)

Q_{cal} : Digital Number (DN)

Q_{calmax} : Maximum grey value (DN=255) equivalent to L_{max} (on 8 bit satellite data)

L_{min} : The spectral radiance scaled to Qcalmin in W/(m^2.sr. µm)

L_{max} : The spectral radiance scaled to Qcalmax in W/(m^2.sr. µm)

When light passes through atmosphere it interacts with the atmosphere and results in atmospheric attenuation. Conversion of at-satellite radiance into surface reflectance reduces the atmospheric effect from satellite data. The atmospheric reflectance of the Earth is computed according to:

$$\rho_p = \frac{\pi \times L\lambda \times D^2}{E_{SUN\lambda} \times \cos(\theta_{zenith})}$$

ρ_p : Planetary reflectance (unitless)

L_λ : Spectral radiance at the sensor's aperture

D : Earth-Sun distance (astronomical units)

$E_{SUN\lambda}$: Mean solar exoatmospheric irradiances

θ_{zenith} : Solar zenith angle in degrees

RESULTS AND DISCUSSION

Derivation of reflectance data from TM images

Each sample collection site was positioned with respect to longitude and latitude using GPS (Global Position System) handheld device by Triton Magellan 400 having an error of ± 3 meter. With the help of GCPs each sampling site was located on the satellite image and the corresponding atmospherically corrected reflectance data were derived. Due to possible influence of the ambient environment of the water (hydraulic changes), Landsat-5 TM data across the area of interest were influenced by sun glint and sensor's errors. It was therefore found reasonable to use a window of 3x3 pixels to improve the signal-to-noise ratio. Taking the fact into consideration, an averaging window of 3x3 pixels was chosen to compute regression equations in this study (Brivio *et al.*, 2001)

Regression Model Development

To derive the models for the extraction of marine pollution data the most commonly used approach is multiple regression analysis. Multiple regression analysis is a good technique to develop correlation structure between water quality and spectral data acquired in visible and infrared wavelengths bands (Yunpeng Wang, 2004). These techniques were adopted in this study. Based on the correlation analysis between turbidity, total suspended solids and biochemical oxygen demand and various spectral bands and band combinations, the multiple regression analysis was performed using 24 observations of each parameter instead of using 25 observation because the 19th sampling site was under cloud cover on the image, so during the development of model, values of the site 19 were omitted. Finaly to assess the goodness of fit of the regression models, MR (multiple correlation), p-values and standard error of the estimate (S.E) were computed.

Model of Biochemical oxygen demand

$\text{Log BOD} = 6.5174 - 30.5189 * \rho_1 - 10.0285 * \rho_2 - 23.2220 * \rho_5 + 25.0576 * \rho_7$
$MR = 0.8724$, $p < 0.003186$, $S.E. = 0.07013$

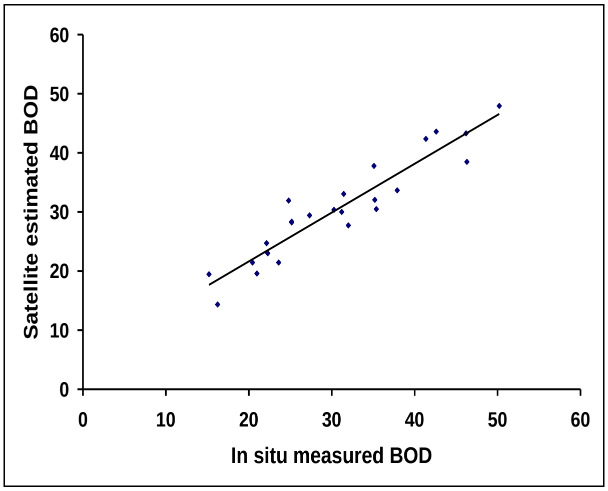

Fig. 2. Linear regression of satellite estimated BOD vs. in situ measured BOD of water in four TM bands.

Model of Turbidity

$\text{Log turbidity} = 7.5134 + 6.5645 * \rho_1 - 60.1681 * \rho_2 - 75.4867 * \rho_1 * \rho_3$
$MR = 0.75$, $p < 0.046$, $S.E. = 0.20708$

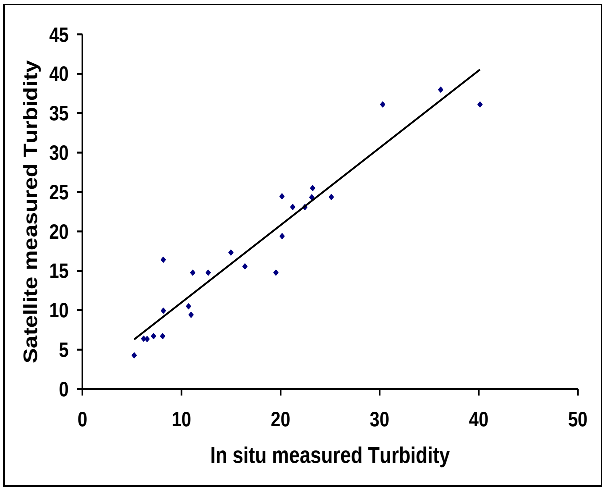

Fig. 3. Linear regression of satellite estimated Turbidity vs. in situ measured Turbidity of water in three TM bands.

Model of Total suspended solids

$\text{Ln TSS} = 22.1661 - 69.4264 * \rho_1 - 55.0293 * \rho_2 - 1.7692 * \rho_4 / \rho_3$
$MR = 0.69$, $p < 0.0309$, $S.E. = 0.33497$

Furthermore, scatter plots were used to compare the *in situ* measured reflectance and satellite estimated reflectance of water in 24 sites (Fig. 2 - 4). The results reveal that the estimated values are close to the measured values; in general, a good fit was obtained (Fig. 2 - 4).

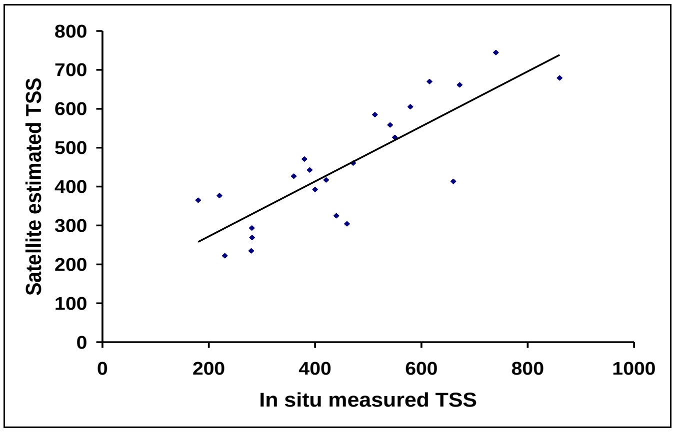

Fig. 4. Linear regression of satellite estimated TSS vs. *in situ* measured TSS of water in four TM bands.

Finally density-sliced maps (Fig. 5 - 7) of the study area for turbidity, total suspended solids and biochemical oxygen demand were produced using the respective models incorporating the estimated parameters. Using these maps one could easily understand that the water body at the outfall of Lyari River has become grossly contaminated with effluents of both industrial and domestic origin. The maps clearly show that the concentration of tested water quality parameters is considerably high near the outfall while the concentration gradually decreases as we proceed further from the outfall site.

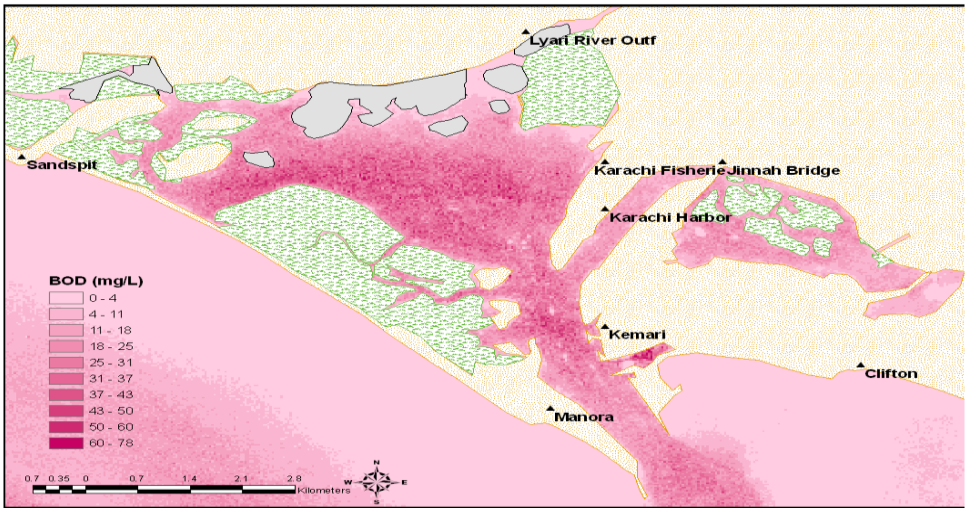

Fig 5. Model derived density-sliced map of BOD.

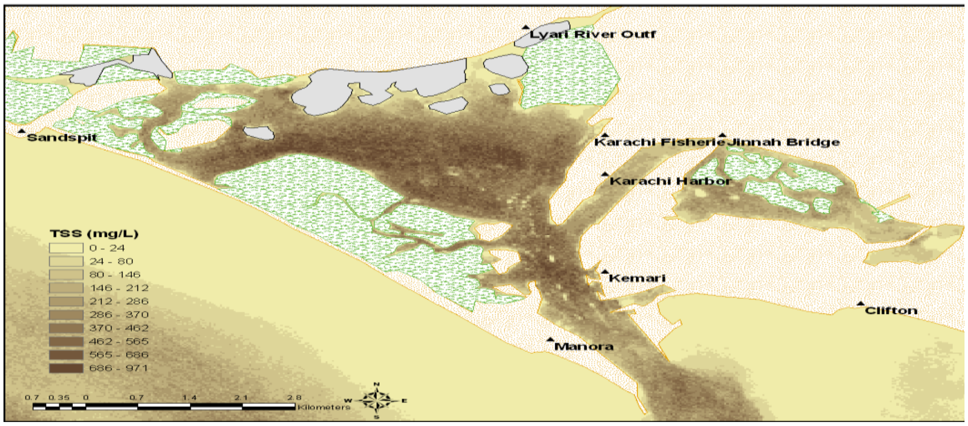

Fig 6. Model derived density-sliced map of TSS.

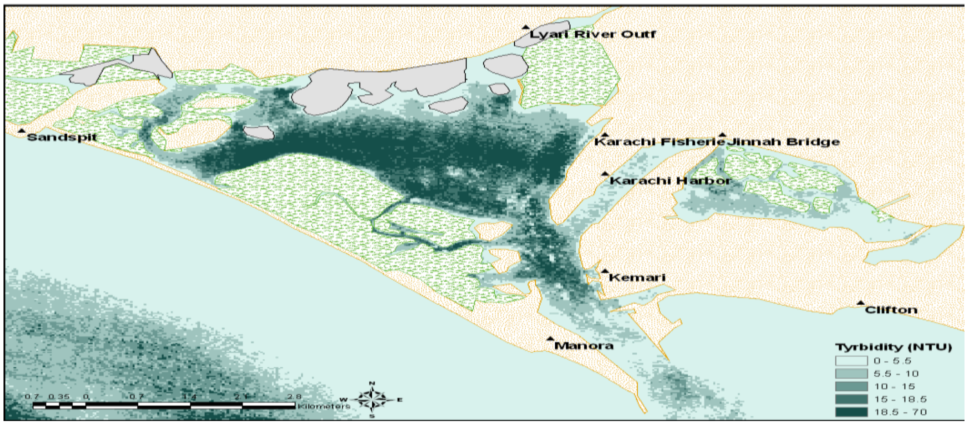

Fig 7. Model derived density-sliced map of Turbidity.

CONCLUSION

Remote sensing provides an efficient means of generating much needed environmental data. Since extensive sampling has practical limitation because of cost and time constraints. A smaller sample size could readily be used to generate predictive models employing the reflectance data and maps of the measured characteristics responding to reflectance for the required area can be derived with sufficient accuracy.

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