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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 11 (5): 711-718, 2008
ISSN 1028-8880

Estimation of Water Turbidity in Gorgan Bay, South-East of Caspian Sea by Using IRS-LISS-III Images

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Abstract: In this research, usefulness of IRS-LISS-III data of Gorgan Bay, South-east of Caspian Sea located in North of Iran for water turbidity mapping, has been tested. After correction of geometric and radiometric errors, the resulting radiance data were used for examination of correlations between the remotely sensed and *in situ* water turbidity data simultaneously measured by the Secchi depth approach. Results of this research showed good relations between the Secchi depth and spectral data. The fitted statistical model was very significant (R^2 = 0.77) and test of the model performance by independent samples was encouraging. Because of the low costs encountered with acquisition and processing of remotely sensed data, further research in larger scales for the purpose of more precise test of the approach for water turbidity mapping and monitoring is recommended

Key words: Water quality, water turbidity monitoring, remote sensing, Gorgan Bay, Caspian sea

INTRODUCTION

Because of being exposed to a wide range of pollution sources, information about the water quality, particularly its turbidity plays a key role for monitoring of the Caspian Sea Environment. Water turbidity is regarded as one of the most important water quality indices for coastal and estuarine waters. Turbidity is one of the primary influencing factors of light attenuation, productivity and biomass distribution in water column (Kirk, 1994; Cole and Cloern, 1987; Fisher *et al*., 1999; Pennock and Sharp, 1994) and as well as on benthic habitats such as seagrass and coral reef (Anthony *et al*., 2004; Moore *et al*., 1997). In coastal waters, turbidity is frequently associated with concentrations of total suspended solids or sediments (TSS). Therefore, acquisition of reliable and timely data of water quality is of prime importance for many organizations, environmental managers, industries and fishery departments. Mapping of turbidity distribution and its variability provided by remotely sensed data, can play a key role for understanding of sediment transport processes and the associated pollutants (Heyes *et al*., 2004).

Evaluation of the waters quality by field-based sampling, can be very expensive and time consuming. Also, because of the high spatial variability, results of these studies may not be a good representative of the whole study area.

Acquisition of regular and continuous information in varying scales, by remote sensing instruments, provides unique advantages. However, because of the complexities of ecosystems and interactions between the terrestrial and water environments in coastal environments, calibration by filed measurements is considered as an important component of water mapping processes by remote sensing.

In recent years, many works have been published about applications of remote sensing for water quality studies. Relations between the Secchi depth measurements and data of CASI and CAESAR sensors have been examined by Dekker (1993). Significant correlations have been observed between the water turbidity and radiance of image bands in 676 and 705 nm and exponential functions have been proposed for relating the water turbidity to radiance in different image bands. In their study of water quality in Ta-Chia River in

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China, Yang and Sykes (1996) concluded that the three spectral channels of SPOT XS data (XS_1, XS_2, XS_3) are useful for monitoring of water quality changes. Based on these findings, indices have been proposed for remotely sensed estimation of Chlorophyll a and phosphorus. Aghighi (2003) studied the water turbidity in part of the Caspian Sea coastal water and observed that MODIS data provides promising capabilities for estimation of the water turbidity. Because of their influence on light penetration in water and change of the Secchi depth, suspended solids and Chlorophyll can be underlined as effective parameters on water turbidity estimation by Secchi depth.

Significant and positive relations between the suspended particles in coastal waters and visible and NIR reflectance values of IRS-LISS and TM data have been shown by Zeaiean Firouzabadi *et al.* (1996). Usefulness of different sources of remote sensing instruments such as SPOT (Lathrop *et al*., 1991), AVHRR (Vos and Schuttelaar, 1995), MSS (Stumpf and Pennock, 1991), TM (Lathrop *et al*., 1991; Xia, 1993; Lillesand, 2001; Ritchie, 1990; Abdullah *et al*., 2000) and CZCS (Morel, 1980; Sturm, 1982; Bricaud and Morel, 1987) for quantification of water quality parameters have been demonstrated in many studies. Diversity of models provided by different researchers in different regions demonstrates the fact that usefulness of most models are limited to local situations and calibration of models for special geographic places is an important requirement.

Regular acquisition of IRS data in Iran, provides valuable opportunities for examination of the practical values of these data for different applications. In this study, utilities of IRS-LISS-III data for water turbidity estimation by Secchi depth in Gorgan Bay located in south-east of Caspian Sea have been evaluated.

MATERIALS AND METHODS

Study area: The study area is Gorgan Bay, located in south-east of the Caspian Sea within longitude of 53°: 23′:27" to 54°: 03′:17" and latitude of 36°: 46′:21" to 36°: 54′:52" (Fig. 1).

Processing of satellite data: LISS-IIII sensor captures images in the visible and near infrared wavelengths and therefore it is suitable for study of surface waters. Time profiles of the satellites pass above the study area was defined and atmospheric conditions were acquired from the National Meteorology Organization and Gorgan Meteorology Office for June 8, 2003. The sky was predicted to be clear and without clouds, therefore filed sampling was planned in the region simultaneously as the satellite crossed over the horizon.

The acquired images were corrected for geometric and radiometric errors by using the orbital information and calibration coefficients. With regard to spatial resolution of the IRS data (23 m), topographic maps of 1/25000 scale were used for geometric correction.

In addition, data of the sun altitude and azimuth angle, satellite and sun zenith angles, were extracted from the image file header and were used for atmospheric correction of satellite data by using the ATCOR model.

Field methods: The secchi disk is s round disk first innovated and used by Fr. Pietro Angelo Secchi for measuring the water transparency in the Mediterranean Sea on April 20 1865 (Carlson, 1995). Because of the

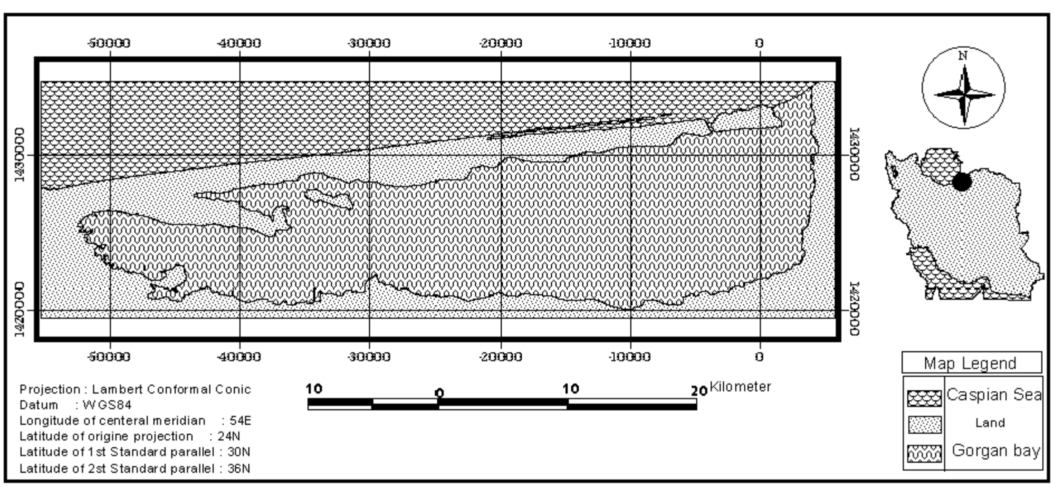

Fig. 1: Map of the study area

budget limitations, the required secchi depths were constructed during the research. Standard shape and form of this device were extracted from the related sources. Circles of 20 mm diameter out of metal pieces with 4 mm thickness (Carlson, 1995) were cut and a handle was inserted in the center for attaching the rope. Also the surface was pierced 27 times with holes of 10 mm diameter scattered along the surface evenly in order to facilitate its penetration into the water. Afterwards each disk was divided into 4 equal sectors and each of two opposite sectors were painted as black and white (Fig. 2).

Two Garmin eTrex hand-held GPS receivers were used to record the geographical positions of the sampled points.

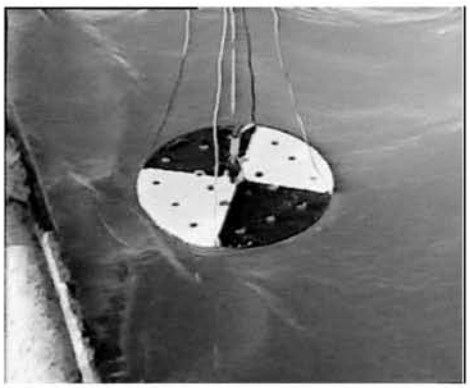

Fig. 2: The constructed Secchi disk for turbidity measurement in the research

Sampling: High variability of water sediment rates in different places of Gorgan Bay, reinforces the need for more intensive sampling than what can be normally expected. Therefore, for the purpose of representing and including different ranges of turbidity in the field sampling phase, suitability of different sampling schemes were examined by consideration of the variability of water turbidity in the study region

Visual examination of the satellite data showed that Gorgan River is the major source of high sediment loads and the resulting turbidity in the area. As a result, turbidity shows a significant decreasing trend as a function of increased distance from the river bed. For better representation of turbidity variation in the area, this pattern of turbidity distribution was considered. By using the systematic-random selection approach, 42 samples were selected so as to include samples of high (river beds) to low turbidity. The operation was performed in a 4 h time span with a reasonable overlap with the time of IRS Sensor Satellite pass over the area for June 8, 2003. Spatial distribution of these samples is shown in Fig. 3. In addition to secchi depth, location of all samples were recorded and the resulting data were entered in a geographical information system for analysis and modeling.

Physical relations were used for correction of errors in secchi depth estimates resulting from refraction effects of light (Verschuur, 1997).

Modeling: Multivariate regression approaches were used for modeling relations between the secchi depth estimates

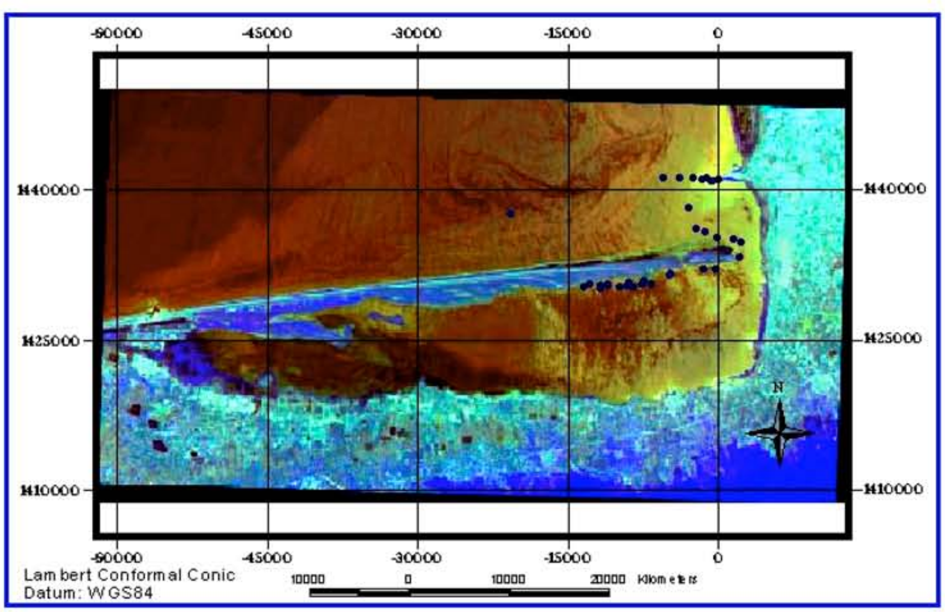

Fig. 3: Spatial distribution of secchi depth measurements (dark circles) in the study area

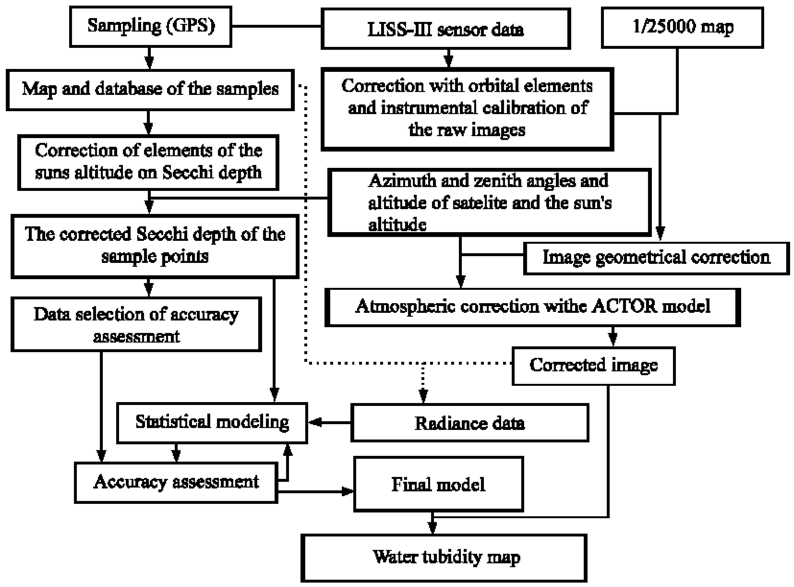

Fig. 4: Main stages of the research

and image-based radiance data. For the purpose of independent evaluation, 75% (32) of field samples were used for modeling and the remaining 25% (10) were used for validation of the resulting multivariate regression models (Niroomand, 2000; Abrishami and Mohammadi, 1995). Main stages of the research operations are shown in Fig. 4.

RESULTS

Statistical analysis: A summary of field measurements (*in situ* data) and spectral properties of 32 sample points in three bands of LISS-III are shown in Table 1.

Matrix of correlations between the radiance of three spectral bands of LISS-III and secchi depth values for 32 sample points are displayed in Table 2.

Because of the high correlations between the radiance of image bands and the secchi depths values, various mathematical-statistical models were examined and results of the three best fitted models are presented in Table 3.

As compared to others, model no one showed better performance, therefore, details of this model and results of variance analysis and test of significance are respectively provided in Table 4 and 5.

F-test (ratio of MS of regression to MS of errors) was used for the purpose of variance analysis. The tested hypothesis were as follow:

$$H_0 : \sigma_1^2 = \sigma_2^2$$
$$H_1 : \sigma_1^2 \neq \sigma_2^2$$

Table 1: Field measurements (in situ data) and spectral properties of 32 sample points in three bands of LISS-III

Variables	Band 1	Band 2	Band 3	Secchi depth *in situ* data
No. of points	32.00	32.00	32.00	32.00
Missing points	0.00	0.00	0.00	0.00
Maximum value	43.00	150.00	103.00	162.00
Minimum value	34.00	44.00	15.00	55.00
Range	9.00	106.00	88.00	107.00
Average	37.71	72.25	34.53	115.90
Standard deviation	2.12	25.25	16.97	29.50

Band 1, Band 2, Band 3 are radiance for LISS-III bands

Table 2: Correlation matrix between the spectral and secchi depth values for 32 sample points

	Band 1	Band 2	Band 3	*In situ* data
Band 1	1	0.723	0.685	-0.795
Band 2	0.723	1	0.940	-0.802
Band 3	0.685	0.940	1	-0.807
In situ data	-0.795	-0.802	-0.807	1

Band 1, Band 2, Band 3 are radiance for LISS-III bands and *in situ* data is Secchi depth *in situ* data

The expected value of F for probability level of 0.01 and freedom degrees of 3 and 28 equals 4.57 which is significantly smaller than the F in Table 5 (31.638),

$$F_c = 31.638 > F_{(3,28),0.01} = 4.57$$

Therefore the null hypothesis is rejected and H1 is accepted with a high confidence level of 99%.

Accuracy assessment: For closer test of the presented models in Table 3, they were used to produce water turbidity maps from the relevant radiance data. Then the calculated Secchi depth values of the check points

Table 3: Summarized results of the three fitted models between the image radiances and secchi depth values

Rank	Model	SE	Residual Sum	Residual Avg.	RSS	R^2	Ra^2	RMSE
1	exp(a*x1+b*x2+c*x3+d)	14.81	-0.13	-0.004	6148.52	0.77	0.75	132.57
2	a*x1+b*x2+c*x3+d	15.11	2.84217E-14	8.88178E-16	6397.33	0.76	0.74	188.57
3	a*x1+b*x2+c*x3	22.68	22.34	0.69	14922.44	0.45	0.41	474.84

RSS = Residual sum of squares, R^2 = Coefficient of multiple determination, Ra^2 = Adjust coefficient of multiple determination, RMSE = Root mean squared error

Table 4: Coefficients and statistical properties for the regression model of model 1 in Table 3

Variables	Value	SE	t-value	Prob(t)
a	-4.28188E-02	1.84946E-02	-2.31519	0.02815
b	4.05487E-04	3.66029E-03	0.11078	0.91258
c	-1.14570E-02	5.73079E-03	-1.99921	0.05538
d	6.70554	0.61725	10.86347	0.0

Table 5: Results of significance test for estimation of secchi depth by model no one

Source	df	Sum of squares	MS	F-ratio
Regression	3	20842.198	6947.399	31.638
Error	28	6148.521	219.590	
Total	31	26990.719		

MS = Mean Squares, df = degree of freedom

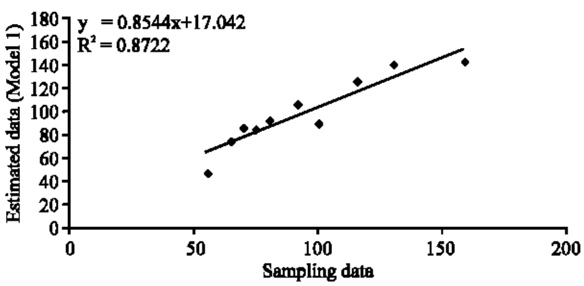

Fig. 5: Correlations between the measured and estimated secchi depth values by the model 1 in Table 3

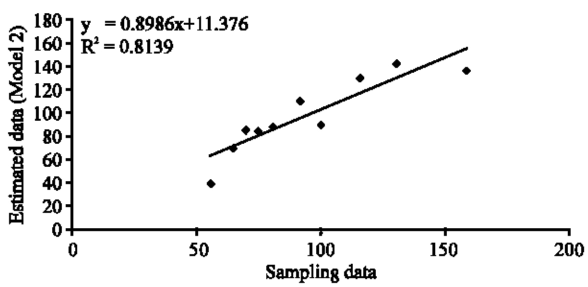

Fig. 6: Correlations between the measured and estimated secchi depth values by the model 2 in Table 3

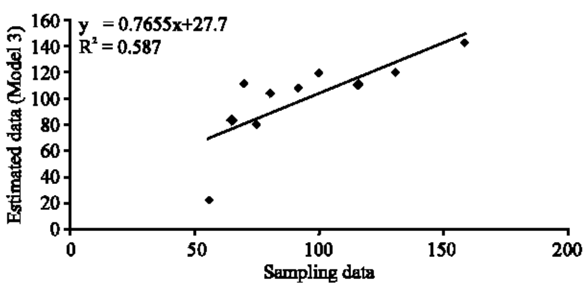

Fig. 7: Correlations between the measured and estimated secchi depth values by the model 3 in Table 3

were extracted for estimation of the accuracy. In the next stage then correlations between the measured and estimated data by the models were examined (Fig. 5-7).

DISCUSSION

The values of radiance in various bands show positive correlations with each other whereas the secchi depth values show negative correlations with the radiance values in all tested bands (Table 2). This implies that with an increase in the secchi depth values the radiance tends to decrease. The turbidity increases as a function of an increase in the suspended solids and sediments in the water. Therefore, depth of light penetration into the water decreases, resulting in the decrease of the secchi depth value which itself is an indicator of an increase in reflection values in high turbidity areas. This observation verifies the interpretation of the higher brightness levels in sedimentary beaches in the satellite images. As the values of radiance and secchi depth display a high correlation, it may be concluded that using all three bands or a combination of them can be useful in the modeling.

As compared to other models, model one show a higher R^2, Ra^2 and RMSE. Therefore, the selected model for estimating the water turbidity in Gorgan Gulf using LISS-III images would be:

$$SD_{(cm)} = \exp[(a * La_{band1}) + (b * La_{band2}) + (c * La_{band3}) + d] \quad (1)$$

The secchi depth map resulting from application of this model (Eq. 1) is shown in Fig. 8.

Significant correlations between the measured and estimated data were observed ($R^2 = 0.7222$). Errors of this estimation for different points were calculated and shown in Fig. 9.

Values of the measured and estimated secchi depths for validation samples, are shown in two separate graphs in Fig. 10. Where differences between the two lines and the points on the lines are indicators of errors for check points.

In Fig. 9 two points with measured secchi depths of 55 and 162 cm show high distances from the fitted line. These points are highlighted as numbers 2 and 8 in Fig. 10 and their secchi depth values are the minimum and maximum measured points. For the purpose of testing

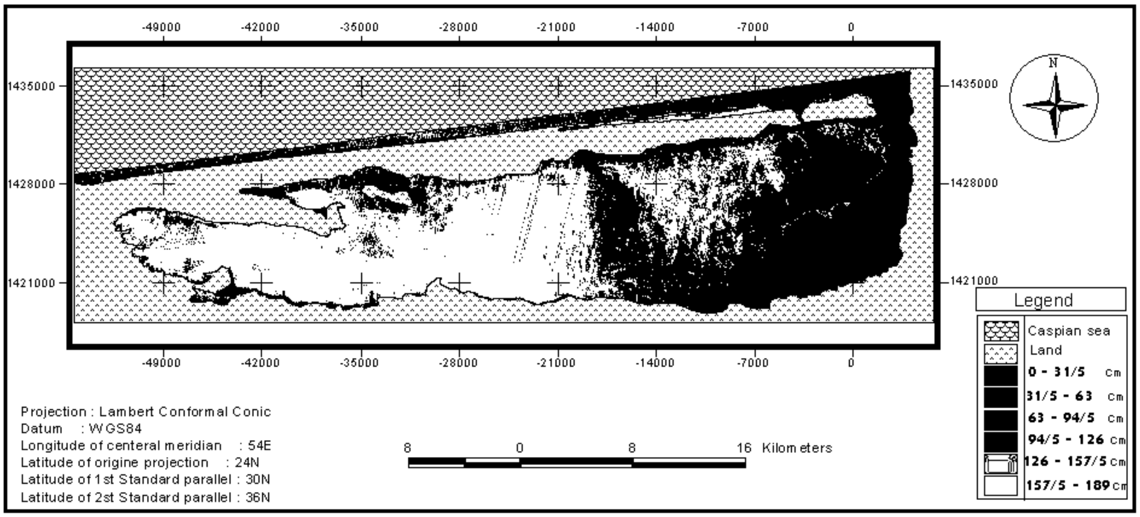

Fig. 8: The secchi depth map resulting from application of formula 1

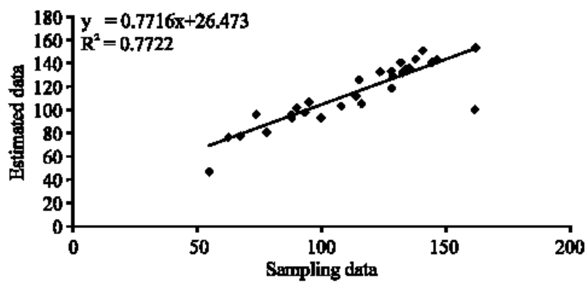

Fig. 9: Correlations between the measured (used in modeling) and estimated secchi depth values by Eq. 1

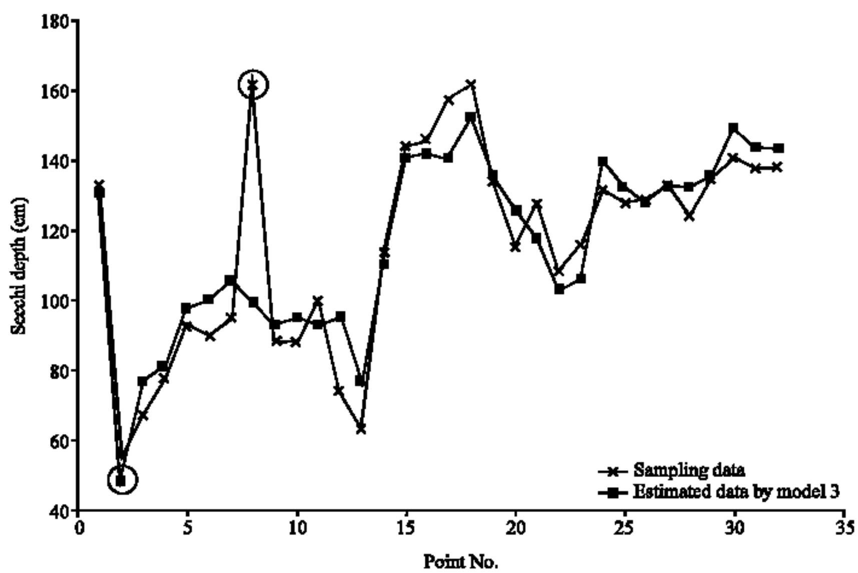

Fig. 10: Differences (errors) between the measured and calculated values by Eq. 1

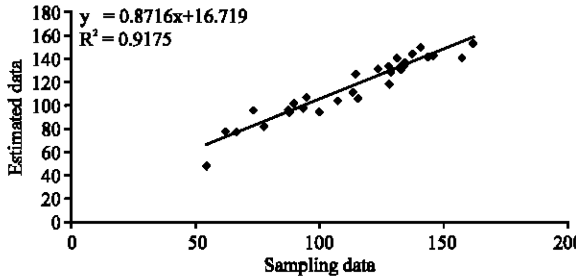

Fig. 11: Correlations between the measured and estimated secchi depth values by the formula one after removing point 8

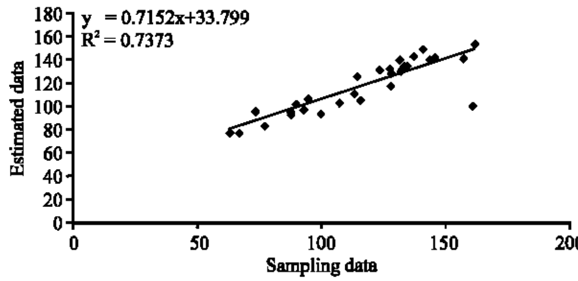

Fig. 12: Correlations between the measured and estimated secchi depth values by the formula one after removing point 2

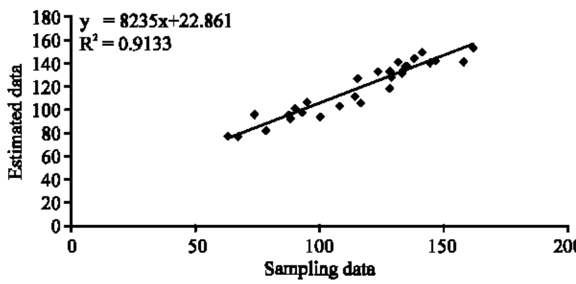

Fig. 13: Correlations between the measured and estimated secchi depth values by the formula one after removing both points 2 and 8

Table 6: The R^2 resulting from removing the minimum and maximum values

	All point	Without Min.	Without Max.	Without Min. and Max.
R^2	0.7722	0.7377	0.9175	0.9133
RMSE	132.5700	190.6600	69.6700	72.7300

limitations of the Secchi depth approach for turbidity estimation, effects of secchi depth on the reliability of estimated turbidity was evaluated by the following three tests:

- Removing point 8 which is the maximum value (Fig. 11).
- Removing point 2 which is the minimum value (Fig. 12).
- Removing points 2 and 8 which means omission of both the minimum and maximum values (Fig. 13).

Examination of the R^2 and RMSE as shown in Table 6, implies that the fitted model is degraded by including the maximum values, because R^2 increases and RMSE decreases when the maximum value is removed. This limitation is not considerable when minimum values are removed, because by doing so both R^2 and RMSE decrease. When both the minimum and maximum values are deleted, R^2 is higher and RMSE is lower than the normal value, but as compared to omission of the maximum value, R^2 shows a slight increase resulting in higher increases in RMSE. Therefore, these results show that reliability of the model depends on the secchi depth values and its applicability seems to be limited to areas with secchi depths lower than 160 cm.

Because of the periodic availability of satellite data and low costs of field measurements with secchi depth, further research for development of more reliable models are recommended. These models can play a key role for efficient use of remotely sensed data for environmental monitoring and water and coastal resources management.

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