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Investigation of using satellite imagery model of one site to predict water depths of other sites in the Red Sea

Saudi Arabia

1.Abstract

The investigation of the reliability of satellite imagery for generating shallow water depth information for navigational purposes has been tested and found to be very useful, therefore the satellite imagery could play a part in updating navigational charts by deriving bathymetry of shallow water areas, specially the area where the traditional survey could not be covered due to the spread of coral reefs, Islands and underwater obstacles.

This paper will focus on using one algorithm model to predict water depth for different locations, the study were applied on two areas in the Red Sea, one is Rabigh area, the second study area is Kishran area, they area about 400km from each other, The algorithm model of 160 observations in Rabigh (first study area) provide 97% accuracy of water depth has been tested to predict the water depth of Kishran area (second study area). One of the valuable conclusions found during the analyses in this project is the possibility of using one algorithm model to predict water depth for different locations. The output image of this model has been investigated and compared with the output image created using the Kishran observation model and found nearly the same. This result could leads us to think deeply about carrying out more investigations using another image of the same area, but in a different season of the year, especially with the presence of water vapour and humidity. The results of these investigations, if successful, will enable us to use this technology for the entire coastal waters of the Rea Sea.

2.Keywords

Satellite imagery, Bathymetry, spatial resolution, accuracy, coastal water, spectral, algorithm, sensor

3.Introduction

Prediction of water depth using satellite imagery have been investigated and found to be very useful, especially in such area like the Red Sea(Alzahrani 2007), where the coral reefs are distributed all over the coastal area. This study aims to clarify the potential of high spatial resolution IKONOS data for estimating water depth. Mapping and deriving water depth using satellite images has several limiting factors, especially those related to the variable effects of the water column on the optical reflectance properties as measured remotely and in situ (Holden and LeDrew, 2001). Although passive optical systems are limited in depth penetration and constrained by water turbidity, the use of such satellite data might be the only possible way to reliably map water depth (Stumpf and Holderied, 2003). However, the use of such satellite data is the only way to safely map coral reef areas due to the difficulty of obtaining water depth by traditional hydrographic depth measurement. In order to measure water depth in regions where coral reefs present a major hazard to navigation and their horizontal extent can be 10 m or less, the optical satellite imagery required to provide a reliable tool for mapping such reefs must have a spatial resolution of 4 m or better. Landsat and SPOT imagery offer global coverage of coral reefs, but they have limitations caused by the pixel sizes of 30 and 20 m, respectively.

The objective of this research is to develop a method for the production of accurate bathymetry maps of shallow water areas in the Red Sea using high spatial resolution multispectral IKONOS satellite imagery and field measurements. Two study area were utilized for this research, representing the extremes of water conditions encountered in the region. The first study area was Rabigh area. The second study area which is 400km a part was Kishran area 200km south of Jeddah region. The two areas were carefully selected, to represent all the common environments which can be found in the whole Red Sea, such as coral reefs, sand, mud and sea grass.

Simple linear regression for both study areas were applied to relate field measured water depths to pixel brightness values in the blue band of IKONOS multispectral imagery that had been corrected to at-satellite reflectance using published calibration coefficients.

4. Depth prediction

Since we have the actual values of depth measurement taken from the Rabigh area and the values of reflectance (band 1) from the preceding steps, the depths in unknown areas can be predicted. Note that data was collected from both turbid and clear water. A simple linear regression technique has been employed. The model can be expressed in the following form:

$$D_i = \beta_0 + \beta_1 R_i \qquad (1)$$

where:

D_i is the value of the actual depth in the ith observation (response variable);

R_i is the value of the reflectance in the ith observation (predictor variable);

β_0 is the R intercept of the regression line. In our study β_0, by itself, has no meaning since the study does not cover reflectance at zero;

β_1 is the slope, i.e. the change rate of reflectance; and

i=1… n where n is the number of observations.

We need to estimate the coefficients of regression in model (1) using the available data. By using Minitab, we could easily derive the model.

$$\hat{D} = 77.2 - 598R \qquad (2)$$

Table 6.1. Regression analysis equation of Rabigh water.

Predictor	Coef.	SE Coef.	T	P
Constant	77.1945	0.9159	84.28	0.000
Ref-1	-598.459	8.707	-68.74	0.000

S = 0.657095 R^2 = 96.8% R^2(adj) = 96.8%

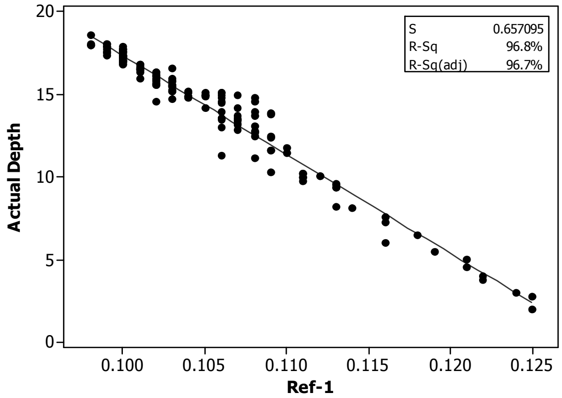

Figure 1. Regression model for all of the Rabigh area, both clear and turbid water.

S = 0.657095 R^2 = 96.8% R^2(adj) = 96.8%

Table 1 Rabigh reflectance, field depths and estimated depths

Long	Lat	Babnd1 Ref	Babnd2 Ref	Field depth	Estimated depth
38 59 33.29	22 44 07.18	0.109	0.107	13.8	13.1
38 59 34.03	22 44 05.94	0.108	0.114	12.5	12.6
38 59 36.00	22 44 11.00	0.104	0.108	14.8	14.7
38 59 38.95	22 44 51.03	0.107	0.11	14.2	13.1
38 59 38.99	22 44 50.43	0.11	0.113	11.5	11.3
38 59 39.00	22 44 46.00	0.104	0.102	14.9	14.7
38 59 39.01	22 44 10.93	0.108	0.108	14.8	15.2
38 59 39.25	22 44 50.01	0.106	0.111	13	13.4
38 59 39.95	22 44 48.99	0.108	0.106	12.7	12.4
38 59 40.02	22 44 10.99	0.106	0.107	15.1	13.9
38 59 40.03	22 44 10.99	0.106	0.107	15	13.9
38 59 40.03	22 44 10.02	0.106	0.107	15.1	13.4
38 59 41.09	22 44 11.33	0.105	0.109	15.1	14.2
38 59 41.11	22 44 07.99	0.107	0.112	15	13.1
38 59 46.59	22 44 49.15	0.106	0.1	14.8	15

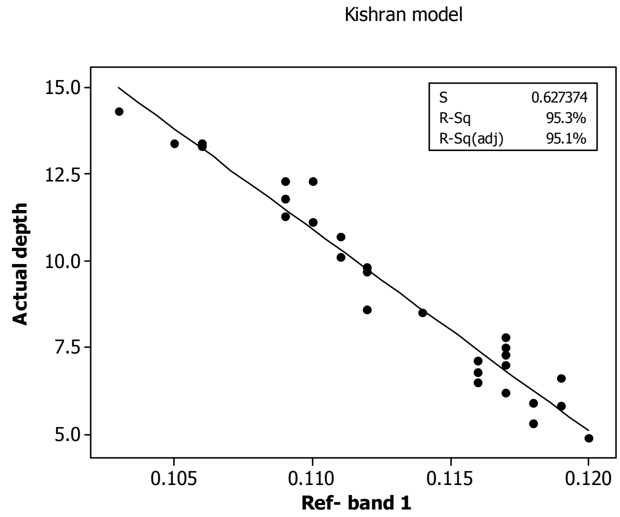

Figure 2 Kishran regression model created using actual depth versus band 1 reflectance.

S = 0.627374   R-Sq = 95.3%   R-Sq(adj) = 95.3%

Table 2 Kishran reflectance, field depths and estimated depths

Long	Lat	B1-Ref	B2-Ref	Field Depth	E- depth
40 1 45.68746 E	20 13 45.9456 N	0.12	0.129	4.9	4.9
40 1 40.205578 E	20 13 26.30964 N	0.118	0.133	5.3	6.1
40 1 44.437736 E	20 13 21.621838 N	0.119	0.123	5.8	5.6
40 1 42.781584 E	20 13 45.244916 N	0.118	0.128	5.9	6.1
40 1 35.526884 E	20 13 31.304856 N	0.117	0.119	6.2	6.6
40 1 34.747806 E	20 13 34.146054 N	0.116	0.123	6.5	7.1
40 1 43.73945 E	20 13 22.738166 N	0.119	0.12	6.6	5.9
40 1 51.70547 E	20 13 15.722098 N	0.116	0.113	6.8	7.6
40 3 9.206536 E	20 13 21.741532 N	0.117	0.12	7	6.7

5. Using Rabigh algorithm model to predict Kishran depths

One of the valuable conclusions found during the analyses in this project is the possibility of using one algorithm model to predict water depth for different locations. The algorithm model of 160 observations in Rabigh (first study area) Figure 1 can be used to build a new model for the Kishran image (second study area 400 km from Rabigh), using the ERDAS Imagine Model Builder module. The output image of this model has been investigated and compared with the output image created using the Kishran observation model. The predicted depths were nearly the same; the overall difference in r2 was just 1.5%. Figure 2 shows the regression model for the Kishran area using actual depth versus the reflectance's (band 1) taken from Kishran observations only. The regression relationship was accurate (r2 = 95.3%). When the model derived from the Rabigh observations was applied to the Kishran imagery, the regression fit versus actual depth showed r2 = 96.8%, as shown in Figure 3, which is more accurate than the model derived by Kishran algorithm, the reason is that the number of observations in Rabigh are more than the observations in the case of Kishran..

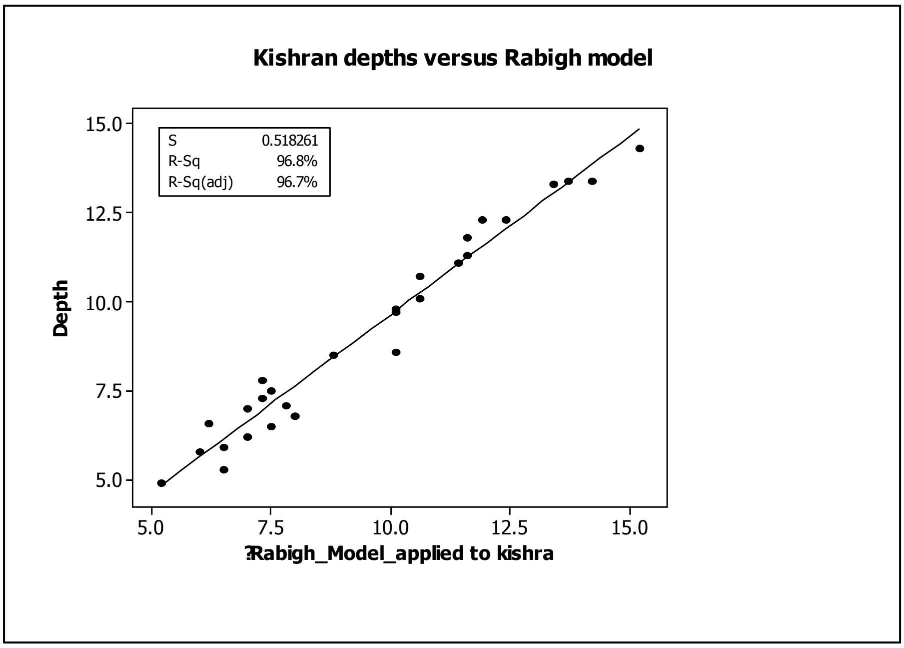

Figure 3 Rabigh model applied to Kishran area.

S = 0.518261 R-Sq = 96.8% R-Sq (adj) = 96.7%

Table 3. The reflectance of electromagnetic waves, field depth and estimated depths using Rabigh algorithm

Long	Lat	B1-Ref	Field Depth	E-depth	E-depths using Rabigh algorithm
40 1 45.68746 E	20 13 45.9456 N	0.12	4.9	4.9	5.2
40 1 40.20558 E	20 13 26.30964 N	0.118	5.3	6.1	6.5
40 1 44.43774 E	20 13 21.621838 N	0.119	5.8	5.6	6
40 1 42.78158 E	20 13 45.244916 N	0.118	5.9	6.1	6.5
40 1 35.52688 E	20 13 31.304856 N	0.117	6.2	6.6	7
40 1 34.74781 E	20 13 34.146054 N	0.116	6.5	7.1	7.5
40 1 43.73945 E	20 13 22.738166 N	0.119	6.6	5.9	6.2
40 1 51.70547 E	20 13 15.722098 N	0.116	6.8	7.6	8
40 3 9.206536 E	20 13 21.741532 N	0.117	7	6.7	7

6. Results

This project has been carried out based on two parts, carried within a short time period. Firstly, the field measurements which included spectral measurement, dGPS, and bathymetric measurements of the two study areas. The bathymetry and dGPS equipment were interfaced to a lap top computer to save each depth against its location.

Secondly the image processing, analyzing and model building according to the research requirements. The first study area consisted of two different environments, one of them the main port used by cargo and oil container ships which caused water turbidity, and the other very clear water over coral reef area located out of the port (about 5 miles). The total number of depth observations taken of this area was 160, of which clear water accounted for 104 and turbid water for 56 observations. Three different models were derived. The first model was for the entire area clear and turbid water (r2 = 97%, Fig 1 and table 1. The procedures applied to Rabigh were repeated for the second study area (Kishran, Fig 2 and table 2) and high R-squared achieved (r^2 = 95.3%). Transferability testing established that models created for the first study area applied to predict water depth in the second study area (Kishran), the output results were excellent with r2 = 96.8%, as shown in Figure 3 and table 3.

7. Recommendations

- The study was focused on the coastal waters, which are important for local shipping.
- It is advised that the procedure adopted in this study to be used and updated using different sensors imagery for creating new navigational charts.
- This study has two acquisition times, which illustrate different results, so the author recommend 12 months satellite images acquisitions and to be processed with the same methodology to investigate what is the suitable time for acquisitions.
- Create new navigational charts with more details for the areas near the coast containing notifications of all hazards that threat the local shipping, and safe passages marked with navigational aids.
- Evaluate applicability of this method to the Arabian Gulf coastal waters and other worldwide locations such as northern Australian.

8. References

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