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Research Paper

Extracting Water Bodies Using a Combination of Several Relational Spectral Reflectance Models

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ABSTRACT: *This paper aims at accurately extracting the water bodies, out of the multispectral satellite images, based on the relation of the band reflectance values. The proposed approach depends on investigating and evaluating the previously introduced shoreline extraction models, that depends on relationships between the band reflectance values, and combining the accepted models. Combining the accepted models to be used for water bodies extraction is conducted by following two different scenarios and evaluating the results of the combination scenarios. The extracting results have been evaluated by utilizing the Digital Shoreline Analysis System (DSAS) module. Three different areas along the northern part of the Suez Gulf, Egypt have been selected as the study area of this research. Each area is around 32 km long. Four different classification models have been used to extract boundary of the water body. The accuracies of the four models were within 1 pixel (30m) for the three areas. For combining the models' results, two scenarios were followed, either the water body is considered when the four models agree upon the classification of pixels as water, or if at least three models agree. By evaluating the results of the two combination scenarios, it is found that the combination scenario which classify the pixels as water when at least three classification models agree is the most accurate with RMSE of 10, 16.58, and 10.18 m for the three areas.*

KEYWORDS: *Water Body Extraction, Remote Sensing, Landsat Images, Spectral Ratio, Egypt.*

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I. INTRODUCTION

Water bodies are one of the most complicated ecosystems with many living and non-living resources. Water bodies are exposed to a series of dynamic natural processes like coastal accretion, erosion, environmental pollution, sediment transport, and coastal development. Therefore, monitoring the water bodies is an important task in protecting environment, and developing projects. In which, water bodies extraction and determination have a great necessity **Error! Reference source not found.**. In the past, extensive field measurements were carried out to measure ground position of water bodies. However, this method is time and effort consuming, and it is cost-ineffective as well. Beside that the human errors are unsystematic; therefore, it is difficult to be corrected. Hence, modern techniques such as remote sensing are required. The advantages of using remote sensing include the large ground coverage, the high geometric resolution, the multiple spectral information, and the ability to acquire the scene in multiple spectral bands.

Optical images are simple to interpret and easily to be obtained. Absorption of infrared wavelength region by water and its strong reflectance by vegetation and soil make such images an ideal combination for mapping the land- water interface. So, the images containing infrared and visible bands have been widely used for water bodies extraction. The Landsat and other satellite images that provide digital imagery in infrared spectral bands, have been intensively used since 1972 [2][3].

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In addition to the common supervised and unsupervised classification algorithms used for determination of water bodies, models that depend on band spectral reflectance values have a great concern of researchers over the last decades [2][4][5][6][7][8][9][10][11][12][13][14].

The objective of this paper is to extract the water bodies, out of the satellite images, accurately. Therefore, the detailed objectives are as following. 1) investigating and evaluating the previously introduced shoreline extraction models, that depends on relationships between the band reflectance values, 2) utilizing the Digital Shoreline Analysis System (DSAS) module to evaluate the extracted shorelines (borders of the water bodies), and 3) combining the most accurate models in different scenarios and evaluate the result of the scenarios to find out the best combination of models to be used for water bodies extraction.

II. STUDY AREA AND DATASETS

Three areas along the coast of the Red sea in Egypt, around 32 km each are selected along the Suez Gulf as shown in Figure 1.

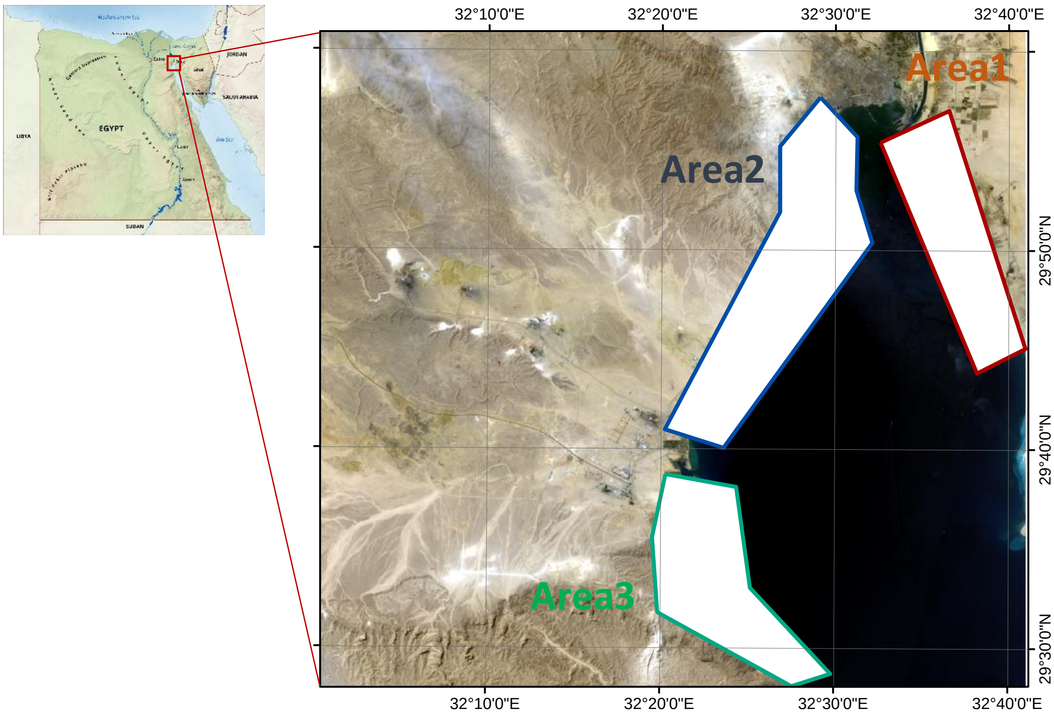

Fig. 1: Study area

Landsat-8 satellite image with row 176 and path 039 was downloaded from USGS website. The specifications of the Landsat8 bands are as shown in Table 1.

Table 1: Landsat-8 OLI and TIRS Bands (μm)

Band	Name	Spatial Resolution	Wavelength (μm)
Band 1	Coastal / Aerosol	30 m	0.435 - 0.451
Band 2	Blue	30 m	0.452 - 0.512
Band 3	Green	30 m	0.533 - 0.590
Band 4	Red	30 m	0.636 - 0.673
Band 5	NIR	30 m	0.851 - 0.879
Band 6	SWIR-1	30 m	1.566 - 1.651
Band 7	SWIR-2	30 m	2.107 - 2.294
Band 8	Pan	15 m	0.503 - 0.676
Band 9	Cirrus	30 m	1.363- 1.384
Band 10	TIR-1	100 m	10.60 – 11.19
Band 11	TIR-2	100 m	11.50 - 12.51

III. METHODOLOGY

To achieve the objective of this paper, firstly, the previous works are investigated, and the that extracting water bodies classification models that depend on bands reflectance values are analyzed. By analyzing the models, it can be noticed that the models can be classified into either band relation models or water indices models. For the water indices, the pixels are considered as part of a water body if the Normalized Difference Water Index (NDWI) is greater than 1. The introduced water index is considering the Blue and NIR bands, as described in Baiocchi et al, 2012. However, for the band relation models, the pixels are assigned to a water body whenever:

i. Reflectance of SWIR band < reflectance of Green band,
ii. Reflectance of NIR band < reflectance of Red band, and
iii. Reflectance of NIR band < reflectance of Green band.

The Digital Shoreline Analysis System (DSAS) is a software developed and published by the United States Geological Survey (USGS) as an extension for ArcGIS. The DSAS permits for automatic calculations of shoreline changes. The program calculates the changes in shoreline between two dates at locations defined by the users. The difference between the two shorelines (the shoreline in two different dates) and the direction of the changes are determined at each location, where these data can be illustrated visually and, in a table, as well. More functions are available in DSAS where the rate of change in shoreline, the absolute shoreline movement can be calculated.

In this paper, however, DSAS function of determining the change between two shorelines will be implemented to evaluate the results of the water bodies extraction models. Where the boundaries of the water bodies extracted by the models will be compared to the actual boundaries. The actual boundaries are called the ground truth in this research work, which is extracted manually by digitizing the line separating the water and land, based on the visual interpretation of the images.

To determine the best model, the standard deviation of the residuals (errors in the water bodies boundaries at the defined locations in DSAS) will be calculated and compared. Since it is expected to obtain different standard deviations with the different models, checking the significantly difference between the results will be conducted through applying the Analysis of variance (ANOVA) on the evaluation results.

The procedure of the workflow is illustrated in Figure 2. The detailed work procedure consists of eight main steps and two more steps for models combinations, if applicable:

1) Importing the satellite image with the relevant bands.
2) Extracting ground truth by on screen digitizing for the image based on the visual interpretation skills.
3) Using the selected models to extract the water body in a binary image where 0 is land and 1 is water.
4) Extracting the water bodies boundaries by converting the binary image to a vector file.
5) Evaluating the results by utilizing the DSAS module, where the distances between the result of each model and the ground truth are calculated at various locations. These differences are called the errors in the results of the models.
6) Determining the mean (μ), and the standard deviation (□), of the calculated errors for each evaluation data of each model results.
7) Checking the significantly differences between the models based on the mean and the standard deviation of the errors. Where, if more than two models are being examined one-way ANOVA will be used, else F-Test will be used.
8) Selecting the final models to be used. Where, if there is no significantly differences between the models, all models will be considered in the water bodies extraction procedure. Otherwise, the model with the highest standard deviation will be removed, and the significantly differences between models will be checked.

To consider two or more models, the following two steps will be followed:

1) Combining the model results by adding the binary files to each other. The produced image will have pixel values (PV) between 0 and the number of models (N).
2) Evaluating each case of the combinations. The combination models will be either the whole models, the line with PV = N, or PV = N-1.

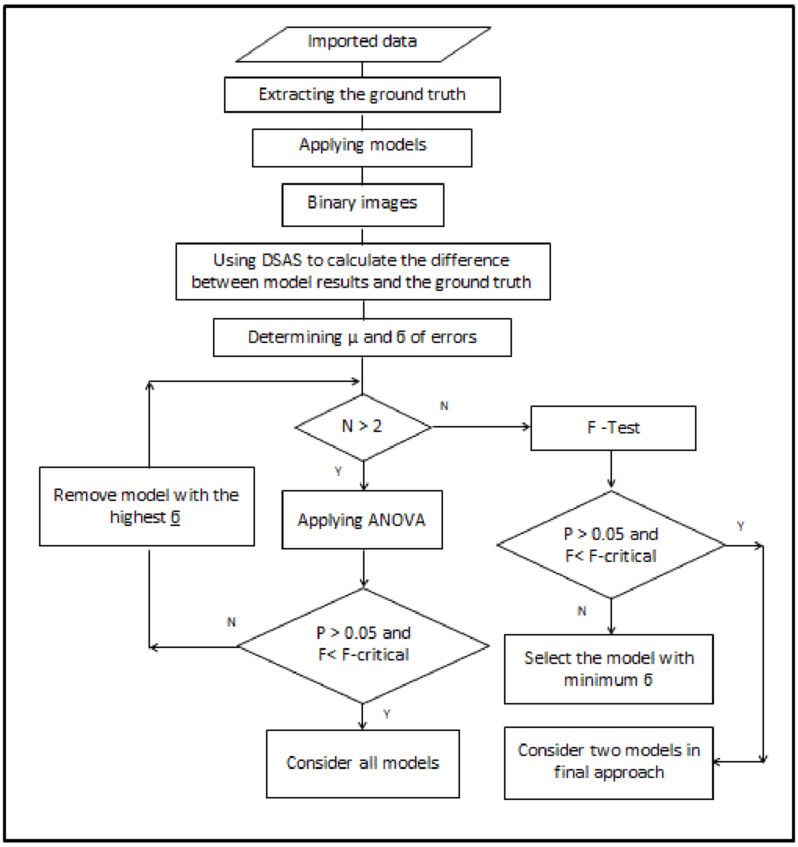

Figure 2: Work procedure for extracting the water bodies

IV. RESULTS AND DISCUSSION

Based on the described methodology, the Landsat image was firstly downloaded, and the actual boundary of the water bodies of the three study areas were extracted manually using the on screen digitizing technique based on the visual interpretation skills. The extracted boundaries of the three study areas are illustrated in Fig 3(a). Then based on the selected models as described earlier, the required Landsat bands were imported separately. The selected models were used to extract the water bodies, then, were separated when the following conditions were fulfilled:

i. Model 1: the reflectance of the SWIR is less than the reflectance of the Green (B6 < B3)
ii. Model 2: the reflectance of the NIR is less than the reflectance of the Red (B5 < B4).
iii. Model 3: the reflectance of the NIR is less than the reflectance of the Green (B5 < B3).
iv. Model 4: the Normalized Difference Water Index (NDWI), based on the Blue band (B2) and the NIR band (B5), is greater than 0 ((B2-B5)/(B2+B5)>0).
v. After extracting the binary images, the lines separated the water bodies are extracted. An example of the results of the four models (Model 1) are illustrated in Fig (3) b.

After extracting the boundary lines of the water bodies, the DSAS module was used on each model results for the three study areas. The transects, which would be used to determine the difference between the models result lines and the ground truth, were defined perpendicular to the boundaries lines with 1 km distance apart. Then the net errors of each model result line were calculated. To analyze the errors of each model result, the standard deviations of the errors were calculated. Table (2) illustrated the standard deviations of the errors for each model for each study area.

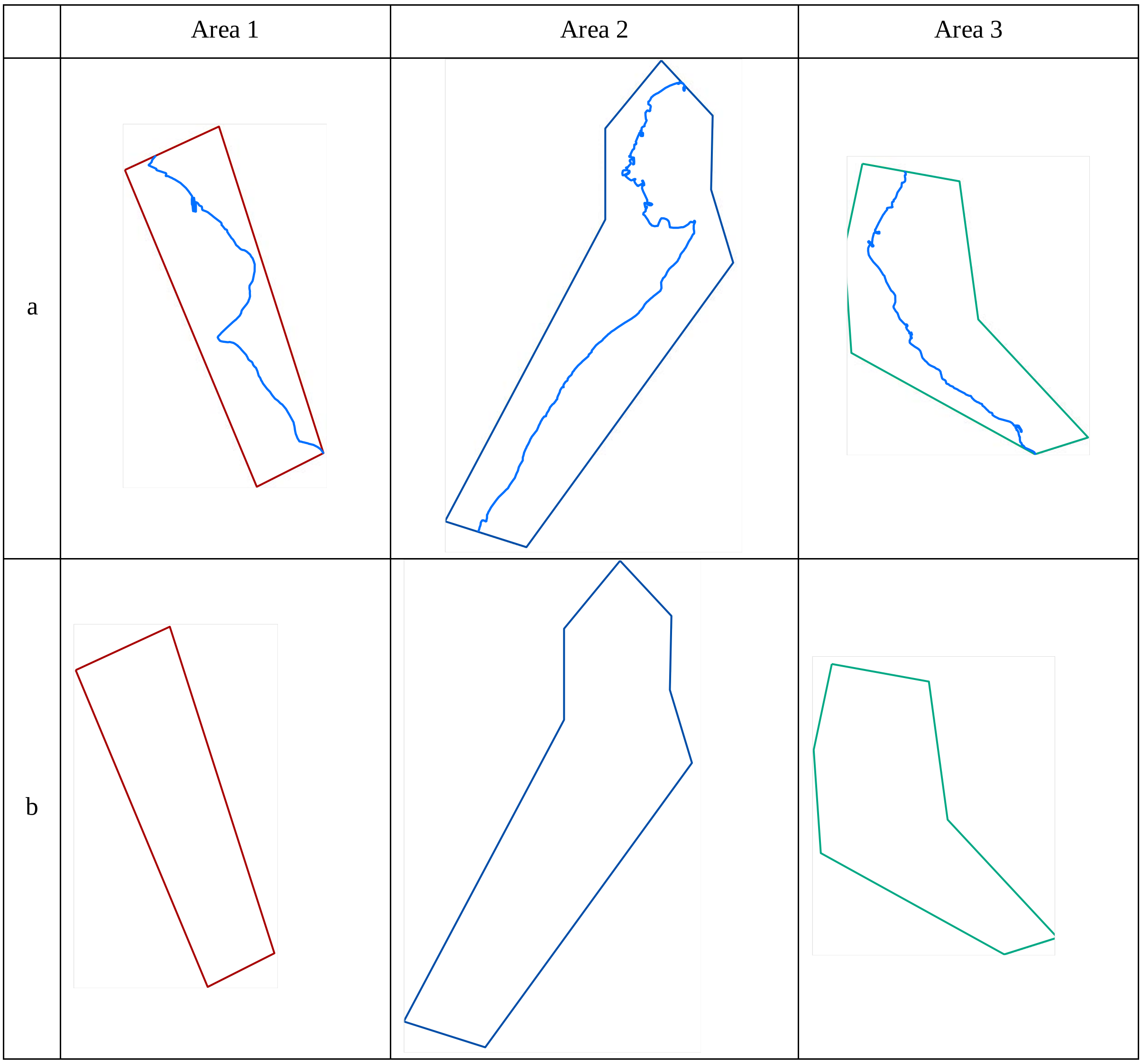

Figure 3: The extracted boundaries lines of the three study areas a) ground truth, and b) Model 1

Table 2: The standard deviation (in meters) for the results of each model in the three areas

	Model 1	Model 2	Model 3	Model 4
Area 1	12.42	9.93	11.94	10.91
Area 2	15.89	16.24	30.06	28.81
Area 3	10.08	10.20	11.44	11.48

By observing the results, it is obvious that there is no certain model that has the least standard deviation in each area to consider it for further work. Thus, the four models would be considered. Before combining the model results, the equality of the results was tested. Therefore, the one-way Analysis of variance (ANOVA) was used to test the hypothesis that the means among the results of the four models are equal, the significance level α was defined as 0.05.

The results of the ANOVA test are illustrated in Table (3).

Table 3: Results of ANOVA test for the evaluation results of the four models

Area	P-value	F	F-critical
Area 1	0.073134	2.383268	2.685643
Area 2	0.723753	0.441393	2.667443
Area 3	0.919042	0.165991	2.703594

It is noticed that the value of F is less than the value of F critical, and the P value is greater than 0.05 ($\alpha = 0.05$), for the three areas. Therefore, the null hypothesis that there is no significance difference in the means and variances is accepted. Thus, the four models would be considered in the model combination for extracting the water bodies.

To combine the four models, the binary images that were extracted by the four models would be added to each other. The results of the addition operation produced an image with pixel values either 0, 1, 2, 3, or 4, as illustrated in Fig (4). The 0 means none of the models classified the pixel as water, and 4 means all the four models classified the pixel as water.

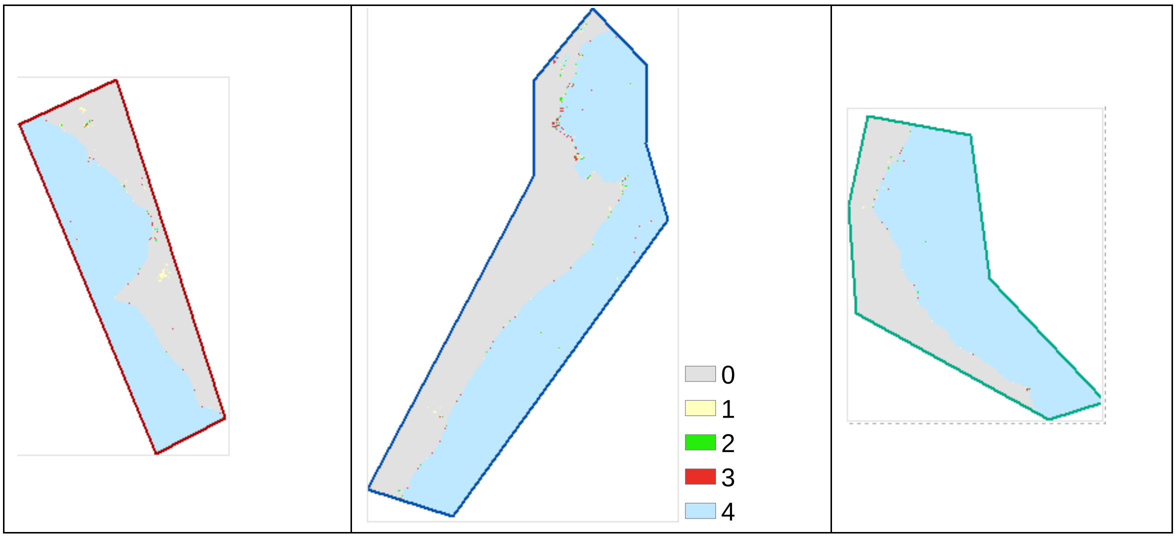

Figure 4: The summation of the four models

To extract the final water bodies, two combination scenarios were followed, the first combination scenario consider the water bodies when the four classification models agree upon the water bodies. The second one, when at least three classification models agree upon the water bodies. In other words, the first combination scenario is extracting the water body when the value is 4, however, the second one is extracting the water body when the value is greater than or equal to 3. Both combination results were evaluated by following the same concept of evaluating each classification model separately. The standard deviation of the combination scenario results based on same transects of the three areas are shown in Table (4).

Table 4:The standard deviations (in meters) of the combination scenarios in the three areas

	Agreement of the four models	Agreement of three out of the four models
Area 1	12.27	10.00
Area 2	38.01	16.58
Area 3	12.48	10.18

It is noticed that for the first area, the standard deviations of the two combination scenarios are almost the same. However, for the second and third areas, the combination of the four models with considering the agreement of three models obtained less standard deviation than those of the agreement of the four models. Therefore, the agreements of three models will be considered for as the best scenario to be used for water bodies extraction. Figure 5 illustrated the final results of the water bodies extraction.

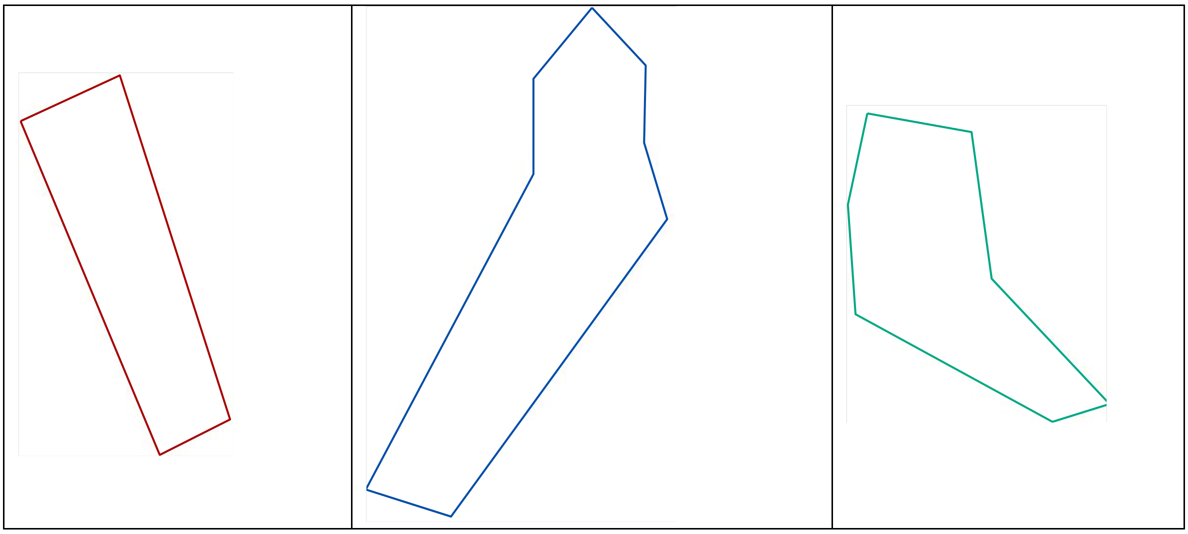

Figure 5: The extracted boundaries lines of the three study areas: a Combination of the 4 models with at least 3 models agreement

V. CONCLUSION

This study aims to extract the water bodies, out of the satellite images, accurately. Several models that depends on the relationship of the band reflectance values of Landsat 8 images were applied on three study areas at coast of the Red Sea in Egypt. Four models were investigated; 1) the reflectance of the SWIR is less than the reflectance of the Green (B6 < B3), 2) the reflectance of the NIR is less than the reflectance of the Red (B5 < B4), 3) the reflectance of the NIR is less than the reflectance of the Green (B5 < B3), and 4) the Normalized Difference Water Index (NDWI), based on the Blue band (B2) and the NIR band (B5), is greater than 0 ((B2-B5)/(B2+B5)>0). To evaluate the results of the used models, the Digital Shoreline Analysis System (DSAS) was implemented. Where the perpendicular distances between the results of each model and the true boundary (ground truth) were measured at locations along the boundary with 1 km distance apart. The true boundary was extracted using the onscreen digitizing technique based on the visual interpretation skills.

The four models produced different results but based on the results of the ANOVA test, the means and standard deviations of the four models had no significant difference with 0.05 significance level. Since the four models considered equal, the combination of the results of the four models were conducted, where the summation of the results of the models was conducted. The final combination scenario was selected to the one where at least three models results were agreed.

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