Journal of Genetic and Environmental Resources Conservation, 2014, 2(2):241-250.
www.jgerc.com

Water depths classification from remotely sensed imagery using experience-conditions technique

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Abstract

The objective of this research is to explore an appropriate way for monitoring and assessing water depths using satellite remote sensing technique of the Al-Habbaniyah lake in Iraq. This research studied the experience-conditions/ (thresholds) of different bands for multi-temporal satellite images with variety of satellite sensors; TM, and ALI to recognize regions of water depths that presented by Naji. As supervised method, a list of thresholds is taken that shows very credibility to separate the Al-Habbaniyah lake image to the required depths (shallow, deep, and very deep). Three-dimension feature space plot had used to represent these regions. The relationship of the mean values of the three separated water regions with all TM and ALI bands are studied. Other lakes in Iraq were used to actualize the validity and accuracy of this technique to find the water depth regions; Al-Qadisiyha and Al-Mosul lakes are in the West and North of Iraq of Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-5 Thematic Mapper (TM) satellite images respectively.

Keywords: Water detection, Experience-conditions, ArcGIS, Remote sensing, TM, ALI.

Introduction

Water managers spend the vast majority of their time undergo with variability in the water supply on the daily to interannual time scales. The readiness to deal with this variability currently depends, in great measure, on the level of investment in situ monitoring. At the national level, this is highly correlated with the level of economic development (Chuvieco, 2008).

Accurately extracting the distribution and variation information of water bodies (rivers, lakes and seas) are always difficult to get, using traditional ground survey techniques, because water bodies can be fast moving like in floods, tides, and storm surges or may be inaccessible. Following the growing availability of satellite images with increasing spatial and spectral resolution, the development of tools for geographic data analysis (GIS platforms) and image processing techniques, with the rapid development of remote sensing techniques, nowadays extracting this information from satellite imagery become a convenient, economical and accurate solution (Wang, 2003; Smith, 1997). Satellite remote sensing has the following advantages: 1) images cover large areas on the ground; 2) it is not time consuming but has sufficient temporal frequency; 3) prices per square kilometer are generally lower than in-situ investigation and monitoring (Baodonga, 2008).

Water is one of the most our critical resources. Visual image interpretation can be used in a variety of ways to help monitor the quality, quantity, and geographic distribution of this resource. In general, most of sunlight that enters a clear water body is absorbed within about a few meter of the surface. The degree of absorption is highly dependent on wavelength. Near-infrared wavelengths are absorbed in only few tenths of a meter of water, resulting in very dark image tones of even shallow water bodies on near-infrared images. From the standpoint of imaging of bottom details through clear water, the best light penetration achieved between the wavelengths of (0.48 and 0.60) µm. Although blue wavelengths penetrate well, they are extensively scattered and an "underwater haze" results. Red wavelengths penetrate only a few meters (Lillesand, 2008).

The precision of water color remote sensing inversion limits its application to water environmental monitoring (Wang, 2004). Various algorithms had implemented to extract water body in recent years, based on the spectral characteristics of this region. These algorithms are able to locate all of the major water pixels. However, they heavily depend on human experts to choose appropriate threshold values.

Histogram analysis of individual band data revealed that the electromagnetic spectrum from 0.7 to 2.5µm, which covers the near and middle infrared portion of the spectrum, is the best region to distinguish between water bodies and land. In this region, the water bodies almost absorb all incident radiant flux while the land surface, typically composed of vegetation and bare soil, reflects significant amount of near, and middle-infrared energy. The combination of the near with the middle-infrared improving the accuracy in detecting the water regions (Wang, 2003).

One of these algorithms used the threshold values of Band 4, and Band 5 respectively by the rule based method, which recognizes water regions (water bodies) if pixel value satisfies the rule; Band 4 < 45 , and Band 5 < 36 (Naji, 2011).

This research presented a technique with experience-conditions to detect water depths to three depths (shallow, deep, and very deep) for Al-Habbaniyah lake with TM and ALI data. Spectrum signature curves and three-dimension feature space plots were used to illustrate these depth regions.

Materials and Methods

Regions of interest and available data: Al-Habbaniyah, Al-Qadisiya, and Al-Mosul lakes lie in Al-Anbar and Ninive governorates. Map location of these interest regions had shown in Figure (1). The samples of satellite images for Al-Habbaniyah lake were used to illustrate the effect of performing this technique is shown in figure 2-(a, b). They extend between latitudes (33° 25' 36.23") to (33° 11' 47.20") north between longitudes (43° 17' 4.94") to (43° 35' 32.95") east, and latitudes (33° 25' 25.26") to (33° 11' 32.52") north between longitudes (43° 17' 15.09") to (43° 35' 44.19") east for the multi-temporal scenes with different sensor Thematic Mapper (TM) which was taken on 4 of March 1990 onboard Landsat-5 satellite, and Advanced Land Imager (ALI) which was taken on 16 of March 2003 onboard the Earth Observer-1 (EO-1) satellite, respectively. The total area of both temporally viewed sets of scenes was (739.56) km^2. These temporal scenes were geometrically corrected and previewed, then followed by smaller size extracted were (916 × 994) pixels with three bands combination (R: 5, G: 4, and B: 3) and (R: 9, G: 6, and B: 5), with the same spatial resolution of (30 m) for all these spectral bands. Hydrogeologically, Al-Habbaniyah lake water depth ranges from (> 1) m, (11-9) m, and (17) m on the surroundings, on the middle, and on the end of lake respectively for the mentioned years, as a field measurements.

Al-Qadisiya lake lies on the Euphrates river, 8 km north of Haditha city west of Iraq with latitudes (34° 26' 6.74") to (34° 7' 35.03") northing, and longitudes (42° 1' 37.68") to (42° 34' 5.10") easting, as shown in Figure 2-c. It covers (1573.47) km^2. The interest data source was the Enhanced thematic mapper Plus (ETM+) image which was taken on 20 of November 2002 onboard Landsat-7 satellite, with three bands combination (R: 5, G: 4, and B: 3). Al-Qadisiya lake water depth was range (138 m), as a field measurements in 2002 year.

Al-Mosul lake located on the Tigris river in Mousl city center nouth of Iraq, geographic coordinates latitude (36° 56' 1.30") to (36° 34' 23.96") N, longitude (42° 27' 9.28") to (43° 4' 13.82") E, Figure 2-d. The available data was thematic mapper (TM) image, which was collected at 4 of October 1992 in three bands combination (R: 5, G: 4, and B: 3). It covers ground area around (2713.42) km^2. Al-Mosul lake water depth was range (318 m) in 1992 year], as a field measurements (LEGOS, 2010).

Detection and separation of water body:

1. To detection and separation of water body for Al-Habbaniyah lake with different depths, the following experience-conditions (thresholds (TH)) technique had written based on bands (Naji, 2013); TM3, TM4, and TM5, with band combination of 5, 4, and 3 for thematic mapper (TM) data, and ALI_5, ALI_6, and ALI_9, with band combination of 9, 6, and 5 for ALI data as RGB, such that

   i. Region of shallow water had delineated with the conditions:

$$TH1 \leq 36 \text{ and } 13 \leq TH2 \leq 79, \qquad (1)$$

   ii. Region of deep water had delineated with the conditions:

$$TH2 < 14 \text{ and } 22 \leq TH3 \leq 71, \qquad (2)$$

   iii. Region of very deep water had delineated with the conditions:

$$TH2 \leq 11 \text{ and } TH3 < 22, \qquad (3)$$

Where:

TH1: is represents the specific threshold value of band 5 for TM data and band 9 for ALI data (MIR-Infrared band).

TH2: is represents the specific threshold value of band 4 for TM data and band 6 for ALI data (NIR-Infrared band).

TH3: is represents the specific threshold value of band 3 for TM data and band 5 for ALI data (RED band).

2. Calculate the mean of digital number (DN) value for each spectral band of the TM have (7 spectral bands), and ALI have (10 spectral bands) scenes, for each water depth classes.

3. Draw the spectral signature curve for each depth (class) according to the results in step 2.

4. Implement the previous steps on other lakes in Iraq with different water depth regions to approve the validity and accuracy of these experience-conditions to find the water depth regions for Al-Razazah, and Al-Qadisiyha lakes scenes.

The study have been performed and built using ArcGIS9.3, ENVI 4.5 software and MATLAB7.9b language.

Results and Discussion

After the correction and matching process experience-conditions technique, as fairly good empirical evidences was implemented on the multi-temporal with variety of satellite sensors; Landsat TM, and EO-1 ALI scenes. These scenes are geometrically corrected in the World Geodetic System 1984 datum "WGS84", and Universal Transverse Mercator projection (zone 38 north) "UTM N38" using the first order (linear) of polynomial function and cubic convolution registration resampling. The Root Mean Square "RMS" error of the image-to-map registration was between 0.07and 0.96 pixels. As appear in table 1, number of Ground Control Points "GCPs" used to correct the ALI scene was 6.

The water body information is accurately extracted from the false color image composed from TM5, TM4, and TM3 (RGB), and ALI_9, ALI_6, and ALI_5 (RGB). These combination provide color contrast, so they have low correlation coefficient, consequently, they contain higher amount of information in comparison to other color composites. Furthermore, they are very similar to the true color composite of earth's surface, and nicely depicts water land interface.

The experience-conditions technique had used to detect the different depths of Al-Habbaniyah lake, as shown in Figure 3-(a, b) by depending on the spectral characteristic of water absorption of these depths. The threshold values that found very appropriate to apply these experience-conditions are listed in equations 1, equations 2, and equations 3. Figure 3-(c, d) illustrated the Al-Qadisiya lake and Al-Mosul lake classification using the previous equations of experience-conditions.

Since regions of water depths detected dependently on three bands, as mentioned previous, thus it was more convenient to explain these regions in three-dimension feature space plot as in figure 4 which illustrated water depth regions. The intensity at a point in this feature space plot is related to the number of pixels for water depth regions at that point. Spectrum signature curves of the water depth regions had drawn as shown in Figure 5 by calculating the mean values, these values for these depth regions to each band are listed in Table 2 and Table 3. The mean statistical is one of the most spectral signatures statistics what discriminate the class from other. They are the most important property of matter makes it possible to identify from other different depth regions (classes) and separate between them, and can be used to have new vision for new method of classification depending on available satellite imagery without the need for field investigation, because the satellite imagery when used properly will provide some clear information on areas without resorting to field work, which is impossible in some places.

Table (1): Al-Habbaniyah lake registration parameters

Total (RMS) Error = 0.58 m							
GCP No.	Base TM Scene, 1990		Warp ALI Scene, 2003		Error (meter)		RMS Error (meter)
	X	Y	X'	Y'	X	Y	
1	835.00	117.25	2484.00	426.00	0.41	-0.40	0.57
2	906.00	721.00	2687.00	2146.00	-0.02	0.07	0.07
3	370.00	902.00	1162.00	2663.00	0.14	-0.28	0.31
4	112.00	73.00	427.00	299.00	0.28	-0.59	0.66
5	174.25	270.25	605.00	860.25	-0.41	0.86	0.96
6	847.00	174.00	2519.00	587.00	-0.40	0.34	0.52

Table (2): Mean pixel values for Al-Habbaniyah lake water depth regions versus TM bands

	Bands						
Regions	1	2	3	4	5	6	7
Shallow Water	98	103	80	23	5	20	7
Deep Water	95	82	36	7	4	13	6
Very Deep Water	72	52	10	4	4	14	6

Table (3): Mean pixel values for Al-Habbaniyah lake water depth regions versus ALI bands

	Bands									
Regions	1	2	3	4	5	6	7	8	9	10
Shallow Water	65	75	109	81	57	19	16	14	12	12
Deep Water	50	56	59	54	32	11	6	6	6	5
Very Deep Water	20	25	24	12	12	10	10	10	10	7

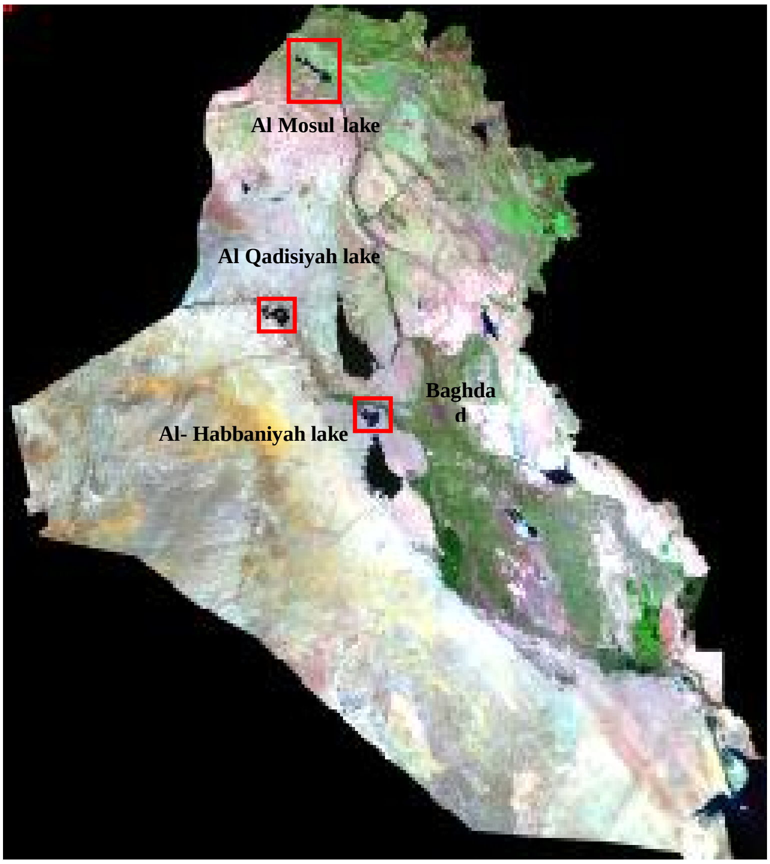


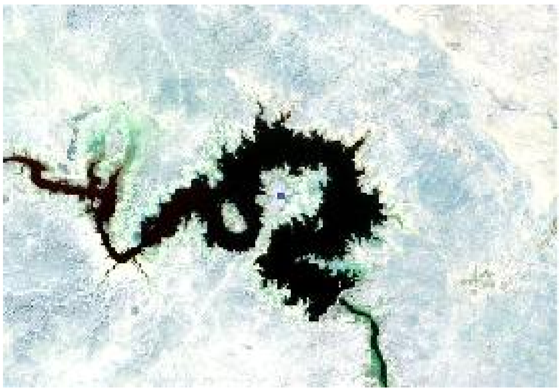
Figure (1): Location map of the study regions (Al-Habbaniyah, Al-Qadisiyah, and Al-Mosul lakes) in Al-Ramadi, Haditha and Al-Mosul cities.

a

TM Scene

ALI Scene

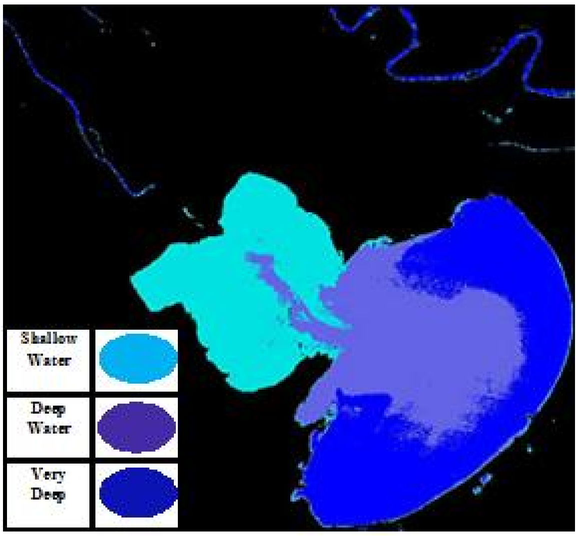
b



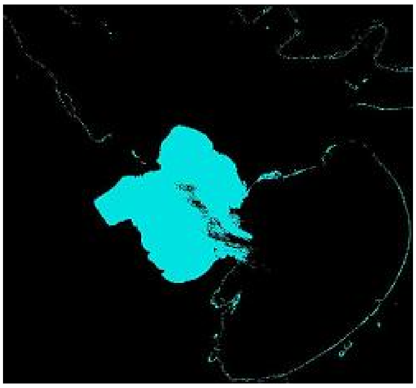
c

d

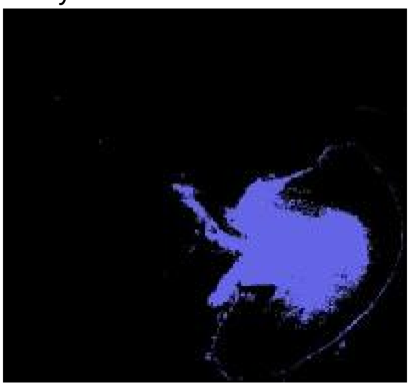
Figure (2): a- EO-1, ALI (RED, NIR, & MIR) Spectral Images, in 2003 West of Iraq (Size 1831 x 3461 Pixels) , b-Muilt-Temporal Al- Habbaniyah lake for Landsat TM & Geo-Corrected EO-1 ALI, in Years 1990, and 2003 (Each of Size 994 × 916 Pixels), c- RGB Color Composite of Landsat 7, ETM+ bands 5, 4 and 3, in 2001 West of Iraq (Size 6514 x 6000 Pixels), and Tested Scene of Al Qadisiya lake (Size 1632 x 1187 Pixels), d- Tested Scene of Al Mosul lake (Size 2393 x 1396 Pixels) in 1992 North of Iraq



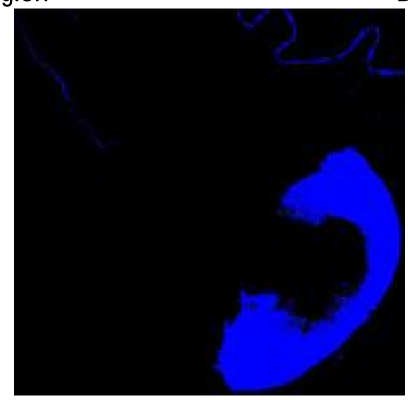
Classified TM image of Al-Habbaniyah lake



Shallow water region

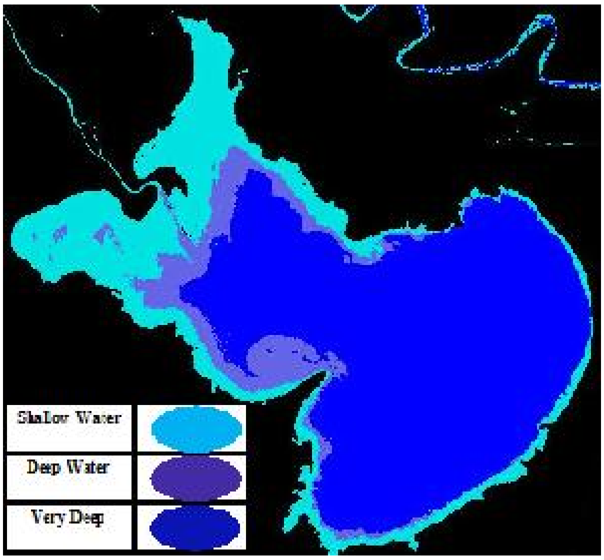


Deep water region

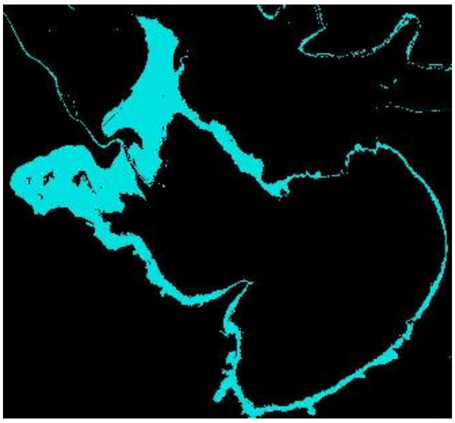


Very Deep Water region

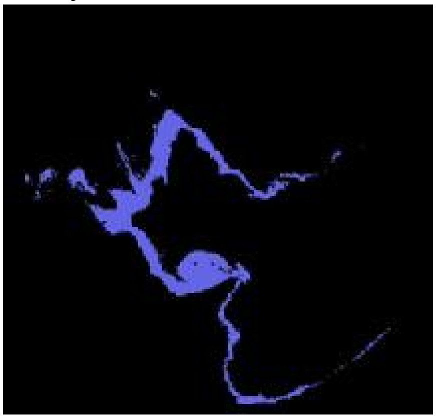
a



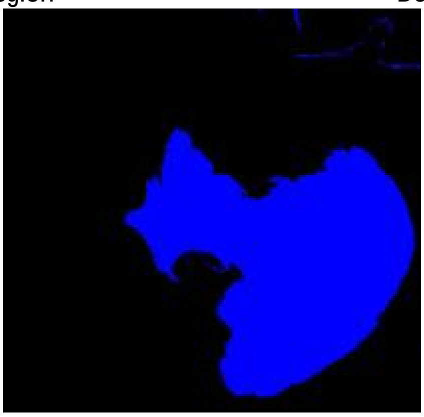
Classified ALI image of Al-Habbaniyah lake



Shallow Water region

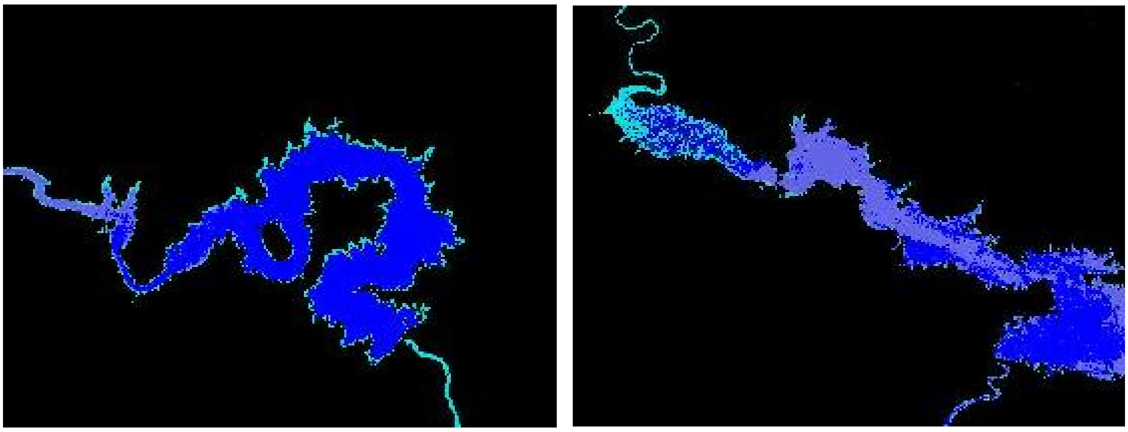


Deep Water region



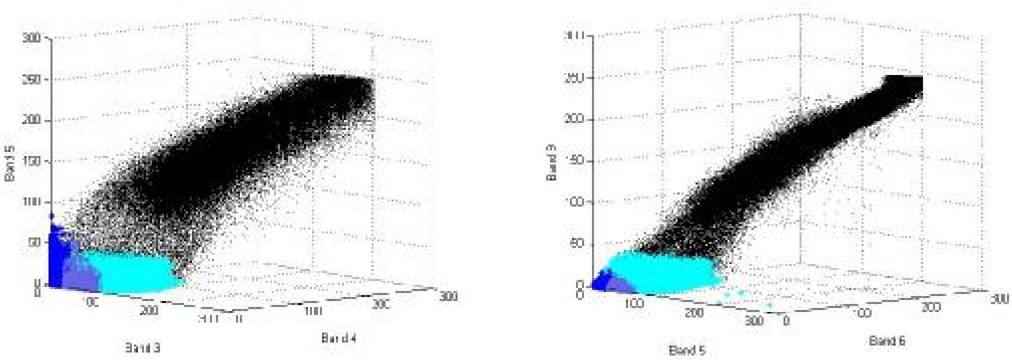
Very Deep Water region

b



c d

Figure (3): a and b Classified TM and ALI images of Al-Habbaniyah lake, c- Classified ETM+ Image of Al-Qadisiya lake, d- Classified ETM+ Image of Al-Mosul lake and they water depth regions



TM scene **ALI scene**

Figure (4): 3-D Feature space plot of the water depth regions for TM and ALI scenes

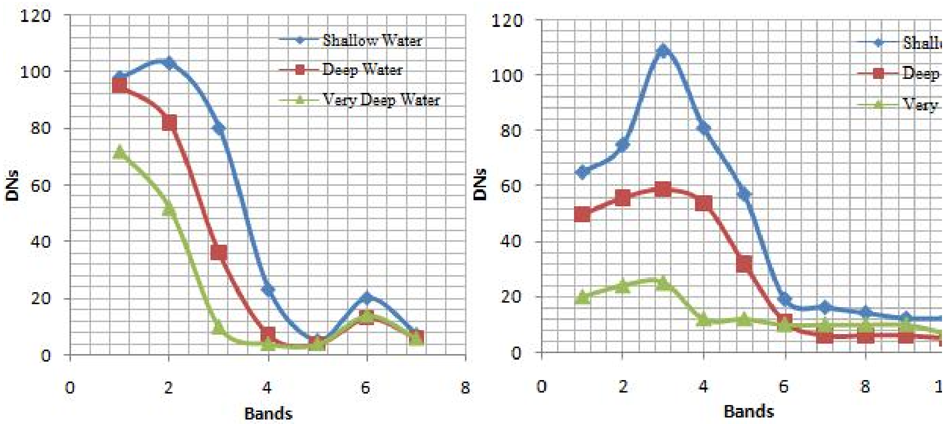


Figure (5): Spectrum signature curves of the water depth regions for TM and ALI scenes

Conclusions

The aim of this research is to present an influential technique to recognize different water depths of an Al-Habbaniyah lake with fast performing from remote sensing data without return to the field studies for the area can not to be reached by using simple conditions.

This technique can be implemented on any lake have the fewer depths such as, Al-Habbaniyah lake. Where this technique was failed to recognize the regions of water depths for some of lakes which have the big depths by correct form such as; Al-Qadisiyha and Al-Mosul lakes, due to the sunlight penetration for the surface of water body about from 2 m to maximum 20 m can be calculated for the visible light and infrared wavelengths, as shown in Figure 3.

The behavior of water depth regions as illustrated in the spectrum signature curve in Figure 5; relatively had low gray tones, since water absorbs most of the incident solar irradiation, but it had high reflectance in band 1 for TM scene since bluish objects and areas generally show this band as lighter gray tones than others. However, shallow water region had different behavior; its band 1 for TM scene reflectance is less than band 2 for this scene, and band 3 for ALL scene in visible region, that indicate to existence of aquatic plants. The reflectance of water changes with chlorophyll concentration involved. Increases in chlorophyll concentration tend to decrease water reflectance in blue wavelengths and increase it in green wavelengths. The difference in reflection degree can be used to delimitate the depth and case of water.

Band 6 for TM scene produces an emitted radiation image in the thermal IR; in general, light tones mean higher temperatures, which give the interpretation to water depth regions behavior. Deeper water region affected by surrounding soil less than others did; therefore, its temperature is greater. Shallow water region had different behavior; its temperature is greater than others are due to aquatic plants. However, there are several limitations in this technique, for example, the misdetection may occur from existence of aquatic plants which effect on water region reflectance and thus, to get more precise in detecting water depth region. The research results are more conformable to fact because it was depended on field measurements, which mentioned in the (regions of interest and available data) paragraph, and was accredited in Al-Habbaniyah lake studying until yet.

The percentage area of each classified region for Al- Habbaniyah lake can be calculated after the river body was extracted from the scene using image processing methods.

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