Utilization of High Spatial Satellite Images Reflectance’s to Estimate the Nautical Charts for the Nile River

Abdallah Saad, Maher M. Amen, Mervat Refaat, Ahmad Morad

ABSTRACT

Background: It has been a long time for the navy research centers to do great efforts and concentrate their researches in developing the used methods for measuring the depths, and increasing their efficiency even this developing is to the traditional methods, or to the remote sensing technique. Due to the presence of the river Nile as a navigational route in Egypt passing from its south to its north, the remote sensing technique was used in this research for measuring the depths, by using multi-spectral band satellite image with resolution 1.65m, which covers an area of almost 15.52 Km² of the river Nile (of width=1Km and length=15.52Km) from Esna to Nagaa Hamadi, the image was corrected geometrically, and The radiances were corrected from the corrected radiance values. From the obtained reflectance, the depths were computed, by using suitable mathematical model. The data analysis mainly depends on the physical principle, which stipulates that upon the passage of electromagnetic waves by aqueous media, it weakens the wave because it passed from a media of a certain density to the media has different densities. The deeper areas will have dark color due to the low light reflected compared with the areas with lower depths. We used the depths measured with echo sounder as reference depths. At the end the estimated depth values were compared with the observed values. The average of the differences was about (1.22 m).

INTRODUCTION

The International Hydrographic Organization defines hydrography as “the branch of applied science which deals with the measurement and description of the physical features of the navigable portion of the earth’s surface [seas, rivers] and adjoining coastal areas, with special reference to their use for the purpose of navigation.” Hydrographic surveying “looks” into the ocean to see what the sea floor looks like. Bathymetric information is important in coastal areas and river. Hydrographic surveys support a variety of activities: nautical charting, port and harbor maintenance (dredging), coastal engineering coastal zone management, and offshore resource development. Most of the surveys are primarily concerned with water depth. Traditional bathymetric technique is a common technique among the world for a bathymetric purpose, In recent decades, airborne bathymetric LDAR (Light Detection And Ranging) systems have been developed to map shallow coastal waters, but we can use multispectral satellite imagery to produce bathymetric maps. This is the first time that the remote sensing bathymetric technique used the reflectance values to estimate the depths of the river Nile in Egypt. There are different pervious experiences some for coastal reef of sea, ocean and other for river bathymetry. In red sea coastal in Saudi Arabia remote sensing used as IKONOS image with spatial resolution of 4 meter multispectral acquired on December 17 2004 at 08:08 GMT , using rabigh model to predict study area coastal water depths by using pixels reflectance's correlation coefficient between the actual depth and the estimated depth was 0.97.

Also, in Coastal Sea waters the Gulf of Lion in France used MERIS Image launched on board ENVISAT in 2002 expanding over 270°*180, the water attenuation model was used to estimate depths. The absolute error ranged from 2 m to 24 m, this error increases with the distance to the training area when the water attenuation is
not homogenous. Remote sensing technique was achieved successfully to estimate the depths wide a world as in Laramie River in United States at Colorado, Wyoming state, River Kelantan in Malaysia, Platte River in the United States at Nebraska state, Soda Butte Creek in the United States at Wyoming State, and in Lake Tana, which is the source of the Blue Nile. In this research, we used the remote sensing technique reflectance’s values for geoeye satellite sensor for estimating the depths of the river Nile, by using the water attenuation model. At the first, measuring the depths by echo sounder instrument. The estimated depths were obtained with a relatively low difference versus the traditional depths, with standard deviation (1.346 m).

MATERIAL AND METHOD

The available data consists of two types of data, the first is about the traditional depths computed from echo sounder and GPS observations, and the second refers to the satellite image, in addition to the used soft wares

Available Traditional Data From Echo Sounder:

Traditional depths were measured by echo sounders with single-beam and GPS receivers were applied in the area of Esna Bridge.

It was essential to carry out fieldwork, using the most modern and accurate equipment in order to obtain useful information about the water depth and river bottom type. The fieldwork was undertaken at (22-6-2009) with the acquisition of the geo-eye satellite imagery. The reason for conducting this survey at the same time as image acquisition was to obtain more accuracy in the study methodology. A differential GPS (dGPS) positioning system was used for this work was an accuracy of ±20cm, to obtain accurate horizontal coordinates.

Traditional depths have many confused data due to the presence of many bodies such as chlorophyll algae and sediments, so the observed depths should be filtered from the wrong values by using hypack software through excluding the observations, which are far away from the average of the observed values (diverged observations), to reach depths that represent the nature of the seabed Nile through the converged observations.

The following table shows the results of the sample of echo sounder data after filtration.

<table>
<thead>
<tr>
<th>DGPS Position</th>
<th>Observed Echo sounder Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>455372.71</td>
<td>2801146.2</td>
</tr>
<tr>
<td>455375.09</td>
<td>2801144.3</td>
</tr>
<tr>
<td>455494.95</td>
<td>2800795.3</td>
</tr>
<tr>
<td>455499.39</td>
<td>2800791.8</td>
</tr>
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<td>2800793.6</td>
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<td>2802632.2</td>
</tr>
<tr>
<td>455004.54</td>
<td>2803178.7</td>
</tr>
<tr>
<td>455007.84</td>
<td>2803184.2</td>
</tr>
<tr>
<td>455042.73</td>
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<tr>
<td>455003.65</td>
<td>2803173.5</td>
</tr>
<tr>
<td>455174.72</td>
<td>2802025.1</td>
</tr>
<tr>
<td>455644.05</td>
<td>2800748.7</td>
</tr>
<tr>
<td>455669.08</td>
<td>2800959.4</td>
</tr>
<tr>
<td>455259.04</td>
<td>2801127.6</td>
</tr>
<tr>
<td>455310.98</td>
<td>2801675.8</td>
</tr>
<tr>
<td>455265.48</td>
<td>2801767.1</td>
</tr>
</tbody>
</table>

Available Satellite Image Data:

A multispectral satellite image with 1.65 m spatial resolution over a chosen area, which has been selected for this study. This high resolution image was collected in 2009-07-10 08:40 GMT by spacing imaging’s GEOEYE satellite. This image has been obtained and rectified (corrected).

The research took the traditional filtered data as a guide for filtration of remote sensing data. We depended on more than 600 points which represent the true nature of the seabed Nile. They don't contain any effect of chlorophyll algae, sediments and the shadow of the Nile. There were many software packages used for achieving the main aim of this research such as, Global Mapper12, ERDAS IMAGINE of version 2010, AutoCAD Civil 2011 and GPS data processing program. The study area was chosen at Esna city in El Oqsor governorate as shown in figure below. Esna city in El Oqsor governorate, and located in zone 36 in UTM projection system. The chosen area is an urban area contains buildings and roads network which is suitable for the study requirements. The traditional filtered data was used as a guide for remote sensing filtration to get more actual data.

Methodology:

The research employs traditional depths as reference guide for validity remote sensing technique depths to approve the efficiency of remote sensing technique for estimating Nile River depths by using Reflectance's
values. The fundamental physical principle underlying the retrieval of bathymetric information from optical remote sensing images is that when light passes through water it becomes attenuated by interaction with the water column. Deep areas appear dark on the image since the water absorbs most of the reflected light. Shallow areas appear lighter on the image since less light is absorbed in the passage through the water column as shown in Fig. (2).

This method started with converting the image from DNs (Digital Numbers) to radiances and after that these radiances were corrected from the effective errors such as, sun glint and atmospheric errors. Finally Nile river reflectance’s values were computed from corrected radiance values as follow:

\[ \rho = \frac{\pi \cdot L \cdot d^2}{E_{\text{sun} \lambda} \cdot \cos \theta} \]  

(1)

\( \rho \) = Unitless planetary reflectance,
\( L \) = Corrected Radiance for spectral band \( \lambda \) at the sensor’s aperture (W/m²/μm/sr),
\( d \) = Earth-Sun distance in astronomical units
\( E_{\text{sun} \lambda} \) = Mean solar exoatmospheric irradiances (W/m²/μm),
\( \theta_S \) = Solar zenith angle.

The solar zenith angle can be calculated by:

\[ \theta_S = 90 - \text{solar elevation angle} \]  

(2)

From satellite image Meta data file, the solar elevation angle was 72.63524 degree, then the solar zenith angle will be 17.36476 degree. Through equation (1) we found that before computing reflectance values, there are some parameters should be computed. First one is Mean solar Exoatmospheric irradiances, then second is Earth-Sun distance in astronomical units.
Mean solar exoatmospheric irradiances, are the amount of radiant energy incident on a surface per unit area per unit time. The radiation from the Sun travels in the space as electromagnetic waves. Above the earth’s atmosphere, sunlight carries 1367 watts of power per square meter. This is known as solar constant. We define solar constant as the amount of solar radiation received outside the earth’s atmosphere on a unit area perpendicular to the rays of the sun, at the mean distance of the earth from the sun. The Earth receives 1.8 x 10^17 W of incoming solar radiation continuously at the top of its atmosphere, but only half of it reaches the earth’s surface. Since the distance between the earth and the sun changes during the year. Solar irradiance outside the earth’s atmosphere also varies between 1325 W/m² and 1420 W/m². The annual mean solar irradiance is known as the solar constant and is 1367±2 W/m².

There are three methods to get irradiances value, the first is directly observed, the second get it from Meteorological satellites, and the third from specialized web site. First method, Direct observation method using Different types of sensors exist to measure the solar irradiance. A Pyranometer measures the global irradiance. Different designs give different levels of accuracy. Fig. 3: shows different Sensors for solar irradiance measurements.

Fig. 4: Sensors for solar irradiance measurements, Pyranometer with thermal sensor for global irradiance measurements (left top) Two-axis tracked pyrheliometer for direct normal irradiance measurements (left bottom) Pyranometer with shading ball for diffuse irradiance measurements (right).

Second method, from Meteorological satellites can also provide irradiance data. Half-hourly meteorological images are compared with clear sky pictures. The result is a cloud index for the whole satellite image. Finally, models that consider the position of the sun, water vapour and aerosols provide the reduction of the extraterrestrial irradiance on the way through the atmosphere. The annual accuracy of satellite measurements compared with ground measurements is not bad.

Table 2: Obtain 15' mean irradiance and irradiation from HelioClim-3.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Day</th>
<th>Time</th>
<th>Irradiance</th>
<th>Lower bound</th>
<th>Upper bound</th>
<th>Code</th>
<th>Top of Atmosphere</th>
<th>Clear-Sky Irradiation</th>
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<td>627</td>
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<td>760</td>
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</table>

Third method from web sites and The World Radiation Data Centre (wrdc-mgo.nrel.gov) and NASA surface meteorology resource website (eosweb.larc.nasa.gov/sse) offer additional global irradiance data. Finally, the European projects S@tel-light (http://www.satellight.com/) and SoDa (http://www.soda-is.com/) provide...
exhaustive data for Europe. With irradiance data that describe the availability of the fuel for solar systems, the planning and prediction of the energy yield of solar systems is possible. The research depends on the third method to get the irradiance value through this web site. http://www.soda-is.com/eng/about/instructions_for_use.html#pro.

Earth-Sun distance in astronomical units, is defined as an Astronomical Unit, which is approximately the mean distance between the Earth and the Sun (1 AU = 149,597,870.691 kilometers). It is a derived constant and used to indicate distances within the solar system. Since an AU is based on radius of a circular orbit. One AU is actually slightly less than the average distance between the Earth and the Sun (approximately 150 million km or 93 million miles). In this research, the satellite image data was taken at Julian day (191). It is between two main day sections (182,196), that means the Earth-Sun Distance in Astronomical units averaged between the two values, so it will be (1.0166) from(Earth-Sun Distance Hand back site) as shown in table (3).

Table 3: Earth-Sun Distance in Astronomical Units(Earth-Sun Distance Hand back site).

<table>
<thead>
<tr>
<th>Julian Day</th>
<th>Distance (Julian Day)</th>
<th>Distance (Julian Day)</th>
<th>Distance (Julian Day)</th>
<th>Distance (Julian Day)</th>
<th>Distance (Julian Day)</th>
<th>Distance (Julian Day)</th>
<th>Distance (Julian Day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9832</td>
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</tr>
<tr>
<td>15</td>
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<td>242</td>
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<tr>
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</tr>
</tbody>
</table>

But, we can get the Earth- Sun Distance in astronomical units value with higher accuracy by Solar Energy Services from this Professional site (http://www.soda-is.com/eng/about/instructions_for_use.html#pro ) as shown in table (4):  

Table 4: Earth-Sun Distance in Astronomical Units (http://www.soda-is.com/eng/about/instructions_for_use.html#pro).

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Day</th>
<th>Day in Year</th>
<th>Declination</th>
<th>Time Difference</th>
</tr>
</thead>
<tbody>
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<td>2004</td>
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<td>10</td>
<td>192</td>
<td>0.38687</td>
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<tr>
<td>2005</td>
<td>7</td>
<td>10</td>
<td>191</td>
<td>0.38742</td>
<td>0.98321</td>
</tr>
<tr>
<td>2009</td>
<td>7</td>
<td>10</td>
<td>191</td>
<td>0.38736</td>
<td>0.98321</td>
</tr>
</tbody>
</table>

After computing the previous parameters, the reflectance values were computed as shown in table (5).

Mathematical Model to Compute Nile River Depth:

The depth estimation method uses the reflectances, which were calculated from the radiances, these radiances were calculated with the sensor calibration files and corrected from the effective errors. ps is the surface reflectance of water is defined as:

\[ \rho_s(\lambda) = [\rho_b(\lambda) - \rho_w(\lambda)] e^{-2k(\lambda)} z + \rho_w(\lambda) \]  

(3)

Table 5: Obtained Radiances and Reflectances against Observed traditional technique points.

<table>
<thead>
<tr>
<th>DGPS Positions</th>
<th>Observed Depth</th>
<th>Radiances</th>
<th>Reflectances</th>
</tr>
</thead>
<tbody>
<tr>
<td>455372.71</td>
<td>2801146.2</td>
<td>15.64</td>
<td>0.293165</td>
</tr>
<tr>
<td>455375.09</td>
<td>2801144.3</td>
<td>15.42</td>
<td>0.27592</td>
</tr>
<tr>
<td>455494.95</td>
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<td>455004.54</td>
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<td>455265.48</td>
<td>2801767.1</td>
<td>-8.1</td>
<td>0.258675</td>
</tr>
</tbody>
</table>

Where:

pw , the deep water reflectance, pb ,seabed reflectance, k , attenuation coefficient, and z, depth In equation (3), ps is known, pw can be averaged under the region of interest(ROI) of deep water, pb doesn’t be known because the reflectance at the seabed equal zero, K is the attenuation coefficient of the river Nile(0.019) it was measured at Victoria lake and Z is the principle unknown. Z is derived from equation (3) as follow.
\[
[\rho_s(\lambda) - \rho_w(\lambda)] = [\rho_b(\lambda)] - \rho_w(\lambda) \cdot e^{-2k(\lambda)z} \quad (4)
\]

Divided by \([\rho_b(\lambda)] - \rho_w(\lambda)\):

\[
\frac{[\rho_s(\lambda) - \rho_w(\lambda)]}{[\rho_b(\lambda) - \rho_w(\lambda)]} = e^{-2k(\lambda)z} \quad (5)
\]

\[
Z = \frac{1}{-2k(\lambda)} \left( \ln \frac{\rho_s(\lambda)}{\rho_w(\lambda)} \right) \quad (6)
\]

\[
Z = \frac{1}{-2k(\lambda)} \left( \ln \frac{\rho_b(\lambda)}{\rho_w(\lambda)} \right) \quad (7)
\]

After Using the previous mathematical models and parameters, we get estimated depth as the following table (6):

**Table 6: Comparing between estimated depths and actual depths.**

<table>
<thead>
<tr>
<th>DGPS Positions</th>
<th>Observed Depth</th>
<th>Estimated Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>455328.83</td>
<td>2802632.2</td>
<td>1.04</td>
</tr>
<tr>
<td>455003.68</td>
<td>2803172.4</td>
<td>1.16</td>
</tr>
<tr>
<td>455042.17</td>
<td>2802989.8</td>
<td>1.19</td>
</tr>
<tr>
<td>455043.28</td>
<td>2802988.4</td>
<td>1.28</td>
</tr>
<tr>
<td>455007.84</td>
<td>2803184.2</td>
<td>1.37</td>
</tr>
<tr>
<td>455007.06</td>
<td>2803165.8</td>
<td>1.4</td>
</tr>
<tr>
<td>455039.39</td>
<td>2802993.2</td>
<td>1.46</td>
</tr>
<tr>
<td>455058.86</td>
<td>2802969.1</td>
<td>1.55</td>
</tr>
<tr>
<td>455373.66</td>
<td>2801145.4</td>
<td>15.79</td>
</tr>
<tr>
<td>455542.61</td>
<td>2801144.7</td>
<td>15.64</td>
</tr>
<tr>
<td>455375.09</td>
<td>2801143.2</td>
<td>14.63</td>
</tr>
<tr>
<td>455376.51</td>
<td>2801143.2</td>
<td>14.63</td>
</tr>
<tr>
<td>455363.68</td>
<td>2801153.4</td>
<td>13.47</td>
</tr>
<tr>
<td>455494.95</td>
<td>2800795.3</td>
<td>13.14</td>
</tr>
<tr>
<td>455376.51</td>
<td>2801142.3</td>
<td>14.63</td>
</tr>
<tr>
<td>455376.51</td>
<td>2801143.2</td>
<td>14.63</td>
</tr>
<tr>
<td>455363.68</td>
<td>2801153.4</td>
<td>13.47</td>
</tr>
<tr>
<td>455494.95</td>
<td>2800795.3</td>
<td>13.14</td>
</tr>
<tr>
<td>455021.13</td>
<td>2800776.2</td>
<td>13.20</td>
</tr>
<tr>
<td>455690.08</td>
<td>2800959.4</td>
<td>8.2</td>
</tr>
<tr>
<td>455289.04</td>
<td>2801127.6</td>
<td>9.5</td>
</tr>
<tr>
<td>455237.86</td>
<td>2801327.7</td>
<td>9.5</td>
</tr>
<tr>
<td>455265.48</td>
<td>2801767.1</td>
<td>8.1</td>
</tr>
<tr>
<td>455263.29</td>
<td>2802165.7</td>
<td>6.9</td>
</tr>
</tbody>
</table>

At a study area the differences between the observed depth and the estimated depth ranges from 0.05m to 2.39 m with mean value of 1.42 m, and standard deviation of 1.346 m for estimated depth and 1.324 m for actual depth.

**Conclusion and Recommendation:**

- The research confirmed on using the new technique in calculating the depths of the river Nile because it is very cheap, has high accuracy and easily applied on the mathematical model.
- The degree of success was proven largely depending on comparability of images in terms of spatial and spectral resolution. The geo-eye multi-spectral band satellite images used in this study are compatible in spectral resolution for estimated depths. The resultant water depths had good standard deviation.
- On applying the mathematical model of the reflectance, we noticed that, it contains parameters such as Mean solar Exoatmospheric irradiances, Earth-Sun distance and the attenuation coefficient almost have observed values, so we calculated these parameters with more than one method to get highly accurate estimated depths.
- It was noticed that the radiance values used in the mathematical model were corrected from the effective factors, such as the atmospheric effect, the sun glint and the water column (green algae and planktons).
- With reference to the mathematical model for calculating the depths, we found that it is Function in attenuation coefficient for the water of the river Nile, the closest value of the attenuation coefficient was used for the study area, it was Lake Victoria.

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