Tabor Reedy
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Satellite Mapping of Environmental Warfare in the Persian Gulf, 1991

ABSTRACT

During the Persian Gulf War in 1991 Iraqi military forces released large amounts of crude oil into the Persian Gulf affecting nearly 400 miles of coastline in Saudi Arabia and Kuwait. This study focuses on distribution of a major oil slick in Ad Daffi Bay on March 4th 1991. Landsat Thematic Mapper bands of 30 meter pixel size are used to identify the spatial distribution and quantify the amount of oil contaminating Ad Daffi Bay. Thematic Mapper bands 4 and 5 in the near and mid infrared provided distinct spectral signatures for oil, land, and water. Using a mask of band 4 and density slice of band 5 a thematic map is created showing primary distribution in the north east of the bay and along the eastern shores. A rough estimate of approximately 500 hectares of oil spilled is the best this approach can achieve without higher spatial resolution or statistical definitions of density slice ranges.

METHODS

In order to address the spatial extent of the oil spill we observed Landsat Thematic Mapper (TM) imagery bands on a subset of a larger Landsat image focused on Ad Daffi Bay in the Persian Gulf. Imagery bands 1, 2, and 3 (TM1, TM2, TM3) are all part of the visible spectrum, band 4 (TM4) is part of the near infrared, bands 5 and 7 (TM5, TM7) are in the mid-infrared, and band 6 is in the thermal infrared. The Landsat imagery bands have a spatial resolution of 30x30 meters. (Wallin, 2015). After initial exploration of the data set using bands in the visible spectrum I explored the area with the other bands to differentiate oil from water. TM5 appears to me best suited for this purpose.

Using TM5 in grayscale, I attempt to differentiate between land, oil, and water, which all reflect the mid-infrared differently. Using the distribution of reflectance values I create a thematic map using a technique called density slicing, where the range of values is arbitrarily divided with a different color assigned to each interval (Campbell, 2011).

To explore ways to differentiate between oil and land we use TM4. TM4 distinguishes between land and liquid well and is used as per lab instructions to create a mask (Wallin, 2006). I use a reflectance value of 17 to distinguish between land and water in TM4, leaving only water and land. With this mask applied over the TM5 image, I reclassify the reflectance values into a new density slice. The new density slice is applied to the TM5 band to show a new image of oil, land, and water classification. Cell statistics tell us the number of cells in each density slice, allowing us to generate areas of oil spill.

RESULTS

Initial exploration Ad Daffi Bay using multispectral data showed that TM5 in the mid-infrared differentiated between water and oil well (Fig. 1). Gray scale of TM5 shows only the reflectance values for TM5 and represents the whole range of reflectance values in the area (Fig. 2). The distribution of reflectance values is represented in Figure 3. Spectral distribution for the first density slice is water 0-25, light oil 26-40, heavy oil 41-59, and land 60-250. Initial results shows a large distribution of heavy oil contamination in the southern part of the map, and throughout areas known to be land in Figure 1 (Fig. 4). Seeking a more accurate result, near infrared band TM4 is to create a land mask, yielding an area resembling the known landmass in Figure 1 (Fig. 5). Using the mask in Figure 2 and a density slice distribution where land is 0-0 and 60-250, water is 1-25, light oil is 26-40, and heavy oil is 41-59, a more accurate map is generated showing less oil contamination and less distribution than Figure 4. Calculations yield areas of oil contamination approximately 7 times lower in the more accurate masked density slice (Table 1).

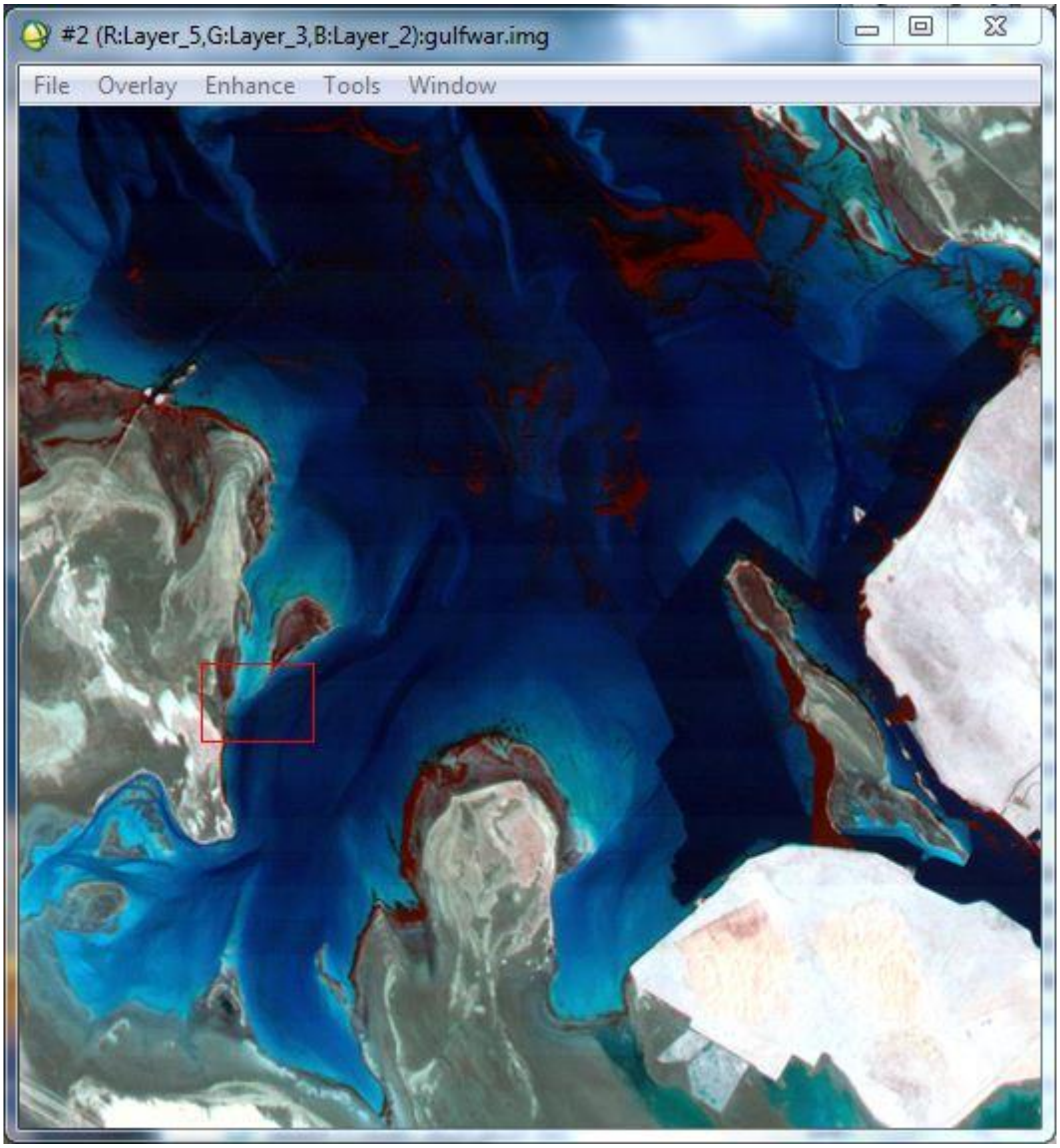

Figure 1. False color image of Ad Daffi Bay with TM5 symbolized in red to show contrast between oil and water. Red represents reflectance in the mid-infrared, which is only weakly reflected by water and is strongly reflected by oil.

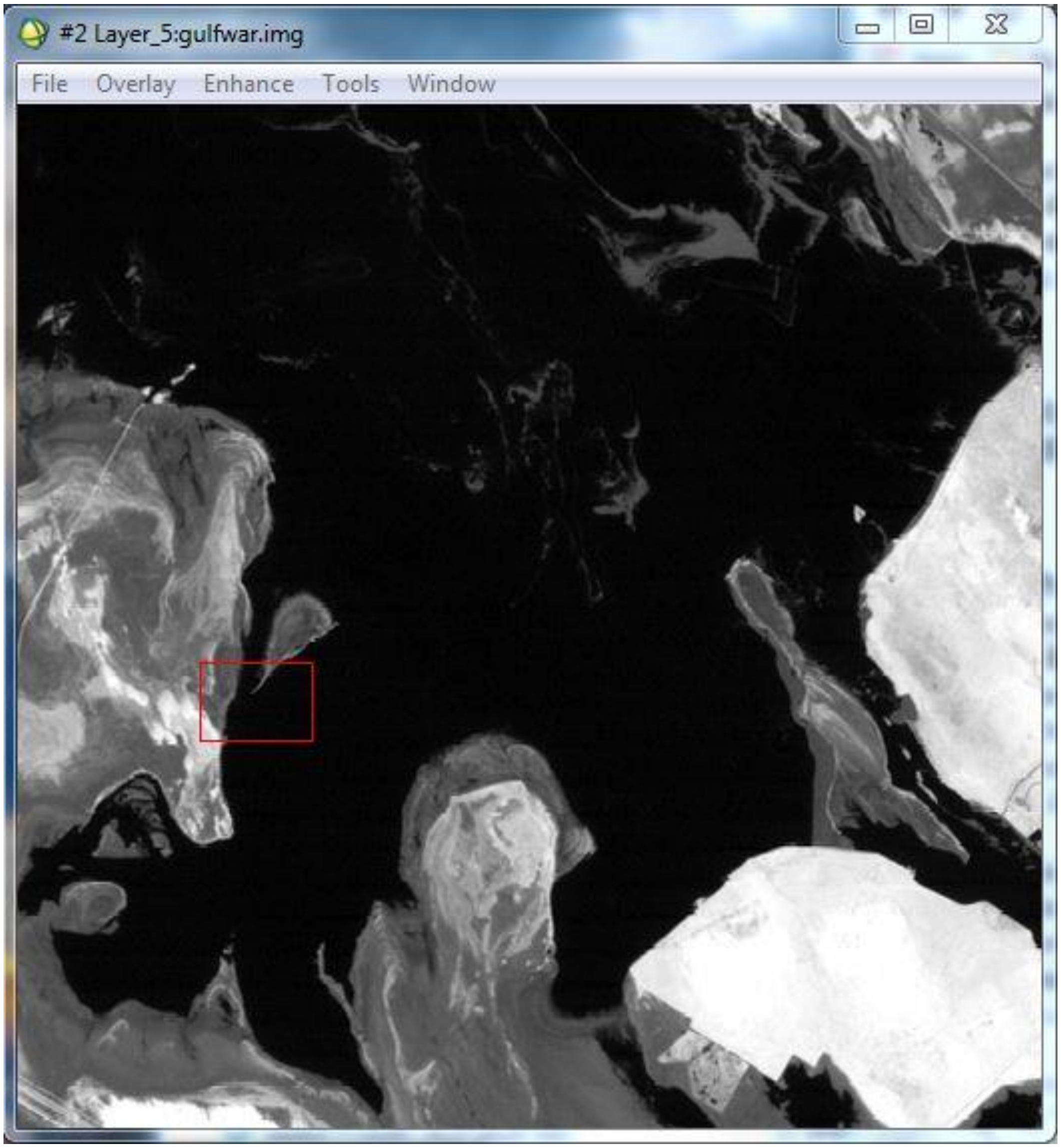

Figure 2. TM5 in grayscale shows the distinction in reflectance values between oil, which appears lighter gray, and water, which appears black. Oil appears primarily in the north east part of the map area.

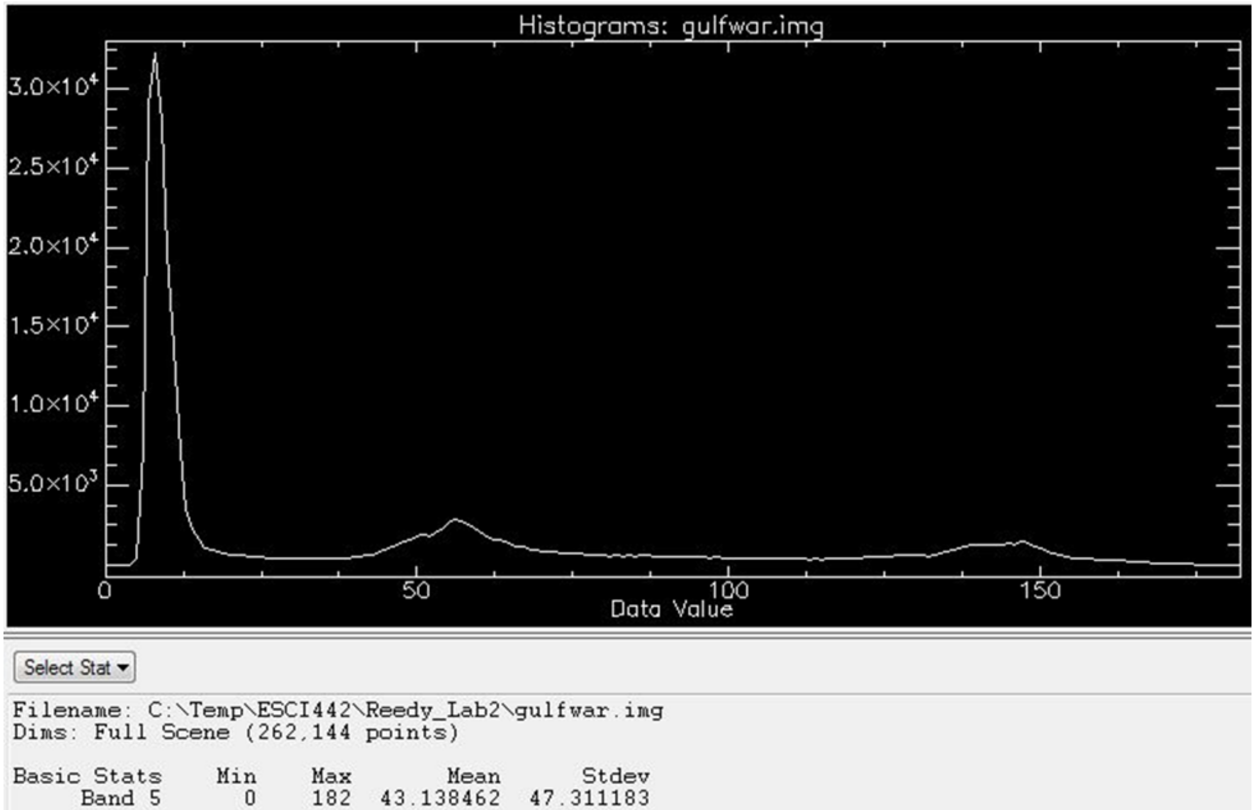

Figure 3. The distributions of reflectance values in TM5. The x-axis "data value" is reflectance and the y-axis is the number of pixels with that value. Low reflectance values correspond to the darker areas of Figure 3, and higher reflectance values are the lighter areas. Peaks from left to right represent water, oil, and land. The designation of peaks is corroborated by the point values in each peak that correspond to water, land, and oil in Figure 1.

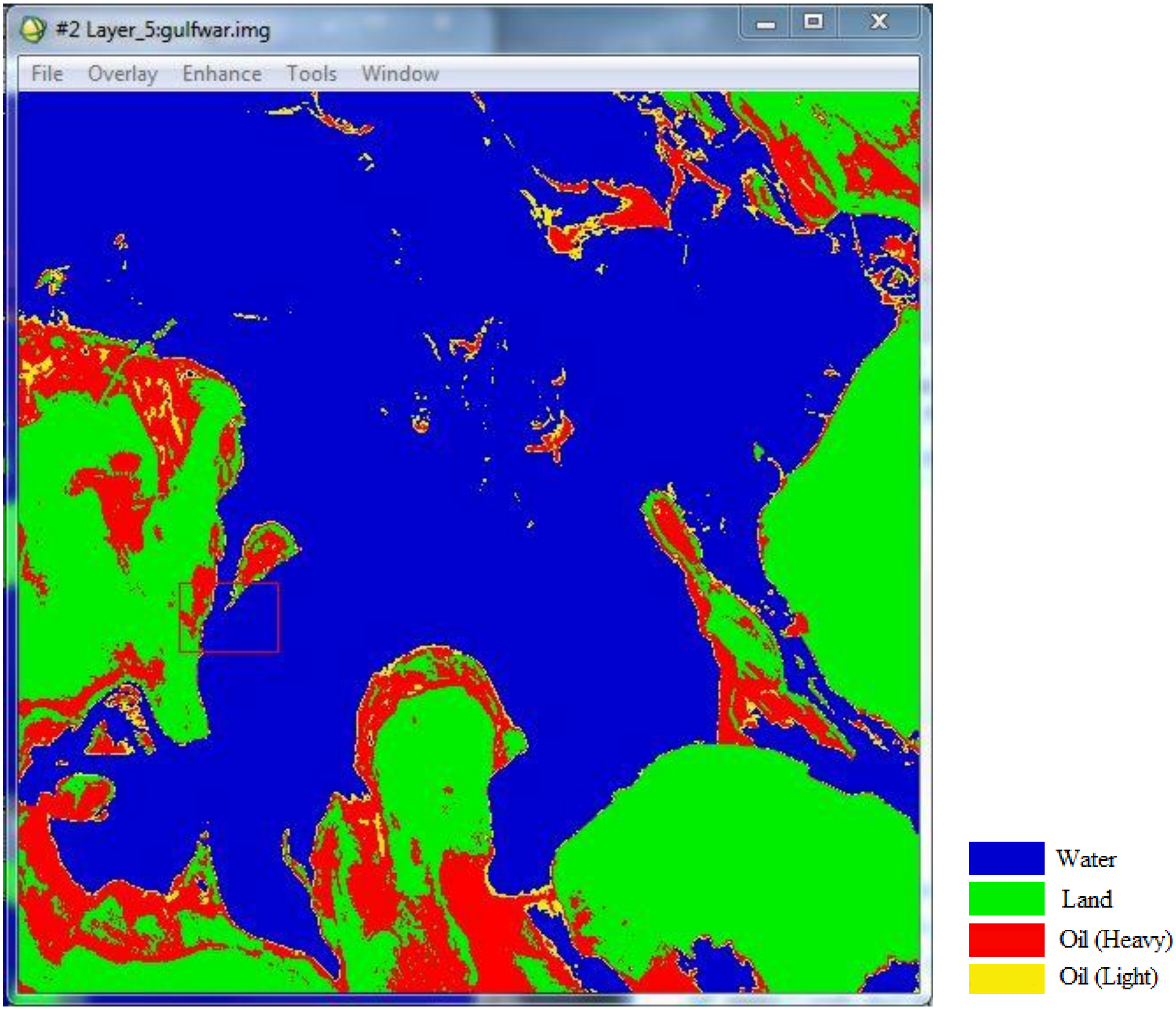

Figure 4. Density slice classification of Ad Daffi Bay, Persian Gulf. Green areas represent land, blue represents water, yellow represents light oil, and red represents heavy oil. Density slice based on reflectance distributions in Figure 3. Areas designated as land in Figure 1 appear to be classified as heavy oil based on their reflectance of TM5.

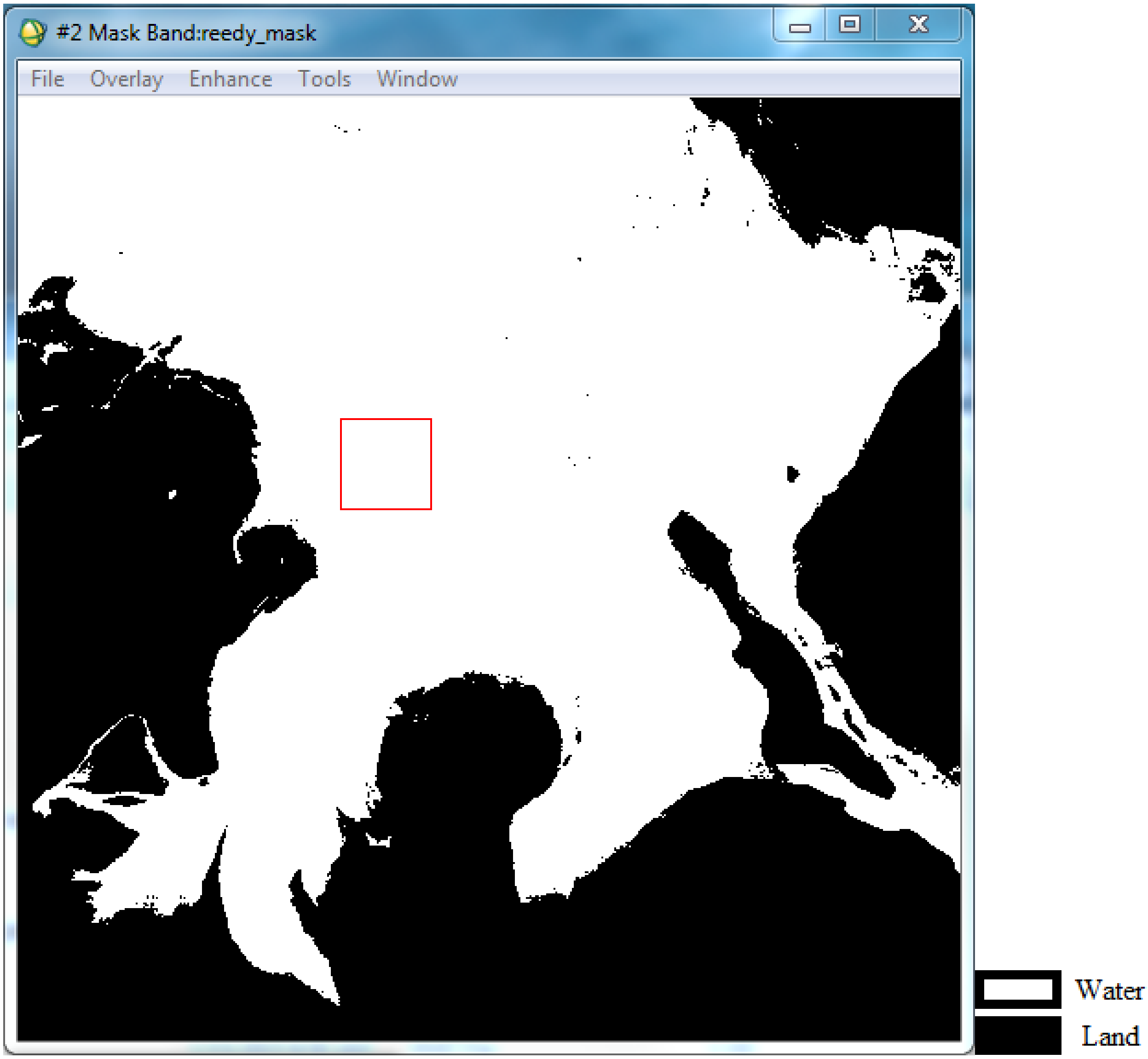

Figure 5. Mask covering land in Ad Daffi Bay, Persian Gulf. The mask is based on reflectance values in TM4 which is useful for differentiates land from water. 0 Values are black and correspond to land. Values of 1 are white and correspond to water and oil.

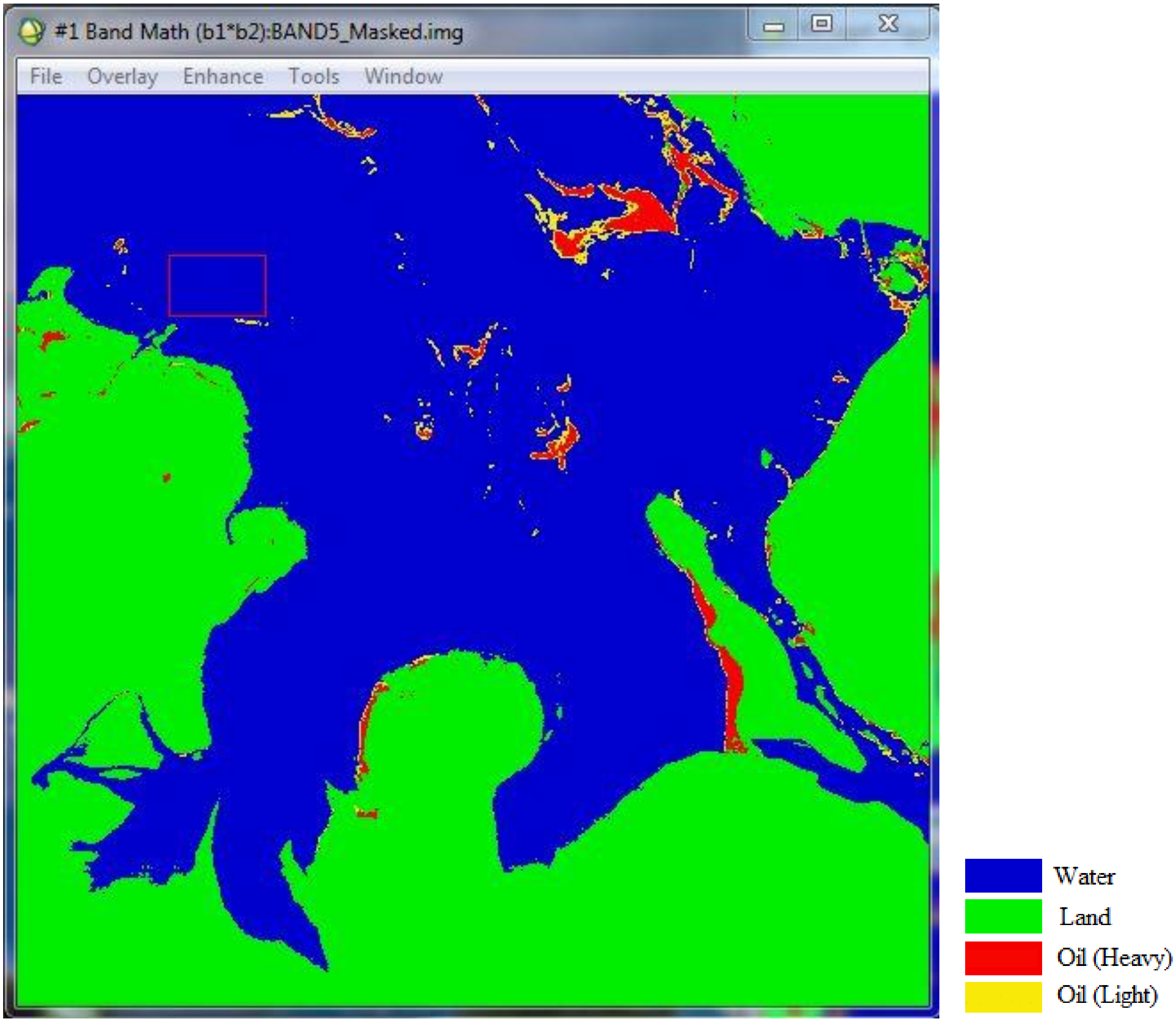

Figure 6. Masked and reclassified density slice classification of Ad Daffi Bay, Persian Gulf. Density slice based on the distribution of values in Figure 3, and the mask in Figure 5. Green areas represent land, blue represents water, yellow represents light oil, and red represents heavy oil. Larger areas in the southern portion of the map are green now after using the mask.

Table 1. Cell Calculations for both the unmasked and masked density slice of TM band 5 in the mid-infrared. Each pixel is 30 meters by 30 meters corresponding to 900 square meters. This allows for a calculation of total area of contamination for Ad Daffi Bay, Persian Gulf.

Cover (Masked)	# Pixels	Area (m^2)	Area (km^2)	Area (Hectares)
Land	118436	106592400	106592.4	10659.24
Water	138168	124351200	124351.2	12435.12
Oil (Light)	2609	2348100	2348.1	234.81
Oil (Heavy)	2931	2637900	2637.9	263.79
Cover (Unmasked)				
Land	73042	65737800	65737.8	6573.78
Water	151311	136179900	136179.9	13617.99
Oil (Light)	6179	5561100	5561.1	556.11
Oil (Heavy)	31612	28450800	28450.8	2845.08

DISCUSSION

The difference of TM5 mid-infrared reflection values between oil and water generally validates this methodology. Ambiguity in reflectance values between parts of land and oil leads to erroneous calculations of area and distribution shown in Figure 4. Understanding the multispectral capabilities of Landsat data allowed for the use of the near infrared TM4, which shows little variation between water and oil, but differentiates well between water and land (Baumann, 2001). Creating a land mask using TM4 which is applied to Figure 2 with a new density slice yields Figure 6, a more accurate depiction of oil distribution.

By relying on human judgment and not statistical techniques to separate density slices in TM5 and the separation between and land water in TM4, error is automatically included in the result. A cell resolution of 30x30 meters also reduces the amount of “light” oil that is not registered easily at this cell size. Using a higher spatial resolution IKONOS type image, or low elevation drones with high spectral resolution would increase the accuracy and validity of this methodology. We also assume that any spectral signal received as oil originates from the current spill and not a previous spill, as it is known that this area commonly functions as a trapping and blocking area for oil flow (Baumann, 2001).

Moderate resolution imagery like Landsat is good for a rough estimate of amount and distribution of oil spilled, especially without using statistical techniques for density slicing. The approach is valid, and overall the study is a success, however there is much room for refining the accuracy of both area and distribution.

LITERATURE CITED

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