

*Supplementary Information*

## **Using the Normalized Difference Water Index (NDWI) within a Geographic Information System to Detect Swimming Pools for Mosquito Abatement: A Practical Approach. *Remote Sensing* 2013, 5, 3544–3561**

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### **1. Introduction**

The goal of the main paper was to “...develop an efficient procedure that would allow a GIS technician to integrate remote sensing, and its capability of detecting surface features, with a GIS, and its capability to spatially analyze data, to identify swimming pools that may not be properly maintained, and therefore, potentially capable of providing habitat for mosquitoes to breed.” The purpose of this supplemental information is to provide a more concise step-by-step instruction of the procedure that was undertaken in the present study. The instructions pre-suppose that ArcGIS® (ESRI Redlands, CA, USA) is the software package used for the analyses, however, there are other GIS software packages that may serve equally as well.

### **2. Application of Normalized Difference Water Index (NDWI)**

#### *2.1. Data Preparation*

##### **2.1.1. Land Parcel Shapefile**

So that locational errors may be minimized, all necessary shapefiles should be acquired and projected to a common projection and datum. A data layer consisting of the boundaries of land parcels must be included in those used in the analyses as it is the most important vector file. The land parcel data layer that was used in the present study lacked a polygon that defined the city right-of-way and which includes roads and sidewalks, and the medians that lay between them [1]. It was necessary to create one by first creating a single polygon that comprised an outer boundary of the land parcel layer, and then merge the two layers. This is required for the zonal statistical analysis, and pixel comparisons, that would be performed later in the procedure. The attribute table should now be edited so that a numeric data field may be created and the records populated with a unique integer value. The feature

identification (FID) in an ArcGIS® attribute table may be used as the source of the number in the new data field. Other software packages may have their own means to generate such a number. Another data field to represent the presence, or absence, of a swimming pool should be added to the attribute table. The population of the records of this data field may be accomplished in many ways. The analyst may have access to a shapefile with the location of swimming pools. There may also exist a database of such information derived from building permits and which would be relatable to the parcel by address, or by the Assessors Parcel Number. The analyst may make direct observation using available high-resolution imagery acquired by aircraft, or by using GoogleEarth® (Google Inc., Mountain View, CA, USA), and the included viewing feature, Historical Imagery® (Memphis, TN, USA). The analyst may employ a combination of all of these, or similar, options.

### 2.1.2. High Resolution Image Data

The high resolution, multispectral imagery must be imported into a format that is usable by the software. The methods vary depending on the software and the reader is directed to follow the instructions included with their software as to how this may be achieved. The unprocessed image data should be geo-referenced to the land parcel layer to minimize positional error. The geo-referenced image data should be converted into top-of-atmosphere (TOA) spectral reflectance using procedures detailed by the image data supplier. This step includes the conversion of raw data to TOA spectral radiance and then converting the spectral radiance into spectral reflectance. Both operations may be accomplished at the same time depending on the software being used. All output files should be formatted as 32-bit, floating point, as an integer format will result in values of zero in the final output. The NDWI is then calculated using Equation (1):

$$NDWI = \frac{(Band\ 2 - Band\ 4)}{(Band\ 2 + Band\ 4)} \quad (1)$$

where Band 2 is the TOA green light reflectance and Band 4 is the TOA near-infrared (NIR) reflectance, and the output file should also be formatted as 32-bit, floating point [2].

## 2.2. Data Processing: Isolation of Water Pixels within Parcels

Because mixed pixels comprised of water and pool decking, and other surfaces, exist in the backyards of residential parcels, it is desirable to isolate only the pixels comprised of water surfaces. This is done to minimize errors of commission that may be attributed to mixed pixels around swimming pools and other low reflectance targets. Only those pixels having the highest NDWI values within the parcel would be later used to select residential parcels with detectable water.

### 2.2.1. Generation of Zonal Maximum Normalized Difference Water Index (NDWI) Within Parcels

The first step is to create a raster grid file within the boundary of the residential parcels comprised of the maximum NDWI within a given parcel. The Zonal Statistics tool in ArcGIS® calculates the statistics on values within zones of another vector- or raster-based dataset. The tool inputs include: the land parcel vector data layer which is used as the “feature zone data”, the unique parcel ID generated in section 2.1.1. which is used as the “zone field”, the NDWI raster file is used as the “input value

raster”, the output raster name is determined by the analyst, and should be a 32-bit floating point file, and the “statistics type” should be set as “Maximum”. The output will be a grid file comprised of cells whose values are the maximum NDWI that was determined to exist within the boundary of each parcel.

### 2.2.2. Determination of Threshold Values for Normalized Difference Water Index (NDWI)

The next step is to determine what, if any, threshold value needs to be applied to the NDWI so as to eliminate those non-water surfaces which may have low reflectance, and possibly positive NDWI values, from further analysis. The analyst should compare the NDWI image with high-resolution imagery to make this determination. In the present study, rooftops had low, but positive NDWI values, and this necessitated thresholding the NDWI to eliminate them.

### 2.2.3. Isolation of Maximum Normalized Difference Water Index (NDWI) Pixels within a Parcel

The isolation of the purest water pixels within the parcels is accomplished by using one, or more, conditional statements that would both threshold the NDWI (if needed) and eliminate pixels below the threshold value. The Raster Calculator tool in the Math Toolset of Spatial Analyst® (ESRI, Redlands, CA, USA) may be used to implement both the thresholding, and the pixel-by-pixel comparison, by using an expression similar to that shown in equation (2) that employs the conditional test expression “Con” with the threshold set to 0.3 for the present study.

$$\begin{aligned} binNDWIMax &= Con((Con(NDWI \geq 0.3, NDWI, -10)) \\ &== "Zonal Max - NDWI", 1, 0) \end{aligned} \quad (2)$$

The use of the tool causes each grid cell of NDWI to be compared to 0.3. If the NDWI value is equal to, or greater than 0.3, then the cell is unchanged, but if it is not, then a value of -10 is assigned to it, and carried to the next element of the expression. If the cell is exactly equal to the zonal maximum value of NDWI found within the parcel, then a value of one is assigned to the output grid cell, if it is not, then a value of zero is assigned. The result of this procedure is a binary file identifying the pixels containing the highest NDWI value within each of the parcels and isolating it from all other pixels.

### 2.3. Identification of Residential Parcels with Swimming Pools but No Surface Water Present

This step in the procedure begins by ensuring that the attribute table of the land parcels layer contains a data field that identifies the property zoning (e.g., single-family residential, commercial, etc.) as this will be used to limit the examination to only residential parcels that may have unmaintained swimming pools. This information may already be present in the attribute table, but if it is not, then it must be determined from other sources. Parcels with apartment complexes may be zoned as “high-density”, or “multi-family”, and may be excluded from further study as previously discussed in the main paper. If such a data field does not already exist, it may be necessary for the analyst to create a data field and to populate that data field with the necessary information to identify parcels that have been zoned for low- or medium-density residential use. Once this task has been accomplished, the binary grid file of maximum NDWI must now be converted into a vector-based file using an appropriate tool in the GIS software. In ArcGIS® the Raster to Polygon tool is used and the “Simplify

Polygon” option is deselected so as to maintain the proper shape of the pixels. Next, the analyst selects the polygons in the vectorized maximum NDWI file with a polygon value equal to one. The attribute table of the vectorized maximum NDWI file is then edited, and a numerical data field labeled “DETECTED” is added. The view of the attribute table should be switched so as to display only the polygons of water. A value of one is assigned to the records of the selected polygons in the data field that is labeled “DETECTED”. Once this has been done, the analyst may clear all selections. The attribute table of the land parcel layer may now be queried to select only those parcels that are zoned for low- or medium- density residential use, and which are known to have swimming pools. The analyst may now remove from the selection, those parcels which a value of one in the “DETECTED” field. The remaining parcels are those that are known to have swimming pools, but the presence of which was not detected. If the backyards of those parcels are not obscured by vegetation, then those parcels are presumptively judged to have swimming pools that are capable of providing habitat for mosquitoes to breed, and thus warrant field investigation. It would be most helpful if the land ownership, including the parcel address, of the remaining parcels could be ascertained. Such information would allow for a list of addresses to be created and then distributed to field technicians for inspection.

### **3. Discussion**

The procedure was designed to be a straightforward means to identify residential parcels that may have empty, or near empty, swimming pools which may provide habitat for mosquitoes to breed. It should be noted that not all software packages, capable of performing the previously described procedure, were evaluated to determine the ease with which they may be used for such a purpose. Although high-resolution, multi-band satellite imagery from the DigitalGlobe® satellite QuickBird was used quite effectively in the present study, there is nothing to suggest that similar results, using data from other image sources, could not be realized. It is the author’s hope that this procedure will be an effective tool in mosquito abatement.

### **4. Conclusions**

The procedure previously detailed is an efficient means by which a GIS technician could identify residential parcels that are known to have swimming pools, but which cannot be detected using a water detection index. The identification of such swimming pools is important as they may provide habitat for mosquitoes to breed.

### **Conflict of Interest**

The author declares no conflict of interest.

### **References and Notes**

1. Woodcock, K. Personal Communication. 14 December 2012.
2. McFeeters, S.K. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *Int. J. Remote Sens.* **1996**, *17*, 1425–1432.

3. California Department of Public Health (CDPH). California Mosquito-Borne Virus Surveillance & Response Plan. Available online: <http://www.cdph.ca.gov/HealthInfo/discond/Documents/2013CAResponsePlan.pdf> (accessed on 10 April 2013).

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