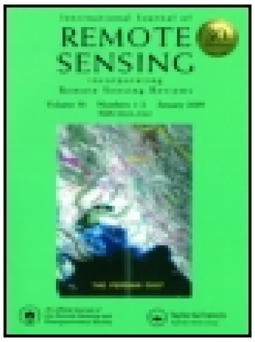

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The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features

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Abstract. The Normalized Difference Water Index (NDWI) is a new method that has been developed to delineate open water features and enhance their presence in remotely-sensed digital imagery. The NDWI makes use of reflected near-infrared radiation and visible green light to enhance the presence of such features while eliminating the presence of soil and terrestrial vegetation features. It is suggested that the NDWI may also provide researchers with turbidity estimations of water bodies using remotely-sensed digital data.

1. Introduction

The assessment of water resources, both in terms of quantity (e.g., surface area) and quality (e.g., turbidity) is a goal often sought by researchers. Various methods of analysing remotely-sensed data have been used by researchers to achieve this goal (Work and Gilmer 1976, Lathrop and Lillesand 1986, Han *et al.* 1994). This letter introduces the Normalized Difference Water Index (NDWI) as a new method for analysing data for water resource assessment.

2. Review of water delineation and enhancement methods

There are several methods that may be used to delineate open water features and enhance their presence in remotely-sensed image data. The methods include, but are not necessarily limited to, those that make use of: (1) reflected solar radiation; (2) emitted thermal radiation; and (3) active microwave emission (Paris 1992). The methods using reflected solar radiation have been implemented for the longest period of time. Researchers using methods involving reflected solar radiation have used either a single band, or a ratio of two bands of data to delineate open water features and enhance their presence in imagery.

The single-band method makes use of digital data or photographic products of reflected near-infrared radiation (NIR) (Work and Gilmer 1976, White 1978, Rundquist *et al.* 1987). This approach has been used because NIR is absorbed strongly by water and is reflected just as strongly by terrestrial vegetation and dry soil. Digital or photographic products derived from NIR data show vegetated surfaces as being white, while water surfaces appear dark (figure 1). Where digital data are used, it may be advisable to convert raw digital numbers to values of radiance or reflectance for comparison to other data sets (Markham and Barker 1986). The frequency distribution, relating the occurrence of such reflectance values of reflected NIR from a digital data source, is used to delineate land from water features (figure 2). This method assumes that occurrences of low reflectance values are associ-

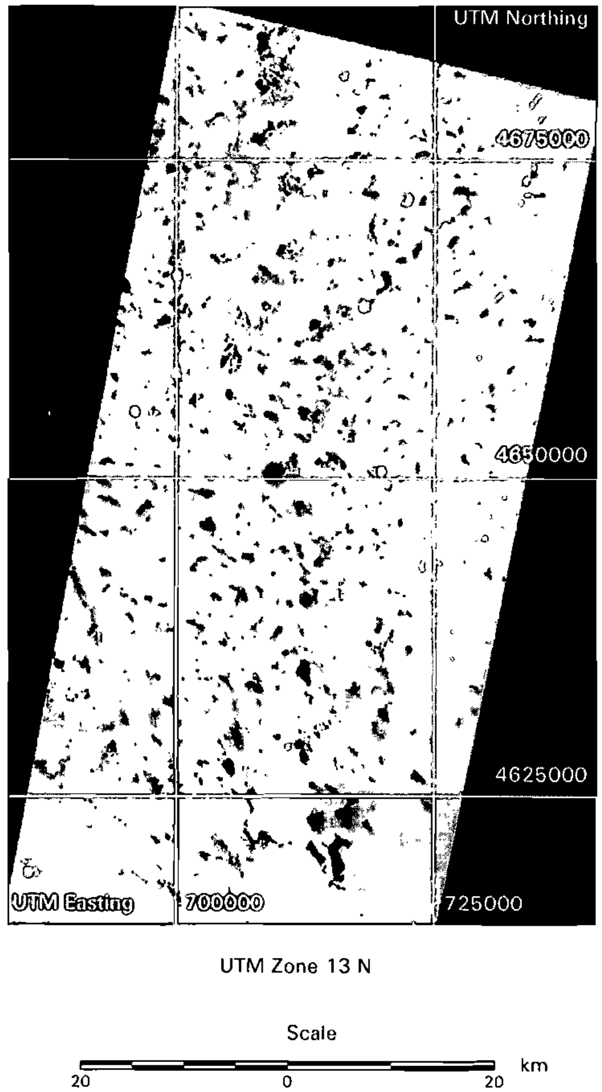

Figure 1. Landsat MSS Band 4 (reflected NIR) image of a portion of the Sandhills region of Western Nebraska, U.S.A. The irregularly-shaped black features are primarily lakes (both freshwater and alkaline). The circular white features are crops irrigated by centre-pivot irrigation systems. The image was acquired by the satellite on 7 May 1987.

ated with the presence of water owing to the low reflectance of NIR by water; high reflectance values are associated with soil and terrestrial vegetation features because of their typically higher NIR reflectance. This procedure may introduce error through:

(1) The analyst deciding which digital numbers would be associated with water and which would not (moist, bare soil could be mistaken for turbid water). This may result in an over- or under-estimation of open water surface area; and
(2) Different analysts not interpreting imagery in the same manner. Such a condition could suggest change where there may be none taking place, except perhaps in the changing of data analysts.

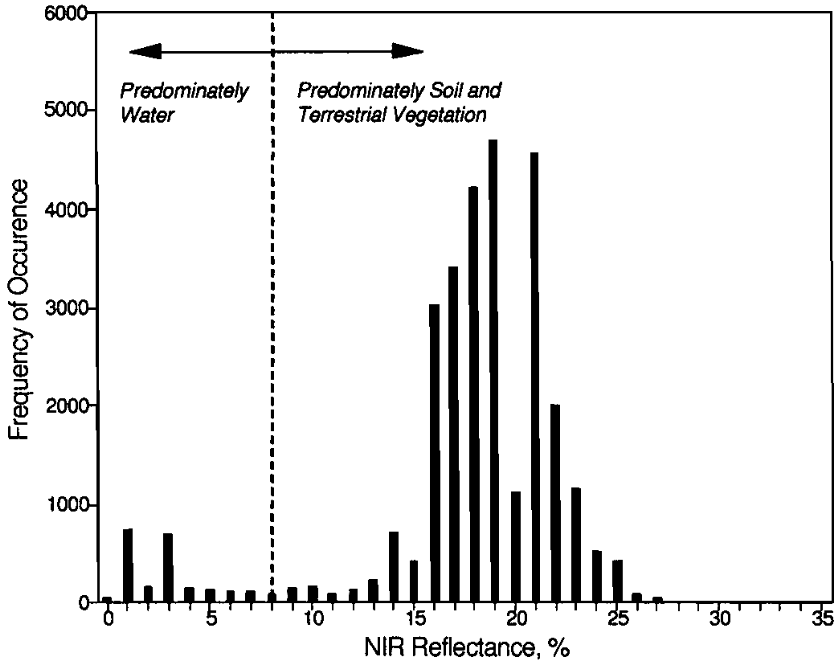

Figure 2. Frequency distribution of NIR reflectance (in per cent) for a typical area surrounding and including several lakes within the region delimited by figure 1.

The band-ratio method takes advantage of the differences in the reflectance of different wavelengths of light off any given surface. In this approach, a multispectral image is used to provide the source data (figure 3). The response from a visible band, such as green or red, is divided by a NIR band response (Boland 1976). The presence of terrestrial vegetation and soil features (which typically have much higher NIR reflectances than open water) is suppressed; the presence of open water features (which typically have a very low NIR reflectance) is enhanced. This is an improvement over the previous method because the delineation between water and non-water (soil and terrestrial vegetation) features is more pronounced (figure 4). The limitation of this approach is that the non-water features in the image have been suppressed, but not eliminated. Elimination of the soil and terrestrial features would facilitate the delineation of open water. The Normalized Difference Water Index (NDWI) has been developed to achieve this goal.

3. Proposed new method—the Normalized Difference Water Index (NDWI)

The assessment of above-ground biomass and primary productivity has been made by researchers using an index called the 'Normalized Difference Vegetation Index' (NDVI) (Townshend and Justice 1986, Tucker and Sellers 1986). The index takes advantage of the condition where the presence of features that have higher near-infrared reflectance and lower red light reflectance (e.g., terrestrial vegetation) will be enhanced, while those with low red light reflectance and very low NIR reflectance (e.g., water) will be suppressed or even eliminated. The index can be derived from data supplied from ground-based, airborne, or satellite platforms that have sensors recording reflected red light and near-infrared radiation (Jensen 1986).

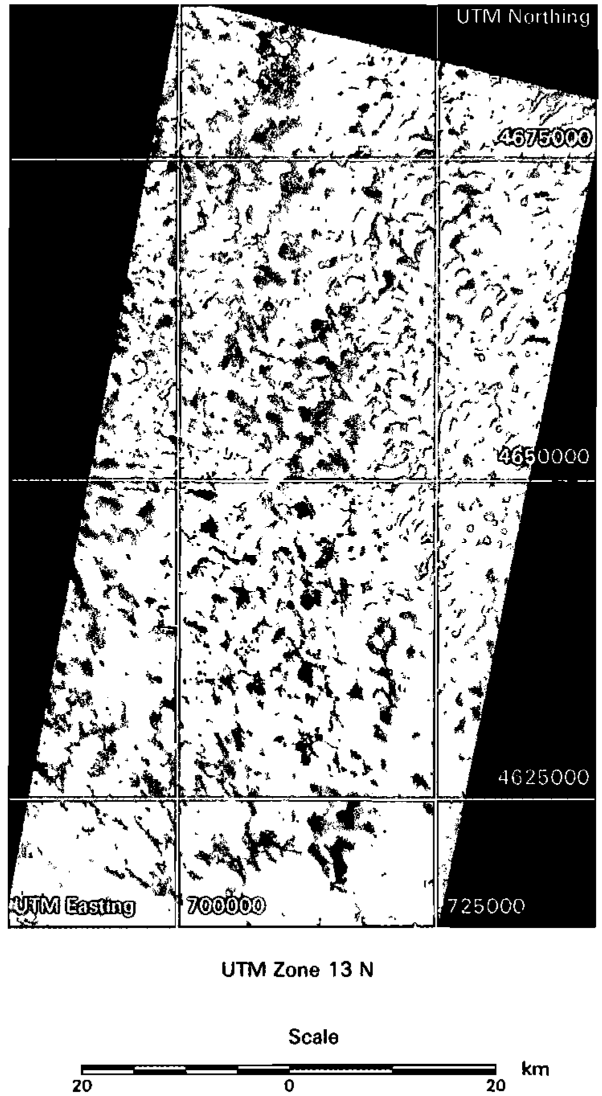

Figure 3. Landsat MSS image of the Sandhills region for 7 May 1987 using bands 4, 2, 1 (RGB).

The index is calculated as follows:

$$\frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})} \tag{1}$$

The results of the index can range from -1 to $+1$. Vegetated surfaces tend to have positive values, bare soil may have near zero, and open water features have negative values. This procedure is satisfactory when the desired goal is to assess above-ground biomass because the presence of vegetation is greatly enhanced, but does nothing to provide information regarding open water. If, however, the variables in the numerator of equation (1) were reversed, and the green band were used instead of the red band, the desired goal of enhancing only the water features would be achieved. The NDWI is proposed as such a method to achieve this goal.

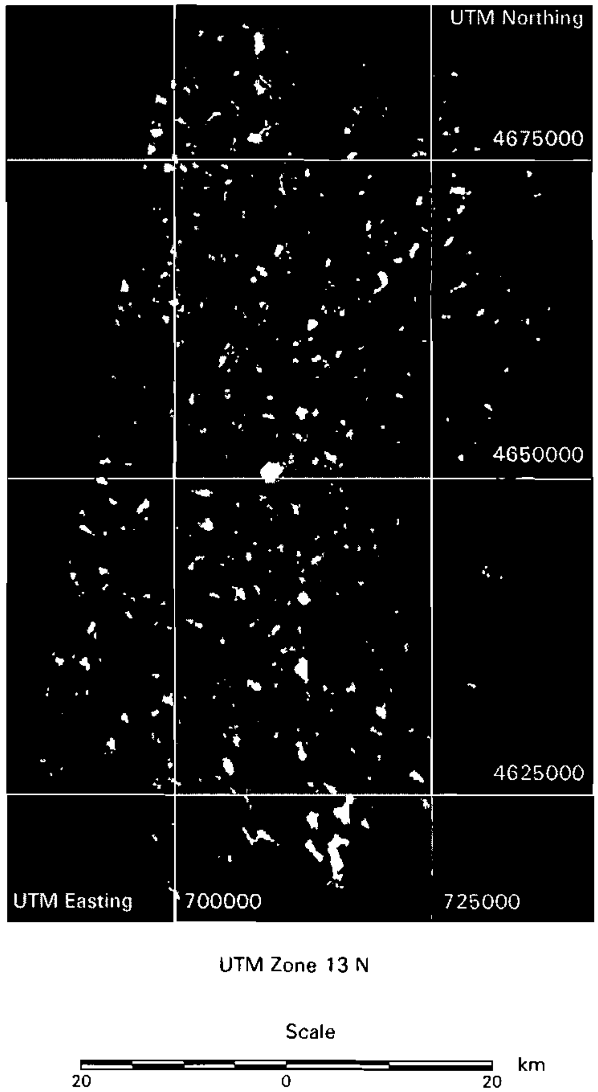

Figure 4. Band Ratio Image ([Green/NIR] × 100) of the region delimited by figure 1.

The NDWI was derived using principles similar to those that were used to derive the NDVI. The NDWI is calculated as follows:

$$\frac{(\mathrm{GREEN} - \mathrm{NIR})}{(\mathrm{GREEN} + \mathrm{NIR})} \tag{2}$$

where GREEN is a band that encompasses reflected green light and NIR represents reflected near-infrared radiation. The selection of these wavelengths was done to: (1) maximize the typical reflectance of water features by using green light wavelengths; (2) minimize the low reflectance of NIR by water features; and (3) take advantage of the high reflectance of NIR by terrestrial vegetation and soil features. When equation (2) is used to process a multispectral satellite image (figure 3) that contains a reflected visible green band and an NIR band, water features have positive values;

while soil and terrestrial vegetation features have zero or negative values, owing to their typically higher reflectance of NIR than green light. Image processing software can easily be configured to delete negative values. This effectively eliminates the terrestrial vegetation and soil information and retains the open water information for analysis. The range of NDWI is then from zero to one. Multiplying equation (2) by a scale factor (e.g., 255) enhances the resultant image for visual interpretation (figure 5).

4. Water quality applications

Researchers have investigated many aspects of water quality (including turbidity) using several methods (Lathrop and Lillesand 1986, Ritchie *et al.* 1990, Bhargava

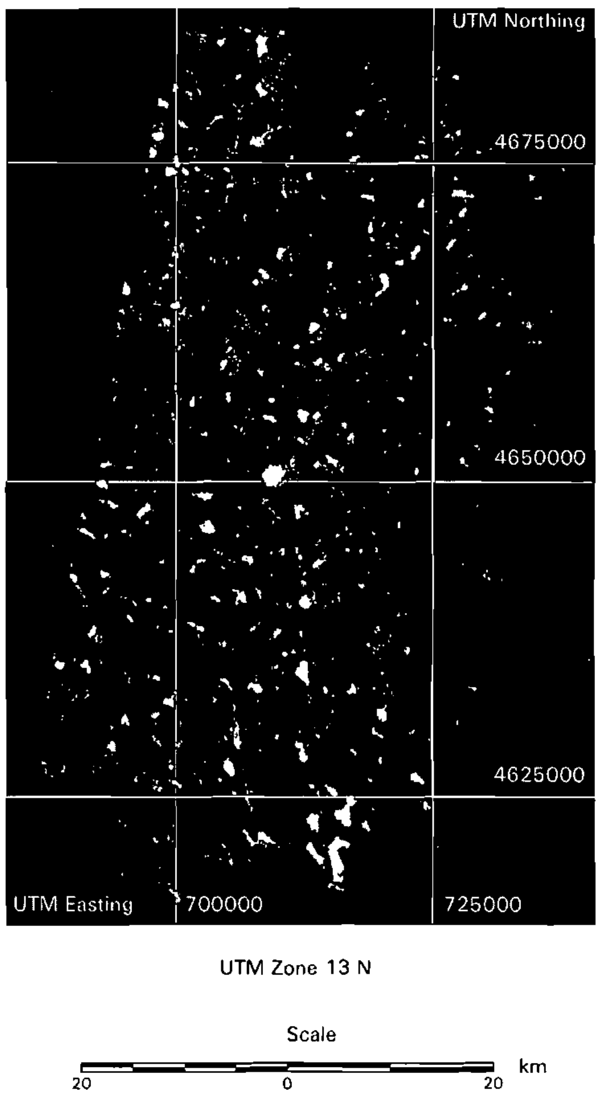

Figure 5. Binary image of region enhanced by the Normalized Difference Water Index [(Green − NIR)/(Green + NIR)] × 255. Open water features are white; soil and terrestrial vegetation features are black.

and Mariam 1992, Han and Rundquist 1994, Han *et al.* 1994). In addition to methods that have already been used in such research, it is proposed that the NDWI may prove useful as another method by which researchers can study aspects of water quality.

Although its broad-band approach may prevent its being able to provide estimations of the proportion of (for example) suspended sediments and chlorophyll *a* within a water body, it is believed that the NDWI may provide an assessment of overall turbidity. Since the NDWI is derived by the same method as the NDVI, it is suggested that the limitations inherent in the former should be similar to those inherent in the latter. This suggestion is made because although the terrestrial NDVI can provide an estimation of above-ground biomass, it cannot provide a discrimination of specific plant species. Therefore, although the NDWI may not be able to distinguish between suspended sediments and chlorophyll *a*, it may provide information regarding the overall turbidity (an aquatic analogue to above-ground biomass).

5. Summary

The NDWI is a new method that has been developed primarily to delineate open water features and to enhance their presence in remotely sensed digital imagery while simultaneously eliminating soil and terrestrial vegetation features. Rapid and efficient estimation of open water surface area in such digital imagery can then be made using image processing software. Additionally, the NDWI may prove to be a useful tool in the study of water quality issues, particularly with regard to turbidity estimations. Further research is needed to investigate the utility of this index in the assessment of water resources both with regard to the quantity and also the quality of such resources.

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