Spectral Responses and Classification of Earth's Features on Satellite Imagery

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***Abstract*—This Remote sensing is fast becoming one of the most successful techniques in studying and classifying land-cover classes. Satellite remote sensing technology has provided environmental managers with a relatively cheap and accessible technique to accurately classify earth's features into common groups based on the similarities in behavior of their component structures. As the sun's electromagnetic light energy reaches earth surface, they are either absorbed and/or re-radiated into the atmosphere, depending on the component and structure of the receiving surface. The extent of absorption or radiation also depends on these components. Space satellite sensors are able to determine the wavelengths of light energy absorbed and reflected by the earth's surface. This paper assesses how three dominant land cover types (vegetation, water bodies and built-up areas which include buildings, pavements and tarmacs) usurp electromagnetic radiation, how satellite sensors are able to measure the radiation wavelengths and how RS technology uses data obtained by remote sensors which measure wavelengths of absorbed and reflected energy. The paper also presents the spectral response of these land cover types and their corresponding mathematical indices; *Normalized Difference Vegetation Index, Normalized Difference Water Index and Normalized Difference Built-up Index* (NDVI, NDWI and NDBI). The paper shows that vegetation absorbs most of the visible light in the electromagnetic spectrum (red and blue) but has a high reflectance in the near-infrared (NIR) band of the electromagnetic spectrum. This is because infrared light inhibits photosynthesis causes desiccation. Deep water bodies, on the other hand, quickly absorb NIR and red wavelengths, and reflects blue wavelength back into the atmosphere. These indices can be used to compute and determine specific land cover types from a constellation of several land cover categories on satellite imageries. LandSat-8 imagery of Nantucket Island, state of Massachusetts, USA was used for the computation.**

Keywords—Remote sensing, Spectral response, Electromagnetic radiation (EMR), Spectral indices, Satellite imagery

I. Introduction

The term remote sensing generally refers to the use of aerial sensor technologies to interact with and acquire information about earth's features, on the surface, in the atmosphere and oceans, by means of propagated signal waves e.g. electromagnetic radiation. In fact, electromagnetic radiation is the basis upon which remote sensing rests [1].

Naturally, a primary way for man to observe features is by looking at it. Light from the sun (Electromagnetic radiation) is reflected by these features, enters the eyes, interacts with sets of receptor cells in the retina and transmitted to the brain where the information is processed. The picture eventually seen and interpreted by the brain is the spectral distribution of the reflected light which arrives as visible light, a portion of the electromagnetic spectrum which the human eyes are sensitive to (Okin and Roberts, 2004). Remote sensors are however designed to detect various wavelengths of EMR, including those in the invisible spectrum. This is to say that while the human eyes are only sensitive to lights of wavelengths which occur in the visible part of the electromagnetic spectrum, remote sensors can detect both visible and invisible radiations. Visible radiant energy is attenuated in the colours of the rainbow, basically all the light the eyes can see, while invisible light include ultraviolet radiation (UV), infrared radiation, (IR), Near-infrared radiation (NIR) X-ray radiation, microwave radiation (MW) amongst others. Each one of these wavelengths has its unique characteristics and attributes, and transmit different information to sensors based upon their interaction with the target objects/materials or the intervening atmosphere [3][2]. A prior knowledge of the characteristics and spectral response of earth's elements (vegetation, water, bare soil, atmospheric particles) to EMR is the basis for classifying and identifying earth's features on satellite imageries.

II. Satellite Image Data and Focus Area

Satellite imageries are imageries of the earth or portions of its surface captured by sensors which are mounted aboard earth observation satellites in space. One of the most prominent satellites is the U.S. government-owned LandSat program; a series of satellites launched between 1978 and 2013. The imagery used in this paper is a LandSat imagery of Nantucket Island, Massachusetts, USA.

Below is a true-colour satellite image of the study area developed for this paper using the image analysis software Imaje-J 1.50b.

Fig. 1. True-colour image of Nantucket Island in 2009.

The island basically consists of vegetal cover, built-up areas, water bodies and some bare ground surfaces. Much of the vegetation consists of field grass, shrubs and trees. Over the years these categories have remained unchanged; however the percentage covers have greatly changed due mainly to the impacts of urbanisation.

III. Spectral Indices, methodology and results

Spectral indices are mathematical combinations of surface reflectance at two or more wavelengths that indicate relative abundance of features of interest. The result of the combination is an image highlighting areas of interest, which share common attributes e.g. vegetal cover. Right from source, surface reflectance values are embedded in the different bandwidths of multispectral LandSat images in a process known as *radiometric correction* (this is done by the United States Geologic Society [USGS], the organisation responsible for maintenance of the LandSat data archive). A multispectral imagery refers to an imagery that comes in more than one spectral band, each band containing image data at specific frequencies across the electromagnetic spectrum [5]. LandSat has seven radiometers, which enables it capture an image (scene) at seven different bandwidths; red, green, blue (visible light ranging from 0.7 µm to 0.4 µm) and near-infrared (NIR), mid-infrared (MI), far-infrared (FI) and thermal (invisible light, from 0.7 µm to 10 µm or more).

Three spectral indices, *Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI)* and *Normalized Difference Built-Up Index (NDBI)*. Image analysis software *ImageJ1.50B* was used for computations.

A. Normalized Difference Vegetation Index (NDVI)

The NDVI is the most commonly used index for land cover and vegetation monitoring [4]. It is an indicator that describes the greenness or photosynthetic activity and relative density and health of vegetation — for each picture element, or pixel, in a satellite image.

The structural components of green plants have evolved to reflect longer wavelength (NIR) radiation (the water in their leaves scatters the wavelengths back into the sky) to protect plants from thermal stress and dehydration. Most of the other visible light (red and blue) are absorbed and used by chlorophyll to drive the chemical reaction ($6CO_2 + 6H_2O +$ light energy $= C_6H_{12}O_6 + 6O_2$) that converts carbon dioxide and water into sugar and oxygen. This is the photosynthetic process [4]. Vegetation reflects IR in its entirety; thus it is easily distinguished from other features by satellite sensors. **Band 5** in LandSat-8 imagery measures the reflected NIR. This band (band 5), thus, combines with the red band (band 4), in the computation of the NDVI. The equation is as follows.

$$NDVI = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$

Where NIR is the reflectance values of the Near-infrared band and Red is the reflectance values of the red band.

B. Modified Normalized Difference Water Index (NWDI)

The NDWI capitalizes on the generally high reflectance of water in the visible spectrum. In the Near IR and Mid-IR regions water absorbs much of the light, making it darker. NDWI is derived by the following formula;

$$NDWI = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}}$$

(Where Green is the reflectance values of the green band (LandSat-7 band 4 and NIR is the reflectance values of the red band (LandSat-7 band 3).

Enhanced water information using the NDWI is however, often mixed with the intervening or surrounding built-up area "noise" such that the area of extracted water is overestimated. This effect can be corrected by applying the modified normalized difference water index (MNDWI) proposed by [6]. The modified model replaces the NIR with shortwave infrared, creating clearer distinction between water and other surrounding surface feature pixels. Thus;

$$MNDWI = \frac{\text{Green} - \text{SWIR}}{\text{Green} + \text{SWIR}}$$

SWIR is the reflectance values of the shortwave infrared band (LandSat-7 band 6)

C. Normalized Difference Built-up Index (NDBI)

Man-made materials such as concrete and asphalt display spectral curves that generally increase from the visible through the near-infrared (NIR), mid-infrared (MI) and shortwave infrared (SWIR) regions. In other words, this index highlights urban areas where there is higher reflectance in the shortwave-infrared (SWIR) region, compared to the near-infrared (NIR) region [7]. The index is defined by the formula;

$$NDBI = \frac{\text{SWIR} - \text{NIR}}{\text{SWIR} + \text{NIR}}$$

It is worthy of note that as concrete gets older it turns darker and as asphalt becomes lighter with age. It is thus important to derive an index that will take into account the changes in properties for accurate classifications.

Below are the results of the various index operations based on the satellite image of Nantucket Island.

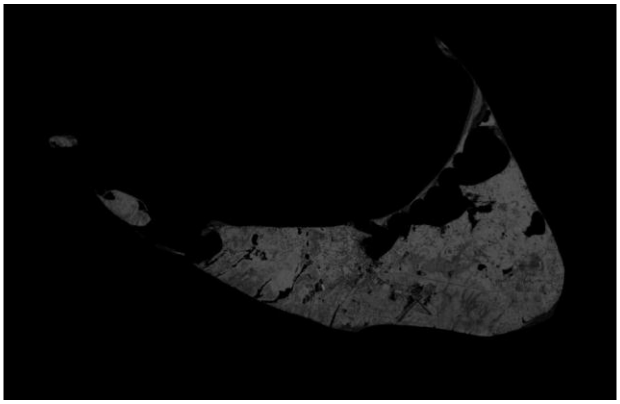

Fig. 2: *NDVI image depicting vegetation in light grey due to high NIR reflectance. Urban cover is shown in darker shade of grey while the water bodies (including the surrounding ocean is black.*

Fig. 3: NDBI showing urban cover in black and other cover categories in different shades of grey.

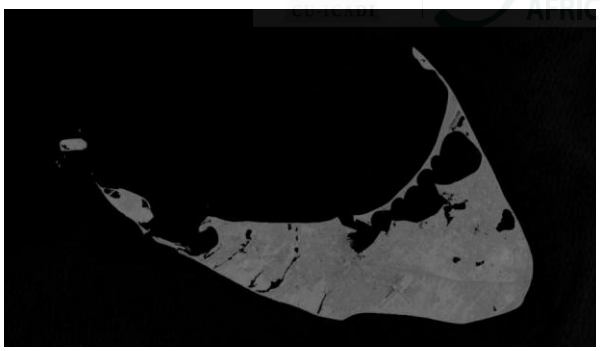

Fig 4: NDBI imagery depicting water bodies in black.

These "normalized" indices generally have values ranging from -1 to 1. Values closer to 1 indicate higher intensity of the target surface feature. For instance healthy (green) vegetation ranges from 0.2 to 0.8 on the NDVI index, the smaller values indicating less complex vegetation such as grasses and shrubs while higher values indicate the presence of complex canopied vegetation like trees. Similarly in NDWI imagery, marshlands appear lighter in colour than whole water bodies like streams, ponds, rivers etc.

IV. CONCLUSION

After The advent of remote sensing technology as well as the relatively cheap accessibility to data and resources has greatly impacted the works of environmentalists across the globe. As against tradition methods of survey and data acquisition which would require researchers to have boots on the ground, researchers can now utilise this technology to gather and query loads of information, and accurately too. Asides the ability to identify and classify different land cover types, resources are also available to determine their extents; that is the areas of space they occupy. This is extremely useful in land use studies and management as shown in a study by Oniemayin *et al*., 2016.

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