3.3 Normalised Difference Vegetation Index (NDVI)

3.3.1 NDVI: A non-technical overview

The Normalised Difference Vegetation Index (NDVI) gives a measure of the vegetative cover on the land surface over wide areas. Dense vegetation shows up very strongly in the imagery, and areas with little or no vegetation are also clearly identified. NDVI also identifies water and ice.

Vegetation differs from other land surfaces because it tends to absorb strongly the red wavelengths of sunlight and reflect in the near-infrared wavelengths. NOAA satellites (and LANDSAT) measure the intensity of the reflection from the Earth's surface in both these wavelength ranges. The Normalised Difference Vegetation Index (NDVI) is a measure of the difference in reflectance between these wavelength ranges. NDVI takes values between -1 and 1, with values 0.5 indicating dense vegetation and values <0 indicating no vegetation.

NDVI has proved to have an extremely wide (and growing) range of applications. It is used to monitor vegetation conditions and therefore provide early warning on droughts and famines. Section 5.1 Using satellite data in Zambia gives details of how NDVI can be used to estimate evapotranspiration. It is also used to identify regions suitable for locust development (see Section 5.2 Locust prevention). Finally, techniques are being developed to use NDVI imagery to identify particular ecological zones with important implications for disease prevention (see Section 5.3 Using satellite data to identify farming systems). Since 1982, NASA has produced NDVI images of Africa three times a month, building up a valuable archive of the conditions in Africa over the period. This allows present conditions to be compared with those in previous years.

In Section 3.3.2, we will look at how NDVI images are produced, particularly what satellites they come from and how NDVI is calculated. The products that are available from ARTEMIS will be examined, in Section 3.3.3. Although NDVI data has proved to be extremely useful it can only be used properly when the user is aware of the many limitations of the data. These are discussed in Section 3.3.4. Finally, although NDVI is the most widely used vegetation index, we must not overlook others indices. These are discussed in Section 3.3.5.

3.3.2 NDVI: How it is produced

When the first NOAA satellites were launched, channels 1 and 2 on the AVHRR were designed to monitor clouds, ice and land/water boundaries. More details on the AVHRR are found in Section 2.4.2 NOAA satellites. However, researchers quickly realised the two channels could be combined to detect vegetation using the different reflectance of vegetation in the two channels. Chlorophyll absorbs light in the red channel 1 (0.58-0.68 microns) and foliage reflects light in the near infrared channel 2 (0.72-1.10 microns). This is shown in Figure 3.3.1. Therefore, higher photosynthetic activity will result in lower reflectance in the red channel and higher reflectance in the near infrared channel. This signature is unique to green plants.

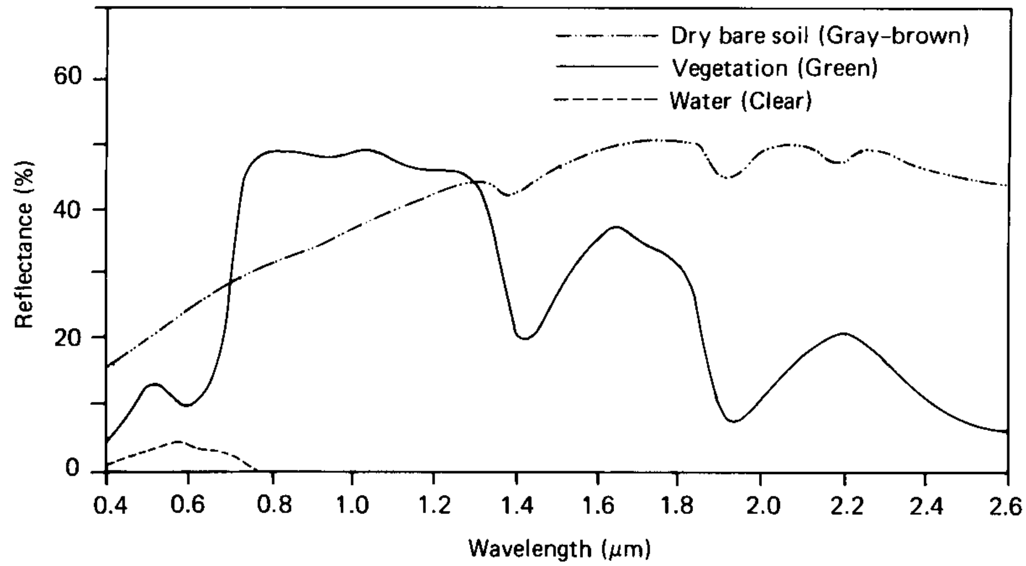

Figure 3.3.1: Typical reflectance curve for vegetation, soil and water [Lillesand and Kiefer, 1994]

By combining the two channels in a ratio or difference, allows the response to vegetation growth to be distinguished from the background signal. The method, developed by NASA is known as the Normalised Difference Vegetation Index (NDVI) and is given by the equation (NIR-RED/NIR+RED), where RED and NIR correspond to channels 1 and 2 respectively. By normalising the difference in this way, the values can be scaled between a value of -1 to +1. This also reduces the influence of atmospheric absorption. Figure 3.3.2 shows typical reflectance values in the red and infrared channels, and the NDVI for typical cover types. Water typically has an NDVI value less than 0, bare soils between 0 and 0.1 and vegetation over 0.1.

COVER TYPE	RED	NIR	NDVI
Dense vegetation	0.1	0.5	0.7
Dry Bare soil	0.269	0.283	0.025
Clouds	0.227	0.228	0.002
Snow and ice	0.375	0.342	-0.046
Water	0.022	0.013	-0.257

Figure 3.3.2: Typical NDVI values for various cover types [Holben, 1986]

3.3.3 NDVI: ARTEMIS products

ARTEMIS provides NDVI data for Africa in both the LAC and GAC forms (see Section 2.4.2 NOAA satellites. LAC data is received by two stations; by the Centre Agrhymet in Niamey, Niger and by the Department of Meteorological Services in Harare, Zimbabwe. An example image is shown in Figure 3.3.3, where the areas of high NDVI are indicated by the blue and green colours.

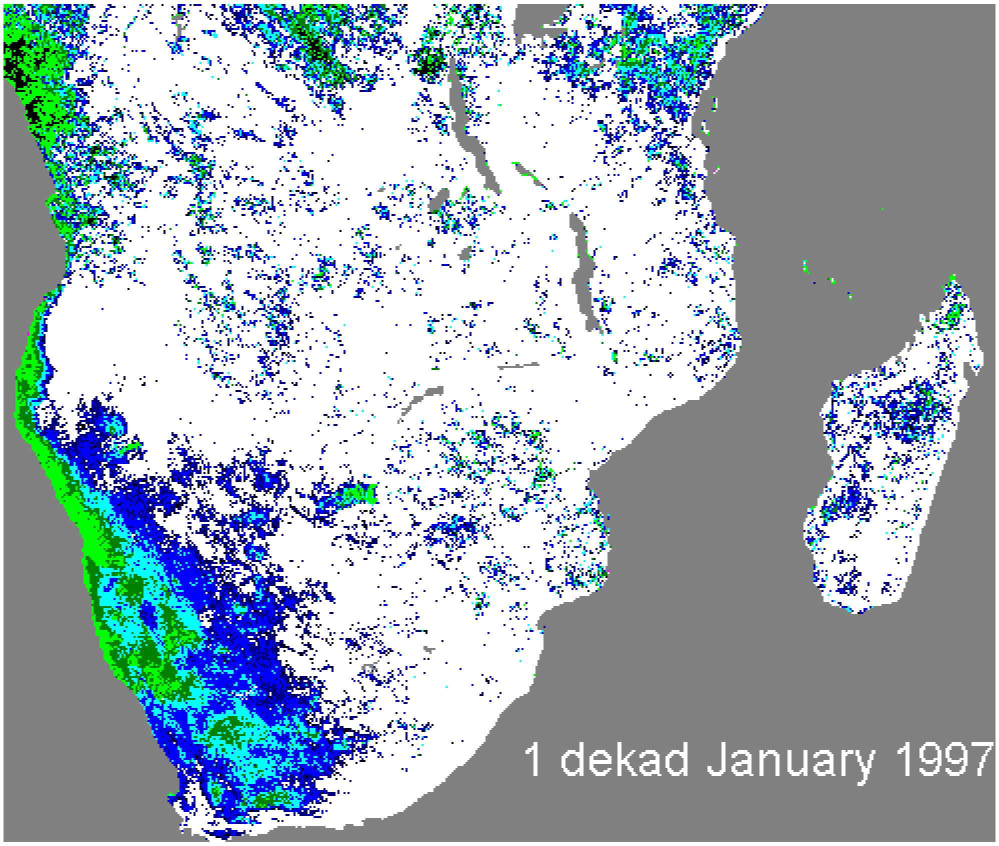

Figure 3.3.3: LAC image from Harare.

When the satellite views an area at any one time, a large part of the image may be cloud, which has a very low NDVI (approximately 0.002). This gives no information on the state of the vegetation beneath the cloud. This problem can be at least partially solved by using maximum value composite images (known as MVC's). In this process the maximum value is found for each pixel over a time period such as ten days or one month. The maximum pixel value over such an interval is likely to be a cloud-free pixel. The time period is a trade-off: a longer period decreases the amount of cloud interference, but it means missing short-term variations. However, as vegetation does not change much on a time scale of days, the technique is useful. This process can be carried out using an image analysis packages, such as IDA, described in more detail in Section 4.2.5 Image manipulation with IDA. MVC's have the added advantage of reducing the effects of other unwanted influences on the NDVI values (such as atmospheric interference and off-nadir viewing). These will be discussed in Section 3.3.4 NDVI: Limitations. For most routine operational purposes a 10-day maximum is normally used.

3.3.4 NDVI: Limitations

Temporal resolution

It is important to get the right balance between the temporal resolution of data and the timescale of variation in the quantity measured. For example, maximum value composites of NDVI data are rarely less than dekadal. Consequently, NDVI MVC's should not be used to investigate short-term events like forest fires. It is more appropriate to use NDVI data to monitor longer-term events like the growth of vegetation through a season, or annual rates of deforestation.

Atmospheric Interference

Light is scattered in all directions by particles in the atmosphere. This is discussed in more depth in Section 2.2.1 Radiation in the Atmosphere. Scattering tends to increase the amount of red radiation received by the satellite as red is more readily scattered in the atmosphere than near infrared. This has the effect of reducing NDVI values. For short periods, this problem is minimised by taking the maximum value composite because each pixel's maximum value is likely to have occurred when scattering was at a minimum. However, in extreme cases of long-term, large-scale aerosol events, such as ash clouds from the Mt. Pinatubo eruption in June 1991, maximum value compositing will not work.

Mt. Pinatubo erupted in the Philippines explosively in June 1991. The vertical force of the eruption pushed massive amounts of material into the stratosphere, the upper levels of the atmosphere. These stratospheric aerosols had a great effect on the clarity of the atmosphere and artificially reduced NDVI values. A correction procedure was developed by NASA, but not all the corrected images were of high quality.

Land cover types

With the exception of very large irrigation schemes and commercial agriculture, an NDVI pixel very rarely covers a single homogeneous agricultural region. Instead it may cover roads, buildings, bare soil, small water bodies, natural vegetation and agriculture, all within one pixel. An NDVI pixel is the sum of the radiation reflected from all the land cover types within the area covered by the pixel. NDVI is an indicator of the condition of the overall vegetation in an area, including natural vegetation and agriculture. In rain-fed agriculture, natural vegetation may follow similar patterns to the agriculture. More often however, agriculture is more susceptible to adverse conditions and follows different growth cycles. When looking at NDVI, always remember that you are looking at general conditions and not necessarily the condition of a specific crop.

Sparse vegetation and soil-type

Light reflected from the soil can have a significant effect on NDVI values (changing the values by up to 20%). Generally, the greater the radiance reflected from the soil, the lower the NDVI values. The soil-type therefore is an important factor. Given two soil types, one with a greater reflectivity but with similar vegetative conditions, the soil with the greater reflectivity will on average produce lower NDVI values. Huete and Jackson (in the References section) found that the soil-type had the greatest effect on NDVI values between 40 and 75% vegetative cover.

Sensor degradation

Section 2.2.1 Satellite radiometers describes how the overall relationship between the radiation received by the satellite and the pixel value is given by the radiometer's calibration. However, the satellite radiometer degrades over time. Consequently, the calibration coefficients are not constant. The thermal channels of the AVHRR have internal systems of calibration, but the visible channel (1) does not. The simplest technique for calibration of channel 1 is to use stable targets on the Earth's surface such as desert sands and oceans. Corrections are applied directly to the NDVI using the deviation from the expected values found in the Sahara desert. The use of an offset to the NDVI is simplistic because the correction factor may vary over the range of NDVI values, but it is better than no correction at all. The corrections for the offsets to the NDVI for NOAA-7, -9, and -11 (up to 1989) are shown in the table below. When using NDVI imagery, care must be taken to ensure the data has been corrected, and if not, then to make the corrections yourself.

YEAR	1981	1982	1983	1984	1985	1986	1987	1988	1989
NDVI	0.022	0.037	0.043	0.038	0.027	0.027	0.006	0.002	0.060

Figure 3.3.4: Table of corrections to be made to NDVI data from NOAA 7, 9 and 11 satellites, up to 1989.

Off-nadir effects

The scanning system of the NOAA satellites is discussed in Section 2.4.2 NOAA satellites. As the radiometer scans across the Earth, there is only one point, in the centre of the scan, that is directly underneath the radiometer (called the sub-point or nadir). The distance from the radiometer to the ground increases away from the sub-point. This results in increased atmospheric interference as the light must pass through more atmosphere before reaching the radiometer, and therefore reduced NDVI values. These 'off-nadir' effects are limited by simply dropping the pixels too far from the nadir. For quantitative work, only 40^0; on either side of the sub-point can be used.

In addition, the viewing angle at which the radiometer surveys vegetation has an influence on the NDVI value. For example, directly above a region of crops the crops *and* the soil will be visible to the radiometer. However, viewed at an angle, the region may seem to have continuous vegetative cover. In this case, the NDVI values will be lower directly beneath the radiometer.

3.3.5 Other Vegetation indices

The NDVI is not the only vegetation index to have been developed. Other indices are used, with a range of complexities. Indices are chosen depending on their application. The simplest vegetation index is the Ratio Vegetation Index (RVI). A more complex index is the Perpendicular Vegetation Index (PVI) that takes into account the soil emissivity (one of the major limitations of NDVI).

The Ratio Vegetation Index (RVI)

The simplest vegetation index is the RVI, which takes the ratio of the near infrared (NIR) and red (R) radiances.

$$RVI=NIR/R.$$

The Perpendicular Vegetation Index (PVI)

It has been found that there is a more or less linear relationship between Red and NIR reflectances from bare soils. This was tested for several different soil types, including sand, pebbles and clay. It was even true when the roughness and moisture of the soil varied. This relationship is called the soil line (shown in Figure 3.3.5) and is given by

$$NIR_{soil}=a\ R_{soil} + b;$$

In calculating the PVI of a surface with vegetation, the reflectance in the red and NIR ranges are measured and plotted on a graph. The PVI is the perpendicular distance of the measured point from the soil line, defined as follows:

$$PVI=1/sqrt(a^2+1) \times (NIR - aR + b)$$

where a and b are the slope and gradient of the soil line respectively. This is shown in Figure 3.3.5. In this way, the PVI measures the changes from the bare soil reflectances caused by the vegetation. In this way it gives an indication of vegetative cover independent of the effects of the soil.

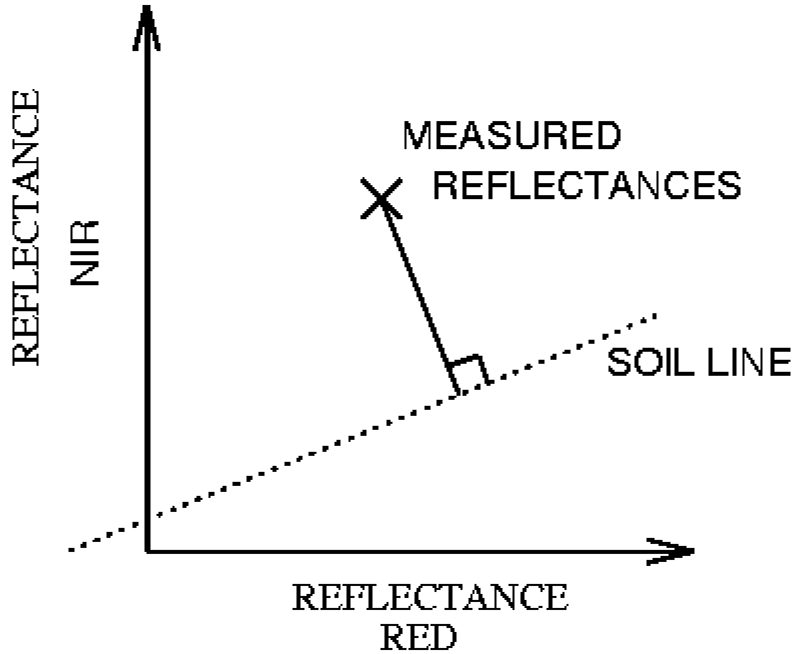

Figure 3.3.5: The cross represents the measured red and infrared reflectances. The dashed line is the soil line.

Previous Section Index Next Section