Locating Changes in Land Use from Long Term Remote Sensing Data in Morocco

Maliha S. Nash, Deborah J. Chaloud, and William Kepner
US Environmental Protection Agency, 944 East Harmon, Las Vegas, Nevada, 89119, USA

Abstract

We present a method that allows mapping changes in vegetation cover over large areas quickly and inexpensively, thus providing policy makers with the capability to locate and assess areas undergoing environmental change, and improving their ability to positively respond or adapt to change. Using Morocco in the southern Mediterranean Region as an example, changes in vegetation cover were assessed over a 23-year period (1981-2003) using 8-km Normalized Difference Vegetation Index (NDVI) data derived from Advanced Very High Resolution Radiometer (AVHRR). A regression model of NDVI over time was developed to identify long-term trends in vegetation for each pixel in the study area. Results were mapped using ArcView for visualization of specific areas. Patches of decreasing or increasing vegetation cover were identified. A decreasing trend in vegetation cover is an indicator of stress, either natural (e.g., drought, fire) or anthropogenic (e.g., excessive grazing, urban growth) that affects the life-support function of the human environment. Our analyses offer results that can be mapped at different scales (locally and regionally) and can be used to assess trends over time and space; plus, the approach can easily be applied to other locations.

Keywords: Morocco; Southern Mediterranean; anthropogenic; socioeconomic factors; AVHRR, changes in NDVI; autoregression.

Study Area

This work is part of the NATO Environmental Security, and hence we chose Morocco as a case study and an approach to examine the entire region (Figure 1). Morocco was chosen because of moderate size, variation in topography and land cover types, it has had experienced landscape change over the last decades, it has increasing socioeconomic pressures in parts of the country, and primary and ancillary data for the country are available. Data sets used in this study are:

1- NDVI composite images generated from AVHRR data (United States Geological Survey (USGS) (http://earlywarning.usgs.gov/adds/imgbulks3.php?imgtype=nd&spextent=a). The NDVI data set consisted of 10-day composite NDVI data over a 23-year period (1981-2003). This provided a maximum of 810 observations per pixel (8x8 km),

2- Morocco land cover (USGS land cover/land use Modified Level 2 for 1993), and

3- 1990, 2000 population density and their differences (GPWv3; http://sedac.ciesin.columbia.edu/gpw).

Figure 2 provides a spatial representation of the distribution of average NDVI for each of the four-year intervals roughly corresponding to periods of drought and adequate rainfall. It is evident in this figure that the majority of land in Morocco falls into the sparsely vegetated (NDVI values between 25 and 50) and bare (NDVI < 25) classifications. The highest NDVI values (> 126), representing dense vegetation, are located in the mountains and in urban areas on the Mediterranean coast; for example, where the cities of Elbiutz, Faham, Mraheddebane and Beneelouidane are located. South of the mountains, NDVI values decrease, indicating the sparser vegetation cover of the desert lands. Within the desert areas close to the Algerian border, the Draa River valley supports oases of date palms around the cities of Zagora, Benizouli, and Asrir n'llemchance (Figure 2). As mentioned earlier, the Drâa River originates in the Atlas Mountains, flowing south through the desert to the Algerian border. The foothills of these mountains receive significant amounts of rainfall from rainy episodes in late summer to early autumn (Knippertz et al., 2003). In addition to date palms, agriculture in the area includes vegetable farms, primarily located around the town of Ouarzazate near the Algerian border.

Statistical Analyses

Time series regression (autoregression) was used to estimate significant trends in NDVI at the single-pixel level. This type of analysis was selected because errors in temporal data may be dependent. If such dependency exists, then the standard error of the estimate (e.g., slope) will be inflated, and the significance level of the slope will not be correct. Auto-Regression first built a model as:

$$ndvi = B_o + B * time + \xi_t$$

where:

$ndvi$ is the response variable

B_o and B are the regression model coefficients

$time$ is in dekadal

ξ_t is the error

Auto Regressive (n) error model is built as:

$$\xi_t = -\varphi_1 \xi_{t-1} - \varphi_2 \xi_{t-2} - \varphi_3 \xi_{t-3} - \varphi_4 \xi_{t-4} - \varphi_5 \xi_{t-5} - \ldots + \varepsilon_t$$

where:

t is time in dekadal
t-1, *t-2*, … is lag time *1*, *2*, …

ε_t *is* $\mathrm{N}(0, \sigma^2)$.

Autocorrelation up to 36 lags (one year) were tested for significance in the model. Stepwise autoregression with "backstep" selection was used to sequentially remove the non-significant lags. The final model contains only the significant lag(s) with independent error, for example a model may retain none or few lags as described below.

$$ndvi = B_o + B * time + \xi_t$$
$$\xi_t = -\varphi\xi_{t-1} - \varphi\xi_{t-2} - \varphi\xi_{t-5} + \varepsilon_t$$

The statistical analysis software *SAS* was used for all analyses (proc autoreg; *SAS/ETS*, 1999).

The complete time series includes 810 observations for each 8x8 km grid cell. The significant slopes for the NDVI are mapped for the study area. From the map, patches of both positive and negative significant NDVI change over time are identified and marked. Ancillary data sources are then consulted to assist in identifying the probable causes of the significant changes. These ancillary sources include literature, maps, regional experts, satellite aerial photography from Google Earth and Google Maps, Interagency Vegetation Mapping Project (IVMP) utility land cover datasets, rainfall data, and datasets from the World Database on Protected Areas (http://www.unep-wcmc.org/wdpa/).

Results

The slope of NDVI over time represents the direction of change in vegetation cover (Figure 3). In this analysis, vegetation increases are indicated for 75% of the study area, although only 11% of the area has experienced a significant increase. In a complementary fashion, 25% of the area has experienced vegetation decreases, and 3% has significantly decreased. Mapping pixels with significant slopes identifies locations where significant changes have occurred (Figure 3). Most of the significant increases in vegetation cover are in the Rif Mountains, adjacent to the Atlas Mountains, and in the Drâa River valley. Additionally, clusters of pixels with significant increase in greenness are found along the northeast border with Algeria. Areas exhibiting significant decreases in vegetation cover are primarily in the northwestern part of Morocco where a large part of the Moroccan population resides; the dominant land uses in this area are urban and agriculture, including animal grazing. Particular areas of significant vegetation increase are shown in circles in Figure 3 and labeled A1 through A6 while the five areas of significant vegetation decrease are depicted within rectangles in Figure 3 and labeled B1 through B5.

Population distribution for 1990 and 2000 (Figure 4 a & b) was most dense in areas close to the coast in the northern and western parts of the country and much less dense in the desert areas, especially in southern Morocco north of Western Sahara. Population density increased and the boundaries of the major cities; Agadir, Casablanca, Mohammedia, Rabat, Tanger, and Oujden expanded between the two censuses. The spatial pattern and variability of population change over time (Figure 4 c & d) shows the non-uniform distribution of population around major cities (Agadir, Marrakech, Casablanca, Mohammedia, Rabat, Tanger, Meknes, Fes, Oujda) and expansion into the mountain and valley areas. In Figure 3, significant decreases in NDVI (red pixels) coincide with the expansion of the urban areas. The most recent (2006) population estimate for Morocco is 33.2 million (http://lcweb2.loc.gov/frd/cs/profiles/morocco.pdf).

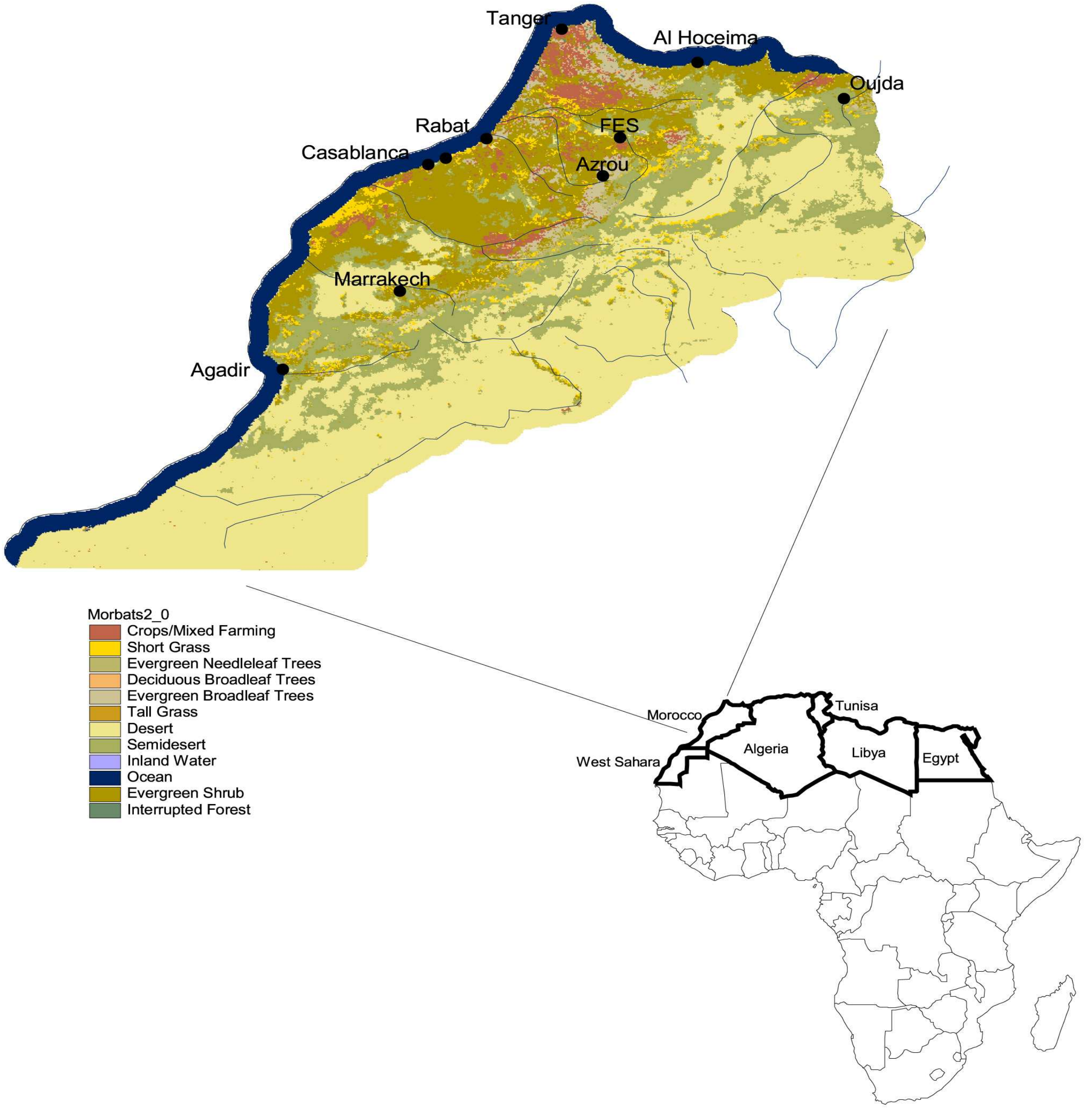

Figure 1: Morocco land cover (USGS land cover/landuse modified level 2 for 1993), major cities and geographical location in Africa. Desert and semi desert are represented by dark- and light-gray shading, respectively. Black represents in a) evergreen needle leaf trees, deciduous broadleaf trees, evergreen broadleaf trees and interrupted forest, b) crop, short and tall grass, and c) evergreen shrub. Lines represent rivers. Buffer of 25 km surround Morocco.

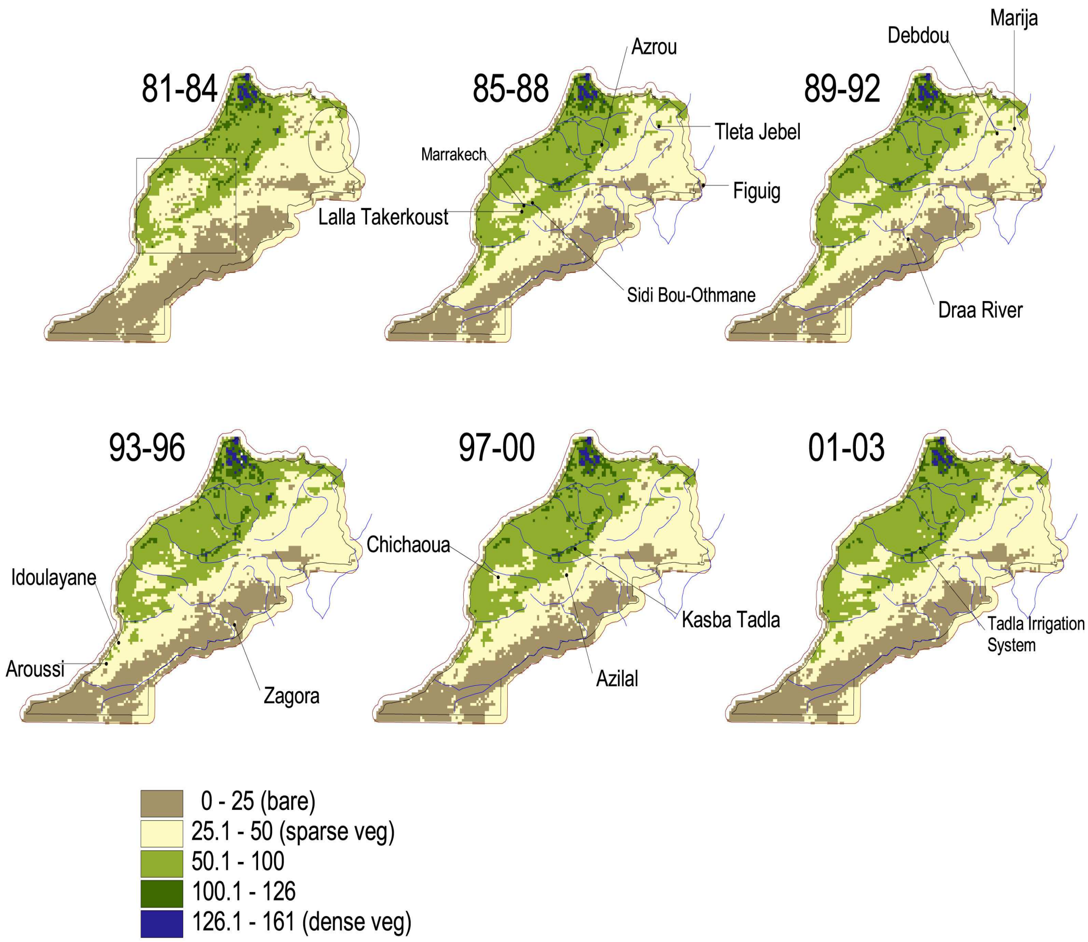

Figure 2: Average NDVI across Morocco for each 4-year temporal group. The marked circle and rectangle designate specific areas discussed in text. (Data source: United States Geological Survey; http://earlywarning.usgs.gov/adds/imgbulks3.php?imgtype=nd&spextent=a). Within the rectangle, a large patch of sparsely vegetated area (NDVI 25 – 50) is evident in the first four-year interval (1981 – 1984). In the next interval (1985 – 1988) it appears to have shrunk considerably, replaced on the margins with the next-higher average NDVI group. This corresponds very well to the conditions of that time, i.e., 1974 – 1984 was a period of drought throughout the inland desert areas of Morocco and the African Sahel while 1985 and 1986 had higher-than-average rainfall. Similarly, the circled area shows a patch with the lowest average NDVI in the early time intervals, which has been gradually replaced over time with the next-higher average NDVI group.

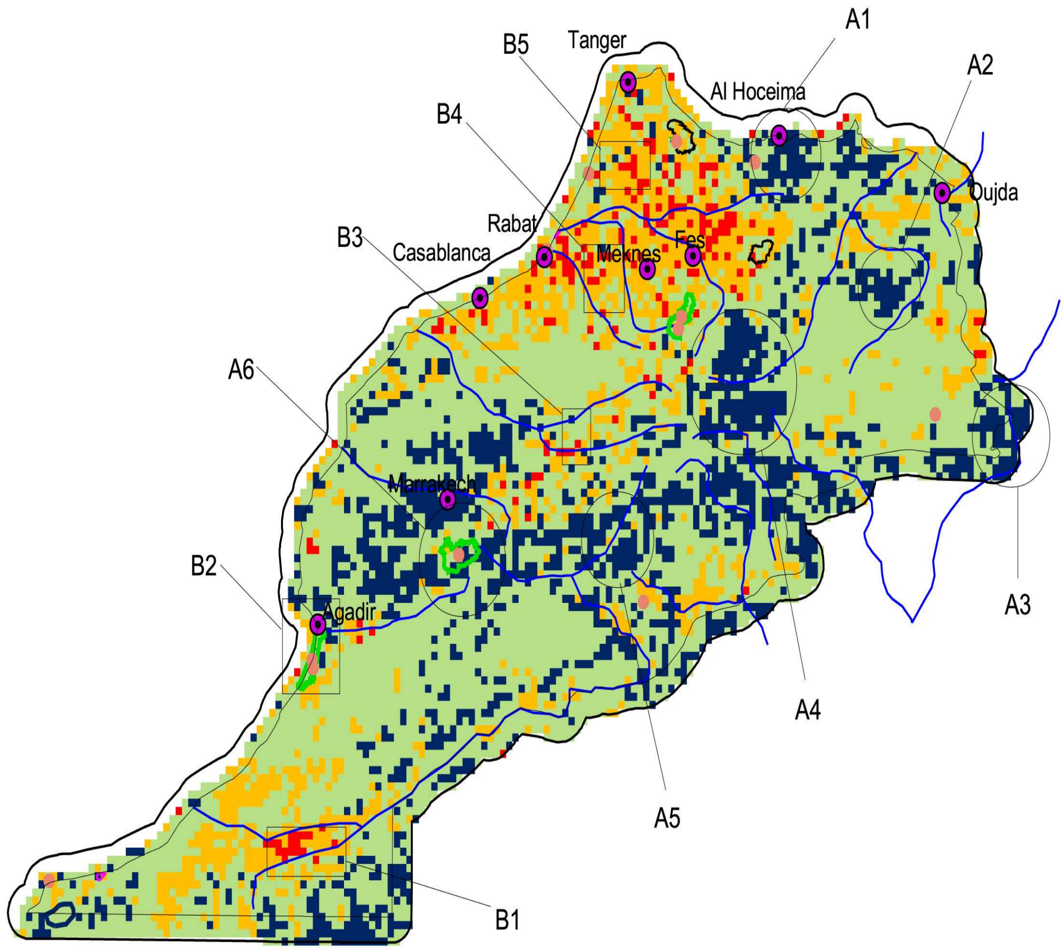

Figure 3: Pixels with significant gain (blue) and loss (red), non-significant gain (green) and loss (orange) in greenness for Morocco between 1981- 2003. Marked areas A1-A6 and B1-B5 are for evaluation using an ancillary data. Significant level < 0.05.

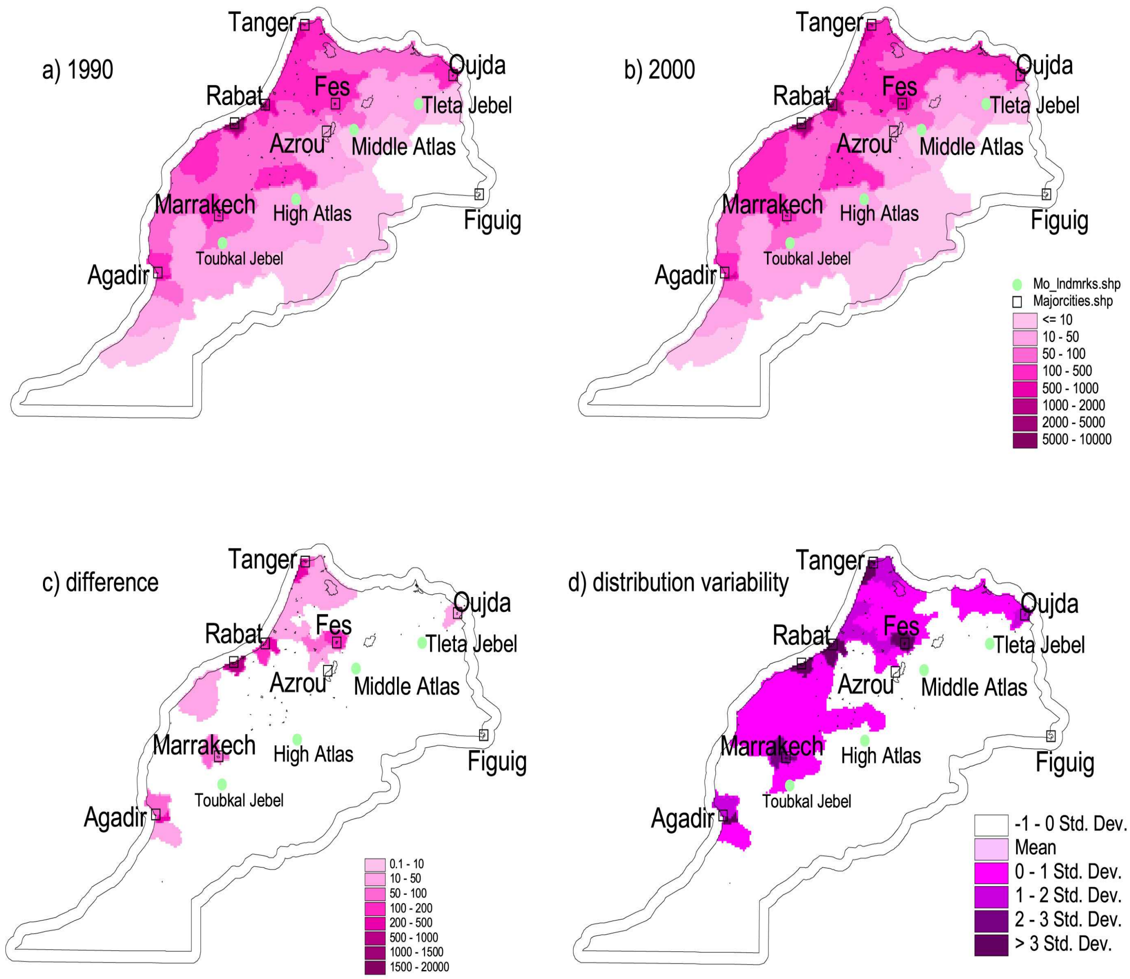

Figure 4: Population density for a) 1990 and b) 2000, and c) difference and d) spatial variability of the population density (person/km^2) distribution over time. Small polygons represent National Reserves and Parks. “Std. Dev” is standard deviation.

Conclusions

We developed a simple method to locate changes in vegetation cover, which can be used to identify areas under stress. The method only requires free or inexpensive NDVI data, which can be derived from many sources, and basic statistical and mapping software. AVHRR data are useful for evaluating large areas, but finer-scale studies can be performed using higher resolution imagery. The use of remotely sensed data is far more cost effective than field studies and can be performed more quickly. Use of data over long time periods permits analyses of historical change and identification of long-term trends.

We also incorporated ancillary data, including some precipitation data to identify rainfall trends. Drought appeared to be the most common natural cause of decreased vegetation cover. Areas with decreasing vegetation cover but unchanged or increasing rainfall are likely under stress from a source that can be managed, such as excessive timber harvesting, overgrazing, or urban growth. These areas may represent optimal locations for land managers to take protective measures. In arid and semiarid ecosystems, degradation represented by decreasing vegetation cover may lead to desertification unless action is taken. Our analyses offer results that can be mapped for different scales (locally and regionally) reflecting the diversity in landscape that can be integrated in making the optimum decision to prevent land degradation. Incorporating of socio-economic data into our empirical model which was not available at the time of the analyses will provide the quantitative linkages of environmental and socio economic.

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