REGIONAL ASSESSMENT OF LANDSCAPE AND LAND USE CHANGE IN THE MEDITERRANEAN REGION

Morocco Case Study (1981–2003)

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Abstract: The ability to analyze and report changes in our environment and relate them to causative factors provides an important strategic capability to environmental decision and policy makers throughout the world. In this study, we linked changes in land cover with changes in human demographics and natural phenomena, including rainfall. The methodology presented here allows users to locate and map changes in vegetation cover over large areas quickly and inexpensively. Thus it provides policy makers with the capability to assess areas undergoing environmental change and improve their ability to positively respond or adapt to change. Morocco was used as an example and changes in vegetation cover were assessed over a twenty-three-year period (1981–2003) using 8-km Normalized Difference Vegetation Index (NDVI) data derived from the Advanced Very High Resolution Radiometer (AVHRR). A regression model of NDVI over time was developed to identify long-term trends in vegetation cover for each pixel in the study area. Patches of changes in vegetation cover were identified using ArcView for visualization of specific areas. A decreasing trend in vegetation cover is an indicator of some type of stress, either natural (e.g., drought, fire) or anthropogenic (e.g., excessive grazing, urban growth), that affects the life-support function of the environment for humans. Although Morocco was the only country used in this case study, the described approach has broad application

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throughout the world and offers an opportunity for combating changing ecological conditions that affect populations.

Keywords: Morocco; Southern Mediterranean; anthropogenic; natural and socioeconomic factors; AVHRR; changes in NDVI; autoregression; ecological services; desertification

1. Introduction

Unplanned and uncontrolled use of land may exacerbate environmental degradation and have profound consequences on human well-being. For local communities to thrive in an area, the natural systems that support them with good soil, water, and vegetation need to be maintained and monitored. When the natural resource support system degrades because of climate or anthropogenic causes, local communities begin to search for alternatives to support their needs. While some communities migrate to nearby or distant locations, others are attached by their heritage so they remain in their native land and continue using local resources.

The Argane Forest, located in southwest Morocco, is an example, where the Argane tree species (*Argania spinosa*) has an essential role in the ecology, economy, and social relations of the local communities (Belyazid, 2000). Felling (timbering) of trees as a source of income, drought episodes, and the slow regeneration of the Argane trees have degraded most of this habitat. The Argane Forest provides an important example of the necessity of monitoring that can be used to assess current conditions and past trends. Similar relationships between the ecological state and the socioeconomic prosperity of communities that depend on keystone species, such as the Argane tree, can be found at other sites in Morocco.

Changes in vegetation cover over time can be used to assess the ecological condition of a given area. Reforestation and restoration of grazed areas, for instance, will increase vegetation cover, while increasing impervious surface area due to urban growth will decrease vegetation cover (Nash et al., 2006). Mapping changes in vegetation cover using the Advanced Very High Resolution Radiometer (AVHRR) is an inexpensive technique to monitor and assess changes in environmental conditions over large areas.

Changes in vegetation were studied to monitor spatial-temporal dynamics of vegetation using the Normalized Difference Vegetation Index (NDVI) (Minor et al., 1999; Lanfredi et al., 2003; Gurgel and Ferreira, 2003; Nash et al., 2006). Long-term monitoring using a simple and inexpensive method may help provide environmental decision makers with early warning signals of areas where land sustainability is being degraded, or alternatively, to confirm improvement in land cover. Changes in vegetation cover and environmental conditions can be detected and quantified using current communication technology combined with remote sensing data, historical data, published research, and expert knowledge (Schmidtlein, 2005; Nash et al., 2006). NDVI has been used in desert and semidesert areas in many African countries and over broad spatial scales. For the African Sahel, data from 1981–2003 were used to examine the synchronization between drought and the decrease in greenness for specific time and spatial scales (Anyamba and Tucker, 2005). Our study focused on Morocco as a case study that could be used as an approach to examine the entire region (Figure 1). Morocco was

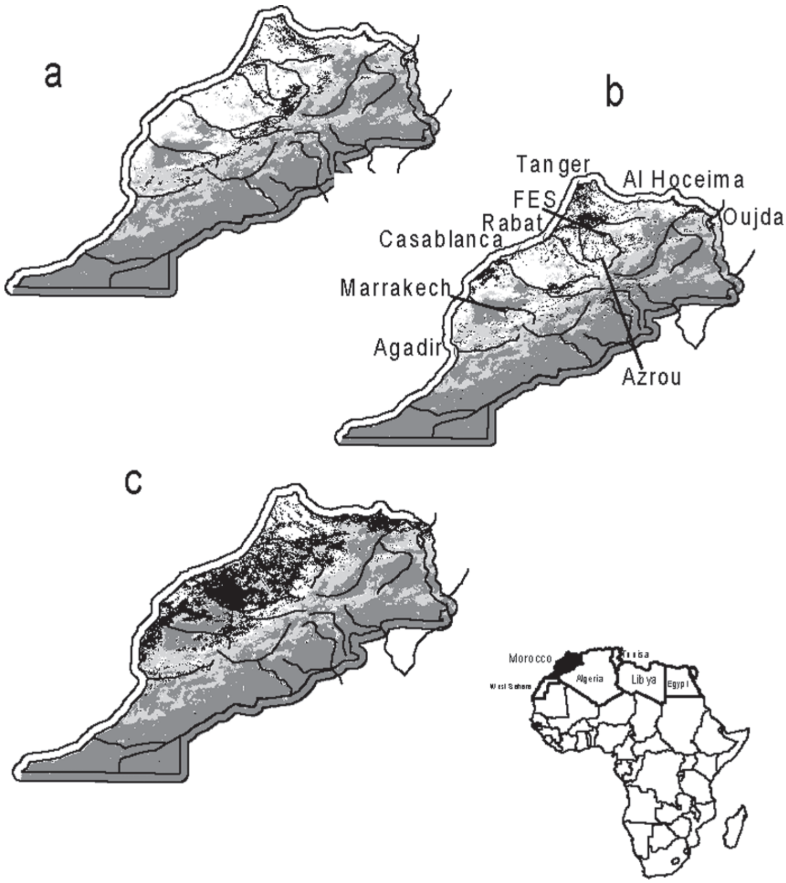

Figure 1. Morocco Land Cover (USGS Land Cover/Land Use Modified Level 2 for 1993), Major Cities, and Geographical Location in Africa. Desert and Semidesert Are Represented by Dark- and Light-Gray Shading, Respectively. Black Represents (a) Evergreen Needle Leaf Trees, Deciduous Broadleaf Trees, Evergreen Broadleaf Trees, and Interrupted Forest, (b) Crops, Short and Tall Grass, and (c) Evergreen Shrubs. Lines Represent Rivers. A Buffer of 25 km Surrounds Morocco.

chosen for a number of reasons, including: (1) it is moderate in size, (2) it has variation in topography and land cover types, (3) it experienced significant landscape changes over the last several decades, (4) it has a history of increasing socioeconomic pressures in parts of the country, and (5) primary and ancillary data for the country are available. Time-series analyses were used to quantify changes per pixel. The changes in vegetation cover were determined using the slope value of the regression model for NDVI ($n = 810$/pixel). Statistical analyses were performed for each pixel over a twenty-three-year period, and results were mapped using ArcView 3.3 for visualization and assessment at local and regional scales. The objective of the work presented in this paper was to use an approach that could have broad applications relative to identifying areas of environmental instability and trends over multiple spatial and time scales. Further, the research presented in this paper was intended to explore the links between natural and social sciences as they relate to solving contemporary environmental problems, especially those that are trans-boundary in nature. Specifically, this research was used to locate areas in Morocco that experienced significant changes in vegetation cover, as indicated by significant changes in NDVI values, and to determine, where possible, the likely cause of the change. Ancillary data such as human population distribution and change were mapped to be synchronous with that of NDVI changes. However, the overall intent was to develop a relatively inexpensive and simple process that could be employed to examine environmental sustainability at multiple scales, including catchments, national scale, or regions such as the Mediterranean. Collectively, the combination of socioeconomic data with NDVI change data will assist in promoting trans-boundary cooperation and may result in providing a coordinated response to environmental challenges.

2. Data and Methods

2.1. STUDY AREA DESCRIPTION

Morocco covers an area of 44,630,000 ha with elevation ranging from 4,165 m at the Jebel Toubkal (south of Marrakech) to 55 m below sea level at the Sabkha Tah (close to the Western Sahara and 22 km south of the city of Tarfaya) (Google Map & Google Earth).

Morocco is within the Mediterranean bioclimatic classification (Berkat and Tazi, 2004). The combined influence of the sea and ocean and the presence of the Atlas Mountains that transect the land from north (Rif Mountains) to south in the Sahara Desert create a diverse climate range for Morocco. Within this topographically diverse region, normal annual precipitation varies from less than 100 mm/year in the deserts and coastal plains to 1,200 mm/year in the Rif and the Middle Atlas mountains and exhibits a bimodal precipitation pattern. Most precipitation occurs as rainfall during October–December and March–April.

Water comprises only 0.06 percent of the total Moroccan land cover. Many of the rivers are intermittent and are mainly used for irrigation and generating electricity. The Moulouya River drains to the Mediterranean Sea while most of the other major rivers (Sebou, Bou Regre, Oum Rabia, Tansift, and Souss) drain to the Atlantic Ocean. The largest river in Morocco is the Drâa River, which originates in the Atlas Mountains and flows southeast through the cities of Ouarzazate and Zagora before crossing the border into Algeria and eventually winding west toward the Atlantic. It drains into the ocean only when river flows are sustained by prolonged periods of precipitation.

Morocco experienced periods of drought in 1979–1984 and throughout most of the 1990s. Socioeconomic conditions are directly related to precipitation in that most of the arable lands are located in semiarid areas (precipitation 250–500 mm/year). Approximately 22 percent of the land use in Morocco is arable and contains permanent crops (MONGABAY.com, 2000). While crops are primarily located along rivers in the coastal plain and semidesert Saharan areas, much of the low-productivity Saharan steppes are utilized as rangeland, accounting for approximately 75 percent of the land use. Forests account for less than 10 percent of the land cover (Figure 1).

2.2. DATA

The primary data source for this study was NDVI composite images generated by the National Oceanic and Atmospheric Administration (NOAA). The NDVI is calculated as:

$$NDVI = (IR - R) / (IR + R)$$

where IR is the Near Infrared Layer and R is the Visible Red Layer of the electromagnetic spectrum (Rouse et al., 1973; Tucker, 1979). The near infrared band of the spectrum emphasizes the contrast between vegetation and water. In the Visible Red Layer, vegetation appears darker than man-made structures. The calculated NDVI ranges from -1 to 1. For our study we used AVHRR data available from the United States Geological Survey (USGS) (ftp://edcftp.cr.usgs.gov). The images (*.bil) for the continent of Africa were converted to a grid, defined to a common projection, and clipped to a buffered (25 km) boundary of Morocco. NDVI were scaled to range from zero to 255, where 255 is water and 253 is a designated "invalid" or missing value. Therefore, NDVI values between 0 and 252 were used in the analyses. The NDVI data set consisted of ten-day composite NDVI data over a twenty-three-year period (1981–2003). This provided a maximum of 810 observations per pixel (8 × 8 km), which resulted in a total of 6,289,650 observations.

Another important data set used for this study was the Gridded Population of the World, version 3 (GPWv3, 2005). Population data used in the analyses were adjusted to match the UN total population figures. Change in populations between 1990 and 2000 were mapped and used as overlays to areas of significant change in vegetation cover.

2.3. 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 (i.e., autocorrelated). 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. The Statistical Analysis Software (SAS) was used for all analyses (proc autoreg; *SAS/ETS*, 1999). In addition to the time series analysis that used all available data points over the full period, maps of averaged NDVI were created for four-year intervals (1981–1984, 1985–1988, 1989–1992, 1993–1996, 1997–2000, 2001–2003), roughly corresponding to known periods of drought and above-average rainfall (Figure 2). These maps facilitate observations of vegetation patterns over the study area and changes in the level of greenness or photosynthetic activity over time. Average NDVI values are divided into five groups of increasing greenness, starting with “no vegetation” (NDVI ≤ 25) and ending with “dense vegetation” (NDVI ≥ 126; Table 1).

The complete time series includes 810 observations for each 8 × 8 km grid cell and a total of 7,765 grid cells were utilized in the analyses. The slope value obtained from the regression corresponds to changes in vegetation cover. A negative slope indicates loss of vegetative cover while positive slope indicates an increase in vegetation cover. We use a value of 0.05 as a significance level for the probability of the slope. 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, and datasets from the World Database on Protected Areas (WDPA).

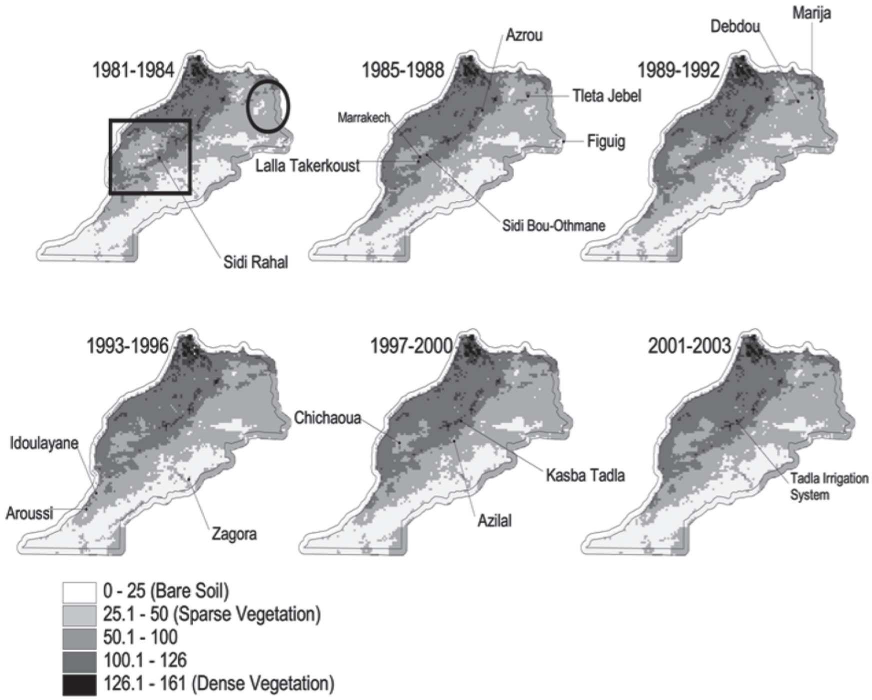

Figure 2. Average NDVI Across Morocco for Each Four-Year Temporal Group. The Marked Circle and Rectangle Designate Specific Areas Discussed in Text and to Follow Changes Over Time. Cities, Rivers, and Irrigation Systems Were Posted on the Maps for Geographical Positing and Referencing. There Were Several Drought Periods Since 1970; Drought Was Recorded in Year Groups (e.g., 1980–1985, 1990–1995) and a Few Wet Years Were Also Observed During the Mid-1980s and 1990s, Especially Along the Atlantic Coast and South of the Atlas Mountains.

TABLE 1. Changes in the Relative Distribution of Greenness with Time in Morocco. NDVI Group 0–25 Is Characterized by Desert (Bare) Area. NDVI Values ≥25.1 Are an Indication of Vegetation Presence. NDVI of 126 and More Indicate Dense Vegetation. Values Are Percent of Land Surface.

	0–25.0	25.1–50	50.1–100	100.1–126	126.1–157
Years			(%)		
1981–1984	34.9	41.0	17.7	3.8	2.7
1985–1988	31.6	42.1	18.0	4.4	4.0
1989–1992	29.9	42.5	19.5	4.7	3.4
1993–1996	29.4	43.5	19.7	4.0	3.4
1997–2000	28.7	43.2	20.6	4.6	3.0
2001–2003	29.3	44.1	19.3	4.5	2.8

3. Results

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 Drâa River valley supports oases of date palms around the cities of Zagora, Benizouli, and Asrir n'llemchance (Figure 2). In addition to date palms, agriculture in the area includes vegetable farms, primarily located around the town of Ouarzazate near the Algerian border.

The relative distribution of vegetation groups for each of the four-year intervals is quantified and summarized in Table 1. Bare (NDVI < 25) and sparsely vegetated (NDVI between 25 and 50) together account for more than 70 percent of the land area in each interval. The bare classification has decreased slightly over time, from 35 percent in the first interval to 29 percent in the 1997–2000 interval, while the sparsely vegetated category has increased, from 41 percent in the 1981–1984 interval to 44 percent in the 2001–2003 interval. This shift in greenness is likely due to increased irrigation and drought recovery. Dense vegetation, primarily forested land in the mountainous areas where rainfall is generally higher, increased from 2.7 percent to 4 percent between the first two intervals, but has been decreasing in each subsequent interval. The initial increase is likely due to drought recovery in the latter half of the 1980s, while the decreases since that decade are likely due to a combination of drought and tree cutting for firewood.

Of particular interest over the four-year intervals are the areas denoted with a rectangle and a circle in Figure 2. 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, that is, 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. In the subsequent two time intervals, this patch remains roughly the same size and then shrinks to its smallest size in the 1997–2000 interval. In the most recent time interval (2001–2003), the patch appears to have enlarged. 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. This patch is located in a desert area (Figure 1) within the high plains eco-region and is affected by the Mediterranean coastal climate. It is possible that this area received enough rainfall in the years following the drought of 1974–1984 to nourish vegetation. This increase in greenness is consistent up through the 1993–1996 interval, after which these areas shrank. In the last available time interval (2001–2003), the areas of increased vegetation are still larger than those of the drought years of 1981–1984. Landscape classes in this patch range from desert to evergreen land cover types (Figure 1).

In the time series regression using all available data for each pixel, the slope of NDVI over time represents the direction of change in vegetation cover (Figure 3). In this analysis, vegetation increases are indicated for 79 percent of the study area, although only 20 percent of the area has experienced a significant increase. In a complementary fashion, 21 percent of the area has experienced vegetation decreases, and 3 percent 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 use in this area are urban and agriculture, including animal grazing. Particular areas of significant vegetation increases 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 4a and 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 of Agadir, Casablanca, Mohammedia, Rabat, Tanger, and Oujden expanded between the two censuses. The spatial pattern and variability of population change over time (Figure 4c and d) show the nonuniform distribution of population around major cities (Agadir, Marrakech, Casablanca, Mohammedia, Rabat, Tanger, Meknes, Fes, and Oujda) and expansion into the mountain and valley areas. In Figure 3, significant decreases in NDVI (gray pixels) coincide with the expansion of the urban areas.

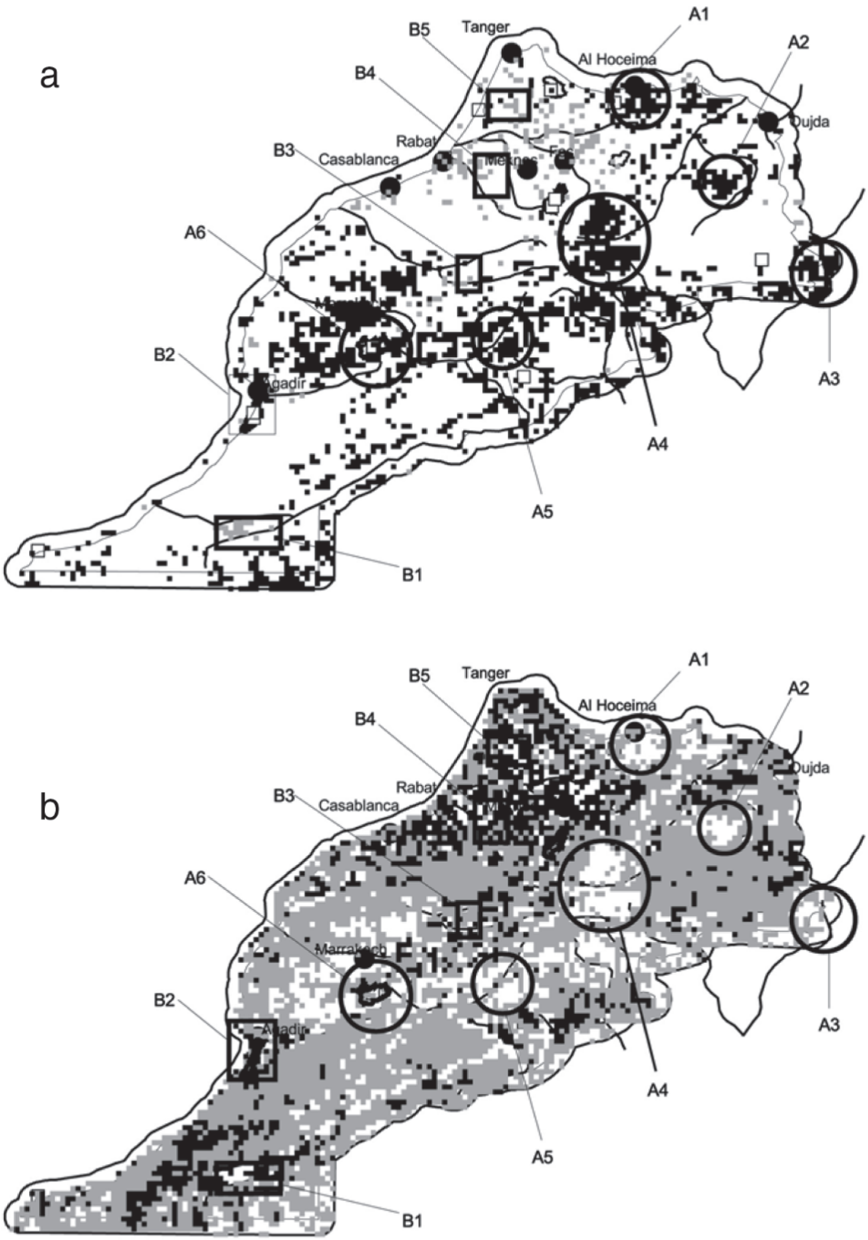

Figure 3. Pixels with (a) Significant Gain (Black) and Loss (Gray) and (b) with Nonsignificant Gain (Gray) and Loss (Black) in Greenness for Morocco, Based on Time Series Analysis for the Years 1981–2003. Marked Areas A1–A6 and B1–B5 Designate Specific Areas of Significant Vegetation Increase and Decrease, Respectively, Evaluated Using Ancillary Data.

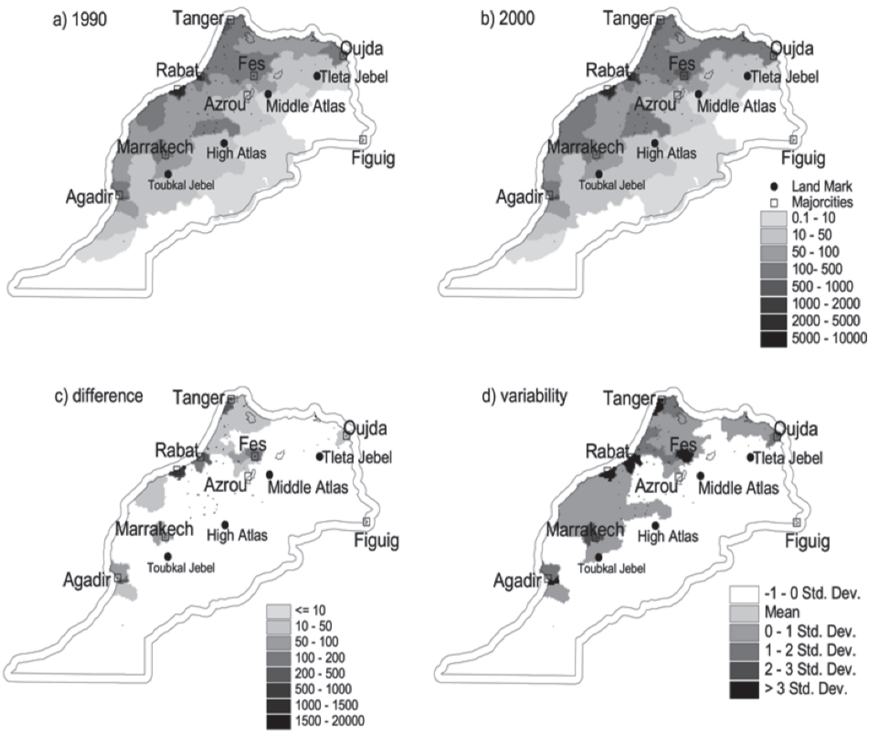

Figure 4. Population Density for (a) 1990 and (b) 2000, and (c) Difference and (d) Spatial Variability of the Population Density (person/km^2) Distribution Over Time. Small Polygons Represent National Reserves and Parks. "Std. Dev" Is Standard Deviation.

4. Discussion of Changes in Greenness

The results of the two different analyses (i.e., mapping/averaging NDVI by time interval and time series analysis of NDVI) each reveal distinct features of changes in the landscape over time. The maps of NDVI average per four-year interval highlight temporal contrast between areas with high and low vegetation cover. Slope maps, on the other hand, show the rate of change in vegetation cover over the entire twenty-three years contained in the data set and whether these changes are significant or not.

4.1. MAPS OF NDVI FOUR-YEAR INTERVALS

Morocco, as with other African countries, experienced a period of drought in the 1970s followed by a period of drought recovery in the years between

1982 and 1985, when rainfall was close to the long-term precipitation mean (Nicholson, 2005). However, in complex topography, precipitation can vary widely across an area the size of Morocco even in periods of widespread drought. By using rainfall data from several rainfall stations in Oum Er Rbia Basin, Chaponniere and Smakhtin (2006) demonstrate the spatial and temporal variability of rainfall in the basin area represented in the rectangle in Figure 2. Near Chichacouca, the average annual rainfall over thirty-four years (1965–2001) was 175 mm. Annual mean rainfalls 1981–1987 and 1999–2000 was lower than normal but exceeded the normal in 1988 through 1998. Sidi Rahal, located 40 km east of Marrakech, had an annual mean rainfall approximately double that of Chichacouca, 344 mm/year for 1970–2001.

Sidi Rahal is located within areas with NDVI 50–100 (Figure 2) reflecting sparse vegetation cover. It is also 6 km northeast of an agricultural area. Higher rainfall and presence of annual crops in Sidi Rahal may be the reasons behind the greenness over the years in Figure 2. The size of the patches of low NDVI within the rectangle area increased and decreased with time reflecting the response to the rainfall for these years. From a rainfall station (Sidi Bou-Othmane) located in the Jiblet Mountains, 25 km north of Marrakech, Znari et al. (2002) reported the extent in annual rainfall variation from 1993 to 1998. While the mean and standard deviation were 290 and 126 mm, respectively, annual rainfall varied from 460 mm in 1995 to 103 mm in 1998. Although the trend in rainfall over time was not significant, the increasing trend in annual rainfall between 1993 through 1996 (slope = 67 mm/year, $R^2 = 0.42$, $p = 0.35$) may be the driving force behind the shrinkage of the patches with low NDVI values within the rectangle in Figure 2.

While rainfall is generally the primary factor in vegetation changes affecting NDVI greenness, irrigation may also result in vegetation increases. Reservoirs are the principal source of water for irrigation systems in Morocco. In the area bounded by the rectangle in Figure 2, the Azib Douirani dam was built on the Douirane River near Chichacouca in 1987 to provide stable water supplies and flood control. The Ait Quarda and Bin el Ouidane dams were established in 1953 to provide irrigation and hydroelectricity; they feed the Tadla irrigated area that is located north of Azilal and southeast of Kasba-Tadla. In 2001, the Dchar El Oued dam was built to feed the northern part of the Tadla agricultural area. The irrigated area can be seen in Figure 2 in patches of pixels with NDVI values 100–126. The irrigated agricultural land produces citrus, olives, and sugar beets.

Patches of greenness in the circle (Figure 2) increased over time. The circle spans an area near or encompassing the cities of Marija, Elrahebat, Fouchel, Bordj-Doglat-Sedra, and Sidi-Ali-Doglat. This area contains desert, semidesert, evergreen shrub, and evergreen needleleaf tree land cover types. The dam establishment database (FAO, 2007a) indicates no recent dam construction; hence gains in greenness within the circle are not linked to irrigation. While the villages of Esraf and Sidi-Bou-Djemila are located within cultivated land and noncultivated rigid terrain, respectively, the village of Debdou is an oasis within the middle Atlas Mountains surrounded by lush orchards, oaks, and thuja forest. Debdou is in the subhumid climate region, so this village and surrounding area receives higher rainfall. Gains in greenness to the west of Debdou over time (Figure 2) may also be linked to growth of the cities Mahirija and Ain-et-Guettara where agricultural land is a dominant land cover.

4.2. TIME SERIES ANALYSES AND AREAS OF SIGNIFICANT CHANGE

The result of the time series analysis is a slope map (Figure 3) showing the direction of change over the study period. Significant positive increases in NDVI suggest a pronounced recovery from deforestation, restoration of degraded land, introduction of irrigation, or preservation of land natural resources. Significant negative slopes indicate a loss of vegetation; common causes include fire, overgrazing, urbanization, and forest cutting. Positive nonsignificant trends in NDVI appear to indicate that greenness has stabilized over time. Negative nonsignificant trends appear to indicate that degradation is occurring. The nonsignificant changes, both positive and negative, may signal a cautionary call for monitoring to further investigate the conditions underlying gradual vegetation changes that may threaten long-term sustainability.

Changes in vegetation cover of Morocco over the years have been driven by many factors. Drought is a major stress factor that Morocco and other surrounding countries have experienced. These countries need to enhance the areas of irrigated lands. Dams were constructed to aid irrigation by diverting water from regions with surplus to regions with water deficits. A total of 105 dams were constructed in Morocco between 1929 and 2003 (FAO, 2007a); 68 percent of these dams were built between 1980 and 2000. Irrigation has permitted expansion of agriculture into sparsely vegetated semidesert and desert regions. Urban areas have expanded to accommodate population growth. Depletion of the natural resources (e.g., trees) for human use in the Atlas Mountains helped influence migration of some of the nomadic people to urban centers or areas outside the country.

Eleven areas were identified for further evaluation, six with decreased vegetation cover and five with increased vegetation cover (marked areas;

Figure 3). Ancillary data were consulted to ascertain a specific cause of change. Area A1 is located near the town of Al Hoceima, a port on the Mediterranean Sea and one of the major towns within the Rif. The Rif is part of the Mediterranean conifer and mixed forest eco-region that extends from north Morocco to northwestern Tunisia. Tourism is the main revenue for Al Hoceima. This town is within Al Hoceima National Park, which was established on 470 km^2 by the World Bank Funds in 1991. The vegetation in this park is Mediterranean forest (evergreen sclerophyllous), woodland, and scrub. The park encompasses many marine and coastal ecosystems with diverse species. The local population has utilized the land for grazing, firewood, and fishing for years. These resources began to decline and became insufficient for the local inhabitants, which led to migration to neighboring countries and Europe in search of better economic opportunities (UNDP-GEF SGP, 2000). Preservation of habitat for humans, animals, and vegetation was recommended in 1995 via ASASHA (L'Association Solidarité pour l'Action Sociale et Humanitaire d'Al Hoceima), a nongovernment organization. Consequently, a Small Grants Program (SGP) through the United Nations Development Program (UNDP) was established in 2000 to educate local populations regarding natural resources and preserving vegetation to provide income from ecotourism and the sale of medicinal plants (UNDP-GEF SGP, 2000). A decline in forest cover in areas within the Rif Mountains in 1997–1999 was found to be minimal (Louakfaoui and Casanova, 2000). Preservation of the natural resources in this area may help enhancing greenness, causing the significant NDVI increase. Both Figures 2 and 3 show an increase over time in the number and size of green patches in this area.

The areas marked A2 through A5 in Figure 3 are all located near rivers in mountainous areas and the observed vegetation increases are likely due to increased rainfall and irrigation diversions from the river. Area A2 is located north of the Oued Charef River in a mountainous region. Area A3 is bounded from the south by Jebel Melah and Ras el Yhoudi and encompasses a number of mountains such as Jebel es Seffah and Rokna el Kahla. The Oued Moulouya River flows through area A4 in a mountainous location. The mountains north of the river are: Jebel Ouchilas, Jebel Hariga, and El Hajj. Mountains south of the Oued Moulouya River are: Jebel Bourr and Bou Tazert. The Assif Iriri Dades River passes through area A5 just south of the mountains of Jebel Talat n' Mensour, Jebel Arg, and Jebel Tilohah, and just north of the mountains of Jebel Bou Tabrha, Amlal, and Iskin n' Abid.

Area A6 includes the mountain peak Jebel Toubkal (4,200 m) at the end of the High Atlas Mountains. The High Atlas Mountains consist of a series of longitudinal crests with a SW–NE orientation. The Middle

Atlas Mountains are located at the center of the state, south of the Rif Mountains between the central and high plateaus north of the High Atlas Mountains with a SW–NE orientation. Thuriferous juniper, evergreen oaks (*Quercus ilex*), and Cedar (*Cedrus atlantica*) grow on these mountains. The thuriferous juniper is known for its tolerance to the extreme climatic conditions in these mountains and it plays an essential role for the surviving nomadic Berber population. The height and circumference of this tree can reach 19 m and 16 m, respectively. The foliage and wood provide a critical source of income for the Berber population. This area is densely populated compared to the Moroccan average. The population in the villages of Azzaden, N'Fis, Ourika, and Ait Bou Gamez increased 30 percent between 1971 and 1981. The thuriferous juniper cover has been reduced 90 percent due to grazing and human use since 1938 (Fromard and Gauquelin, 1993). This degradation has endangered the livelihood of mountain dwellers, leading to their emigration to other parts of the country. In an attempt to conserve the remaining forest, Toubkal National Park (polygon inside area A6, Figure 3) was established in 1942 encompassing an area of 380 km^2 (15 × 25 km). It is located 110 km west of Ouarzazate and 70 km south of Marrakech. Ifni Lake is within this park located southeast of Jebel Toubkal (PAWHP, 1988). In 1997, studies were initiated in an attempt to protect Toubkal National Park and help to revegetate the land with thuriferous juniper seedlings. Many field studies were conducted in the High Atlas of Azzaden Valley and Marrakech (Gauquelin, 1988; Badri, 1990).

The area marked B1 in Figure 3 is in a desert landscape situated between the intermittent streams of the Cap Drâa (drain to the Atlantic Ocean), Drâa, and Oued Tigzerte rivers. Mountains such as Lahouid and Taskalouine Jebel are to the north of B1 patch. This area is within the region just south of the Atlas where yearly rainfall variability is twice that of the area north and adjacent to the coast (Knippertz et al., 2003). The decrease in vegetation cover may be related to a decrease in rainfall in the mountains necessary to support stream flow at this downstream location. Rainfall data are needed to verify this causal effect.

Although not significant, the decrease in NDVI within the marked area B2 is notable. The marked area B2 contains the Arganeraie Biosphere Reserve, situated on 25,687 km^2 within the 828,000 ha Argan Forest in southwest Morocco around the city of Agadir. This forested area encompasses many reservations and national parks. This area is bordered to the north and east by the High Atlas and Anti Atlas mountains, to the south by the Sahara Desert, and to the west by the Atlantic Ocean. It covers several different land cover types: forest, cultivated, steppe, dunes, cliffs, sandy beaches, and wetlands. The natural cover in this ecosystem is rich in plant species with important ecological and socioeconomic roles. The local population utilizes this vegetation for pasture, wood, medicine, oil, and cosmetics.

Faced with desertification from the south and overutilization of the land for agriculture, in 1998 Morocco initiated the preservation of the Argan tree and designated the Arganeraie Biosphere (MAB-UNESCO, 1998) within the previously established (1991) Souss-Massa National Park. The Argan trees are tolerant to drought and other environmental stress factors; hence conservation, preservation, and perhaps enhancing their establishment especially to the south as a wind barrier will have a positive impact on the environment.

The areas marked B3, B4, and B5 in Figure 3 all show significant decreases in vegetation change, apparently due to urbanization. In a study assessing urbanization impact on agricultural lands, urban and rural growth were monitored in three cities, Béni Mellal (B3), Khémisset (B4) and Ksar El Kébir (B5) over two decades (Belaid, 2003). An area of $30 \times 30\,km^2$ was centered on each city and growth was monitored for three decades. The most significant expansion in urban and rural areas was in Ksar El Kébir city where urban and rural classifications increased by 344 percent and 160 percent, respectively. Urban and rural areas were the result of converting rain-fed fruit orchards and rangelands. In 1979, Oued El Mkhazine Dam was constructed near this city to permit irrigation of land that was previously rain-fed agricultural land. While Béni Mellal experienced 180 percent expansion in urban and 200 percent in rural areas, less expansion was noted in Khémisset (70 percent in urban and 60 percent in rural). Northwest of Rabat along the Atlantic coast, the Maâmoura National Forest, which covers 150,000 ha, experienced a decline in cork oak tree cover from 1955 to 2000 at a rate of 1,600 ha/year (Assali and Falca, 2006). Declines in forest cover in Maâmoura National Forest were evident in 1997 and 1999 using NDVI (Louakfaoui and Casanova, 2000). Felling, grazing, and drought are among stress factors that reduced greenness in this national forest. Monitoring changes in forest cover in this national forest using remote sensing from 1989 to 1991, changes can be linked to felling or other stress factors (FAO, 2008). To remediate degradation, a program was established by Morocco through an international partnership to plant 20,000 ha with cork oak trees in Maâmoura Forest (Maghreb Arab Presse, 2007). The severity of changes is less with proximity of B3 where Béni Mellal city is located (B3, Figure 3). Béni Mellal city is within the Tadla irrigation system in the Oum Er Rbia watershed. As mentioned earlier, Ait Ouarda Dam was built in 1953 and another nearby dam (Ait Messaoud) was built on 2003 to accommodate the expanding irrigated fields. Bouknadel Dam was established near the town of Khémisset in 1998 on the Serou River.

5. General Discussion

5.1. LANDSCAPE STRESS FACTORS

More than 85 percent of Morocco is classified as rangeland, which includes forests, steppes, high meadows, and Saharan lands. These rangelands provide food for livestock. As a result of intensive grazing without proper management, the state of Morocco realized that millions of hectares of rangeland are being degraded, especially in the northeastern zone, the *Argania spinosa* ecosystem, and the sub-Saharan and Saharan zones. Grazing on steep slopes in the Rif Mountains (northeastern zone) accelerated the removal of vegetation and exposed soil to erosion. One hundred kilometers south of Marrakech, the Quneine watershed spans 20 villages where 10,000 Berbers live, utilizing the land for agriculture and grazing. The watershed area is 200 km^2 located in the High Atlas Mountains, with an elevation that varies between 832 m and 2,746 m. Natural vegetation includes trees (thujas, junipers, chestnut, oaks), and aromatic and medical herbs. The vegetation cover pattern is patchy, exposing much of the soil surface to erosion. Local residents utilize a small proportion of the watershed land for agriculture using spring water; the remainder of the 200 km^2 watershed is used as a rangeland. In sparsely vegetated land, grazing and other domestic uses of trees and vegetation without proper management exacerbates land degradation. Rainfall can influence land degradation over time, resulting in gullies and rills reflecting the severity of the erosion process. From three years' study using the Revised Universal Soil Loss Equation (RUSLE) model, Klik et al. (2002) found that average soil loss was 33.7 t/ha/year in this watershed. Erosion was spatially variable within the watershed and associated with grazing and timbering. Several land management strategies were recommended to reduce the effect of erosion and to preserve sustainable land production for the local communities.

Another concern is deforestation. A study of the Tleta watershed (180 km^2), located between the cities of Tangeris and Tetouan upstream of the Ibn Battouta Dam, was established to collect monitoring data for assessing the sustainability of the western part of the Rif Mountain forests and rangeland. The land use/land cover of 1977 indicated that cereal crops comprised 50 percent of the watershed, forests comprised 40 percent of the watershed, and the remaining was scrubland used for grazing. The cultivated land increased to 65 percent and to 66 percent in 1991 and 1996, respectively, with a proportional decrease in forested area. The land was transformed by 1 percent of the total area per year from natural forest/scrubland to cropland between 1963 and 1987 in a nearby watershed

(Merzouk et al., 2003). Cultivation, grazing, and logging were cited as the main reasons for the decline in forested areas within 1977–1988.

5.2. POPULATION STRESSORS

The 2006 population estimate for Morocco is 33.2 million (LC-FRD). While the total population of Morocco at the turn of the last century (1900) was estimated to be five million, the predicted total population by the year 2044 is estimated at 46 million (Bennis and Sadeq, 1998). The estimated rate of population growth was the highest between 1952 and 1960 (2.8 percent) but has since declined, reaching a rate of 2.06 percent in 1994. The decline in population growth rate may be attributed to environmental stress, an increase in emigration, and many social factors. More than five million registered Moroccans were recorded in Europe between 1982 and 2004 (Haas, 2005).

While the growth rate has decreased, the distribution of the population within the country is changing and becoming more concentrated within the proximity of major cities. During the 1980s and periods of drought, the rural population migrated to urban areas seeking jobs. The population growth rate in urban areas was five times that of rural areas throughout the 1980s. Additionally, immigration and population displacement from neighboring Sub-Saharan countries (due to drought, famine, poverty, survival), as well as illegal transition toward Europe, are all posing a tremendous cost burden, on both the Moroccan environment and economy. Specifically, sporadic and somewhat orderly economically driven urbanization ensues. Take, for instance, the recent precipitous growth of impoverished areas in Marrakech and vicinity; the build-up of a whole city, Tamsluht, at 250,000, just a few miles north of Marrakech; and the construction in such large cities as Casablanca, Tangiers, Rabat, Agadir, Kenitra, Oujda, El Jadida, Fes, and Meknes.

To support the increasing urban population with food and other daily life commodities, it is necessary to increase or create new sources of these goods. This led to increases in irrigated agriculture, deforestation, and overuse of rangeland for livestock, thereby jeopardizing the long-term sustainability of the environment. Belyazid (2000) reported that as a result of overgrazing, deforestation, and conversion to agriculture to meet the needs of the populations of Oujida and Rabat, the sustainability of the Argan will not last more than two decades if proper management steps are not taken.

5.3. SOCIOECONOMIC FACTORS AND ENVIRONMENT

While welfare is often measured by economic factors such as growth rate of per capita Gross Domestic Product (GDP), and population growth, social issues are essential factors too. Education, health, and unemployment are some of the social indicators that are recently being considered in many economic studies (Sekkat, 2004). Environmental variables have also become important factors and were incorporated in growth accounting regression models. Sekkat quantified the effect of lagged income, investment rate, population growth, secondary school, inflation rate, and drought on GDP per capita growth rate from 1960 to 1997. Population growth rate and drought had a negative impact on economic growth due to the higher population density in rural areas where agriculture is the main commodity. Agriculture is an activity that is less conducive to economic growth because of its dependence on rainfall. The establishment of dams over the years did not meet the water demand for available agricultural land and the majority of crops are produced on nonirrigated land. In comparison, only 13 percent of Moroccan agricultural produce comes from irrigated land versus other countries that may reach as high as 40 percent. Hence, drought plays a major role in affecting economic development as indicated by GDP. To overcome losses from the agricultural sector and to preserve reasonable GDP, alternatives to agriculture such as industry or services have been considered for introduction.

6. Conclusions

We presented a simple method to locate and map 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 periods permits analyses of historical change and identification of long-term trends.

Although acquisition of all ancillary data for the entirety of Morocco was not possible, we incorporated the available 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 and 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 decision makers to take protective or remedial actions. In arid and semiarid ecosystems, degradation represented by decreasing vegetation cover may lead to irreversible desertification unless action is taken. Our analyses offer results that can be mapped at different scales (locally and regionally) and can be used to assess trends over both time and space; plus the approach can easily be applied to other locations.

New challenges are emerging in the relationship between the environment and the issue of security and are being given important consideration throughout the world. The question of the relationship between the environment and security is now a primary interest among both the scientific and policy communities. Landscapes change continually as an outcome of both natural and human-induced stress (i.e., land use is the primary result of the interaction of humans and natural ecosystems). The decrease in both quantity and quality of ecological resources, population growth, and equal access to resources are important factors related to environmental security risks. Renewable resources such as water and vegetation in arid environments are crucial factors in security issues, especially with respect to instability and migration. Thus both scarcity and degradation of resources leading to the risk of losing ecosystem goods and support services can contribute to instability, migration, and social conflict in both the national and international context.

Environmental degradation has various impacts on perceptions, behavior, and human social interactions. The NDVI change analysis approach provides an excellent process for statistically measuring and visualizing environmental change (i.e., both degradation and improvement) over broad geographical areas. However, it will undoubtedly take the combined thinking from both the environmental and social sciences to fully understand human-environment interactions, linkages, and their true meaning to security and world peace.

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