A Remote Sensing Approach to Drought Monitoring for Range Management at the Hopi Tribe and Navajo Nation

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Introduction

The Hopi Tribe and Navajo Nation are situated in the northeastern corner of Arizona, on the Colorado River Plateau. For more than a decade, the area has faced extensive and persistent drought conditions that have impacted vegetation communities and local water resources while exacerbating soil erosion. In addition to the ecological threats they have spawned, the droughts continue to hinder socio-economic development in the region.

Objectives

The general objectives of this study are:

- To evaluate the magnitude of inter-annual variability of vegetation productivity and to quantify its temporal variability relative to rainfall variation during the period 1989-2010,
- To detect any long-term vegetation productivity changes by performing a trend analysis over the study period, and
- To investigate the relationships between changes in vegetation productivity and rainfall trends over this period, in order to understand the impact of climate change.

Data and Methods

- Multi-sensor NDVI time series data were acquired from the Vegetation Index and Phenology project site (vip.arizona.edu) from 1989 to 2010 at 5.6 km.
- Climate data were acquired from Oregon State University's Parameter-elevation Regressions on Independent Slopes Model (PRISM).
- We limited our analysis to the snow-free period from March to November of each year and generated the following growing season and productivity related parameters : 1) Annual Cumulative NDVI, 2) Maximum annual NDVI, and 3) Annual relative NDVI amplitude.

These growing season parameters have been shown to be strong proxies of vegetation productivity and integrate the impact of climate and climate change rather well.

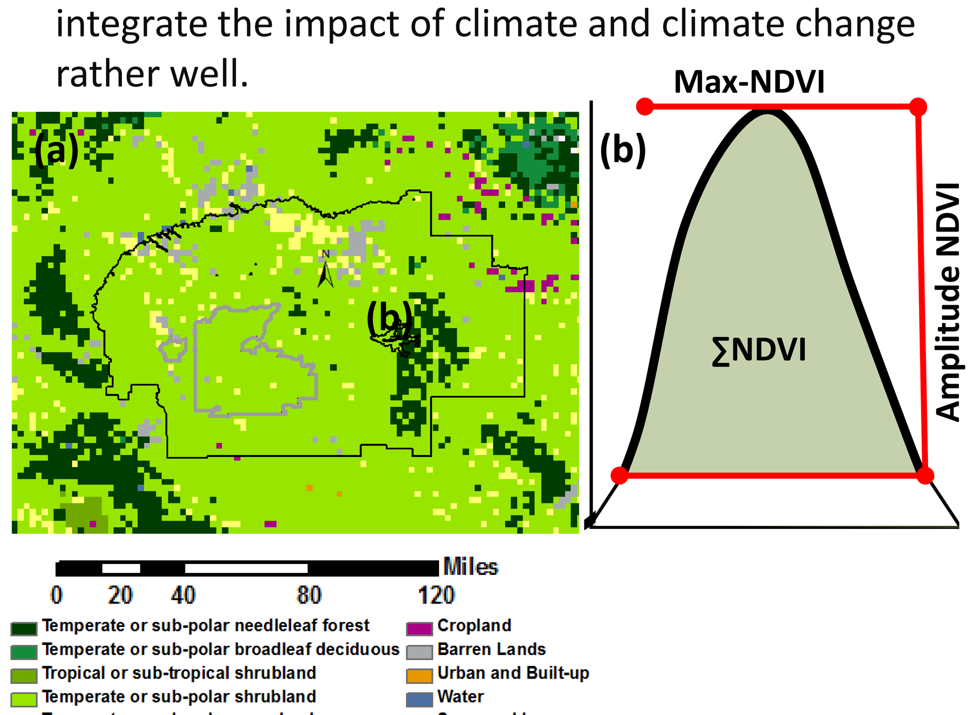

Figure 1: (a) Map of the dominant vegetation types (2005 North American Land Cover at 250 m spatial resolution database), and (b) Conceptual model of the NDVI related productivity parameters derived in this study.

Results

Vegetation Dynamic Assessment

The vegetation dynamics were characterized by the long term (inter-annual) average-NDVI related productivity-parameters. As expected, the vegetation productivity is highly correlated with rainfall gradients, which are in turn highly correlated with elevation (increase in precipitation with increased elevation).

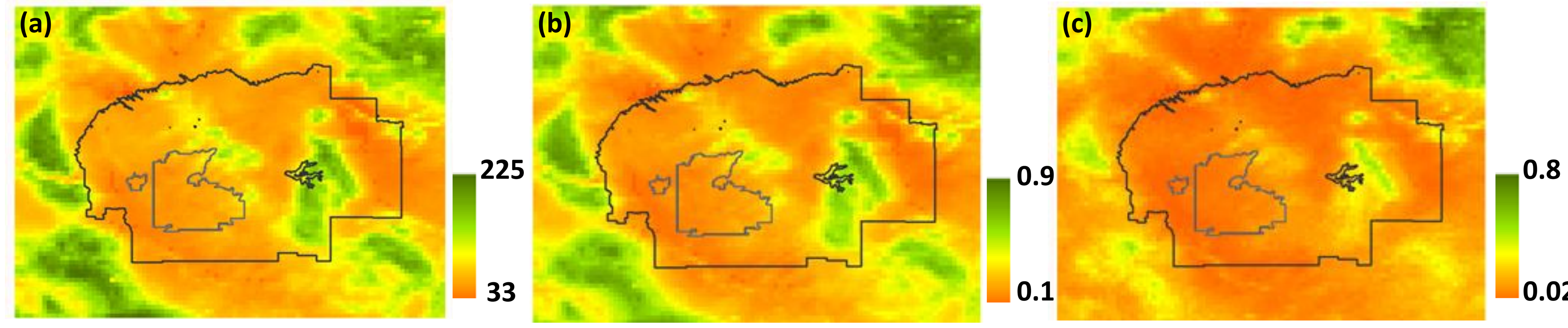

Figure 2: (a)Mean Inter-annual ∑NDVI (VI unit), (b) Maximum NDVI, and (c) NDVI amplitude (difference between Max and Min NDVI)

Spatial correlation between vegetation productivity and rainfall

The goal was to evaluate the spatial inter-annual variations in the regression parameters (Ordinary Least Squares Linear Regression) by examining the strength of the correlation coefficients (R^2) and the spatial variation of the model residuals. A strong correlation was observed (Fig. 3) with R^2 values between 0.79 – 0.86 for ∑NDVI, Max-NDVI, and Amplitude-NDVI versus rainfall.

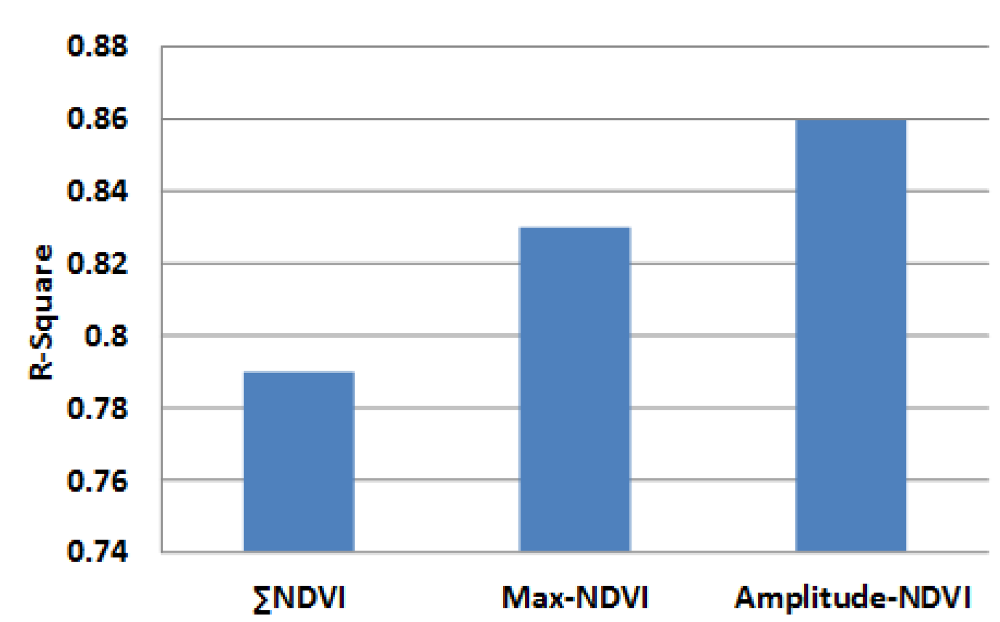

Figure 3: R^2 of the relationship between the mean inter annual NDVI related productivity parameters and mean inter annual rainfall.

Figure 4 illustrates the ∑NDVI-Rainfall OLS regression analysis at the 95% confidence level. These results confirm the strong dependency of productivity on rainfall in arid and semi-arid regions. The residuals map (Fig.5) of the observed ∑NDVI and the ∑NDVI modeled by regression (Figure 4) reveal the areas where the correlation is weak and/or where the changes in vegetation productivity were controlled by more factors than rainfall.

The residuals of the model vary between -214 and 98 (VI unit) over the study area with a standard deviation of 17 at the 95 % confidence level. The range between [-214 to -35] corresponds to overestimation, while [35 to 98] indicates underestimation. Values between [-34 to 34] correspond to the 95% confidence level and a strong correlation.

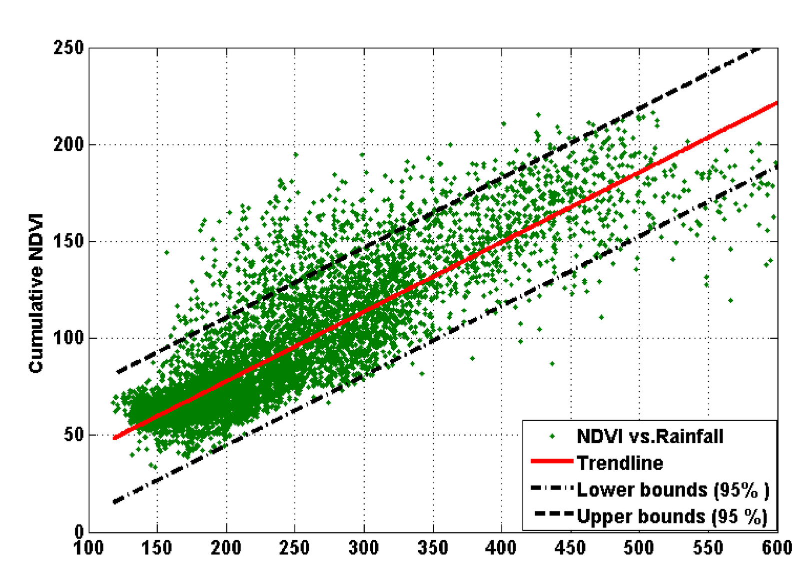

Figure 4: Correlation between mean inter-annual ∑NDVI and mean inter-annual rainfall

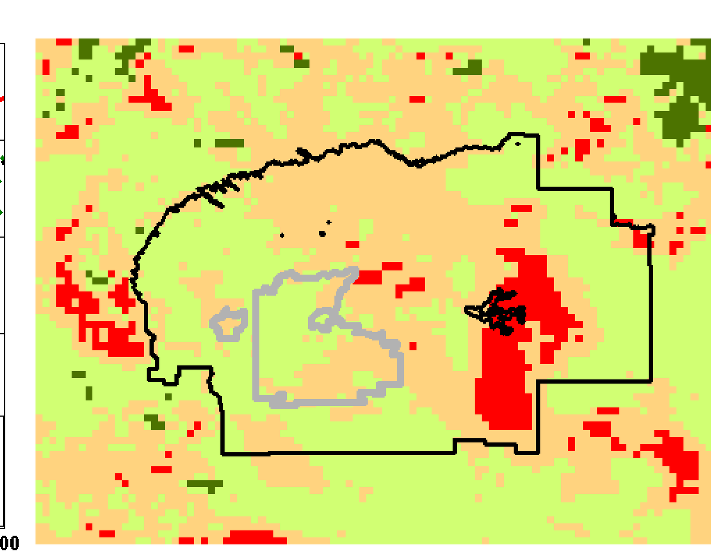

Figure 5: Residual map resulting from the regression model between mean inter-annual ∑NDVI and mean inter-annual rainfall

Inter-annual variability by vegetation type

In order to separate the specific response of each land-cover type in the NDVI-rainfall relationship, a linear regression model was developed for the three major land cover types in the area: grassland, shrubland, and needle-leaf forest . The strongest correlations were observed for grassland and shrubland, while forest exhibited a weaker correlation. Once again, the amplitude showed the strongest correlation across all vegetation types.

NDVI related productivity	Grassland	Shrubland	Forest
∑NDVI	0.83	0.73	0.26
Max-NDVI	0.88	0.79	0.45
Amplitude-NDVI	0.92	0.81	0.39

Table1: R^2 values of the regression models between the mean inter-annual NDVI related productivity parameters and mean inter-annual rainfall.

Long term trends in vegetation productivity

The OLS linear regression model was used to detect changes in NDVI-related productivity over the study period. In the model, time (22 years) is the independent variable, while the dependent variables were the NDVI-related productivity parameters. Figure 6 shows the mean inter-annual ∑NDVI decreasing by 74 %, the maximum NDVI decreasing by 62 %, while the amplitude decreased 41 %.

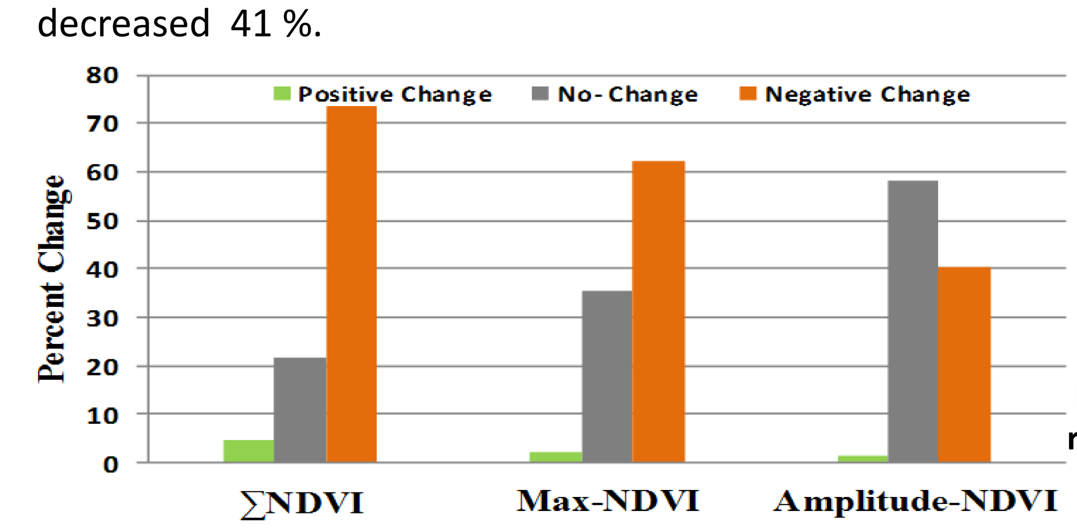

Figure 6: Changes in NDVI related productivity

Spatiotemporal Trends in ∑NDVI

Using a spatiotemporal linear regression we evaluated the trend over time, the strength of the correlation coefficients (R^2), and the slope of the regression, which indicates the direction and strength of change over time.

The results were based on the pixels that showed significant changes at the 95% confidence level. Figure 7 shows the areas experiencing a negative trend in productivity. Only 5% showed a slight increase in productivity, mainly at higher elevations.

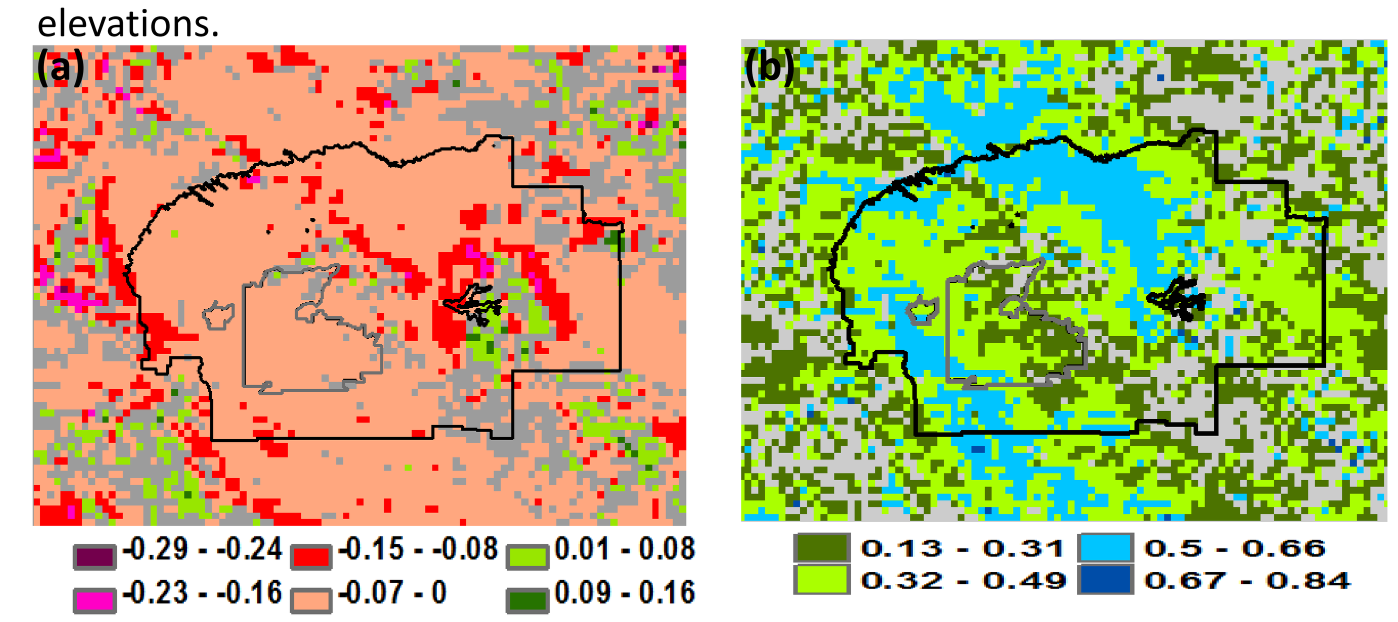

Figure 7: (a) slope of the significant trends in ∑NDVI and (b) linear correlation coefficient along the period (1989-2010) with a confidence level of 95% (p<0.05). Gray color indicates no-significant change

Rain-Use Efficiency (RUE)

RUE is the ratio of aboveground net primary production (ANPP) to annual rainfall. It is often expressed as the amount of dry plant material production on 1 hectare in 1 year per 1 mm of rainfall.

In this study we identified areas where RUE dropped over time due to either decreased soil moisture or increased evaporation. Figure 8 shows a predominantly decreasing trend in RUE for 19% of the area, while only an insignificant 2% showed a slight increase.

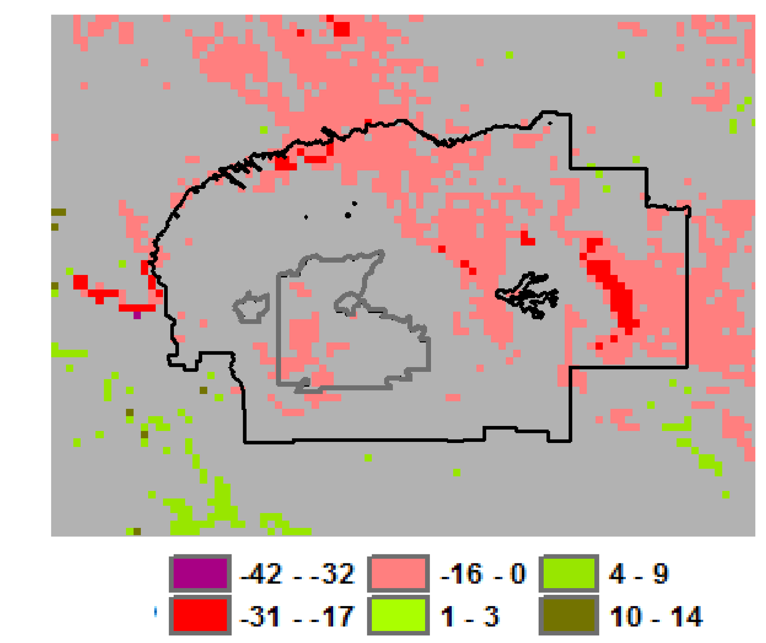

Figure 8: Spatial distribution of the RUE slope (unit: VI/mm)for the period 1989-2010. Gray color indicates no-significant change

Conclusions

Our study illustrates how remote sensing data and simple statistical tools can be used to 1) assess drought effects on vegetation productivity; 2) inform range management about land conditions; 3) and help identify areas where adaptive management actions could be applied.

- As expected for such an arid area, rainfall is the most fundamental and driving factor of vegetation productivity , especially for areas dominated by grassland and shrubland (limited root depth).
- The forested areas at higher elevations were less prone to rainfall variability. This reduced dependence can be explained by factors related to rooting depth, size, and resiliency of trees . Rooting depth determines a tree's ability to access deeper soil moisture during dry periods, and thus influences its intrinsic resiliency to precipitation reduction through its capacity to store water.
- Over the last two decades the region's vegetation has experienced a significant decrease in productivity.
- The RUE-based analysis did not show any widespread or significant changes. This seems to support the finding that rainfall patterns only explained 21% of the changes in vegetation productivity.
- The use of multi sensor seamless NDVI data (vip.arizona.edu) enabled us to successfully extend our analysis back to 1989.

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