COMPARING PARAMETRIC AND NON-PARAMETRIC APPROACHES FOR ESTIMATING TRENDS IN MULTI-YEAR NDVI

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ABSTRACT

The aim of this study is to systematically compare parametric and non-parametric techniques for analyzing trends in annual NDVI derived from NOAA AVHRR sensor in order to examine how trend type and departure from normality assumptions affect the accuracy of detecting long-term change. To generate annual data, the mean NDVI of a four-month long 'green' season was computed for fifteen sites (located in Africa, Spain, Italy, Sweden, and Iraq) from the GIMMS product for the periods 1982-2006. Trends in these time series were then estimated by Ordinary Least-Squares (OLS) regression (parametric) and the combined Mann-Kendall test with Theil-Sen slope estimator (non-parametric), and compared using slope value and statistical significance measures. We also estimated optimal polynomial model for the annual NDVI, by using Akaike Information Criterion (AIC), to determine the trend type at each site.

Results indicate that slopes and their statistical significances obtained from the two approaches at sites with low degree polynomials (mostly linear) and steep monotonic (gradually increasing or decreasing) trends compare favourably with one another. At sites with weak linear slopes, the two approaches had similar results as well. Exceptions include sites with abrupt step-like changes resulting in departures from linearity and consequently high degree polynomials where the least-squares method outperformed the Mann-Kendall Theil-Sen method. In sum, we conclude that OLS is superior for detecting NDVI trends using annual data though further investigation using other techniques is recommended.

INTRODUCTION

Trend analysis of satellite data-derived vegetation greenness with robust techniques can help us to increase our knowledge about changes in vegetation and land surface phenology. Time series of the Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI) product, with a span of 26 years (1981-2006) is specifically suited for estimating long-term trends in vegetation greenness.

Parametric (distribution dependent) approaches have been commonly used for NDVI trend estimation purposes (e.g. (1)). However, parametric trend results might not be reliable when normality assumptions are not met. On the other hand, non-parametric (distribution free) trend tests and estimators have also been applied in many vegetation trend studies (e.g. (2)). But if the assumptions of this method (no autocorrelation) are not met, the reliability of results could be negatively affected. To the best of our knowledge, we are not aware of any study that has directly compared these two approaches using the GIMMS-NDVI data, or any other data sets for that matter, and have provided guidelines for selecting the best approach for trend estimation.

In this paper, we apply two commonly used parametric and non-parametric trend estimation approaches; Ordinary Linear Squares (OLS) regression and the combined Mann-Kendall test (3, 4) with the Theil-Sen slope estimator (5, 6) to time series of the GIMMS-NDVI data for 15 study sites. Our aim is to systematically compare the approaches and examine how trend type, trend slope and departure from normality affect the accuracies of trend estimation.

METHODS

Data and study sites

We used the GIMMS-NDVI product for the period 1982-2006 at fifteen study sites (Table 1). These were selected because they cover a range of temporal vegetation trajectory patterns. The GIMMS-NDVI is a bimonthly maximum value composite data set with global coverage and 8-km spatial resolution, corrected for variations arising from calibration, view geometry, volcanic aerosols, and other effects not related to actual vegetation change (7).

Table 1: Study sites names and locations.

Site name	Latitude	Longitude	Site name	Latitude	Longitude	Site name	Latitude	Longitude
Sudan site 1	13.796	23.741	Ethiopia	5.259	42.441	Sudan site 2	18.133	37.205
Iraq site 1	31.450	47.600	Mali	14.496	-1.704	Cameroon	6.643	13.589
Chad	12.678	18.659	Iraq site 2	30.850	46.750	Spain	37.550	-6.300
Guinea	8.896	-9.486	Benin	11.296	2.659	Italy	44.900	9.250
Burkina Faso	13.623	-2.723	Eritrea	13.042	42.077	Sweden	56.700	14.400

Annual data generation

As we were mainly interested in analyzing trends in annual vegetation greenness we selected NDVI data for a 4-month long 'green' season when most plant growth occurs. We then generated the annual NDVI series, at each site, for a period of 25 years (1982-2006). To do this, the original data was first converted to monthly data through a simple averaging of every two bimonthly NDVI values. Then for each year, the mean of the four largest values was computed.

Parametric approach

OLS is a commonly applied model and it assumes that the errors are normally distributed with zero mean with an unknown but constant variance. If the slope value is significant (checked with a t-test), the null hypothesis that a trend exists is not rejected. Note that the results of hypothesis test are reliable if the model assumption is valid. To assess the validity of this assumption we performed Jarque-Bera (JB) test (which tests the null hypothesis that the residuals originate from a normal distribution with unknown mean and variance) (8), the t-test (to test if the residuals have a zero mean), while also generating scatterplots of the residuals versus fitted NDVI values (to examine the constancy of the residuals). All statistical tests in this study were performed at 5% significance level.

Non-parametric approach

The Mann-Kendall test (3, 4) is one of the most commonly used rank-based tests. Let $Y = y_1, y_2, \ldots, y_n$ be a time series of the annual NDVI for years 1 to n. To test the null hypothesis that the time series values are independent and in a random order against the alternative hypothesis that they contain a time-dependent trend, the Kendall's statistic, S, is calculated as (4)

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(y_i - y_j) \quad ; \quad sign(y_i - y_j) = \begin{cases} 1 & if \quad (y_i - y_j) < 0 \\ 0 & if \quad (y_i - y_j) = 0 \\ -1 & if \quad (y_i - y_j) > 0 \end{cases} \qquad (1)$$

S tends to normality when $n \geq 8$ with mean and variance given by

$$E(S) = 0 \quad ; \quad Var(S) = n(n-1)(2n+5)/18 \qquad (2)$$

The standardized Z test statistic is computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & for \quad S > 0 \\ 0 & for \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & for \quad S < 0 \end{cases} \qquad (3)$$

The significance of the trend is tested by comparing the Z statistic with the standard normal variate at the desired significance level of α (0.05). The null hypothesis (no trend) is rejected if the absolute value of $Z > Z_{\alpha/2}$. A positive Z value indicates an increasing trend whereas a negative value indicates a decreasing trend. The Mann-Kendall test indicates only the presence of a monotonic (increasing or decreasing) trend and for estimation of the trend magnitude, the non-parametric Theil-Sen technique (5), modified by Sen (6) is normally used. The Theil-Sen estimator is the median of the total number of $n(n-1)/2$ slopes calculated between the y values at all pair-wise time steps. This technique is robust against outliers (9). To assess the Mann-Kendall trend assumption of no auto-correlation between observations, we computed Autocorrelation Function (ACF) for different lags with 95% confidence bounds. The ACF values, which are effectively zero, lie within the confidence bounds.

Optimal polynomial model

In order to differentiate trend types at the sites, we used the Akaike Information Criterion (AIC) (10) to determine an optimal model (in the form of polynomial regression models) for the annual NDVI data series at each site, and considered the degree of the obtained polynomial as an appropriate indicator of trend type. According to Akaike's theory, the optimal model has the smallest AIC value.

RESULTS AND DISCUSSION

At the first seven sites (group 1 sites including top first row graphs, and the Ethiopia and Mali sites in Figure 1) overall trends are seen in annual NDVI throughout the period. These changes occur gradually and linearly whereas at the next four sites (group 2, which include the Iraq site 2, Eritrea, Benin and Sudan site 2) changes are abrupt. The final four graphs, group 3, do not show an overall increase or decrease in the NDVI seen throughout the period.

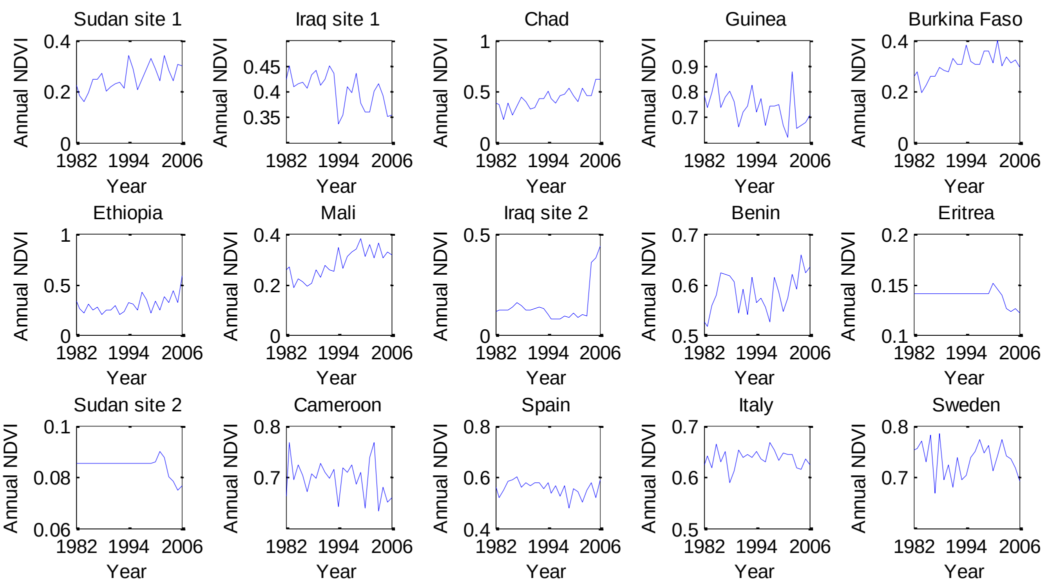

Figure 1: Time series of the generated annual GIMMS-NDVI at the study sites in 1982-2006.

Parametric versus non-parametric

Both approaches allocated similar trends for the group 1 sites with steep slopes and low degree (mostly linear) polynomials (Table 2, Figure 2). At group 2 sites (abrupt changes in the annual NDVI resulting in optimally fitted polynomials with relatively high degrees), the parametric approach estimated statistically significant linear trends while the non-parametric approach estimated trends that are not statistically significant. Iraq site 2 shows that the parametric approach estimated a positive trend despite the failure of the normality assumption. In this case, the trend was highly non-linear due to the large jump in NDVI in 2004 (Figure 1). By contrast, the non-parametric approach only found a statistically insignificant negative trend at this site and ignored the actual abrupt change by treating it as an outlier (Table 2). At group 3 sites, where both approaches found no significant trends, the slopes were generally weak and the optimal polynomials found (using the AIC) had low degrees, with zero in most cases (Table 2, Figure 2).

Table 2: Estimated trends slopes and their significance derived by the parametric and non-parametric approaches for the annual GIMMS-NDVI time series at the study sites, 1982-2006.

Group	Site name	Parametric			Non-parametric			DOP
		Significance	Slope	Assumption	Slope	Significance	Assumption	
1	Sudan site 1	s	0.0043	v	0.0045	s	v	1
	Iraq site 1	s	-0.0026	v	-0.0026	s	v	1
	Chad	s	0.0095	v	0.0095	s	nv	1
	Guinea	s	-0.0042	v	-0.0042	s	v	1
	Burkina Faso	s	0.0039	v	0.0033	s	nv	3
	Ethiopia	s	0.0065	v	0.0052	s	v	2
	Mali	s	0.0059	v	0.0062	s	nv	3
2	Iraq site 2	s	0.0055	nv	-0.0006	ns	nv	4
	Benin	s	0.0021	v	0.0022	ns	v	4
	Eritrea	s	-0.0005	nv	0.0000	ns	nv	3
	Sudan site 2	s	-0.0002	nv	0.0000	ns	nv	8
3	Cameroon	ns	-0.0013	v	-0.0011	ns	v	0
	Spain	ns	-0.0012	v	-0.0013	ns	v	3
	Italy	ns	0.0001	v	-0.0002	ns	v	0
	Sweden	ns	-0.0005	v	-0.0005	ns	nv	0

s: significant, ns: non-significant (α=0.05), v: valid, nv: non-valid. DOP stands for Degree of Optimal Polynomial based on the Akaike Information Criterion (AIC).

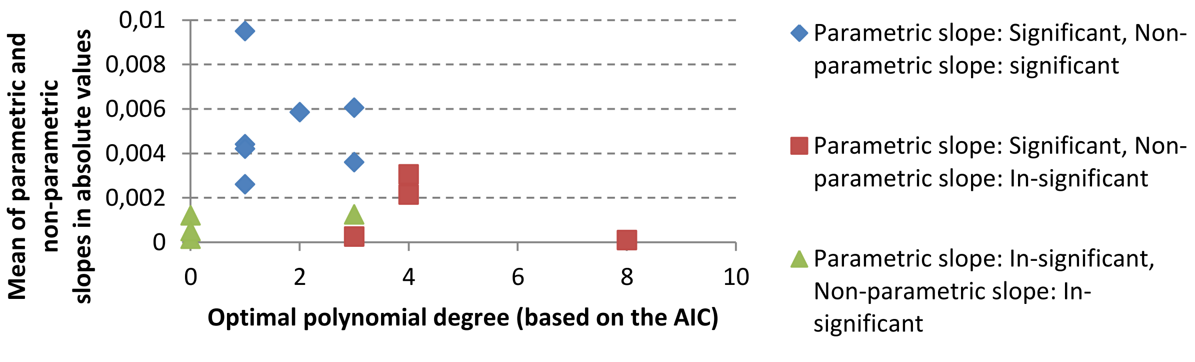

Figure 2: Scatter plot of the mean of the trends slopes estimated by the parametric and non-parametric approaches versus the degree of optimal polynomial (based on the AIC) fitted to the annual NDVI values (1982-2006) at the study sites.

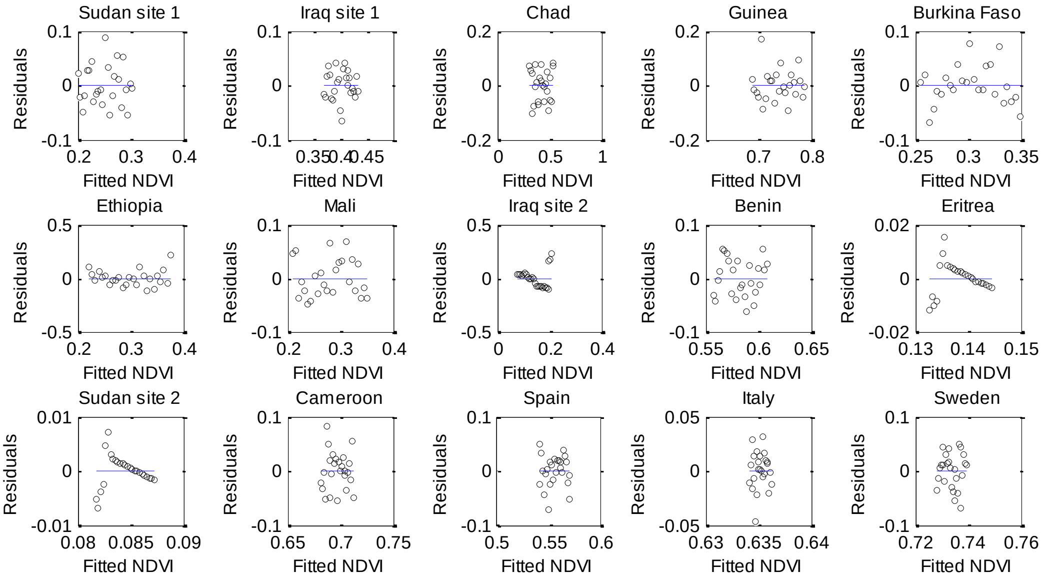

Figure 3: Scatter plots of residuals versus fitted NDVI values derived by the parametric approach at the study sites.

Validity of the approaches assumptions

Based on the results of the JB test and t-test performed on residuals from the parametric approach, we could not reject the null hypothesis of normal distribution for errors with zero mean at all the sites except the Iraq site 2, Eritrea and Sudan site 2 (from sites group 2) with abrupt behaviour. In addition, residuals at these three sites showed clear negative trends with increases in the fitted values while at other sites, residuals were randomly distributed around zero (Figure 3). Therefore, the estimated trends and their statistical significances obtained from the parametric approach were reliable at all sites except these three specific sites where the assumptions of the parametric assumption were not met.

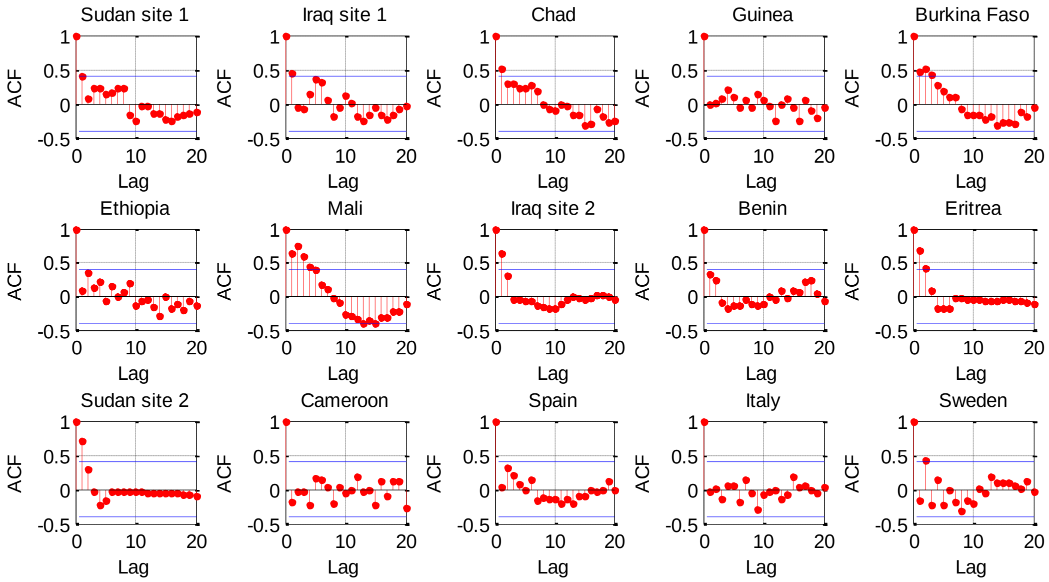

Figure 4: Auto-Correlation Function (ACF) plots of the annual NDVI time series (with 95% bounds shown by horizontal blue lines) at the study sites, 1982-2006.

On the other hand, the annual NDVI values at these three sites and at some other sites (Chad, Burkina Faso and Mali from group 1 and Sweden from group 2) exhibited autocorrelations at different lags, and therefore did not meet the assumption of no autocorrelation for the non-parametric test (Figure 4). Hence the non-parametric results were unreliable at these sites. In spite of this, the estimated slopes and their statistical significances were similar to the best results from parametric approach at sites group 1 and 3 (Table 2).

CONCLUSIONS

We conclude that the parametric and non-parametric approaches perform similarly for detecting and quantifying statistically significant trends for the sites where optimal NDVI models are low degree polynomials with steep linear slopes. Both approaches couldn't detect trends for sites having weak slopes, and optimal polynomials of low degrees (mostly zero). At sites having abrupt changes and high degree polynomials, the parametric approach outperformed the non-parametric approach. Although the annual NDVI at most of the sites with abrupt NDVI behaviour failed the normality assumption, the parametric approach succeeded in flagging significant trends whereas the non-parametric approach did not. In sum, we tentatively conclude that the parametric approach is superior for detecting NDVI trends using annual data. However, we recommend further testing with other parametric and non-parametric approaches on a greater range of temporal behaviours.

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