Time Series Analysis of Climate and Vegetation Variables in the Oreto Watershed (Sicily, Italy)

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Abstract: During the last ten years several hydrological and climatological studies showed significant changes in the climate characteristics of several zones on the planet. These researches confirmed that frequent drought phenomena are affecting southern Mediterranean areas. Rainfall and temperatures, in particular, are affected by significant variations at spatial and temporal scale. One of the effects of a persistent drought is the modification of the vegetation cover and biomass. The aim of our research is to analyze climatic time series and vegetation data within Oreto watershed, located in Sicily. In order to do this, a monthly dataset, from 1988 to 2005, of NOAA-AVHRR multispectral images was acquired and then processed and calibrated. Time series analysis has been applied both on the NDVI and precipitation, temperature, SPI, RDI datasets in order to study the temporal dynamics of vegetation during the period under investigation and to relate the vegetation evolution to the climatic evolution. Results confirm a negative trend for rainfall and a positive trend for temperature. No significant trends have been found for vegetation confirming a substantial stability of vegetation in the study area.

Keywords: SPI, RDI, NDVI fluctuations, trend analysis, temperature, rainfall.

1. INTRODUCTION

Sicily, like most areas of the southern Mediterranean shore, is subject to a risk of desertification (Kosmas et al., 1999; Geeson et al., 2002). The analysis of trends in the climatic time series in general and, specifically for drought indices, has become a subject of considerable interest. This is due to the fact that trends presence could be a signal of a climate change under way, as well as the knowledge of evolution of these sizes, in particular the precipitation, may become a supporting tool in the definition of possible future scenarios in the management and planning of water resources within a territory.

The international bibliography shows a number of researches about the rainfall variations at different time scales (daily to annual) in several Earth zones. Daily time series analyses showed positive trends of daily rainfall intensities and an increase of extreme events during the last decades (Houghton et al., 1996).

Rainfall intensity shows positive increasing trends in wide areas like the Unites States (Karl et al., 1995; Trenberth, 1998; Kunkel et al., 1999), Australia (Suppiah and Hennessey, 1998; Plummer et al., 1999), South Africa (Mason et al., 1999), United Kingdom (Osborn et al., 2000), northern and central Italy (Brunetti et al., 2000, 2001). In most of the areas characterized by rainfall intensity, an increased positive trend of total rainfall has been detected (Groisman et al., 1999). In Italy, the increase of extreme intensity events follows a general annual rainfall decreasing trend, (Brunetti et al., 2001). An increase of the number of areas threatened by flooding and drought phenomena has been detected (Dai and Trenberth, 1998). Gemmer et al. (2004) analyzed a rainfall time series of 160 Chinese rain gauges; this analysis highlighted the presence of trends in some months of the year, following a cluster pattern, especially in the Northern and North-Eastern areas of China.

In the Mediterranean region, several studies demonstrate a substantial reduction of annual rainfall in the Eastern zone (Amanatidis et al., 1993; Kutiel et al., 1996), in the central area
A number of studies have shown the presence of trends in rainfall recorded in Sicily; one of these researches (Cannarozzo, 1985) found a general decrease in the annual rainfall. Agnese et al. (2002) used a moving average on time series recorded by five Sicilian rainfall gauges from 1916 to 1999 in order to study long term rainfall trends. Aronica et al. (2002) found a reduction in annual rainfall and in maxima annual rainfall values for some rainfall gauges in the Palermo area (North Sicily). Bonaccorso et al. (2005) analyzed trends of annual rainfall maxima, and they found a different behavior depending on time scale; in particular, for short duration rainfall they found an increasing trend, whereas long duration rainfall showed a negative trend.

The use of satellite images can provide an essential contribution to research on the degradation of vegetation, allowing vegetation indices to be quickly determined for large areas and at a moderate spatial resolution. Indices such as the Normalized Difference Vegetation Index (NDVI) are usually used to describe the vegetation amount. This index is defined by the difference of the reflectance of the Near InfraRed (NIR) and Red bands normalized by their sum (Rouse et al., 1974).

NDVI values can be computed using the following equation:

\[
NDVI = \frac{NIR - Red}{NIR + Red} = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1}
\]

where \(\rho\) refers to the reflectance values of the second and first channel of AVHRR images. Since, for vegetated areas, NIR reflectance is greater than the Red reflectance, NDVI values greater than 0 are expected for these areas. If the vegetation biomass increases, the NDVI values may increase up to 1 (theoretical limit).

Vegetation dynamics are strongly dependent on variations in climatic conditions. Some authors applied the Principal Component Analysis (PCA) to characterize the annual and interannual variability of vegetation types and the connection with the ENSO (El Niño Southern Oscillation) phenomena (Gurgel and Ferreira, 2003). Some studies have confirmed this correlation (Saugier, 1996; Richard and Poccard, 1998), and have noted a time lag before the response of vegetation to climatic variations. It is very difficult to determine the length of this delay, since it depends on the type of climate, soil and vegetation. For example, Aber et al. (2002) found that in a forest environment in Kansas (USA), the time lag between climatic changes and vegetation response was between one and two years. Woldu Tamrat (1997) found that vegetation responds well to the total precipitation for the preceding two months in semi-arid environments, while other research reports that the lag period varies (Richard and Poccard, 1998). Other authors found a strong relationship between vegetation response and rainfall at continental and global scale (Zhang et al., 2005). Martiny et al. (2006) found significant correlation between rainfall and NDVI regimes in several regions of Africa.

Recently Cuomo et al. (2001) have published a study on NDVI fluctuations in the southern part of Italy showing a clear reduction in vegetation activity during the 1985-1999 period. In order to describe vegetation dynamics, other authors found that the use of precipitation alone is insufficient, and have therefore added other parameters such as temperature to their analysis (Wang et al., 2001; Potter and Brooks, 1998; Schultz and Halpert, 1993).

The general aim of this study is to detect the presence of significant trends in rainfall, temperature, potential evapotranspiration, SPI, RDI and the NDVI time series within a Sicilian study area and to study the possible correlations.

2. THE STUDY AREA

The Oreto watershed (an area of 129 km²) is located in the northern part of Sicily; among Mount La Pizzuta, Mount Gibilmesi and Tyrrhenian Sea (Fig. 1); it is surrounded by Jato watershed (south-
west), Belice watershed (south) and Eleuterio watershed (east). The basin includes the municipalities of Altofonte, Monreale and part of Palermo.

The main river of watershed is the 20 km long Oreto River that originates from Mount Matassaro, Mount Renna and Mount Cozzo Aglisotto. The profusion of groundwater causes an adequate flow even during the warm months. The soil is composed of limestone with alluvial debris near the outlet.

The mean annual precipitation ranges between 620 mm (coastal areas) to 582 mm (hill areas) while maxima values of rainfall are recorded in the mountainous area. The runoff is measured since 1924 through the gauge station of “Parco” located at 608 m a.s.l (about 76 km$^2$ of relative watershed).

![Fig. 1. The study area: Oreto watershed](image1)

![Fig. 2. Map of mean annual NDVI for the Oreto watershed](image2)

With regard to the mean NDVI map (each pixel value was computed averaging the 1988-2005 monthly values), displayed in Fig. 2, it gives an idea of mean vegetation density distribution within the Oreto basin: the north eastern zone (Palermo) is covered by urban area; the northern part is covered by high density forest (conifers) while the western and the south-western parts are characterized by lower amount of vegetation biomass, typically covered by crop.

3. AVAILABLE DATA

The datasets used in this study are of different types: rainfall and temperature data are point data while the satellite images data are in digital raster format.

Monthly rainfall data records for the period of 1918-2000 from raingauge stations across the Sicily, and monthly temperature data records for the period of 1964-2000, from the Osservatorio delle Acque dataset, have been used to derive a time series of monthly precipitation and monthly temperatures.

The available images are a set of NOAA-AVHRR scenes, acquired between January 1988 and May 2005, with a frequency of one month (209 images). These images have been made public by National Environmental Satellite, Data and Information Service (NESDIS) (www.class.noaa.gov) in the level b format. The images have been recorded by different platforms (from NOAA-9 to NOAA-17).

4. METHODS

The data have been processed using two different techniques:
1. a method of spatial interpolation (geographically weighted regression with a residual kriging) has been used to create a complete raster climatic data set (temperature and precipitation) with a cell size equal to 100 m for the above mentioned period (Bono et al., 2005);
2. a chain of image processing algorithms for satellite remotely sensed data.

Rainfall and temperatures were used to generate the drought indices, SPI and RDI, and to calculate the potential evapotranspiration (EPT) distribution following the Thornthwaite method (Thornthwaite and Wilm, 1944).

The whole satellite images dataset were geocorrected (UTM - datum European 1950). Then, a chain of calibration process has been implemented. The first two channels (Red and NIR) have been firstly calibrated in radiance and then in reflectance. A simple atmospheric correction method has been applied.

Fig. 3 shows a flow chart of procedure applied to the two different dataset in order to obtain the variables used in this study.

Thornthwaite's basic formula for computing monthly potential evapotranspiration $ETP$ is:

$$ETP = 1.6 \left( \frac{10T}{I} \right)^a$$

where $T$ is the monthly mean temperature [°C], $I$ is the heat index which is constant for a given location and is computed as a sum of 12 monthly index values $i$, where $i$ is a function of the monthly normal temperatures using the following formula:

$$i = \left( \frac{T}{5} \right)^{1.514}$$

and $a$ is an empirically determined exponent which is given as a function of $I$ by the following relationship:

$$a = 6.75 \cdot 10^{-3} I^3 - 7.71 \cdot 10^{-5} I^2 + 1.79 \cdot 10^{-2} I + 0.49$$

Starting from the rainfall and temperature maps, the areal mean time series of both the climatic variables have been derived over the Oreto watershed. These time series have been used to compute the RDI (Tsakiris et al., 2007a) and SPI drought indices (Fig.4) at annual scale by means of the DrinC (Drought Indices Calculator) software (National Technical University of Athens, Lab. of Reclamation Works and Water Resources Management; Tsakiris et al., 2007b).
In order to study the vegetation evolution in terms of NDVI, two different cases have been selected (Fig. 5): the first analyzed area within the watershed is covered by natural forest (conifers) whereas the second area is covered by vegetation crop. The NDVI values for these two pixels have been extracted from the NDVI images in order to process the signal of these two areas within the watershed.

Finally, a Time Series Analysis (TSA) both on the NDVI (forest and crop), temperature and rainfall datasets has been carried out in order to:

- detect the presence of statistically significant trends in the time series of different climatic variables and vegetation indices, like precipitation, temperature, potential evapotranspiration, SPI, RDI and NDVI;
- analyze the temporal dynamic of vegetation in terms of biomass in areas affected by persistent drought phenomena and subjected to the risk of desertification;
- correlate the vegetation evolution with climatic indices (precipitation, temperature).

In order to detect vegetation index trends, anomalies, evolution and its relationship with the temporal distribution of the climatic variables, a TSA of NDVI and climatic variables datasets has been carried out using the trend analysis and cross-correlation analysis techniques.

With regard to the former analysis, the time series of precipitation, temperature and NDVI have been analyzed using the Mann-Kendall non-parametric test for trend. Mann (1945) originally used this test and Kendall (1962) subsequently derived the test statistic distribution. This test allows inquiring on the presence of a tendency of long period in rainfall data, without having to make an assumption about its distributional properties. Moreover, the non parametric methods are less influenced by the presence of outliers in the data compared with other methods.
In trend test, the null hypothesis $H_0$ is that there is no trend in the population from which the dataset is drawn; hypothesis $H_1$ is that there is a trend in the analyzed records. Mann-Kendall test was applied to the monthly dataset. The test statistic, Kendall’s $S$, (Kendall, 1962) is calculated as:

$$S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \text{sign}(y_j - y_i)$$  \hspace{1cm} (5)

where $y$ are the data values at times $i$ and $j$, $n$ is the length of the data set and

$$\text{sign}(\vartheta) = \begin{cases} 1 & \text{if } \vartheta > 0 \\ 0 & \text{if } \vartheta = 0 \\ -1 & \text{if } \vartheta < 0 \end{cases}$$  \hspace{1cm} (6)

The Mann-Kendall test has two parameters that are of importance for trend detection. These parameters are the significance level that indicates the test strength, and the slope magnitude estimate that indicates the direction as well as the magnitude of the trend. Under the null hypothesis that $y_i$ are independent and randomly ordered, the statistic $S$ is approximately normally distributed when $n \geq 8$, with zero mean and variance as follows:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18}$$  \hspace{1cm} (7)

The standardized test statistic $Z$, computed by:

$$Z = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases}$$  \hspace{1cm} (8)

follows a standard normal distribution (Kendall, 1962). In this analysis confidence level at 90, 95 and 99 percent were considered, respectively. The non-parametric robust estimate of the magnitude of the slope, $\beta$, of linear trend, determined by Hirsch et al. (1982), is given by

$$\beta = \text{Median} \left( \frac{(y_j - y_i)}{(j-i)} \right)$$  \hspace{1cm} (9)

With regard to the cross-correlation analysis, it has been used to analyze the link between current vegetation and antecedent climatic conditions of the past few months and to determine the characteristic time lag between climate and vegetation. The NDVI-precipitation relationship has been demonstrated using the cross-correlation analysis. The cross-correlation (Von Storch and Zwiers, 1999) is a measure of similarity of two signals, commonly used to find features in an unknown signal by comparing it to a known one. It is a function of the relative time between the signals and it is based on the cross-correlogram that is the graph of the cross-correlation coefficients versus the time lags $l$.

Another TSA tool used in this paper, the sample autocorrelation functions or auto-correlogram, which is the graph of the correlation coefficient as function of the time lags $l$. When the autocorrelogram decays rapidly to zero after a few lags, it may be an indication of small persistence
or short memory in the time series, while a slow decay may be an indication of large persistence or long memory of the physical process.

5. RESULTS

5.1 Trend analysis on precipitation, temperature, potential evapotranspiration and NDVI, SPI and RDI indices

Figs. 6 and 7 show the NDVI (for forest and crop respectively) signal from 1988 to 2000 compared with the monthly precipitation and monthly mean temperature for the same period.

The trend analysis at seasonal and monthly scale has also been applied. The trend analysis has been performed at an annual time scale on all the considered variables. The trend analysis on precipitation, potential evapotranspiration, temperature and NDVI has been also applied at seasonal
and monthly scale.

Tab. 1 shows the results of Mann-Kendall test on the different time series used in the study (P, T, EPT, NDVI_crop, NDVI_forest, SPI, RDI). Initially, the trend analysis was carried out at an annual and seasonal time scale.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Significance level</th>
<th>Trend coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a = 0.1</td>
<td>a = 0.05</td>
</tr>
<tr>
<td>P</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>T</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>EPT</td>
<td>•</td>
<td>0.44749</td>
</tr>
<tr>
<td>NDVI_crop</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>NDVI_forest</td>
<td>•</td>
<td></td>
</tr>
<tr>
<td>SPI</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>RDI_normalised</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>RDI_standardised</td>
<td>•</td>
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</tr>
</tbody>
</table>

At an annual scale, the analysis shows negative trends for any significance level for precipitation, SPI and RDI. Especially for precipitation, the negative trend coefficient is quite high. Mean annual temperature and potential evapotranspiration show a positive trend for higher significance level.

Annual precipitation negative trend and temperature positive trend also cause a negative trend of drought indices. No trends were found for the two NDVI time series at an annual scale. Only a slightly increase was found for the winter season. This confirms a substantial stability of the vegetation in this part of Sicily.

At a monthly scale, the trend analysis shows a negative trend for precipitation in January and February (Tab. 2). Annual precipitation probably decreases due to this significant negative trend in winter months. With regard to temperature trend analysis, a significant positive trend in fall months has been found.
5.2 Cross-correlation analysis

The normalized mean seasonal cycle of NDVI (crop and forest), temperature and precipitation, obtained as monthly mean values divided by the annual mean and shown in Fig. 8, points out a time lag between the precipitation and NDVI variables equal to four months (December for precipitation and April for NDVI).

Similar information can be obtained from the analysis of the cross-correlogram between the NDVI, temperature and precipitation time series for the Oreto basin (Fig. 9).
It can be observed that correlations between precipitation and NDVI change with lag and are positive at lags of 0-6 months in most cases; higher correlations tend to occur at 4 month lags. The peak of the cross-correlogram indicates that the maximum of influence of precipitation on vegetation index occurs at the fourth month. With regard to the temperature – NDVI correlation, it must be pointed out that negative correlations occur at time lags between 0 and 5 months with a negative peak at 2 months time lags. This means that vegetation is sensitive to precipitation occurred during the previous 4 months and to mean temperatures of the previous 2 months. For higher precipitation of the previous 4 months and for lower mean temperature of the previous 2 months a decrease in vegetation vigor is expected.

The amount, or vigor, of the current vegetation is highly affected by antecedent vegetation vigor of the past few months. The changes in vegetation vigor have a low-frequency pattern as compared to atmospheric phenomena. This was confirmed by autocorrelation analysis of both NDVI time series. A positive autocorrelation was detected at time lags of up to 2 months, but decreased with increasing time lag and demonstrated a short memory or small persistence in the process of vegetation development. Correlation coefficients are usually greater than 0.6 at a time lag of 1 month and then decrease to 0.3 at lags of 2 months (Fig. 10).
Once it was determined where the maximum correlation between NDVI and the two selected variables (P and T) occurs, a further analysis has been carried out in order to evaluate which of the months of the year show a maximum correlation between the selected variables (P and T) and NDVI. In other words, correlations between all the pair of months at characteristics time lag were analyzed.

Particularly, it can be noted that NDVI (crop and forest) is strongly correlated with precipitation in the pair April-December (Figs. 11a and 11b): this means that higher biomass values occur in April if four months before (December) the precipitation which occurred was high.

With regard to the correlation between NDVI and temperature (Figs. 11c and 11d) a maximum negative correlation occurs in the pair April-August for crop (and also June-October for forest): this means that higher values of NDVI (biomass) occur for lower mean temperatures occurred 8 months before.
6. CONCLUSIONS

The aim of this research was to detect the presence of statistically significant trend in the time series of climatic variables as precipitation, temperature, potential evapotranspiration, SPI, RDI and vegetation indices as NDVI, to analyze the temporal dynamic of vegetation in terms of biomass in areas affected by persistent drought phenomena and subjected to the risk of desertification and to try to correlate the vegetation evolution and distribution with climatic variables (precipitation and temperatures).

The analysis of climatic trends in the Oreto watershed showed a statistically significant negative trend in annual precipitation and a statistically significant positive trend in mean annual temperature.

The annual precipitation negative trend causes a statistically significant decrease in SPI while the same trend, together with the temperature positive trend, causes a statistically significant decrease in RDI. No significant trend has been found in NDVI for crop and forest.

The cross-correlation analysis between NDVI, precipitation and temperature showed a characteristic time lag value which varies from 4 (P-NDVI) to 8 months (T-NDVI). The NDVI in the growing season (April) is positively correlated to the precipitation in December (lag 4) and negatively correlated to the temperature in August (lag 8). This implies that the vegetation condition at the beginning of the growing season depends strongly on the precipitation amount during winter (especially in December) and by the absence of high temperature during the late summer.

Further analysis has to be performed in order to evaluate correlation between vegetation dynamics and climatic variables over several types of natural vegetation. The use of distance based vegetation indices instead of NDVI is also needed. In fact, in areas characterized by sparse vegetation, a robust vegetation index should take into account the spectral soil characteristics.

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