# A Study on the Relation between Temporal NDVI and Economy and Population

*A Case on Chongqing City in Three Gorges Region, China*

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*Abstract*- **In the context of global climatic change, the distribution and variety of vegetation on continental ecosystem are important indices well responding to the climatic change. It is an effective approach to study the impact of human activities upon natural environment by analyzing dynamic trends of vegetation on time series. In this paper, we use 1 km resolution NDVI products from the Earth Observing System SPOT/VGT to analysis the relationship between NDVI and economy (indicated by Gross Domestic Product, GDP) and population (POP) in Chongqing city in three gorges region of southwestern China. It is found that the vegetation does not increase steadily and rapidly like GDP and POP with sustainable increasing trends from 1998 to 2005. In the second section, we deeply analyze the correction between NDVI and GDP and POP in six main districts on spatial distribution in 2000. It is pointed out that there are all negative correlation between some measurements of NDVI and GDP and POP respectively. But the similar correlation cannot be found, if the region is enlarged to the whole Chongqing city. Thus we evaluate correlation coefficient between NDVI and GDP and POP respectively by the mean of moving windows in every window. As a result, correlation coefficient is smaller if location is more far from the economic center of city.**

## I. INTRODUCTION

Vegetation, both native and cultivated, covers much of the earth and strongly influences the environment. The vegetation, in general, is a sensitive indicator of environmental condition, which exhibits swift temporal and spatial changes. Frequent monitoring of vegetation is therefore important to understand the environmental processes [1]. Until recently adequate data were lacking for mapping the composition, concentration, and dynamics of the world's vegetation. Remote sensing provides the only practical means of mapping and monitoring changes in major ecological regions that, although not directly used for production of food, have great long-term significance for mankind.

The NDVI is derived from the Red: Near-infrared reflectance ratio (NDVI= (NIR-RED)/(NIR+RED), where NIR and RED are the amounts of near-infrared and red light, respectively, reflected by the vegetation and captured by the sensor of the satellite). Values of NDVI range from 1.0 to -1.0. Higher values indicate higher concentrations of green vegetation. Lower values indicate non-vegetated features, such as water, barren land, ice, snow, or clouds. The high temporal resolution and global coverage of some satellite sensors, e.g., NOAA AVHRR, SPOT VEGETATION and Terra/Aqua MODIS make it possible to monitor vegetation at different spatial and temporal resolutions globally. Time-series of NDVI data have proven to be adequate for the detection of long-term land-use/cover changes and for modelling terrestrial ecosystems on global, continental, and regional scales [2]. During the 1980s, pioneering research was conducted to map and monitor vegetation on continental scales using data acquired by the U.S. National Oceanographic and Atmospheric Administration's (NOAA) meteorological satellite, the Advanced Very High Resolution Radiometer (AVHRR). Then the better quality, but short-term NDVI time-series, including (i) the Moderate Resolution Imaging Spectroradiometer (MODIS/TERRA) data set (250-1000 m resolution) extending from 2000 to the present, and (ii) the Satellite Pour l'Observation de la Terre–Vegetation (SPOT/VGT) data (up to a few meters resolution) extending from 1998 to the present [3]. Recently, many studies have successfully used those time-series NDVI data sets to gain novel insight into direct and indirect effects of environmental change [4]-[6].

In this paper, temporal SPOT/VGT NDVI data sets are used to analysis the vegetation change, and to detect the relationship between NDVI and economical development and population (POP) across space and time in Chongqing city in three gorges region of southwestern China.

## II. DATA

### *A. Study Area*

Chongqing city, located at longitude of 105°17′ E to 110°11′ E and latitude of 28°10′ N to 32°13′ N, is selected for this study. The climate belongs to sub-tropical humid monsoon climate with four distinct seasons, and is determined by summer rains (May-October) and winter humidness (November-April). Annual average temperature is 18.20□. And annual total precipitation is over 1010.90 mm. The study area, approximately 82.40 thousand km$^2$, is located the two sides of Yangtse rive, Jialing river, Wujiang river, Daning river and so on, and posses more over 3,000 thousand people. The junction place of Yangtse rive and Jialing river is the center of the city. The topography is generally rolling with Daba Mountain in the northeast and Wuling Mountain in the southeast, and only 10% of area is flat. The mean elevation is about 729 m, and range of elevation is more than 2000m. The five main vegetation types are broadleaf forest, needleleaf forest, bamboo forest, scrub and grassland with scattered trees, in which sub-tropical evergreen broadleaf forest is dominated. The Chongqing city, known for hills and Yangtse river, is the youngest and the biggest municipality directly under the central government since 1997. Now the economy of Chongqing city develops rapidly, and gradually becomes one of the most important economic centers in western China. Because the Chongqing city is located in the heart area of three gorges reservoir, and in the important eco-environment protection region of upper Yangtse river, how to correspond the correlation between quality of nature environment and economic development, that is ecological security, is always concerned by most of Chinese scientists, even many scientists all over the world.

*B. Temporal NDVI Data*

SPOT/VGT NDVI (10-day compositing, S10) images (total 279 images) covering the study region are acquired from April 1998 to December 2005. These products have a low spatial resolution (1km), but provide a very effective source for the examination of intra- and inter-annual vegetation variations because of a high temporal resolution. Preprocessing of the data was done by the Flemish institute for technological development (VITO) in the framework of the Global Vegetation Monitoring project (GLOVEG). The preprocessing consisted of atmospheric correction by SMAC and compositing at 10-day intervals based on the Maximum Value Compositing (MVC) criterion. The MVC selects individual pixels with the largest NDVI over every 10-day period to eliminate most clouds. The NDVI's real value of every pixel is related to the Digital Number (DN) via the specific formulation:

$$\textit{Real value} = 0.004 * DN - 0.1$$

All images are freely downloaded from the VITO's website: http://free.vgt.vito.be.

*C. GDP and POP Data*

The statistic data of Gross Domestic Product (GDP) and Population (abbreviation POP.) from 1998 to 2005 are all acquired from the yearbooks of Chongqing city (1998-2005) published by China statistical publishing house. Furthermore, data of GDP and POP in 2000 have been already interpolated to raster images (ARC/INFO GRID, 1km resolution) by the institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences (CAS). And these raster images are accurately corrected to the same projection and coordinate as NDVI images. Then the NDVI, GDP and POP images are all masked by the boundary of Chongqing city by GIS software.

## III. Analysis Methods

*A. Trend analysis from 1998 to 2005*

Firstly, the NDVI images (S10) of SE-Asia region are downloaded from VITO's website. Then the NDVI images of the study area are extracted by a smart software (CROP_VGT- Win32 Version 0.7, written by Silvio Griguolo). The NDVI provides information about the spatial and temporal distribution of vegetation communities, vegetation biomass, vegetation quality for herbivores and the extent of land degradation in various ecosystems. Using the method of MVC, the highest NDVI pixel value is calculated from the 3 images of every month. It can indicate the best status of vegetation cover under the best weather condition in one month. In a similar way, the maximum NDVI of one year can be calculated from 36 images, which indicate the best status of vegetation in one year. The mean NDVI of one year also can be calculated, which indicates mean status of vegetation cover. There are only 27 images in 1998, because the SPOT/VGT NDVI (S10) data sets are produced from April 1998. But vegetation begins to green in the Chongqing city in the first three months, so NDVI values are generally lower. Thus it does not affect the maximum and mean NDVI value in one year. Fig.1 shows the status of vegetation cover by maximum and mean NDVI in 2005. It is easy to found that vegetation in the east region and on the south side of Yangtse Rive is good. But the concentration of green vegetation in west region and around the center of city is lower, where the vegetation is always degraded because of intense human activities.

In this case, the index of Sum NDVI (SNDVI) is used to reflect the overall productivity and biomass in the whole study area. SNDVI looks like Integral INDVI (INDVI, sum of positive NDVI values over a given period [3].) or $\Sigma$NDVI (sum of NDVI over the NDVI level at the time of onset during the above 'duration' [7].). SNDVI is an integral NDVI on space, however, INDVI or $\Sigma$NDVI is an integral NDVI on the time series. In this paper, the SNDVI is defined sum of NDVI value of pixels with positive NDVI over a maximum or mean NDVI image. They are respectively marked with maximum SNDVI and mean SNDVI. So these two indices are calculated in every year from 1998 to 2005, which trends can show the vegetation of whole Chongqing city to a large extent

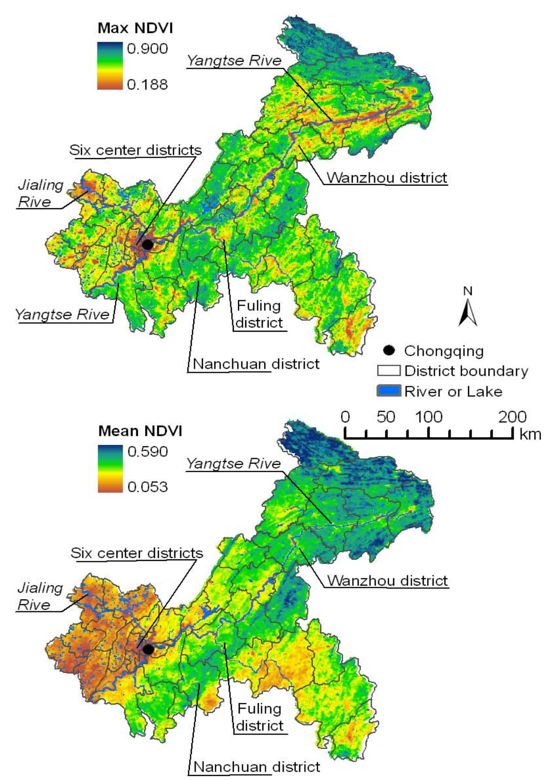


Figure 1. Maximum and mean NDVI images in 2005

in Fig. 2 (a). The trends of GDP and POP in this period are also delineated in Fig. 2 (b).

Maximum SNDVI curve has a sustainable ascending trend, and two sharp jumps in 1999 and 2003. But mean SNDVI curve is more fluctuant. It is interesting that when maximum SNDVI rapidly increase, mean SNDVI rapidly decrease yet. This specific character implies a certain extent that inter-annual variability of vegetation cover is big, and vegetation unevenly distributes on the entire city in these two years. Maximum SNDVI only increases 8% from 1998 to 2005, yet mean SNDVI decrease 14%. In the same period, however, GDP presents rapid ascending trends with a rate of 115%, and POP increases 3%. The vegetation does not distinctly increase along with the increasing of GDP and POP on the time series from 1998 to 2005.

*B. Correlation between NDVI and GDP and POP on Spatial Distribution*

In this section, we deeply analyze the correlation between NDVI and GDP and POP in detail on spatial distribution in 2000. The pixels of water are masked before the values of pixels are accounted. We have calculated such types of measurements as maximum, minimum, mean, median, standard deviation and the first three principal components of 36 10-days NDVI images in 2000.

In order to make the output reliable, the subregion (six center districts) approximately 4,872 $km^2$ is firstly selected around the center of Chongqing city. Then NDVI images, GDP and POP raster images are accurately corrected into local coordinate system with no more than one pixel error. Next, we extract the variables of NDVI (maximal, minimum, mean, et al.), GDP and POP pixel by pixel on the same location as table by ArcGIS9.0. To clarify the geographical difference of the effect of GDP and POP on vegetation activity, correlation analysis was applied between NDVI and GDP and POP respectively. The spatial correlation coefficients between

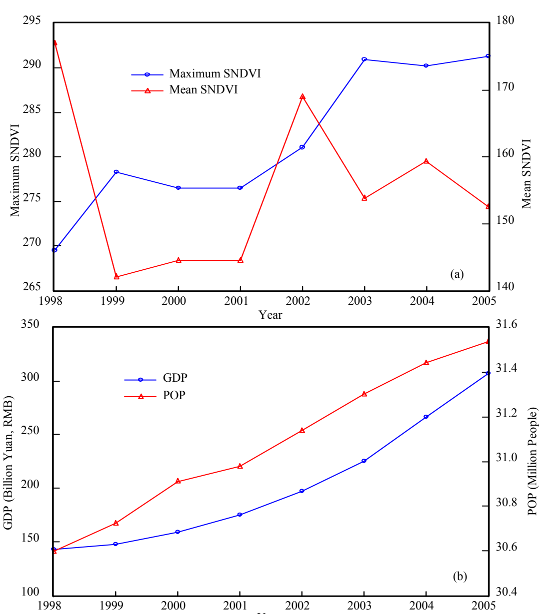


Figure 2. The change trends of SNDVI, GDP and POP from 1998 to 2005

variables of NDVI and GDP and POP in 2000 are calculated in the subregion (4,872 $km^2$, that is 4,872 samples), and are showed in Tab.1.

It is pointed out that there are all negative correlation coefficients between these NDVI variables and GDP and POP respectively. The GDP has a strong relationship with POP ($r = 0.89$), so they have almost same trends correlation with all measurements of NDVI. Especially, the GDP and POP all have stronger correlation with some measurements of NDVI, for example, maximal, mean, median, the first and the third principal components, particularly strongest relationship with the maximal NDVI. Furthermore, it shows good single linear regression relationships between NDVI (maximal, mean, the first principal component ) and GDP, POP respectively ($r^2 > 0.70$). But significant multiple linear or non-linear regression equation does not occur.

In this subregion, urbanization is more and more high with average growth rate of 12% every year. In fact, the area of vegetation is only 22 % of this area. Most lands of the downtown are used as construction. And only parks and some public open spaces are covered by planted trees and grasses. Large areas of vegetation especially trees mostly distribute at the Jinyun mountain, Zhongliang mountain and Tongluo mountain outside the urban, which are considered as green guard owing to the crucial ecological functions to the environment. But natural vegetation is further deforested and degraded with rapid urban expansion and population increasing. Negative correlation coefficients in Tab.3 well confirm this trend.

But the similar correlation cannot be found so highly, if the region is enlarged to the whole Chongqing city about 82.4 thousand $km^2$. The correlation coefficients between GDP and Max NDVI and Mean NDVI in whole Chongqing city respectively are only -0.28 and -0.25. And the correlation coefficients between POP and Max NDVI and Mean NDVI respectively are only -0.28 and -0.35. In order to clarify this regional difference of the effect of GDP and POP on vegetation, the $10 \times 10$ pixels windows (100 $km^2$) are selected to evaluate correlation coefficient between NDVI and GDP and POP respectively in every windows. Fig.3 shows the local correlation coefficient image, on which the values of some windows are assigned 0 if these correlation coefficients are not significant.

TABLES 1

CORRELATION COEFFICIENTS BETWEEN NDVI AND GDP AND POP

| Variables | Maximum NDVI | Minimum NDVI | Mean NDVI | Median NDVI |
|---|---|---|---|---|
| GDP | -0.72 | -0.46[a] | -0.68 | -0.61 |
| POP | -0.69 | -0.44 | -0.66 | -0.59[a] |
| Variables | NDVI Std. | NDVI PC1 | NDVI PC2 | NDVI PC3 |
| GDP | -0.42 | -0.66 | -0.36 | -0.67[a] |
| POP | -0.39 | -0.64 | -0.34 | -0.65 |

(a. T-test cannot pass, that is, correlation coefficients are not significant at the 0.05 confidence level.)

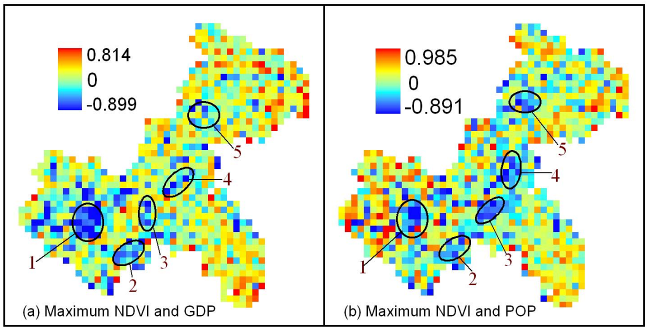


Figure 3. Spatial distribution of correlation coefficients between Maximum NDVI and GDP and POP
1, Six center districts; 2, Nanchuan district; 3, Fuling district; 4, Qianjiang district; 5, Wanzhou district.

There are negative correlations in some regions especially in six center districts (area 1 in Fig. 3) and other districts along rivers (area 2, 3, 4 and 5 in Fig. 4), implying that rapid economic development and lots of human activities negatively influence vegetation. It means that rapid economic development accompanies with plenty of deforestation. On the contrary, fringe regions around of the whole Chongqing city have positive correlation coefficients becoming more smaller if location is more far from the economic hearts of the city, particularly Daba mountain in the northeast and Wuling mountain in the southeast. In Fig.3 (a), the numbers of cells with negative coefficient occupy 63% of total cells, whereas numbers of cells with positive coefficient only occupy 37% of total cells. And there is approximate proportion in Fig.3 (b). It is said that negative correlation are more strong if human activities are more intensive. The reasons of weak negative correlation in the further area are that the changes of GDP and POP are not obvious, and cannot be accurately recorded in one 1×1 km pixel especially in vast rural area. But those regions often are well covered by vegetation, so the changes of vegetation are distinct from neighbor pixels. Where correlation coefficients are positive, cell values of GDP and POP are low, and cell values of NDVI are also low. It carries the connotation that economy is undeveloped, but deforestation is distinct.

## IV. Summary And Discussion

This study analyzed the correlation between NDVI and GDP and POP across the time and space using SPOT/VGT data and economic and population data. The results can be summarized as a number of points.

(1) As a whole, GDP and POP increase rapidly from 1998 to 2005, but SNDVI only has a little increasing trend with dramatic fluctuation. It does not assort with the critical important location in the weak eco-environment region of the three gorges reservoir. Quantity and quality of vegetation should be further improved with the rapid economic development in Chongqing city.

(2) Taking the year of 2000 as an example period, the correlation is analyzed across the space. In the subregion of six center districts, strong negative correlation is found between NDVI and GDP. Similar correlation exists between NDVI and POP because POP is highly consistent with GDP. But correlation is not so strong if the subregion is expanded to the whole Chongqing city region, that regional difference of correlation is analyzed. It is found, in several typical areas, that human activities are more intensive because of rapid developing of economy and negative correlation are more strong. It is no wonder that high positive correlation coefficients occur in some rural area far away from the town; GDP and POP is low with the absence of vegetation in these areas.

(3) In such strong negative areas as six center districts, maximum NDVI or mean NDVI has rather only a simple negative relationship with GDP or POP on spatial distribution, than Environmental Kunzites Curve (EKC) which is hump-shaped relationships (inverse U shape) between economical development and pollutant in natural environment [8].

Because raster data sets of GDP and POP only in 2000 are available, regional difference of correlation coefficients on time series cannot be analyzed. At the same time, the conclusion is not enough satisfying due to the relatively coarse resolution of data sets used in this paper. So there are many hard work to do on this issue in the future.

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