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INFLUENCE OF POPULATION AND ECONOMIC DEVELOPMENT ON VEGETATION
——A CASE STUDY IN CHONGQING CITY

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Abstract: Vegetation is an important variable in earth system. Influence of human activities on vegetation is obvious on certain scales. This paper, taking Chongqing City as an example, analyzed the correlation between artificial factors and vegetation spatio-temporal distribution based on time series NDVI data. It is shown that vegetation distribution and growth does not increase steadily nor rapidly like GDP and population with sustainable increasing trends from 1998 to 2005. There is always negative correlation between vegetation and GDP and population in terms of time series. However, the correlation appears significantly heterogeneous in space. The obvious negative correlation is observed in relatively developed areas nearby the center of the city where rapid economic development and urbanization make vegetation decrease both in distribution and productivity; whereas positive correlation is observed in those areas away from the city especially in underdeveloped areas.

Key words: vegetation; time series NDVI; population and economy development; spatial correlation field; Chongqing City

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Vegetation, both natural and cultivated, covers much of the earth and influences the environment. The vegetation, in general, is a sensitive indicator of environmental condition, which exhibits swift temporal and spatial changes[1]. Monitoring vegetation is therefore important in understanding the environmental processes. The data from satellites provide us first opportunity to monitor the vegetation on earth surface in a systematic and repetitive manner[2].

Normalized Difference Vegetation Index (NDVI) is well established in literature as a good representation of vegetation growth and vigor on land surface[3]. The NDVI is derived from the Red: Near-infrared reflectance ratio, shown as NDVI = (NIR - RED)/(NIR + RED), in which NIR and RED are the amounts of near-infrared and red light, respectively, reflected by the vegetation and captured by the sensor of satellite. NDVI is a nonlinear function that varies between -1 and 1. Values of NDVI for vegetated land are generally greater than 0.1, and values exceeding 0.5 indicate dense vegetation. Lower values indicate non-vegetated features, such as water, barren land, ice, snow, etc. The high

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temporal resolution and global coverage of some satellite sensors make it possible to monitor vegetation at different spatial and temporal resolutions. Time-series NDVI data has been proven to be adequate for the detection of long-term land use/land cover changes and for modelling terrestrial ecosystems on regional, continental and global scales[4]. In 1980s, some pioneering research was conducted to map and monitor vegetation on continental and national scales using data acquired by the U. S. National Oceanographic and Atmospheric Administration's meteorological satellite, the Advanced Very High Resolution Radiometer (NOAA/AVHRR)[5]. Then better quality, but short-term time-series NDVI was developed, including (1) the Moderate Resolution Imaging Spectro-radiometer (TERRA/MODIS) dataset (250～1 000 m resolution) extending from the year 2000 to present, and (2) the Satellite Pour l'Observation de la Terre-Vegetation (SPOT/VGT) data extending from the year 1998 to present[6]. Recently, many studies have successfully used those time-series NDVI datasets to gain novel insights into direct and indirect effects of environmental change[7～11].

Although vegetation distribution and growth are determined by such climate factors as temperature, precipitation and topography in long time, they are intensively influenced by human activities in short time especially in rapid developing regions[12]. The influence of artificial factors on vegetation was considered as an important research area in Land Use/Cover Change (LUCC)[13], but the studies in this field are rarely reported. The impact of human activities on vegetation may result from the following aspects[14]: (1) rapid urbanization destroys most of the vegetations around cities, (2) impervious surface in a city makes the soil structure changed, which changes directly the nourishment absorbed by vegetation, (3) air pollution in a city damages the sponge structure in leaves of vegetation and makes vegetation absorb less energy from sunshine and so reduces the vegetation productivity, and (4) heating island effect (HIE) in a city alters the vegetation phenology which determines directly the vegetation productivity. In this paper, time series NDVI datasets (SPOT/VGT) are used to analyze the vegetation change, and to detect the relationship between vegetation distribution and economic development and population across space and time in Chongqing City.

1 Data and Method

1.1 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 is defined as subtropical 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 1 010.90 mm. The study area, approximately 82.40 km^2, is located on the two sides of the Yangtze, Jialing, Wujiang and Daning Rivers, and has a population of more than 30 million. The junction place of the Yangtze River 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. The five main vegetation types are broadleaf forest, needleleaf forest, bamboo forest, scrub and grassland with sparse trees, in which subtropical evergreen broadleaf forest dominates. The Chongqing City, known for hills and the Yangtze River, is the youngest and biggest municipality directly under the central government since 1997. Now the economy of Chongqing City develops rapidly and becomes gradually one of the most important economic centers in western China. Because the city is located in the heart area of Three Gorges Reservoir and in the important eco-environment protection region in the upper reach of the Yangtze River, the relationship between environment quality and economic development in this area, has always been geratly concerned by the public.

1.2 Data

1.2.1 Time series NDVI data

SPOT/VGT NDVI (S10) dataset from April 1998 to December 2005 (total 279 images), are freely downloaded from VITO's website (http://free.vgt.vito.be). Despite the coarse resolution (1 km) these products provide a very effective approach to detect intra-annual and inter-annual variations of vegetation because of a high temporal resolution (10 days). 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 consists 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 errors resulted from clouds. NDVI's real value of every pixel is related to the Digital Number (DN) via the specific formulation: Real value = 0.004 × DN - 0.1. Then NDVI images of the envelope of the study area are extracted with longitude and latitude by a smart software CROP_VGT-Win32 Version 0.7 ①, written by Silvio Griguolo. And then, time series NDVI images of the study area are produced through masking tool by the boundary of Chongqing in ArcGIS9.0.

1.2.2 GDP and population data

The statistic data of Gross Domestic Product (GDP) and population from 1998 to 2005 are all acquired from the yearbooks of Chongqing City (1998～2005) published by China statistics press. The data of GDP and population of China in 2000 have been already interpolated to raster images (ARC/INFO GRID, 1 km resolution) by the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences (CAS). These grid data were interpolated based on county vector polygon with GDP and population statistic data and based on the impact of such natural factors as topography, river and road on human activities and population distribution ②. As an important research production, these grid data have been released to researchers in the field of geography, environment and ecology, and have been used widely[15].

1.3 Method

1.3.1 Smooth of time series NDVI data

NDVI datasets are generally well-documented, quality-controlled data sources, and synthesized in 10-day intervals based on MVC. Some noises, however, still present on these images. Therefore, time-series NDVI images need to be smoothed before being applied.

Firstly, moving average is used to replace the false value. For the value on a specific point in a specific period, if it is labeled as a false value according to the information derived from Satus Map, it will be replaced with average values of 2 decads before and 2 decads after this period, that is 4 adjacent points' values on the point. If it is not labeled as a false value, the original value is retained. In addition, values of points with a random NDVI increase more than 0.6 during 2 decads are also replaced by average value using the 4 adjacent points' values, as such increase cannot be caused by natural vegetation change.

Values of NDVI time series at the same point should follow the gradual process of the annual vegetation cycle, so sudden falls that are not compatible with the process can be regarded as noises. Savitzky-Golay (SG) filter is used to smooth the NDVI noise value and produces new time series NDVI data recovering real long-term trend of vegetation activity[4]. Through experiments on random samples, two best parameters are chosen for SG filter: the degree is 4 and the span is 7. The processing is accomplished in Matlab software with a set of codes. Combining the two methods of moving average and SG filter, 279 new images are acquired. The processing is accomplished in ArcGIS and Matlab software with a set of codes. Flowchart of data processing is displayed in Fig. 1.

① http://www.free.vgt.vito.be

② http://www.geodata.cn

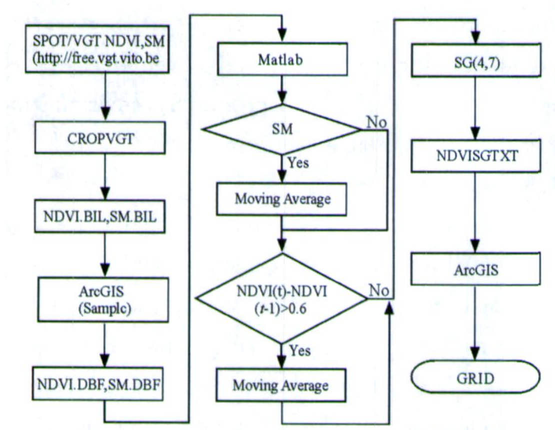

Fig. 1 Flowchart of Data Processing

1.3.2 Moving window correlation

Sampling on every pixel throughout the study area, large pairs of samples are easily acquired to calculate the global correlation between NDVI and GDP and population. However, the correlation should not be constant across the whole study area due to the heterogeneity of vegetation distribution and economic development in space. In order to describe the spatial variation of the correlation, moving window correlation is used which is often employed when data are measured on regular grids or when dealing with time series data[16]. Firstly, a set of windows is constructed over the study area. These windows are usually square although in theory any shape of window could be defined. In this study a window is defined 10 pixels × 10 pixels, and the study area is completely covered by windows with the same size. The correlation coefficient model (Pearson correlation) is then calculated with all 100 pairs of pixels that lie within the window and the process is repeated for all windows. The resulting local correlation coefficient is assigned as the window. After all windows are calculated, a smoother surface of correlation coefficient is produced, which is named spatial correlation field[17]. The correlations coefficients are calculated by modelling in ArcGIS9.0.

2 Results

2.1 Vegetation distribution

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 a year can be calculated from 36 images, which indicates the best status of vegetation in a year. The mean NDVI of a year also can be calculated, which indicates mean status of vegetation cover. There are only 27 images in 1998, because the SPOT/VGT NDVI dataset is produced from April 1998. But vegetation becomes green in Chongqing City in the first three months, NDVI values are generally lower. Thus it does not affect the maximum and mean NDVI value in 1998. Fig. 2 shows the status of vegetation cover by maximum and mean NDVI in 2005. It is easy to find that vegetation in the east and on the south side of the Yangtze River is good. But the concentration of green vegetation in west and around the center of the city is lower, where the vegetation is always degraded because urban expansion destroies vegetation.

2.2 Global trend of vegetation, GDP and population from 1998 to 2005

In this case, the index of Sum NDVI (SNDVI) is used to reflect the overall productivity and biomass in the whole study area in a year. SNDVI looks like Integral INDVI[13] or ∑NDVI[18]. SNDVI is an integral NDVI in space; however, INDVI or ∑NDVI is an integral NDVI in the time series. In this paper, the SNDVI is defined as the sum of NDVI value of pixels with positive NDVI on annual maximum image or annual mean NDVI image. They are marked with maximum SNDVI and mean SNDVI, respectively. So these two indices are calculated in every year from 1998 to 2005, and used to display the vegetation trend of the whole Chongqing City (Fig. 3 (a)). The trends of GDP and population in this period are also delineated in Fig. 3 (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. This specific character implies that inter-annual variability of vegetation cover is big, and vegetation distribution is unevenly on the entire city in these two years. Maximum SNDVI only increases by a factor of 8 % from 1998 to 2005, yet mean SNDVI decreases by a factor of 14 %. In the same period, however, GDP presents rapid ascending trends with a rate of 115 %, and population increases by a factor of 3 %. The vegetation does not distinctly increase along with the increasing of GDP and population in the time series from 1998 to 2005.

GDP and population rasters are accurately corrected to the same projection and coordinate as NDVI images. The error of correction is less than one pixel. The pixels of water are masked before the pixels are accounted. We have calculated such types of measurements as maximum, minimum, mean, median, standard deviation and the first three principal components (PC1, PC2 and PC3) of 36 NDVI images in 2000.

In order to make the output reliable, the subregion (six center districts) approximately 4 872 km^2 was firstly selected around the center of Chongqing City. Then NDVI images, GDP and population raster images were accurately corrected into local coordinate system with no more than one pixel error. Next, we extracted the variables of NDVI (maximal, minimal, mean, etc.), GDP and population pixel by pixel on the same location as table by using ArcGIS9.0. To clarify the geographical difference of the effect of GDP and population on vegetation activity, correlation analysis was applied between NDVI and GDP and population respectively. The spatial correlation coefficients between variables of NDVI, GDP and population in 2000 were calculated in the subregion (4 872 km^2, that is 4 872 pairs of samples). They are shown in Tab. 1.

It is pointed out that there are all negative correlation coefficients between these NDVI variables and GDP and population respectively. The GDP has a strong relationship with population ($r = 0.89$), so they have almost the same correlation trends with all measurements of NDVI. Especially, the GDP and population 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), GDP and population respectively ($r^2 > 0.70$). But significant multiple linear or non-linear regression equation does not occur.

In this subregion, urbanization level is relatively high with average growth rate of 12 % every year. In fact, the vegetation area is only 22 % in this area. Most lands in the downtown are used for construction. Only parks and some public open spaces are covered by planted trees and grasses. Large areas of vegetation especially trees are mostly distributed at the Jinyun mountain, Zhongliang mountain and Tongluo mountain outside the urban, which are considered as green kernel owing to the crucial ecological functions to the urban ecosystem. But natural vegetation is further deforested and degraded with rapid urban expanding and population increasing.

Tab. 1　Correlation Coefficients Between NDVI, GDP and Population

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

* T-test cannot pass, that is, correlation is not significant at the 0.05 confidence level.

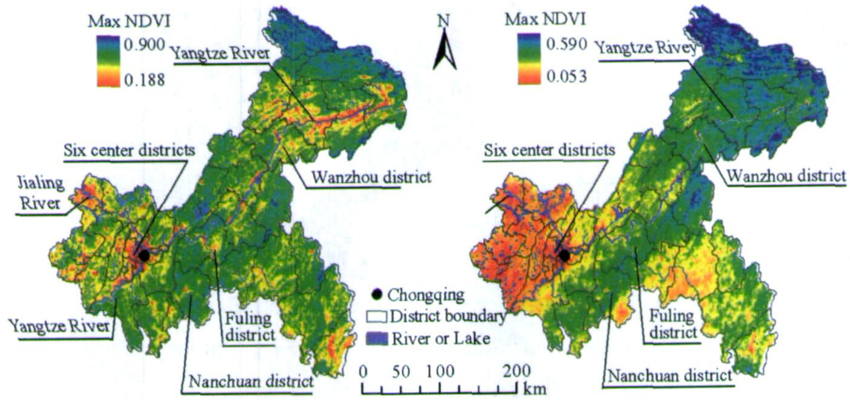

Fig. 2 Maximum and Mean NDVI Images in 2005

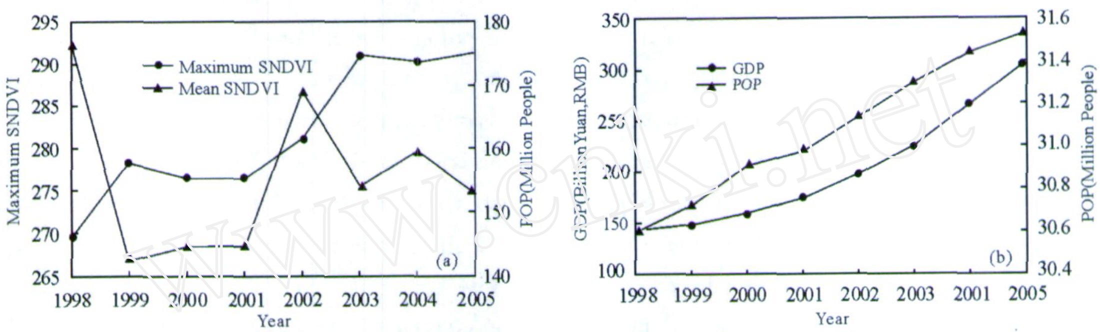

Fig. 3 Change Trends of SNDVI, GDP and Population (POP) from 1998 to 2005

2.3 Spatial correlation field

Although there is a stronger global correlation in six central districts, a good correlation cannot be found if the region is enlarged to the whole Chongqing City about 82.4 km^2. The correlation coefficients between GDP and Max NDVI and Mean NDVI in whole Chongqing City are respectively only - 0.28 and - 0.25. The correlation coefficients between population and Max. NDVI and Mean NDVI are respectively only - 0.28 and - 0.35. That is to say, local difference of correlation is obvious.

In order to clarify this regional difference of the effect of GDP and population on vegetation, the method of moving window correlation is selected to evaluate correlation coefficient between NDVI, GDP and population respectively in space. Fig. 4 shows spatial correlation fields, in which the values of some windows are assigned 0 if these correlations are not significant.

There are significant negative correlations in some regions especially in central districts (Area 1 in Fig. 4a) and other districts along rivers (Areas

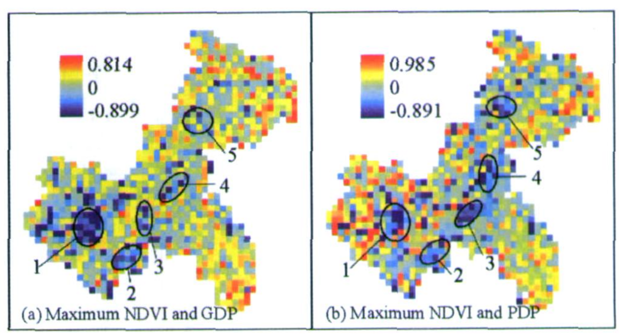

Fig. 4 Spatial Correlation Field

(1, Six center districts; 2, Nanchuan district; 3, Fuling district; 4, Qianjiang district; 5, Wanzhou district)

2, 3, 4 and 5 in Fig. 4b), implying intense influence of rapid economic development and high population density on vegetation. It means that rapid economical development accompanies with serious deforestation. On the contrary, fringe regions around the whole Chongqing City have positive correlation coefficients becoming much smaller, if they are located much further from the center of the city, particularly in Daba Mountain in the northeast and Wuling Mountain in the southeast. In Fig. 4 (a), the number of windows with negative coefficient accounts for 63% of total windows, whereas the number of windows with positive coefficient only for 37 % of total windows. And there is approximate proportion in Fig. 4 (b). It is said that the negative correlation is stronger, if human activities are more intensive. The reasons of weak negative correlation in areas are that changes of GDP and population are not obvious, and cannot be accurately recorded in one 1 km ×1 km pixel especially in vast rural area. But those regions are often well covered by vegetation, so changes of vegetation are distinct from neighbor pixels. Where correlation coefficients are positive, cell values of GDP and population are low, and pixel values of NDVI are also low. It carries the connotation that economy is undeveloped, but deforestation is distinct.

3 Conclusions and Discussion

This study analyzed the correlation between NDVI, GDP and population across time and space using SPOT/VGT NDVI data, economic and population data. The results can be summarized as the followings.

(1) As a whole, GDP and population increased rapidly from 1998 to 2005, but SNDVI only had a slight increasing trend with dramatic fluctuation. It ill assorts with the critical important location in the fragile eco-environment region of the Three Gorges Reservoir. The 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, the correlation is analyzed across the space. In the subregion of six central districts, strong negative correlation is found between NDVI and GDP. Similar correlation exists between NDVI and population because population increase is highly consistent with the rise of GDP. But the correlation is not so strong, if the region is expanded to the whole Chongqing City due to the heterogeneity of vegetation distribution and human activities in space. In order to display the difference among regions, spatial correlation fields are produced.

In several typical areas, it is found that the more intensive the human activity is, the much stronger negative correlation is. The high positive correlation coefficients occur in some rural areas far away from the town, where the GDP and population are all low accompanying with the deforestation or absent vegetation in these areas.

(3) In such strong negative areas as six central districts, maximum NDVI or mean NDVI has only a simpler negative relationship with GDP or population spatially, than Environmental Kuznets Curve (EKC) which is hump-shaped relationship (inverse U shape) between economical development and pollutant in natural environment[19].

Because raster datasets of GDP and population are only available in 2000, regional differences of correlation coefficients in other years cannot be analyzed. So there are many hard works to interpolate population and GDP in the future, and to analyze the spatio-temporal pattern of correlation between vegetation and socio-economic factors.

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人口与经济发展对植被的影响研究
——以重庆市为例

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摘　要: 植被是陆地表面主要的覆盖物，也是许多地球系统过程的重要变量。人类活动对植被的影响在区域尺度上是显著的。以重庆市为例，使用滑动平均和 SG 滤波对 SPOT/VGT-NDVI 时间序列数据进行了平滑处理，结合 GDP 和人口栅格化数据，从时间序列和空间相关场两个方面分析了植被与人类活动因子之间的时空相关性。结果表明，从 1998 到 2005 年，植被的分布和生长状况并没有随 GDP 和人口的持续增加而增加。在时间序列上，植被覆盖与 GDP 和人口之间总体上呈显著的负相关关系；在空间上，这种相关关系表现出了较强的异质性。空间相关场表明：较强的负相关主要发生在相对发达的主城区周围，反映了快速的经济发展和城市化使得植被面积和生产力降低；然而在偏远的山区，由于经济落后同时植被覆盖较少，出现了正相关。

关键词: 植被; 时间序列 NDVI; 人口与经济发展; 空间相关场; 重庆市

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