ANALYSIS OF VEGETATION DISTRIBUTION IN URBAN AREAS: SPATIAL ANALYSIS APPROACH ON A REGIONAL SCALE

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KEY WORDS: Vegetation, Spatial Autocorrelation, Spatial Continuity, NDVI, Seasonal Fluctuation, Ridgeline

ABSTRACT:

Recently, it is required to investigate the spatial distribution of vegetation in urban areas on a regional scale for not only the improvement of urban environment but also the conservation of ecosystem. In addition, the seasonal fluctuation of vegetation should be also analyzed because the vegetation distribution can be used for urban landscape management. The purpose of this study is to analyze the spatial distribution and seasonal fluctuation of vegetation on a regional scale. We defined the NDVI calculated from four kinds of Landsat ETM+ data as the potential of vegetation abundance and applied them to the spatial analysis using local spatial autocorrelation. As the results, it was obvious that the areas of high NDVI were extracted independently of seasonal fluctuation while there were various kinds of the extractions depended on seasonal fluctuation. We discussed the integration of the seasonal information on the spatial features of vegetation.

1. INTORODUCTION

It is required to investigate the spatial distribution of vegetation in urban areas on a regional scale for not only the improvement of urban environment but also the conservation of ecosystem. Satellite remotely sensed data have contributed to the regional analysis generally because of their spectrum information on vegetation. Wu and Murray (2003) estimated the distribution of impervious surface, vegetation cover, and soil cover through a fully constrained linear spectral mixture model using Landsat ETM+ data for monitoring urban areas and understanding human activities. Normalized Difference Vegetation Index (NDVI) calculated from satellite remotely sensed data has been traditionally applied to the remote sensing of urban heat islands, the estimation of vegetation cover ratio, the mapping of the urban forest carbon storage, etc (Wilson, et al. (2003), Myeong, et al. (2006)). NDVI, which can save time and money and speed the process of various kinds of urban mapping, has been conducive to regional scale analysis.

In the urban environment, the spatial continuity of vegetation plays an important role for the preservation of ecological balance. In general, the spatial continuity of vegetation is defined and described as a green corridor on master plans for parks and open spaces by selecting greenery areas along linear objects such as roads, rivers, and so on. However, there are few methods of extracting the spatial continuity through the analysis of the spatial distribution of vegetation on a regional scale. In addition, the seasonal fluctuation of vegetation should be also analyzed because the vegetation distribution can be used for urban landscape management. Combination of spatial and multitemporal analysis technique may provide the understanding of urban ecosystem.

The purpose of this study is to analyze the spatial distribution and seasonal fluctuation of vegetation on a regional scale. The whole area in Osaka prefecture, which had master plans for parks and open spaces, was dealt as the area of interest. We adopted four kinds of Landsat ETM+ data, acquired in April 2001, August 2000, October 2001, and December 2000, as regional-scale data including the information on vegetation. For the spatial and multitemporal analysis of vegetation on a regional scale, we defined the NDVI calculated from Landsat ETM+ data as the potential of vegetation abundance.

The data of NDVI were applied to the spatial analysis using local spatial autocorrelation. We proposed a potential map that consisted of positive spatial autocorrelation areas. They were overlaid on the map depending on the radius of local areas for the calculation, from wide range to narrow range, under “no-overhang rule”. This new map, which we call the Spatial Scale of Clumping vegetation areas (SSC), presents contour lines based on fluctuations in the number of the layers of the positive spatial autocorrelation areas. The top layer of the map denotes that the dense distribution area of high-vegetation abundance exists from narrowest range to widest range. Therefore, the area means a high-potential area on spatial continuity of vegetation. On the other hand, the bottom layer of the map also means that the dense distribution area of high vegetation exists within widest range even though there is no/negative spatial autocorrelation in the neighborhood of that. The four SSCs were produced by the application of four seasonal NDVI, respectively. The SSCs revealed in common that the areas of high spatial continuity were located in mountainous areas.

For considering conservation of ecosystem, there should be green corridors connected between the core areas and sparse areas of vegetation such as the top layer and the bottom layer on the proposed map. We applied the SSCs to the hydrological analysis for extracting ridgelines that could be expected to contain high spatial continuity of vegetation in between the core areas and sparse areas of vegetation. For reviewing the appropriateness of the ridgelines as spatial continuity of vegetation, it is required to investigate the statistics of NDVI in the neighborhood of the ridgelines. We carried out the local calculation of NDVI statistics along the ridgelines. In this investigation, the calculation of NDVI statistics was carried out whenever the range of local area varied from widest radius to narrowest radius. We got the lowest values of top 10% NDVI in each local area and compared the average of these values between the ridgelines and the green corridors in the master plans for parks and open spaces. As the results, it was obvious that the areas of high NDVI were extracted along the ridgelines irrespective of seasonal fluctuation, while there were various kinds of the extractions depended on seasonal fluctuation.

Finally, we discussed the integration of the seasonal information on the spatial features of vegetation. It is required to be noted that spatial continuity of vegetation has to be extracted from steady areas unaffected by the seasonal fluctuation of vegetation. Based on this viewpoint, we overlaid four SSCs and selected lowest layer of them every local area. Through the statistical observation of local NDVI data, it was shown that the areas of high NDVI were extracted along the ridgelines derived from all seasons.

2. MATERIALS AND METHODS

2.1 Study Area

In this study, the whole area in Osaka prefecture was adopted as the area of interest. This area is located in Kansai district, the western part of Japan. It covers about 1,900 km^2 and contains 33 cities, 9 towns, and 1 village. The Osaka prefecture has master plans for parks and open spaces.

2.2 Satellite Remotely Sensed Data

Landsat ETM+ data, observed on April 2001, August 2000, October 2001, and December 2000, were adopted as basic data. We applied atmospheric correction based on MODTRAN and geometric correction to the data. We defined the NDVI calculated from Landsat ETM+ data as the potential of vegetation abundance.

2.3 Methods

2.3.1 Spatial Autocorrelation: We used the spatial autocorrelation method described with Equation (1).

$$G_i(d) = \frac{\sum_{j=1}^{n} w_{ij}(d)x_j}{\sum_{j=1}^{n} x_j} \quad (1)$$

where G is G statistics, w_{ij} is a symmetric one/zero spatial weight matrix with ones for all links defined as being within distance d of a given i; all other links are zero including the link of point i to itself (Getis, et al. 1992). We assigned a NDVI to a variable x. If the null hypothesis is that the set of x values (NDVI) within d of location i is a random sample, we derive Z value described with Equation (2). Positive or negative spatial autocorrelation is obtained depending on whether Z value is positively or negatively greater than specific level of significance. As the results of the statistical tests, the area of interest was divided into three kinds of the results of the statistical test with the significance level of 10%, as in positive spatial autocorrelation, no spatial autocorrelation, and negative spatial autocorrelation.

$$Z_i(d) = \frac{G_i(d) - E[G_i(d)]}{\sqrt{VarG_i(d)}} \quad (2)$$

2.3.2 Distance Parameter d: We focused attention on distance parameter *d*, which meant the range of a local area where G statistics and *Z* value were calculated. We examined the fluctuation of the ratio of correlation areas to non-correlation areas with increasing distance *d*. Figure 1 shows the result for NDVI in August 2000 as an example. As *d* is increasing, it is indicated that positive and negative spatial correlation areas are increasing. The figure shows that both of correlation areas spread to the non-correlation areas with increasing ***d***. For investigating the range of distance *d*, the differences of areas between adjacent distances were calculated as Δa. Figure 2 reveals the convergence of   appears when *d* is more than 1050 m. We researched the fluctuations and convergences of Δa for four kinds of NDVI and got the range of distance *d*, respectively (see Table 1).

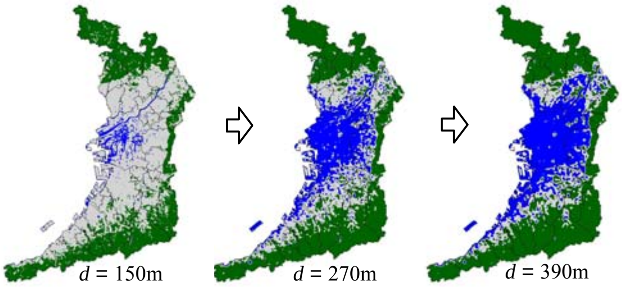


Figure 1. Fluctuation of correlation areas for NDVI in August 2000 as an example. The green area means a positive spatial autocorrelation area. The blue area means a negative spatial autocorrelation area. The gray area is no spatial correlation area.

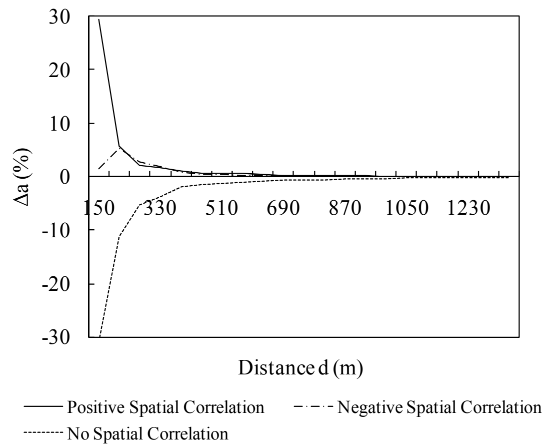


Figure 2. Fluctuation of the differences of areas between adjacent distances for NDVI in August 2000 as an instance.

NDVI	Range of *d* (m)
April 2001	90 - 1100
August 2000	90 - 1050
October 2001	90 - 870
December 2000	90 - 870

Table 1. Ranges of distance *d* derived from the research of the difference fluctuation.

2.3.3 Spatial Scale of Clumping (SSC): We proposed a potential map that described spatial continuity of vegetation (Kumagai, 2006). The map consists of positive spatial correlation areas. They are overlaid on the map depending on *d*, from wide range to narrow range, under "no-overhung rule". This new map, that we call the Spatial Scale of Clumping vegetation areas (SSC), presents contour lines based on fluctuations in the number of the layers of the positive spatial autocorrelation areas. The concept of SSC is shown in Figure 3. For instance, the area "A" in Figure 3 denotes that the dense distribution area of high vegetation abundance exists from narrowest range to widest range. Therefore, the area might mean a high-potential area on spatial continuity of vegetation. On the other hand, the area "D" also means that the dense distribution area of high vegetation exists within only widest range even though there is no/negative spatial autocorrelation in the neighborhood of that. The four SSCs were produced by the application of four seasonal NDVI, respectively.

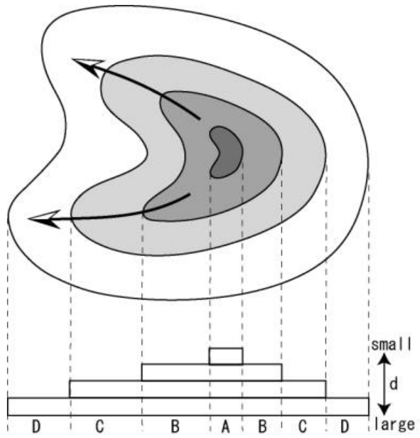


Figure 3. Concept of Spatial Scale of Clumping (SSC).

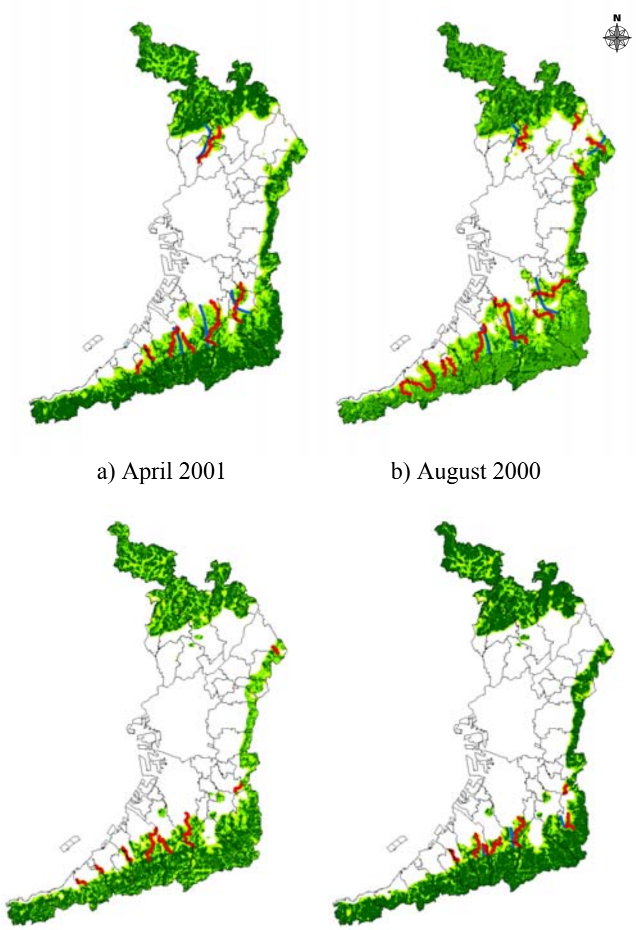
2.3.4 Extraction of the spatial continuity between the core areas and sparse areas of vegetation: For considering conservation of ecosystem, there should be green corridors connected between the core areas and sparse areas of vegetation such as the areas "A" and the areas "D" in Figure 3. Then interpreting the proposed map as a topographic map, we applied a kind of geomorphological analysis to the map. We applied the SSCs to the hydrological analysis for extracting ridgelines that could be expected to contain high spatial continuity of vegetation. The image of the ridgelines is described as two arrows in Figure 3.

3. RESULTS AND DISCUSSION

3.1 Results of SSC

Figure 4 shows the results of the proposed method. These SSCs contain 14-18 layers of positive spatial autocorrelation areas. The figures reveal in common that the areas of high spatial continuity are located in mountainous areas; north, east, and south part of this test site. Red lines in Figure 4 mean the ridgelines extracted through the application of SSCs to the hydrological analysis. It is shown that the ridgelines lie between the mountainous areas and the plain that includes a spread of urban areas.

There are many ridgelines in south part of test site in all SSCs. There have been the lower pressures of development in the south areas than in other areas. It seems that there may be a lot of natural land cover areas in this areas. The result of summer NDVI (August 2000: Figure 4 b)) indicates that the number of ridgelines is most abounding and their length is almost longest because the areas of spatial continuity in summer SSC spread most largely than in other SSCs.



a) April 2001 b) August 2000

c) October 2001 d) December 2000

Figure 4. Results of the proposed method. We obtained 14-18 layers of positive spatial autocorrelation areas. Red lines mean the ridgelines extracted by hydrological analysis. Blue lines mean the green corridors in the master plans for parks and open spaces.

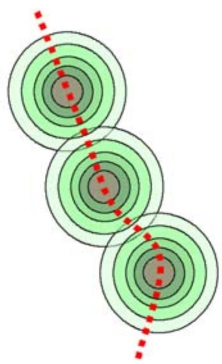


Figure 5. Concept of the calculation of local NDVI statistics along the ridgeline.

3.2 Local statistics of NDVI

For reviewing the appropriateness of extracting the ridgelines, it is required to investigate the statistics of NDVI in the neighborhood of the ridgelines. We carried out the local calculation of NDVI statistics. Figure 5 shows the concept of the calculation along the ridgelines. In this investigation, the calculation of NDVI statistics was carried out whenever the range of local area varied from widest *d* to narrowest *d*. We got the lowest values of top 10% NDVI in each local area and compared the average of these values between the ridgelines and the green corridor.

Moreover, we carried out the statistical test of the difference of the averages of the NDVI statistics between the ridgelines and the green corridors. Figure 6 shows the results of the statistical test between the averages. It is indicated that the differences of the NDVI statistics between the ridgelines and the green corridor planned are increasing as *d* is decreasing in all SSCs. It is obvious that there are differences of statistical significance between the ridgelines and the green corridor in neighborhood of them. It seems apparent that the areas of high NDVI are extracted along the ridgelines. Hence, it is suggested that the ridgelines in all SSCs might play a role as bridges between the core areas and sparse areas of vegetation.

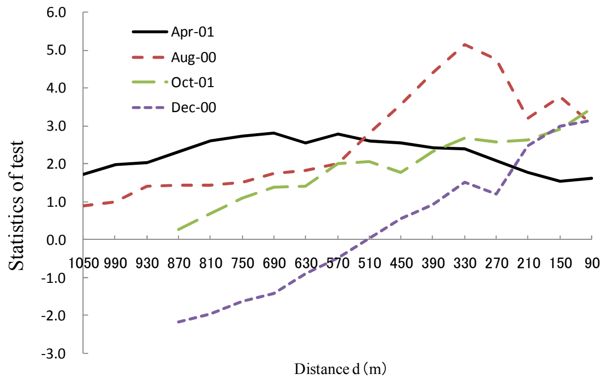


Figure 6. Results of the statistical test for the difference of the averages of the NDVI statistics between the ridgelines and the green corridor planned. In case where the statistic of test shows more than 0, the average of NDVI statistics along the ridgelines is greater than the green corridor.

3.3 Discussion

In Figures 4, there were various kinds of ridgelines in the SSCs. It seems that the shape and length of ridgelines depend on seasonal fluctuation of NDVI. Using all ridgelines in the SSCs is one of the analytical methods in consideration of the seasonal fluctuation of vegetation. However, on the other hands, retrieving definitive ridgelines throughout all SSCs can be expected to lead to the extraction of steady areas unaffected by the seasonal fluctuation of vegetation. Based on this viewpoint, we compared between layers of four SSCs and had an integrated result newly through selecting lowest layer. Figure 7 indicates the result of the integration of four SSCs and ridgelines derived from that. As in case with section 3.2, we compared local statistics of NDVI between the ridgelines and the green corridors. Figure 8 shows the results of the comparison. It was shown that the areas of high NDVI were extracted along the ridgelines derived from all SSCs.

In Figures 6 and 8, there are certain differences of the statistics of test. The range of the statistics in Figure 6 is larger than in Figure 8. Likewise, the maximum value of the statistics in Figure 6 is higher than in Figure 8. Nevertheless, all components in Figure 8 show more than 0. In addition, all gradients in Figure 8 are almost positive even though there are various gradients in Figure 6. It means that the NDVI statistics along the definitive ridgelines become higher certainly the smaller *d* is. Therefore, it seems that the definitive ridgelines derived from all SSCs extract the steady areas of the spatial continuity of vegetation irrespective of seasonal fluctuation.

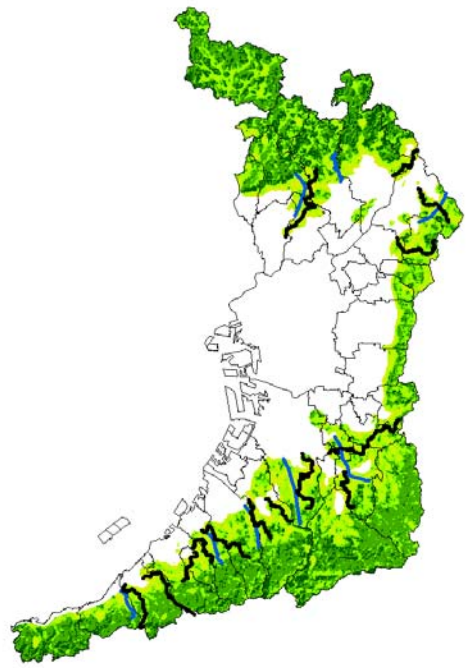


Figure 7. Results of the integration of four SSCs. Black lines mean the definitive ridgelines extracted by hydrological analysis. Blue lines mean the green corridors in the master plans for parks and open spaces.

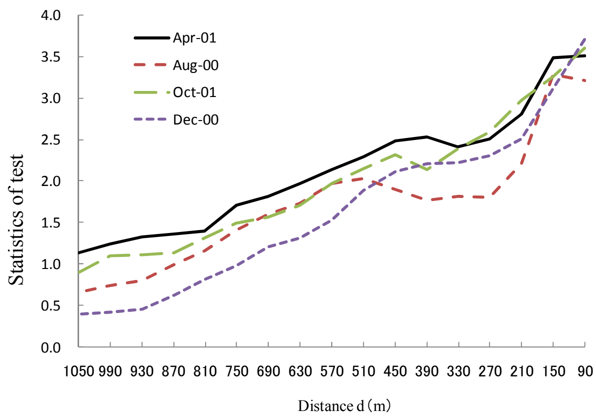


Figure 8. Results of the statistical test for the difference of the averages of the NDVI statistics between the definitive ridgelines derived from Figure 7 and the green corridor planned.

4. CONCLUSIONS

For extracting the spatial continuity and seasonal fluctuation of vegetation on a regional scale, we adapted NDVI calculated from four kinds of Landsat ETM+ data as the potential data of vegetation abundance. The analysis method of spatial continuity based on spatial autocorrelation was proposed and was applied to four kinds of NDVI. Using the result of the application of the method, that we called SSC, we extracted the ridgelines as the potential areas of green corridor connected between the core areas and sparse areas of vegetation. Through the comparison between the ridgelines and the green corridors in the master plans for parks and open spaces, it was obvious that in all SSCs, the areas of high NDVI were dense along the ridgelines that played a role as bridges between the core areas and sparse areas of vegetation. However, there were various kinds of ridgelines in the SSCs. It seemed that the shape and length of ridgelines depended on seasonal fluctuation of NDVI. We attempted to integrate four seasonal SSCs through overlaying them and extracting lowest layer. It seems apparent that the statistics of NDVI along the definitive ridgelines retrieved from the integrated SSCs were certainly higher than those along green corridor planned.

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