

SPATIAL CLUSTER ANALYSIS OF HYDROLOGICAL DROUGHT INDICATOR IN AN OASIS ECOSYSTEM

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ABSTRACT

The objective of this study was to identify the spatial extent of high drought risk areas using remotely sensed drought indices in arid environments. Using remote sensing and geographic information system techniques, this study spatially quantified drought risk using hydrological drought indices derived from satellite data in Ejin Oasis, western China. All indices were computed from the MODIS data in the summer for year 2003. Another group is based on soil moisture, including the Normalized Difference Moisture Index (NDMI), and Standardized Moisture Index (SMI). The use of local Getis statistic (G_i^*) provides insights on the spatial relationships of land cover pattern to drought risk assessment. Specially, locations of significant G_i^* values identified areas where the differences in hydrological drought indices occur and are spatially clustered. This information may then be used to map high drought risk areas and help governments to improve the allocation of local water resources in arid environments.

Index Terms—drought, drought risk, drought indices, remote sensing, local Getis statistic

1. INTRODUCTION

Drought phenomena show a high variability in time and space and are very difficult to identify exactly spatial locations. The state of vegetation and soil moisture content can be acquired using remotely sensed data. Remote sensing methods have been applied over a number of regions worldwide to monitor vegetation changes [1-5]. Land degradation and land cover change were assessed using satellite images and geostatistical methods in the Central Asian deserts [6]. Recent studies suggested that NDMI had a high correlation with wetness [7]. They found that the NDMI is sensitive to canopy moisture content. The index was firstly proposed by Gao in 1996. In his research, the index was demonstrated to be sensitive to changes in liquid water content of vegetation canopies [8]. The NDMI used for monitoring harvesting and other disturbances were

presented to be a promising technique [9]. The NDMI index over the NDVI has been demonstrated its improvement to detect forest cover changes [10]. In their study, the data set has been also shown to have a strong relationship with the spatial pattern and magnitude of forest cover change based on multi-spectral and multi-temporal MODIS data.

Gutman et al. (1996) proposed a land monitoring concept of standardized anomalies. The concept is based on a comparison of the current monitoring region of variable X with its multi-temporal mean. Bhuiyan et al. (2006) used Standardized Precipitation Index (SPI), Standardized Water-Level Index (SWI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI) to analyze spatial and temporal drought dynamics during monsoon and non-monsoon seasons through drought maps computed in geographic information system (GIS) environment. Peters et al. (2002) proposed that Standardized Vegetation Index (SVI) can be presented as an integrated factor of climatic and anthropogenic impacts.

The spatial autocorrelation concept is concerned in Regional Science and has a focus on distance-decay and spatial interaction [11]. Various studies have applied a Getis-Ord's G_i^* statistic (local Getis statistic) to identify clusters for a given phenomena [12-17]. The local Getis statistics were used to quantify the spatial change of a coral reef over time from satellite imagery [14].

Over the past decade, land degradation has been caused by regional climate change and human activities in western China, especially in oases [18, 19]. Using Thematic Mapper (TM) imagery to detect land cover changes, Zhang et al. found that riparian woods were decreased at a rate of 45% during the 1982 to 2000 period in the Ejin Oasis [20]. They found that the area covered by vegetation has shown a clearly decline trend in the Ejin Oasis. The oases are important for agricultural and human activity in this region. In this context, a methodology for local Getis statistic of drought indices is developed to provide a method of quantitative drought risk assessment. This method provides the basis for estimating the spatial extents of high drought risk, thus making possible drought assessment of various management alternatives.

The NDMI combines MIR spectral information and correlates to moisture content [7, 10]. The use of NDMI derived hydrological drought index is related to land surface moisture content and provides important information for drought risk assessment. Standardized moisture index (SMI) have also been used to assess degrees of drought risk spatially. The objective of this study were (1) to evaluate the difference and spatial distribution of drought index (SMI), (2) to explore use of local Getis statistic based on MODIS derived drought indices in arid environments, (3) to identify hot spots of high drought risk spatially in the Ejin Oasis.

2. MATERIALS AND METHODS

The temporal sequence of MODIS data used in our study is bi-weekly MODIS Vegetation Indices 16-Day L3 Global 250m product for the period from June 2001 to August 2008 (2001-2008 used as the base period). In order to assess land surface moisture dynamics in the study area, it was also similar to compute the NDMI for the same temporal sequence of MODIS data. Following data pre-processing, the Normalized Difference Moisture Index (NDMI) was computed using equation (2). NDMI is based on the contrast between MIR and NIR reflectance and sensitive to changes with vegetation leaf structure and water content [10, 21, 22]. For the MOD13 data, the bands labeled “NIR” (near infrared) and “MIR” (mid infrared) were used to calculate the NDMI. It was derived by the equation:

$$NDMI_{ijk} = \frac{NIR_{ijk} - MIR_{ijk}}{NIR_{ijk} + MIR_{ijk}} \quad (1)$$

where, NIR_{ijk} and MIR_{ijk} is the reflectance values at the near infrared and mid infrared wavelengths of MODIS on the TERRA satellite, respectively, for pixel i during season j for year k .

The standardized anomaly, SMI, is computed by subtracting the sample mean of the group which the data are analyzed, and dividing by the corresponding sample standard deviation as expressed in equation (5):

$$SMI_{ijk} = \frac{(NDMI_{ijk} - \overline{NDMI_{ij}})}{\sigma NDMI_{ij}} \quad (2)$$

where $\sigma NDMI_{ij}$ is standard deviation of NDMI for pixel i in bi-week j . The SMI used to identify hydrologic drought condition and relative drought risk.

In order to test the statistical significance of drought clusters, and to determine the spatial extent of these clusters, we applied a geocomputation procedure described by Getis & Ord (1992) to analyze the spatial pattern of relative drought risk in the Ejin Oasis. In this study, the local G-statistic was calculated as a measure of the degree to which high and low values of selected images of drought indices

occurred close together in an array of interested extents [15]. A separation distance of 500m ensured all samples had at least one neighbor at that distance. The equation for local G-statistic was calculated for each pixel using the following equation:

$$G_i^* = \frac{\sum_j W_{ij}(d)x_j - W_i^* \bar{x}}{s[W_i^*(n - W_i^*)/(n-1)]^{1/2}} \quad (3)$$

where W_i^* is the count of the pixels within distance, d , of the central pixel i , d defines the size of the kernel by the number of pixels from the central pixel, i , \bar{x} is the image digital number mean, s is the image digital number standard deviation, and n is the total number of pixels in the image.

The identification of clusters using the local G-statistic may help to filter out spatial dependence or provide an evidence for the occurrence of outliers. The local Getis statistic computed for SMI is to examine the relative drought risk characteristics of the Ejin oasis in arid environments.

3. STUDY AREA

The research was carried out in the Ejin basin (Figure 1). With a semi-arid climate, this area is dry for most of the year except the summer season. The mean annual precipitation is 40.3 mm. The mean annual evaporation is between 3700 to 4000 mm, with a maximum of 4756 mm [23]. The vegetation types are mainly grasslands and *Populus euphratica* forests. The water supply in the basin creates seasonality in vegetation growth. In addition, the seasonal water supplies of melting ice from mountains with elevation higher than 2000m in summer seasons strongly influence land cover variability in the Ejin basin. Therefore, summer is the critical growing season when vegetation activity is at its maximum.

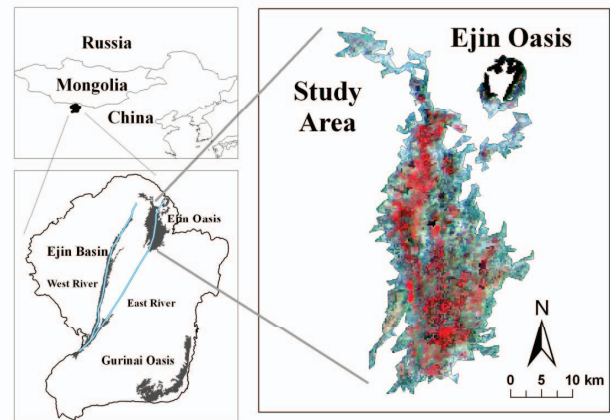


Fig. 1. Location of the Ejin basin and study area (Ejin Oasis).

4. RESULTS AND DISCUSSIONS

4.1 General results

The satellite imagery of MODIS data showed the land cover condition for summer of 2003 (Fig. 1). The NDMI map for summer of 2003 gives an overview of general distribution of moisture condition geographically (Fig. 2).

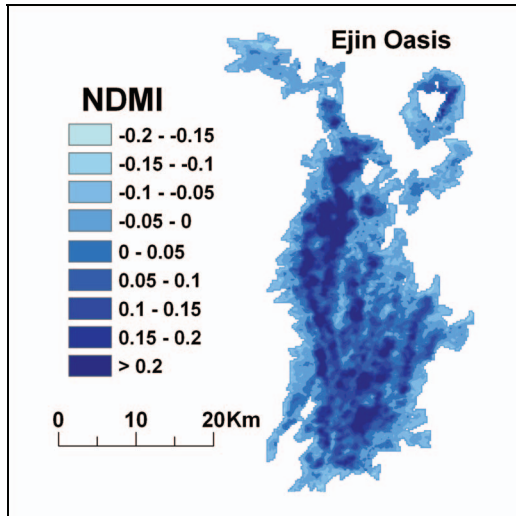


Fig. 2. Spatial distribution of NDMI in the Ejin Oasis during summer of 2003.

4.2 Drought indices

The drought anomaly patterns of SMI for summer in the year 2003 are shown in figure 3. The SMI was used to assess the hydrological drought risk. In the moisture-limited Ejin Oasis, it would be expected that the SMI values vary as a function of changes in drought risk directly.

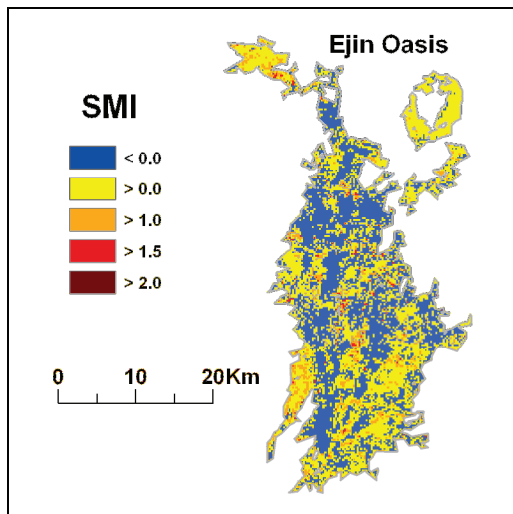


Fig. 3. Standardized moisture index (SMI) for summer in the year 2003.

4.3 Local G-statistic

In this study, the significantly different areas detected by the local G-statistic are termed hotspots for high drought risk.

Fig. 4 shows the significant ($p=0.05$) G_i^* values for the hydrological drought index (SMI). The mean Z score for the region is 5.67, with a maximum Z score of 15.58. The spatial locations of the significant G_i^* values, indicating where high drought risk areas, are spatially clustered. The extent of those spatial clusters distributed over the oasis seems reasonable given the pattern of relative drought risk. The spatial clusters can be viewed as geographic measures for monitoring drought anomaly or detecting relative high drought risk.

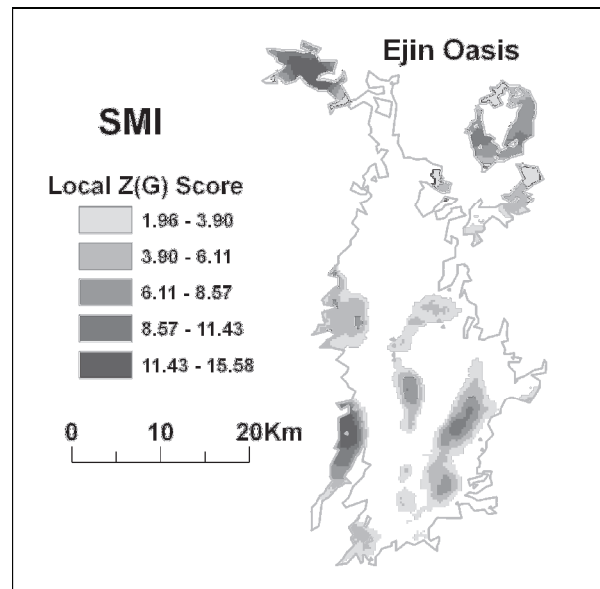


Fig. 4. Spatial clustering of high-value cells in SMI based on the Z scores of local Getis statistic.

5. CONCLUSIONS

This study is successful in delineating detailed spatial information concerning the relative high drought risk areas for summer months in the year 2003. Using MODIS This research presents an alternative way at viewing vegetation and drought conditions, mainly through drought indices and local Getis statistic.

The local Getis statistic, in general, aids the identification of drought conditions at which anomalies and regularities occur in spatial data, and therefore counting the occurrence times for three drought indices facilitates the identification of spatial clusters of relative high drought risk. Through using this approach, practitioners and decision makers can get a better scope of their regional drought conditions and rearrange their water resources to areas with high drought risk. Spatial extent of high drought risk area

can be effectively monitored and assessed using satellite data and these spatial statistics.

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