Study on Vegetation of Northwest Qaidam Basin by Remote Sensing

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Abstract –This paper on vegetation of northwest Qaidam Basin integrates Landsat5 TM data, DEM, and field survey. After comparing various vegetation indices applied to the image data, Spatial Subsection Vegetation Cover Estimation Model was presented, by which fractional vegetation cover was calculated. Eliminating the effect of vegetation, the distributed volumetric moisture was estimated by multi-spectral image data. According to synthesized information mentioned above, study area was grouped into 12 landscape types. Spatial relationships between vegetation and environmental factors (temperature and precipitation) and their indicating significations were analyzed by GIS. The conclusions are that the eco-environment of northwest Qaidam Basin is worsening, and that desertification trend becomes ever stronger. Our result, which is of great significance, shows that the basin interior is mostly endangered by desertification under dual restrictions of aridity and salinity. Urgent measures should be taken, therefore, to save eco-environment from further degradation.

Keywords: Qaidam basin Vegetation index Arid land Eco-environment SS-VCEM

1. INTRODUCTION

With growing degradation of environmental systems, Chinese governments are aware of the importance of establishing policies to protect the eco-environment, which should be based on well understanding of its ecological mechanisms. Vegetation is the most sensitive ecological factor in the regional eco-environment. It is crucial in studying natural rules of eco-system that precise surveying of vegetation and quantitative analysis of the relationship between vegetation and other environmental factors are considered.

Arid land in Northwest China has extremely low vegetation cover, the spatial variety of which is huge and discontinuous, rendering large-scale vegetation monitoring unavailable by traditional field surveying approach. A common estimation method of vegetation cover based on RS and GIS becomes exigent. Northwest Qaidam Basin, playing an important role in eco-system of Northwest China, is an ideal region for modeling. By using a Spatial Subsection Vegetation Cover Estimation Model, this study quantified the status of vegetation cover, soil moisture and soil salts, further discussing their ecological relations.

1.1 Study area

Northwest Qaidam Basin (90°08′~95°37′E, 36°50′~39°20′N), whose lowest altitude is 2675m, abuts upon Altun mountains to the northeast, and Qimantag mountains to the southwest. Climate of this area is cold, dry and cloudless. Mean annual precipitation is below 50 mm in contrast with annual sunshine time exceeding 3200 hours. Main landscape type is salinized desert, populated by few vegetation species with extremely low coverage. Vegetation cover changes dynamically with supply of lake water and groundwater. Because of thick sediment loads of dead lakes and low groundwater table, soils in the basin interior are highly salinized, with salt crusts spread throughout several areas.

1.2 Data

The basic data were Landsat5 TM dataset of the study area of July 1999 and their head-files (© Landsat Image Copyright 1999, NASA). 1:250,000 topographic maps (mapped in 1999) were used as the basic data in GIS platform for generating DEM that contained topographic and altitude information. RS datasets were treated with a series of imagery corrections and enhancements to spatially match the relief maps and were made available for direct spectral calculation. The map of surface water was generated by integrating the relief maps and the remote sensing data.

2. METHODS

2.1 Calculation of various Vegetation Indices

Many applications show that vegetation indices have stronger discrimination in reflecting vegetation cover than single image band, and that they commonly contribute to a much improved results of classification when applied in land-use and land-cover investigations and biomass estimations [Qingjiu Tian et al, 1998; Viegand et al, 1991; Wilson et al, 1987]. This study for universality calculated and analyzed the following common vegetation indices: normalized difference vegetation index (NDVI), perpendicular vegetation index (PVI), optimized soil-adjusted vegetation index (OSAVI), modified soil adjusted vegetation index (MSAVI).

2.2 Linear regression for estimation of vegetation cover and analyses of results

Vegetation cover is a key parameter for ecosystem studies on land degradation and desertification. Field inventory survey is a traditional method to conduct vegetation survey, which may be greatly limited by time and cost. Its validity and accuracy were questioned in the checking experiments [Curran, 1986; Wilson, 1987], so field inventory survey can only be used as supporting information for wide range vegetation investigation.

Traditional RS method to acquire vegetation cover is based on mathematical models, from which a vegetation index is

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transformed to fractional cover. This method has been widely and successfully applied in large-scale vegetation monitoring of many regions [Duncan, 1993; Purevdor, 1998]. Because linear regression is considered to get more catholicity, this study separately constructs linear regression equations for estimating vegetation cover using field survey data and calculated VI data, and analyzes the coherence between estimation outcomes and checkout samples.

NDVI is suitable for monitoring of early booming vegetation or sparsely populated vegetation [Shupeng Chen, 1990]. After matching field survey data with a series of vegetation idiocies, Purevdor et al. showed that NDVI provided more accurate information of vegetation in areas where Soil Line was unavailable and density of steppe cover dynamically changes. The outcome of NDVI process in this study reflects vegetation's spatial status fairly well, especially in basin areas of low vegetation cover and peripheral mountain regions, where NDVI has high resolution in density differences caused by salt and soil moisture's uneven distribution. Although NDVI may be somewhat influenced by background soil, it is a good index for large-scale vegetation monitoring in arid regions with few soil types.

PVI is designed to rule out the influence of soil background. Commonly many different types of soil are seen in large dry lands, making it inadequate to represent soil status by a single Soil Line. In most of the study areas characteristic of high-salinized soil coverage, fractional vegetation cover regressed by PVI is improved to NDVI. Cases are to the inverse in other regions. OSAVI gives outcome similar to PVI and it has a wider data range, which is advantageous to construct quantitative transformation. Error analyses show that OSAVI appears to have less precision and stability in the mountain region than NDVI.

MSAVI introduces a self-adjusting model to minimize soil disturbance, requiring no additional supporting data and has a wide numeric range of application. It is a good index for precisely extracting vegetation information from remote sensing data [Jun Wen et al, 1997]. MSAVI yields perfect regression outcome in the swampy regions [Eastwood, 1997], whereas has much error for salinized deserts according to this study. Estimated vegetation cover data is reversed from survey data in the severely salinized and salt-covered basin regions. Complicated multi-function analysis is needed, if MSAVI is applied to the whole area as the single pointer variable.

2.3 Spatial Subsection Vegetation cover Estimation Model (SS-VCEM)

Owing to the disadvantages of each vegetation index in some arid regional type during wide-range vegetation monitoring, it is inevitable to derivate unacceptable errors if only one index is concerned for the whole area. Therefore, multivariate analysis should be introduced to the regression of vegetation cover from VI and linear model be employed to keep transformation model's catholicity and avoid the complexity of multi-order function analysis. We construct SS-VCEM on the basis of all of these ideas and results explained above.

In SS-VCEM, spatial subsection functions are used to regress vegetation cover data for the given type regions. Different regional types are referred to as different suitable vegetation indices. There are often partial regions that have the mixed characters of two or more adjoining standard regional types, which are called marginal regions. Marginal regions can be expressly carved out or overlapped out by multiple, preliminarily compartmentalized regional types. For these regions, we need aggregate vegetation indices to regress simultaneously and an adjusting coefficient to adapt to different similarity weights.

$$F = \sum_{i=1}^{i} \mathrm{SLRE}_i * \mathrm{SSC}_i \tag{1}$$

Where F = fractional vegetation cover
SLRE = standard linear regression equation
SSC = spatial similarity coefficient
i = total account of relevant standard regional types

SLRE can be regressed respectively by a series of suitable VI and field survey data from a given standard regional type. SSC is dependent on pixels' spatial adjacent relationship, which can be determined through a series of GIS rules. Generally, SSC is assumed to equate with 1 if a pixel is for sure within a standard regional type, and 0 is assigned for exclusiveness of such a type. For marginal regions, SSC can be simplified as 1/i, where "i" is the number of the regional types involved. If the amount of marginal region samples is enough, regressed SSC of a region is thought to be better grounded. SSC can be canvassed to pixel level by calculating the distance from its adjacent standard type regions.

In this study, the whole area is divided into three standard types of regions: mountainous region, basin region, and wetland region. This study applies equal perpendicular density linear regression method of Mixed Pixel Model [Gutman, 1998] in SLRE calculation.

SLRE_{mr} = 3.125NDVI-0.563 for standard mtn. region (2)
SLRE_{br} =1.667OSAVI-0.167 for standard basin region (3)
SLRE_{wr}=2.500MSAVI-0.250 for standard wetland region (4)

SSC of marginal region pixels are calculated by distance squared inverse proportion function. Using equation (1), (2), (3) and (4), processes are performed as below:
(A) Where pixel is included in a standard type region, F = SLRE;
(B) Where pixel in a marginal region and i = 2, F= [1-a2/(a2+b2)] SLRE_{α}+[1- b2/(a2+b2)] SLRE_{β}, (a and b are the distances of the given pixel from the relevant standard type regions α and β);
(C) Where pixel in a marginal region and i ≥3, perform process (B) one another between concerned region types, and then calculate the average data.

Checkout analysis shows that the estimated results are well consistent with field survey, and that SS-VCEM can be used for evaluating vegetation cover of large-scale arid land easily and effectively.

2.4 Soil moisture calculation

Regional soil moisture is significant for studying ecological mechanism of vegetation distributing status, and it is also important associated information in vegetation classification. Considering spectral contribution of vegetation and mirror reflecting effect that is caused by water membrane of soil grain surface [Deng Ruru, 1997], we estimate volumetric humidity of soil surface by the linear correlation between soil spectra reflectance and moisture content.

2.5 Landscape classification based on vegetation

Remote sensing imagery classification is an effective way to ascertain vegetation types and landscape distribution. However, further enhancement of interpretation precision should not rely solely on spectral characteristics [Zhu Honglei, et al, 1997], in that different objects may have the same or alike spectral characteristics, and that spectra of satellite imageries contain rich, extra background information of soil matrix. In addition to these reasons, great variability of dry-land vegetation types, and low vegetation cover all act as adverse factors in our effort to increase the precision of interpretation. Therefore, it is imperative to effectively integrate remote sensing data with auxiliary non-remotely-sensed data in the process of ground vegetation identification by this technique. In recent years imagery comprehension technique based on expert knowledge and experience, which integrates spectra data with other supporting information, has evolved into a key research field of remote sensing application.

This paper adopts both supervised classification and non-supervised classification, and applies theoretical and empirical corrections to the results of classification. We first derive initial classification template by using the method of non-supervised classification. Then according to the initial results of classification and on-the-spot investigation, a new template is formulated and subjected to supervised classification among those selected regions whose vegetation types have been fully identified. During the process of classification, 12 types of landscape are brought in to better meet the reality of study area: water body, saline alkali desert, sand desert, typical desert, steppe desert, desert steppe, alpine steppe, alpine meadow, alpine desert, saline soil meadow, marish meadow and farmland. The preliminary classification outcome with regard to the farmland, saline soil meadow, marish meadow and alpine meadow failed to meet our expectation. Accordingly, zones that were previously and incorrectly classified are incorporated into neighboring maximized patches by integration with on-the-spot knowledge and maps of drainage distributions. This reclassification were done by the following criteria: (1) slopes of saline soil meadows and marish meadows should not exceed 5°; (2) alpine meadows are seen in areas above 3800m in elevation; (3) marish meadows are commonly distributed around streams and lakes, with the volumetric water content of surface soils greater than 60%; (4) farmlands are located around the towns with a large vegetation cover and assume regular geometric shapes.

2.5 Integrative analysis and results

Results of statistical analyses with the support of GIS platform based on map of vegetation types, map of vegetation cover, digital elevation map and soil hygrogram are listed below in Tab.1.

Landscape type	Area ratio (%)	Mean vegetation cover (%)	Mean alt. (m)	Soil humidity (%)
Water body	0.68	—	—	—
Saline soil meadow	6.85	8.81	2756	29.27
Saline-alkali desert	36.57	3.14	2798	13.64
Marish meadow	0.79	44.38	2817	74.00
Typical desert	35.81	5.71	2858	17.99
Farmland	0.01	69.79	2868	53.63
Steppe desert	3.33	8.67	3143	25.61
Sand desert	1.38	6.76	3300	6.80
Desert steppe	3.93	11.12	3400	26.28
Alpine steppe	2.39	16.39	3686	30.26
Alpine desert	7.56	7.56	3904	21.14
Alpine meadow	0.70	18.21	4000	35.41

Tab. 1. Statistics of Indicators of Landscape Types in Northwest Qaidam Basin, China

Integrative analyses of thematic maps and statistics shown in table 1 indicate that the base belt of vegetation in the northwest of Qaidam Basin belongs to inland arid desert vegetation with a very low vegetation cover of 6%. Combined coverage of saline alkali desert, typical desert, sand desert, steppe desert and alpine desert accounts for 84.65% of total study area, among which saline alkali desert that is less than 5% in coverage accounts for some 36.57% of the total area. Alpine meadow and alpine steppe that are relatively higher in vegetation cover slip to no more than 20% compared with that of between 70% and 50% in 1985 [Wu Guanghe, et al, 1985]. The trend of desertification in the northwest of Qaidam Basin shown by our data is consistent with Shi Qingdong et al.

Statistical analyses of meteorological data show that this trend of desertification may result from climatic changes. While precipitation remains little changed based on the data from the northwest of Qaidam Basin between 1985 and 1999, mean temperature for growing seasons (from May through September) and mean annual temperature are markedly increased. For example, growing season mean temperature and mean annual temperature for Dachaidan meteorological station increase by 1.45□ and 0.86□, respectively. And Lenghu station registers relatively smaller amplitude of temperature increase during this time span, with the former indicator up by 0.64□ and the latter by 0.30□ accordingly. Actual surface evapotranspiration in this area is bound to go up due to relatively stable precipitation and markedly increased temperature, subsequently leading to a higher surface aridity. On regional scales this change signals a reduction in soil moisture availability, which aggravates vegetation growth and extends desertification effect. With the alternation of alpine desert, alpine meadow, alpine steppe and desert steppe, vertical spectra of vegetation in the mid and western part of Altun Mountains and in the southwestern Mt. Qimatag are not visually striking. This is because alpine meadow and alpine steppe secured by mountain precipitation are underdeveloped in extremely arid inland climates, and because large-scale invasions of alpine frigid deserts, which is supposed to be on the top of the vertical spectra, down into below the alpine meadow zone, in addition to the well-established deserts in the base belt. East Altun and west Mt. Qilian have a simple structure of vertical spectra, if there is any, but are greatly constrained to local possession.

The excellent correlation (correlation coefficient is 0.95) of vegetation cover with soil moisture makes water availability a pivotal restricting factor of vegetation growth in the study area. Owing to the reality of rare precipitation, however, water table and local distribution of drainage system are regarded as the overriding safeguard of vegetation survival. With the drop in water table by regional tectonic uplifts and with the redistribution of drainage system, the growing desertification contributes to the formation of a sand desert belt around the Qaidam Basin at altitudes between 3200 and 3300m.

The effect of salinization also plays an important role in restricting vegetation growth in the basin interior. Soil moistures of saline alkali desert and typical desert in the interior of the basin, for example, reach 12.3% and 17.99% respectively, each greater than that of sand deserts (6.80%). Both of these two deserts have altitudes similar to sand deserts, but are lower in vegetation cover than sand deserts. This indicates that the comfortableness of habitats in these areas, inflicted by dual constraints of both aridity and salinization, is inferior to the extremely arid sand deserts. In addition, with the removal and destruction of wind-resistant and moisture-keeping salt crust during recent highway construction and exploitation of mineral resources, in collaboration with strong windy climates, the widely-distributed salinized areas are now facing the danger of worsening from extreme desertification into totally sand desertification.

3. CONCLUSIONS

Based on comparative research on remote-sensing interpretation of vegetation, field investigations and statistical analyses of thematic maps in this paper, four conclusions can be drawn as follows. (1) NDVI less influenced by mountain shadows, exhibits a good linear relationship with vegetation cover on a regional scale. PVI and OSAVI are more precise in areas with flat surfaces and relatively simple soil types. OSAVI seems to have greater numerical dynamic ranges than PVI. MSAVI favors with high precision the wetlands of great variability of soil types. (2) Although NDVI, PVI, OSAVI and MSAVI are capable of well representing large-scale vegetation cover in specific regions of arid land, failures of each of these indexes exist in certain areas of different regional types. In these cases, Spatial Subsection Vegetation Cover Estimation Model is the favorite, which returns good estimation that assigns different suitable converting vegetation indexes to different regions of interest. (3) The base vegetation belt in the northwest of Qaidam basin belongs to inland arid desert vegetation, with vertical vegetation spectra underdeveloped in surrounding mountains. Although vertical vegetation spectra are relatively more developed in east Altun and west Qilian, the simple-structured spectra lack continuity in certain localities. Compared with that of 1985, mean vegetation cover in the study area is as low as 6%, indicating a trend of further desertification for ecological environment in this area. (4) Water availability is the most important restricting factor of vegetation growth. Falling water table and redistribution of drainage systems that result from regional tectonic uplifts, contribute significantly to the sand desertification process in peripheral areas of Qaidam Basin. Limited by aridity and severe salinization, widely distributed salinization areas in the basin interior are now facing the danger of degradation from extreme desertification to totally sand desertification. It is imperative, therefore, to strengthen ecological protection and preservation in the study area.

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