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Relationship of Remote Sensing Normalized Differential Vegetation Index to *Anopheles* Density and Malaria Incidence Rate

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Objective To study the relationship of remote sensing normalized differential vegetation index (NDVI) to *Anopheles* density and malaria incidence rate. **Methods** Data of monthly average climate, environment, *Anopheles* density and malaria incidence rate, and remote sensing NDVI were collected from 27 townships of 10 counties in southeastern Yunnan Province from 1984 to 1993. The relationship of remote sensing ecological proxy index, NDVI, to *Anopheles* density and malaria incidence rate was studied by principal component analysis, factor analysis and grey correlation analysis. **Results** The correlation matrix showed that NDVI highly correlated with *Anopheles* density in 4 townships of Mengla, Jinghong, and Yuanjiang counties, but in other 23 townships the relationship was not clear. Principal component and factor analyses showed that remote sensing NDVI was the representative index of the first principal component and the first common factor of *Anopheles* density evaluation. Grey correlation analysis showed that in rainy season NDVI had a high grey correlation with *Anopheles* density and malaria incidence rate. The grey correlation analysis showed that in rainy season the grey degree of NDVI correlated with *Anopheles. Minimus* density was 0.730, and 0.713 with *Anopheles sinensis* density, and 0.800 with malarial incidence rate. **Conclusion** Remote sensing NDVI can serve as a sensitive evaluation index of *Anopheles* density and malaria incidence rate.

Key words: *Anopheles* density; NDVI; Grey correlation analysis

INTRODUCTION

Remote sensing is a modern high technology, its basic principle is to receive and distinguish the electromagnetie waves reflected or produced by objects on land. Based on remote sensing technology, global climate, environmental and ecological information can be acquired consistently and dynamically[1-2]. Ecological proxy indicators such as NDVI, CCD, and LST can be acquired from NOAA/AVHRR[3]. NDVI is an ecological proxy index of vegetation density and distribution. Having no unit and presupposition conditions for application, NDVI can be used to compare vegetation density and distribution in any area and any time period[4]. Malaria is one of the arthropod-borne infectious diseases with distinct seasonal and locality characteristics. Changes in climate, environment, and ecology can influence vector density and malaria transmission and prevalence.

Some researches have shown that remote sensing NDVI has a close correlation with *Anopheles* density and can serve as an index for predicting malaria epidemic situation. In 1998, Hay and Snow collected NOAA data to forecast the malaria epidemic season in Keniya[5]. In 1999, Thomson developed a malaria epidemic prediction regression model. NDVI-S, NDVI-S^2, age, untreated and treated nets, PHC, health card and area have been used as forecast indexes[6]. The objective of our research was to study the relationship of remote sensing NDVI to *Anopheles* density and malaria incidence rate.

MATERIALS AND METHODS

Study Fields and Data Resource

Twenty-seven townships of 10 counties in southeastern Yunnan Province were enrolled as study fields. Data of climate, environment, remote sensing NDVI, *Anopheles* density, and malaria incidence rate were collected from 1984 to 1993. Vector surveillance data included monthly average *Anopheles minimus* and *Anopheles sinensis*

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manpower hourly densities while climate data included monthly average, maximum, and minimum temperatures, rainfall, and insolation amount. Remote sensing data included dry and wet season NDVI. Wet season is from May to October, while dry season is from January to April and from November to December. NDVI data were extracted from NOAA/AVHRR pathfinder products. NDVI is in [-1, 1], NDVI=(Ch2-Ch1)/ (Ch2+Ch1), where Ch1 is the reflecting ratio of visible ray tunnel, and Ch2 is the reflecting of infrared ray tunnel. MVC detecting cloudy and slippage filtrating method was used to compose NDVI products.

Principal Component Analysis, Factor Analysis, and Grey Correlation Analysis

In principal component analysis, multiple evaluation indexes were condensed into several principal components, and the dimensionality of indicators decreased effectively. Range normalization method was used to normalize different indicators. At factor analysis, matrix and eigenvector and latent root were calculated. At grey correlation analysis, the relationship between multiple factors was analyzed objectively, and the important evaluation factors were preserved and unimportant factors were deleted. The essential principle of grey correlation analysis is to compare the geometric correlation of historical data[6].

The definition of grey correlation coefficient is:

$$\xi_{ij}(tl)=\frac{\Delta_{\min}+k\Delta_{\max}}{\Delta_{ij}(tl)+k\Delta_{\max}} \qquad l=1,2,\cdots,N;\ k=[0,1]$$

The definition of grey correlation degree is:

$$R_{ij}= {}^{1}\!/_{n} \sum_{t=1}^{n}\xi_{ij}(tl)$$

Where n is the number of samples, k is the distinguishing coefficient.

RESULTS

The analysis of correlation matrix showed that *Anopheles* density had a good corelation with NDVI, wet and dry season NDVI only in 4 townships of Mengla, Jinghong, and Yuanjiang Counties. In the other 23 study townships the correlation of yearly average *Anopheles* density with NDVI was not clear. Since Mangguoshu and Mengpeng are two neighbouring townships of Mengla County with similar environmental ecological conditions, we analyzed the combined data of these two townships. The results showed that NDVI had a good linear relationship with *Anopheles minimus* manpower hourly density ($r=0.619$, $P<0.05$). Principal component and factor analyses showed that the accumulative contribution of the first three principal components reached 82.91%, so the first three principal components were chosen to reflect the variation of indexes. The evaluation indicators of *Anopheles* density were divided into three groups: remote sensing NDVI group including NDVI, wet and dry season NDVI; climate indicator group including temperature and sunshine indexes; rainfall index group. Rainfall was different from other climate indexes such as temperature and insolation amount, and could be considered as a positive or negative factor for malaria vector breeding. This result was consistent with the reported result[7]. Statistician M. G. Kendall considered that the first principal component could sum up a majority of variations and reflect the main trend of multiple factors. Therefore, the first principal component, remote sensing NDVI, could serve as a sensitive evaluation index of *Anopheles* density. Quartimax factor rotation was used in factor analysis, which showed that remote sensing NDVI was the maximum load of the first common factor.

TABLE 1

Eigenvalues of Correlation Matrix

Principal Component	Eigenvalue	Proportion (%)	Cumulative Percentages (%)
1	4.476	44.760	44.760
2	2.623	26.230	70.990
3	1.191	11.910	82.910
4	0.639	6.390	89.290
5	0.566	5.660	94.960
6	0.285	2.850	97.810
7	0.152	1.520	99.330
8	0.051	0.510	99.830
9	0.017	0.170	100.000
10	0.000	1.000	

TABLE 2

Principal Procedure Results

Indicators	z 1	z 2	z 3
Sunshine Duration	0.182068	0.459381	-.340546
Maximum Temperature	0.222743	0.453588	-.183025
Minimum Temperature	0.307054	0.285341	0.394310
Average Temperature	0.300585	0.443146	0.149584
Rainfall	0.043182	0.332079	0.618345
NDVI	0.437948	0.174846	-.113796
Dry Season NDVI	0.435186	0.003983	-.007148
Wet Season NDVI	0.366167	0.308704	-.197198
An. minimus Density	0.215504	0.257224	0.462435

TABLE 3

Rotated Factor Pattern of Factor Analysis

	Factor 1	Factor 2	Factor 3
Sunshine Duration	0.76154	-0.42943	0.05720
Maximum Temperature	0.10001	0.73147	-0.44875
Minimum Temperature	0.16736	0.82590	0.24036
Average Temperature	0.11557	0.96538	-0.10892
Rainfall	0.11694	-0.14606	0.77936
NDVI	0.93234	0.28313	0.12156
Dry Season NDVI	0.73570	0.51582	0.10144
Wet Season NDVI	0.92863	0.00563	0.11892
An. minimus Density	0.39527	0.08346	0.55784

Elevation, longitude, latitude, monthly average temperature, maximum temperature, minimum temperature, rainfall, insolation amount, remote sensing NDVI, and the proportion of paddy field were chosen as the evaluation indexes of *Anopheles* density. All indicators were divided into wet and dry season indexes. Grey correlation analysis was used to analyze the relationship between evaluation indexes and monthly average *Anopheles minimus* manpower hourly density. According to the grey correlation coefficient threshold 0.7, eight marked evaluation indexes were chosen. The grey correlation of evaluation indexes was ranked in the following order: dry season average temperature > dry season minimum temperature > proportion of paddy field > wet season minimum temperature > wet season average temperature > wet season NDVI > wet season maximum temperature > dry season maximum temperature. According to the grey correlation coefficient threshold 0.8, six indexes had a distinct grey correlation with malaria incidence rate. The grey correlation decreased in the order: dry season minimum temperature > *Anopheles minimus* density > wet season minimum temperature > dry season average temperature > wet season NDVI > wet season average temperature.

DISCUSSION

Climate is the definitive factor of vegetation distribution and function, and energy circulation and water circulation are influenced by vegetation distribution. The changes in environment and ecology can be reflected by vegetation. NDVI index can be calculated by infra red reflecting ratio and near infra red reflecting ratio so that insolation sun angle, terrain, aerosol, and cloud can decline exactly the NDVI, and vegetation distribution can be changed by human activity. Remote sensing NDVI is one of the sensitive evaluation indexes of *Anopheles* density and malaria incidence rate, but it has some limitations when used alone to evaluate *Anopheles* density and malaria incidence rate. Results of analysis showed that the grey correlation of wet season NDVI with *Anopheles minimus* density and malaria incidence rate ranked fifth and sixth, suggesting that multiple sensitive indexes should be used to evaluate vector density and malaria epidemic situation. Simple correlation analysis can only analyze bivariate normal distribution data[8], while grey correlation analysis can analyze any type and number of data[9]. The study on the relationship of remote sensing proxy indexes with vector density and malaria incidence rate is of significance in establishing the early warning system for malaria.

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