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Determination of Spatio-Temporal Variations of Vegetation Cover, Land Surface Temperature and Rainfall and Their Relationships over Sri Lanka Using NOAA AVHRR Data

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ABSTRACT. *Vegetation dynamics is an important indicator of the changing climatic parameters. The use of spectral information coming from the earth observation satellites has been identified as an effective approach in climate related studies. It demands less time and effort as compared to conventional techniques including field surveying. This paper is focused on the results of the preliminary part of the study carried out with the aim of investigating spatio-temporal variability of vegetation cover, land surface temperature and their relationships over Sri Lanka using NOAA AVHRR data.*

Monthly maximum cloud free NOAA AVHRR LAC 1B data were downloaded from the satellite active archives. Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) surfaces were derived for the available images. The LST values were derived using the Split Window Algorithm. Monthly Maximum Value Composites of NDVI and LST were derived for each month. Monthly averages of rainfall were obtained from the rainfall surfaces developed with ground data. Mean pixel values of NDVI, LST and rainfall for each of the selected sample site from three major climatic zones – Dry, Intermediate and Wet- were used in simple regression analysis to establish the correlation among them. Monthly averages of the above parameters were used in studying the spatio-temporal variability of NDVI, LST and rainfall.

The results of the study show that monthly average NDVI values over the island are in the range of 0.24-0.47. LST values derived are in the range of 78.67^0 F– 96.08^0 F with maximum and minimum values reported in March from the Dry Zone and in August in Wet Zone, respectively. Although a strong correlation between lag rainfall and LST could not be observed for Wet and Intermediate Zones it was significant ($P<0.05$) between NDVI and two month lag rainfall for the Dry Zone.

INTRODUCTION

Vegetation is the primary producer of any ecosystem and is one of the most important components on earth as it governs all forms of life. Growth and vigour of the vegetation cover are controlled by factors such as climate, soil and topography. Climatic factors such as rainfall and surface temperature determine the availability of moisture for physical, biological and chemical activities in plants that ultimately lead to a healthy plant (Houghton *et al.*, 2001). Hence, with the seasonal changes of rainfall and temperature, it is possible to observe the changes in vegetation growth. This depends on the levels of water and heat stress to which the vegetation is exposed.

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Over the last century, significant changes at global and regional level have been observed in climate and vegetation cover. The global average surface temperature has increased during the twentieth century by about 0.60^0C (Houghton *et al.*, 2001). Changes in intensity and frequency of precipitation have also been observed at regional as well as global scales at varying degrees.

Remote sensing techniques have a number of advantages over the conventional techniques such as field surveying in vegetation-dynamics studies. Satellite remote sensing has special advantages since it can produce multi temporal images at frequent intervals which facilitate temporal monitoring of vegetation over an area. During the last decade, coarse spatial resolution, high temporal frequency satellite data such as NOAA AVHRR were used extensively to monitor vegetation cover and climatic variability throughout the world (Bayarjargal *et al.*, 2001). Normalized Difference Vegetation Index (NDVI) which is derived using visible red and near infrared bands of the satellite images is the most popular vegetation index. The NDVI helps to study the vigour of vegetation.

Study area

Sri Lanka being a tropical island situated at the southern tip of the Indian sub-continent generally experiences hot and humid climatic conditions. Despite its location of $5'54^0$N to $9'52^0$N and $79'39^0$E to $81'53^0$E geographical coordinates and being in the Asiatic monsoon region, its climate could be characterized as tropical as well as monsoonal. Based on the availability of rainfall and its distribution, the island is divided into three major climate zones namely Dry, Wet and Intermediate. Clear variations in rainfall, temperature and also the ground cover (vegetation characteristics) could be observed among these three different zones.

Variability of climatic parameters

Sri Lanka experiences seasonal variations in rainfall, temperature and relative humidity. These variations could be observed at varying levels among the three major climatic zones. The island receives South West monsoon (SW) during the period from mid May to September and the North East (NE) monsoon from December to February. In between the two monsoons, tropical cyclones, depressions and thunderstorms dominate the climate. The central highlands strongly influences the spatial and temporal variations of climatic parameters and thereby the distribution of different vegetation types and their growth patterns.

The average annual precipitation varies between 1270mm and 1900mm on the southeast plains to between 2540mm and 5080mm on the south west plains. The differences in temperature with regard to altitude are pronounced over the island. The average temperature ranges in lowlands areas from $23\text{-}31^0$C ($73\text{-}85^0$F) and from $14\text{-}24^0$C ($57\text{-}75^0$F) in the highlands.

Vegetation characteristics

Sri Lanka's natural vegetation covers about one-third of the total land area. The climax vegetation (i.e., natural vegetation permitted to develop uninterrupted) in most parts of the country is forest. In the Wet Zone, tropical wet evergreen forest dominates in the lowlands, and submontane and montane evergreen forests prevail in the highlands. The Dry Zone has a climax vegetation of dry evergreen forest and moist deciduous forest, with forests giving way to stunted, shrubby, xerophytic (drought-tolerant) vegetation in its driest parts. In the highest areas of the Central Highlands, forests tend to be sparse and interspersed with grasslands. There is also an Intermediate Zone between the Wet and Dry Zones, formed by a band of tropical semi evergreen rain forest which bounds the tropical evergreen rain forest block in the southwest.

Significance of the study

In the context of Sri Lanka where agriculture still plays a major role in the country's economy, it is important to identify the relationships between changing climatic parameters and vegetation cover which could be used as an indicator of the status of crop production with climate. Analysis of vegetation dynamics with climatic parameters over a considerable time period will be helpful in forecasting climatic variables for better management of agriculture.

With the help of public domain, low resolution high temporal frequency satellite data such as NOAA AVHRR can effectively be used in deriving vegetation indices and relating them with climatic parameters such as rainfall. Long term analysis of climate and vegetation will be helpful in deriving mathematical relationships for forecasting of some selected climatic parameters. In addition, the derived data of land surface temperature could then be used in other research that deal with heat energy flux movement, evaporation and transpiration studies, heat stress physiology of plants, soil physio-chemical studies and other agronomic applications.

Within this background this study was carried out to 1) determine the relationships between Normalized Difference Vegetation Index (NDVI) and rainfall, and 2) identify the pattern of changes in rainfall, land surface temperatures and vegetation cover over the year across the three major climatic zones of the island namely, Dry, Wet and Intermediate Zones.

The present paper summarizes the findings of the preliminary study carried out for the year 1993.

METHODOLOGY

Input data

Monthly maximum cloud-free NOAA AVHRR LAC IB data were downloaded from the NOAA online data archives. For each month the minimum cloud contaminated images were selected through visual interpretation. Monthly average rainfall data were obtained from rain gauging stations all over the country.

Processing of data

Image pre-processing

The images were processed after being imported to ERDAS Imagine Software. Geometric and radiometric corrections were performed. The images were geometrically corrected to a master image using the ground control points.

Generation of NDVI and LST images

For all the available images, Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) images were derived. The NDVI were generated using the data in the red and near- infrared spectral channels as defined by Rouse *et al.*, (1974) as follows;

$$NDVI = (NIR-R)/(NIR+R)$$

where, NIR and R are the radiances or reflectances in the near- infrared and red spectral channels, respectively. The following Split Window Algorithm developed by Price (1984) was used to derive the LST (^0F);

$$LST = T_4 + 1.8(T_4 - T_5) + 48(1 - \varepsilon) - 75\Delta\varepsilon$$

where, T_4 = Brightness temperature obtained from Channel 4 (K), T_5 = Brightness temperature obtained from Channel 5 (K), ε_4 = Surface emissivity in AVHRR channel 4, ε_5 = Surface emissivity in AVHRR channel 5, $\varepsilon = \varepsilon_4 + \varepsilon_5/2$ and $\Delta\varepsilon = \varepsilon_4 - \varepsilon_5$.

The algorithm developed by Cihlar *et al.* (1997) was used to calculate the surface emissivities ε_4 and ε_5 from NDVI;

$$\Delta\varepsilon = \varepsilon_4 - \varepsilon_5 = 0.01019 + 0.01344 \times \ln(NDVI)$$

$$\varepsilon_4 = 0.9897 + 0.029 \times \ln(NDVI)$$

Generation of Maximum Value Composites (MVC)

The NDVI and the LST monthly MVCs were produced from all the images available for each month since the MVCs minimize the effects of atmosphere, scan angle, and cloud contamination during the time of image acquisition (Holben, 1986).

Generation of rainfall surfaces

Monthly rainfall data obtained from rain gauging stations over the country were used to generate the monthly rainfall surfaces at the same spatial resolution as in NDVI and LST images.

Data analysis

The analyses were carried out separately for three major climatic zones. The pixel data of monthly average rainfall surfaces and monthly MVCs of the NDVI and LST data were used in the analyses. Sampling sites were selected for each zone representing all the different agro-ecological zones found within each zone. For each sample site the mean pixel values for rainfall and NDVI were derived and were used in the simple regression analysis to establish the correlations among NDVI and one month and two month lag rainfall. During the process of analysis the effect of clouds that could further exist were eliminated by excluding the cloud contaminated pixels in the MVCs by defining a threshold value for NDVI as the zero.

The annual pattern of changes in NDVI, LST and rainfall during the one year period starting from January 1993 were also studied. The last three month period of the year is not covered due to the unavailability of images for the above period.

RESULTS AND DISCUSSION

Changes in monthly NDVI

The annual variability of vegetation cover is reflected by the changes in monthly NDVI images. Fig. 1 illustrates the pattern of variability in NDVI in the three different climatic zones - Dry, Wet and Intermediate zones during the study period.

The monthly average NDVI values of the three different zones show a similar pattern of variability which varies within a small range from 0.24-0.47. This observed range lies within the range that was reported for the natural vegetations over Asia for the period of 1982 to 1985 (Malingreau, 1986). Since the used spectral data covers the land cover information at low spatial resolution (1.1km), it basically provides the information of land cover over Sri Lanka which is predominantly the natural vegetation.

According to Suppiah *et al.* (1984) the island generally experiences a marked wet season from October to February and a dry season from May to September in the Dry Zone. In the observed pattern of changes in NDVI, a clear reduction in NDVI during this dry season and relatively higher values of NDVI during the wet season were observed in both the Dry and Intermediate zones. Bayarjagal *et al.*, (2000) has shown a greater possibility of using NDVI values derived from NOAA AVHRR data to monitor the occurrence of dry and wet seasons over the arid and semi arid regions of Mongolia.

Accordingly, the findings of the present study shows the possibility of using NDVI data of NOAA AVHRR LAC 1B data for studies on vegetation dynamics and in monitoring the occurrences of dry and wet spells over Sri Lanka.

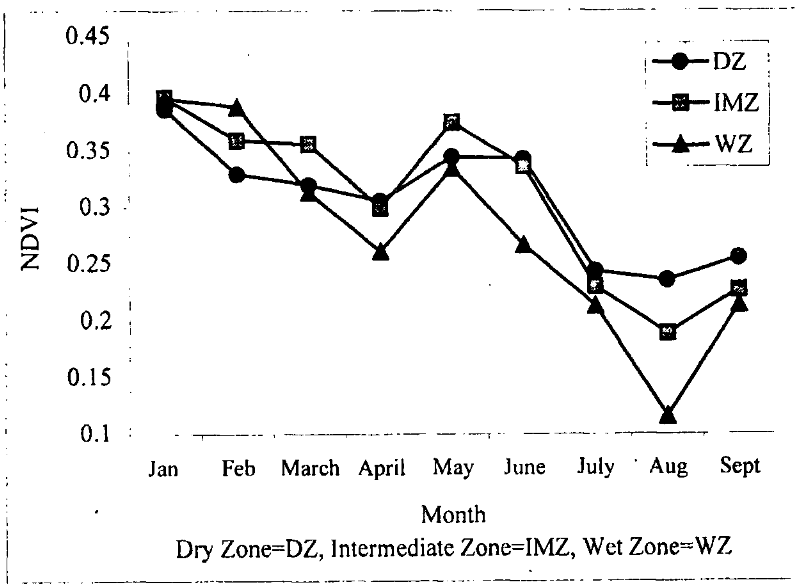

Fig. 1. The pattern of changes in NDVI in three Zones over the study period.

Although it was expected to have higher values for NDVI in Wet Zone where dense cover of natural vegetation exists as compared to two other Zones, the observed values were much lower than those in Dry and Intermediate Zones except for the months of January and February. This may be attributed to the poor representation of the area in selected samples due to their smaller sizes. This problem could not be avoided with the limitation imposed by the occurrence of heavy clouds over the Wet Zone all over the year. The process of deriving Maximum Value Composites (MVCs) for NDVI removes the effect of cloud cover. However, it needs to have a good collection of minimum cloud cover images which was not found for the Wet Zone. This reduction in the NDVI values could also be due to the greater population densities which cause higher disturbances for natural vegetations by human activities. Therefore, with the results of the present study, it is not possible to get a better understanding on the condition of vegetation cover over the Wet Zone.

Changes in monthly LST

The monthly averages of LST values derived from the images were used to study the pattern of variability in surface temperature over the ground surfaces across three major climatic zones of the island. The results are shown in Fig. 2.

A similar pattern was observed in all three zones in terms of variation in monthly average LST values. However, a clear difference was observed among three zones with higher values ranging from 87.75^0 F- 96.09^0 F in the Dry Zone and lower values ranging from 78.67^{0}F to 88.60^{0}F in the Wet Zone. In all three zones the maximum LST value was reported during the month of March. This may be attributed to the occurrence of shorter distance between the sun and the earth during the month of March. The lower values of LST reported in the Wet Zone during the months of June, July and August may be caused by the presence of cloud cover that brings south west monsoon rains to the Wet Zone during this period.

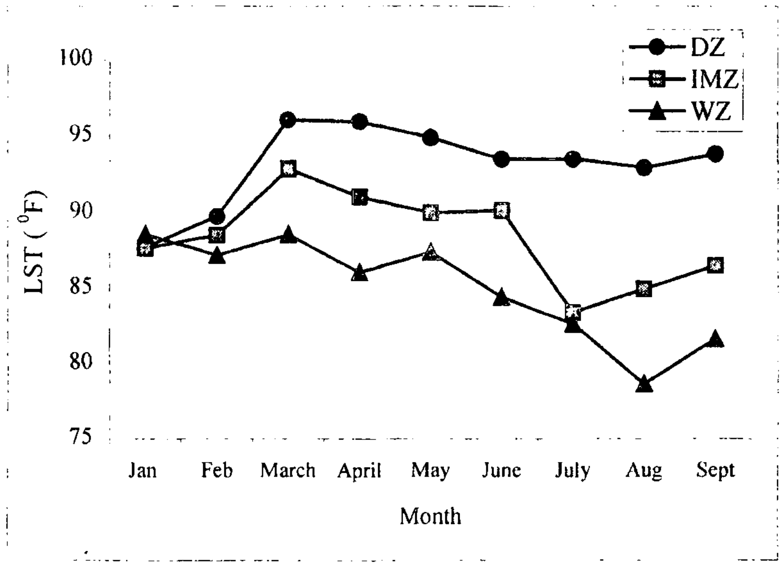

Fig. 2. The pattern of changes in LST in three zones over the study period.

The LST values in the Dry Zone show a clear difference between the wet season and the dry season. The dry season generally occurs in the Dry Zone during October to February and May to September (Suppiah *et al.*, 1984). This study reported relatively lower values of LST during January and February and much greater values of LST during May to September. However, this difference was not clear in the two other zones where such clear difference in the occurrence of dry and wet seasons is not observed. In general, the LST values derived from NOAA AVHRR data using the Split Window Algorithm developed by Price (1984) show a greater possibility for monitoring the occurrences of dry and wet spells over the island.

Changes in monthly rainfall

The pattern of variability in monthly average rainfall was studied using the data extracted from the monthly average rainfall surfaces, which were developed using ground data of selected rain gauging stations representing all the agro-ecological zones of the island. Fig. 3 shows the pattern of variability of monthly average rainfall across the three major climatic zones.

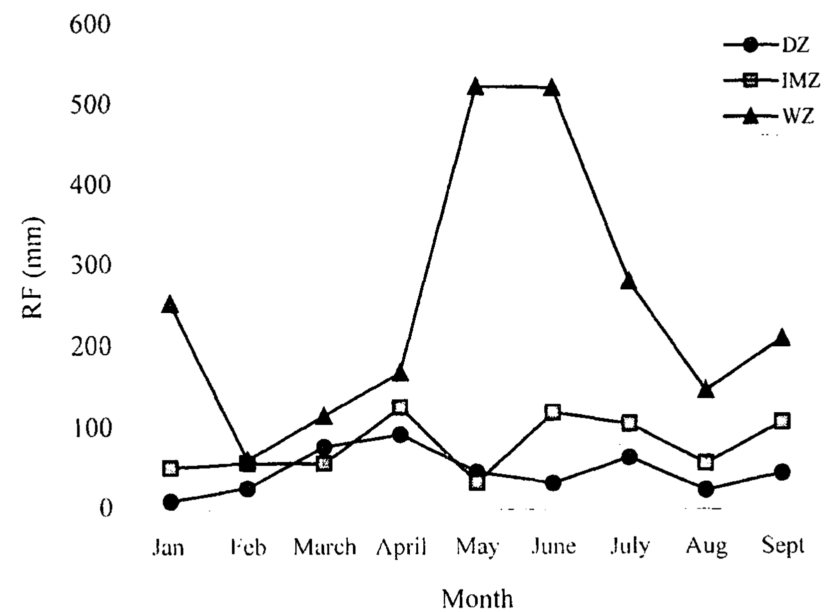

Fig. 3. The pattern of changes in rainfall in three zones over the study period.

A clear difference exists among the three major climatic Zones in terms of rainfall occurrence and the magnitude. It demonstrates a higher magnitude of well distributed rainfall throughout the year in the Wet Zone, lower magnitude with clear two peaks in the Dry Zone and in-between values in the Intermediate Zone. However, the marked difference in the Dry Zone as wet and dry seasons during May to September and October to February respectively as defined by Suppiah *et al.* (1984), could not be observed in the pattern of variability of monthly average rainfall values during the study period. Hence, it may not be possible to define such variability depending solely on the pattern of changes in the rainfall and therefore it may be possible to use all NDVI, LST and rainfall values for the demarcation of such seasonality for the study period.

Relationship between NDVI and rainfall

The relationships between NDVI and lag rainfall in three different zones were evaluated in this study. Both the one month and two month periods were used to obtain the lag rainfall values and coefficient of determination (R^2) for both one and two month lag periods were derived. Fig. 4 and 5 show the relationships observed between NDVI and lag rainfall in three different zones.

A significant relationship at 95% confidence level between NDVI and one month lag rainfall could not be reported in any of the three different zones. This may be due to the perennial nature of the natural vegetation over the country that accounts for more than one third of the ground cover. Generally, the perennial crops show a slow rate of response to the changing climatic conditions. Therefore, these vegetations may not show a rapid response to the changing rainfall within a period of one month. This same fact could also be explained with the comparatively higher values of correlation coefficients between NDVI and the rainfall reported in all three zones for the lag period of two month than that of one month period.

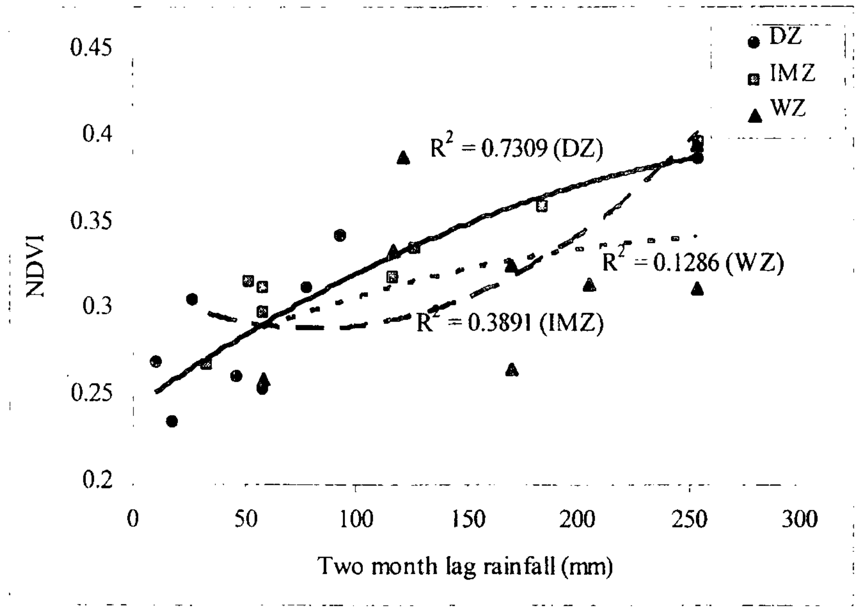

Fig. 4. Relationship between two months lag rainfall and NDVI in Dry, Intermediate and Wet Zones.

The correlation coefficients reported for Wet Zone were much less than that of the other two zones. This may be due to the availability of sufficient moisture levels in the Wet Zone soils due to the well distributed rainfall over the year. Hence, the occurrence of rains may not cause much influence on the changes in the vegetation cover.

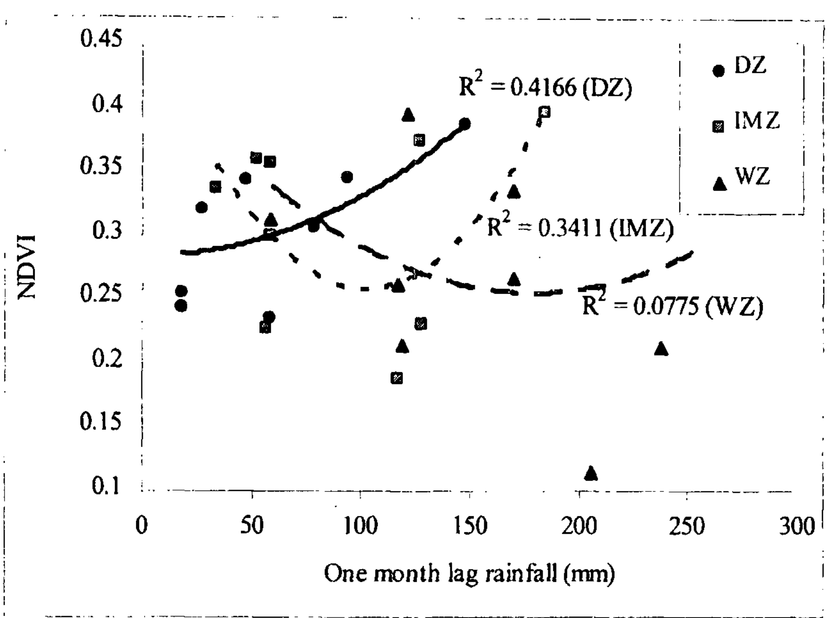

Fig. 5. Relationship between one month lag rainfall and NDVI in Dry, Intermediate and Wet Zones.

A significant correlation ($P<0.05$) between NDVI and two month lag rainfall was reported for the Dry Zone with a high R^2 value of 0.7309. Hence, it is highly reliable to use the NDVI values derived for the Dry Zone from NOAA AVHRR data in back casting the rainfall values for a two month lag period. However, it is necessary to establish this relationship using data of longer period in order to realize its real applicability to derive reliable data of rainfall values for missing locations and time series.

CONCLUSIONS

The monthly average NDVI values of the three different zones as observed in the present study varied within a smaller range from 0.24 to 0.47 as expected generally for the natural vegetations found within the country. However, the NDVI values observed for the Wet Zone was found to be not appropriate for the vegetation types that exist within the Wet Zone compared to the values reported for the other two zones due to the problem of cloud cover and also due to the greater disturbances for natural vegetations with the rapidly increasing human population density in Wet Zone. Therefore, it is necessary to adopt a suitable approach for the elimination of the effect of cloud cover that exists in the images.

The derived LST values are in the range of 78.67^0 F– 96.08^0 F with the maximum and minimum values reported in March from the Dry Zone and in August in Wet Zone respectively. These values are within the acceptable range as reported from the ground observations. Therefore, low resolution spectral imagery of NOAA AVHRR are found to be a promising approach for estimating temperature of ground surfaces.

A sound correlation between lag rainfall and NDVI could not be observed for both Wet and Intermediate Zones. A sound correlation ($P<0.05$) was observed only between the two month lag rainfall and NDVI in Dry Zone.

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