Estimation of the severity of Forest Fire Damage and the Recovery Using Landsat Data

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Abstract

This study presents the results of classification of vegetative cover, and its change with time using Normalized Difference Vegetation Index (NDVI), which resolves to \((\text{band } 4 - \text{band } 3)/(\text{band } 4 + \text{band } 3)\) of Landsat Thematic Mapper (TM) data.

A study area including a fire damage site was chosen for the research. Three sets of TM data of the same area, i.e., before the fire (May 1984), just after the fire (April 1985) and five years later (March 1990), were used for analysis. They were geometrically corrected and superimposed over 1:25,000 map.

The NDVI values of 1984 TM data were computed for training samples selected from land use maps. It was found that NDVI can be used to delineate vegetative cover from other types of land cover. The NDVI values of 1985 TM data showed significant changes in the area which was classified as vegetative cover using 1984 TM data. This variations were used to identify the fire damaged area.

Fire damage was interpreted into three severity of damage classes using aerial photographs of just after the fire. NDVI values were computed for randomly selected samples from each of these classes and 1985 TM data was classified into these three damage classes using the computed NDVI values. Photographs obtained five years after the fire were interpreted into four regeneration classes and classified the 1990 TM data into these classes by the same method. The accuracies of fire damage and regeneration classifications were 73% in both the cases when compared with aerial photo interpreted maps.

The differences of NDVI values of the overlaid TM data were analyzed for detecting the dynamics of change of vegetative cover in time scale. It was possible to identify the major changes which were observed in aerial photo interpretation.

Key words: Landsat, NDVI, forest fire, regeneration

L. SAMARAKOON* 岸原信義・小川 滋・井上章二・戎 信宏: ランダサット TM データによる林野火災の燃焼程度と植生回復の評価
林野火災の被災地を含むエリアを対象に、ランダサット TM データの (Band 4−Band 3)/(Band 4+Band 3) で表される NDVI を指標として、森林植生とその変化に

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Key words: Landsat, NDVI, forest fire, regeneration 林野火災地、ランダサット TM データ、植生回復
1. Introduction

It is an established fact that the vegetation on the earth’s surface influences certain phenomena, such as CO₂ concentration, hydrological cycle and global climatic patterns. Accurate information on the distribution of global vegetative cover and its change is a requisite for the better understanding of the above phenomena. Traditional methods, such as Land Surveys and Aerial Surveys could be replaced by satellite observation in mapping and monitoring vegetative cover more economically in the long run and in the repetitive basis. Many researches have demonstrated the use of satellite data in identifying water bodies, forest cover, agricultural lands etc.

It is revealed that the reflected radiation in the red wave band (0.6-0.7 μm) and infrared (0.8-1.1 μm) are highly correlated with green biomass and leaf area index (Tucker 1977, 1979 and Sellers 1985). Chlorophyll concentration is negatively correlated with the reflected red radiation and near infrared radiation is positively correlated with the internal structure of the leaves (Wooley 1971, Curren 1985). It is observed that changes in the reflection of red (r) and near infrared (nir) is related to the changes in chlorophyll concentration and leaf structure (Sinclair 1971, Thomas 1977).

The Normalized Difference Vegetation Index (NDVI), which resolves to \( \frac{(nir - r)}{(nir + r)} \) is being widely used in remote sensing. This index can be derived from any sensor which is installed with visible and near infrared bands. Correlation of NDVI with green biomass has been investigated and this index has been used to map vegetation regionally and continentally (Tucker 1985, Sader and Joyce 1988). Application of these two bands for recovery of forest fire has been reported (Jie, 1989). This has also been applied in yield modeling (Ashcroft, 1990) and biomass estimation (Jensen, 1990).

The increasing popularity of NDVI in remote sensing applications are; Its high correlation with biophysical parameters, it reduces the volume of data to a single channel and it is easy to incorporate into mathematical models for its semi-continuous nature of the value (Sader 1988).

This paper presents a comparison of NDVI classification of forest fire damage and regeneration with existing aerial photographs and land use maps. Also, an experimental result of multitemporal application of NDVI using three Landsat scenes acquired on three different dates for detecting changes in time scale, is presented.

2. Study Area and Data

In February 1985 a mountain range in the East of Kawano city in Shikoku Island of Japan, experienced a forest fire destroying about 390 ha. of forest. Emphasis for the research work was laid upon the mapping of severity of this forest fire damage and the estimation of regeneration after a period of five years from the date of the fire.

To facilitate this, three Landsat Thematic
Mapper (TM) data sets were purchased which were acquired by Japanese Landsat data receiving center on 1984.05.08, 1985.04.09 and 1990.03.22. These three sets, i.e., 1984, 1985 and 1990 represents the state of the study area before the fire, after the fire damage and regeneration in a period of five years, respectively. The layout of Landsat data scenes and the location of the forest fire is shown in Fig. 1. Each Landsat data set consisted of 512 x 400 pixels. Two sets of aerial photographs, just after the fire and four years later (1989), were acquired for preparing maps to be taken as ground truth data. Three fire damage groups were interpreted on aerial photographs (Samarakoon 1988) and traced on a 1:25,000 scale base map. The interpretation was based on the degree of damage to the forest cover. Groups identified were, 1) severely damaged, 2) all crowns damaged and 3) slightly damaged. 1989 aerial photographs were interpreted for regeneration and mapped into four groups, specifically:

1. Bare lands (landslides and cleared for plantation).
2. Partially recovered. 1. Scattered vegetation, about 60% bare.
3. Partially recovered 2. Small trees but the under cover can be seen.
4. Fully recovered area.

Existing land use maps were obtained for areas which were not covered by the aerial photographs. Only the land cover classes inside the study area were analyzed for the present research though the acquired Landsat data cover the surrounding area also.

3. Method

3.1 Registration of Landsat data.

To make the cross checking easier with photointerpreted maps and land use maps, all the scenes were brought to a same map coordinate system. About 10 control points scattered over the images were used for registration. The resultant standard errors in the three scenes were less than 1/2 of a pixel in both row and column. Nearest Neighbour resampling technique was used in producing images on 30 meter grid using a bilinear mapping polynomial. A computer program was developed to carry out the investigation.

3.2 NDVI and Atmospheric Correction Problem.

The remote sensing data available for this study are not quantitatively corresponding to the actual physical values on the earth surface. This however is due to the fact, that the presence of the atmosphere and difference in the suns irradiance attenuate the irradiance at the sensor detector. Experiments that uses temporal images requires to correct the raw data for atmospheric effects and spectral irradiance.

Image irradiance at the sensor $E_i k$ for given wavelength interval $k$, can be expressed as follows:

$$E_i k = K (E_k \rho_k \tau_{ok} + \pi L_{ok}) \tau_{ok}$$

where, $E$ = the irradiance at the ground feature of reflectance $\rho$.

$K$ = a function of the factors effect the image plane irradiance.

$\tau_{ok}$ = the atmospheric transmission between ground and the sensor.

$L_{ok}$ = the upwelling atmospheric radiation between ground and the sensor.
\[ \tau = \text{the transmission of the optical system.} \]
\[ \rho = \text{surface spectral reflectance.} \]

\[ E_1 \tau_1 = E_2 \tau_2, \quad L_{s1} = L_{s2} \quad \tau_{\alpha 1} = \tau_{\alpha 2}, \]

for two different spectral bands, a ratio \( R \) is computed as,

\[ R = \frac{E_{s1} - E_{s2}}{E_{s1} + E_{s2}} = \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} \quad (\text{Slater 1980}). \]

By doing this the factor \( K \) which includes \( \cos^2 \alpha \) falloff, vignetting is eliminated. Thus, the ratio \( R \) depends only on the reflectance properties of the ground features as far as the approximations hold. By choosing bands which are closer to each other the approximation would be in a better order (Slater 1990).

Substituting the bands in the visible and near infrared region into the ratio calculation, the \( R \) resolves to the NDVI. Therefore, temporal analysis of Landsat data could be done with NDVI values without correcting them for atmospheric distortions by rigorous models.

### 3.3 Analysis of NDVI values.

Computer Programs were developed for the Graphic Work Station of Ehime University for calculating NDVI images.

Pre-analysis was done to evaluate the possibility of NDVI application in fulfilling research objectives. NDVI values were computed for three dates and statistical parameters were calculated for forest cover, damaged area, built-up lands and sea, Fig. 2. The dramatic decrease of the 1985 NDVI values in damaged area could be used to delineate the forest fire damaged area, Table 1. Slightly higher NDVI values of the damaged area in 1990 could be attributed to the regeneration, and large standard deviation could be due to the presence of different stages of regeneration. Calculation of the index was done using the following equation.

\[ \text{NDVI} = (\text{nir} - \text{r}) / (\text{nir} + \text{r}) \quad \text{for equation (1)} \]

For temporal analysis two new difference images were computed in the manner given below.

\[ D_1 = \text{NDVI} (84) - \text{NDVI} (85) \quad \text{for equation (2)} \]
\[ D_2 = \text{NDVI} (85) - \text{NDVI} (90) \quad \text{for equation (3)} \]

The resulting NDVI values of equation (1) represent a continuous distribution with +1 and -1 as maxima and minima. To facilitate image analysis it is required to bring them to a more wider range (7 or 8 bit), with positive

### Table 1 Distribution of NDVI Values.

<table>
<thead>
<tr>
<th>Land Class</th>
<th>1984</th>
<th>1985</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>mean</td>
<td>0.36</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>sd</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Urban Area</td>
<td>mean</td>
<td>-0.05</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td>sd</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Sea</td>
<td>mean</td>
<td>-0.24</td>
<td>-0.25</td>
</tr>
<tr>
<td></td>
<td>sd</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Fire Damaged Area</td>
<td>mean</td>
<td>0.33</td>
<td>-0.09</td>
</tr>
<tr>
<td></td>
<td>sd</td>
<td>0.05</td>
<td>0.08</td>
</tr>
</tbody>
</table>

sd-standard deviation.

\( D_1 \) and \( D_2 \) explain the changes between 1984, 85 and 1985, 90 respectively.

Theoretically nine possible combination of \( D_1 \) and \( D_2 \) exist, Table 2. This shows that \( D_1 \) and \( D_2 \) could be used to identify nine types of changes occurred in the area in two different time interval; 1984 to 1985 and 1985 to 1990.
4. Results and Discussion

4.1 Vegetative cover estimation by NDVI.

NDVI images for three Landsat images were calculated with the equation (4) setting a and b to 0.7 and 60 for all scenes to make the comparison among them easier. The TM bands used for the analysis were band 3 (0.63-0.69 µm) and band 4 (0.76-0.9 µm), which response to red radiation and near infrared radiation.

Ground truth data were obtained for forest, urban areas, sea, orchard and paddy field from the existing land use maps and aerial photographs. Corresponding NDVI values were extracted from the calculated image of 1984 for each of the above mentioned land use classes. Mean and standard deviation were calculated, Table 3 1984 column, and NDVI ranges for each land cover class were obtained. Two times of the standard deviation was used to calculate the minimum and maximum values of NDVI in this study. The calculated minimum and maximum values define the NDVI range for the particular class.
Fig. 3 is the pseudo color image of NDVI of 1984. The study area is outlined and referenced. Green color represents high values of the NDVI and it was observed that prior to the fire, almost the entire study area was covered with forest. Red, yellow, white and blue colors were assigned to built up land, orchards, paddy fields and sea to keep the comparability of images to be easier with existing maps.

Similar colors were assigned to 1985 NDVI image, and the fire damaged area appeared red in color showing a drastic change in the forest cover. Effort was made to identify the different degrees of damage by further classification of the fire damaged area.

To perform this, about 60 points were selected on the photo-interpreted fire damage base map to cover all the three fire damage classes. Statistical parameters were calculated, as shown in Table 3, 1985 column. NDVI ranges for fire damaged classes were estimated using their statistical values. These three fire damage classes and other land cover classes which were used for classifying 1984 scene were used to assign colors to 1985 NDVI image. Resulted image is given in Fig. 4. Red, yellow and white colors inside the fire damaged area represent damage groups 1, 2 and 3 respectively. The classification accuracy was compared with prepared fire damage map. Hundred and twenty points were randomly selected over the fire damage map covering the three damage classes. Comparing the damage class of each of these selected point with the classified class of the corresponding point on the NDVI image, a confusion table was prepared, Table 4. The accuracy of mapping the severity of fire damage by NDVI was about 73%.

Table 4

<table>
<thead>
<tr>
<th>TM Data Classification by NDVI</th>
<th>Aerial Photo Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe Damaged</td>
<td>All crowns Damaged</td>
</tr>
<tr>
<td>Severe Damaged</td>
<td>4</td>
</tr>
<tr>
<td>(75%)</td>
<td>(73%)</td>
</tr>
<tr>
<td>All Crown Damaged</td>
<td>11</td>
</tr>
<tr>
<td>(73%)</td>
<td>(71%)</td>
</tr>
<tr>
<td>Lightly Damaged</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>59</td>
</tr>
</tbody>
</table>

Table 3, 1990 column gives the statistics for randomly selected training samples for all the four regeneration groups described in section 2 of 1990 aerial photo interpretation. NDVI value ranges were decided on the statistics of these classes and colors were assigned to 1990 NDVI image, Fig. 5. The accuracy of the NDVI classification was investigated. Hundred and thirty five points were randomly selected over the photo-interpreted regeneration map and their land cover classes were compared with the estimated land cover classes of the corresponding points on the classified NDVI image. The confusion matrix for comparison is shown in Table 5. It was found that the classification accuracy was about 73%. The reduced accuracy of group 3 could be due to the subjective nature of the aerial photo interpretation.

The classified fire damage NDVI image was compared with the classified regeneration NDVI image to estimate the trend of regeneration with the severity of damage. Hundred and ninety pixels were randomly selected over the three fire damaged classes on the 1985 NDVI image and compared their classified land cover classes on the 1990 NDVI image. The comparison is shown in Table 6.

It shows that the severely damaged areas are turned to bare lands or the regeneration is very slow. Whereas, slightly damaged areas show a high degree of regeneration. The moderately damaged group, the recovery is not correlated with the regeneration. In generally it could be said that the regeneration in the study area has a correlation with the severity of damage. This could be due to the fact that the top soil in the severely damaged areas have disturbed greatly
Fig. 3  Classification of 1984 TM data using NDVI.

Fig. 4  Classification of 1985 TM data for severity of fire damage classes using NDVI.

Fig. 5  Classification of 1990 TM data for the recovery classes using NDVI.

Fig. 7  Temporal analysis of the three Landsat data sets using NDVI.
Table 5  Comparison of Severity of Fire Damage with the State of the Regeneration in Pixel Units.

<table>
<thead>
<tr>
<th>TM Data Classification by NDVI</th>
<th>Aerial Photo Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bare Land</td>
</tr>
<tr>
<td>Bare Land</td>
<td>19 (76%)</td>
</tr>
<tr>
<td>Partially Recovered 1</td>
<td>6 (28%)</td>
</tr>
<tr>
<td>Partially Recovered 2</td>
<td>0 (8%)</td>
</tr>
<tr>
<td>Fully Recovered</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 6  Comparison of Severity of Fire Damage with the State of the Regeneration in Pixel Units.

<table>
<thead>
<tr>
<th>Fire Damaged Classes</th>
<th>Regeneration Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bare Land</td>
</tr>
<tr>
<td>Severely Damaged</td>
<td>29 (41%)</td>
</tr>
<tr>
<td>All Crowns Damaged</td>
<td>11 (16%)</td>
</tr>
<tr>
<td>Slightly Damaged</td>
<td>2 (4%)</td>
</tr>
</tbody>
</table>

than in the slightly damaged areas. Further analysis are required to understand the pattern of recovery with severity of fire damage, incorporating factors like ground slope, aspect, elevation, ground water, which could influence the regrowth.

4.2 Change Detection by NDVI.

The time-series approach to change detection may be useful for assessing rates and trends in land cover conversion processes. This was tried with the Landsat TM imageries acquired on three dates.

New data files were calculated from the NDVI images in section 4.1 using equation (2) and (3). The constant value added for both D1 the D2 was 60.

Changes in land cover occurred during the period 1984 to 90 were identified on existing land use maps, aerial photographs, fire damage map and regeneration map, and the changes were grouped on the basis of the nature of the change (increase or decrease in vegetative cover) and when the change took place (before the fire or after the fire). The following groups, (a) to (d), were able to identify mainly inside the study area, and it was possible to extract enough number of pixels for each group for further analysis.

(a). No appreciable change of the vegetation in 84 to 85 but decreased later. This later
decrease could be attributed to the damage caused by excess runoff resulting from the damaged area. Most of the vegetation not destroyed by the fire, especially in some valleys, were washed out.

Same nature of change was observed outside the damaged area where a highway was constructed after 1985.

(b). Decrease in vegetation before and after the forest fire. The continued decrease is attributed to the further deterioration of vegetative cover after the fire damage.

(c). Decrease in vegetative cover in 84 to 85 and an increase in the period 85 to 90. These were the places where the forest fire has affected the vegetation and an appreciable regeneration could be seen afterwards.

(d). No changes in 84 to 90.

It was not possible to further identify areas for other possible changes defined in Table 2.

D1 and D2 values were obtained for arbitrary selected samples for each of the above groups (a) to (d), and were plotted in a scatter diagram shown in Fig. 6. The plotting directions of mathematically expected groups 1 to 9 in Table 2 were compared with the plotting positions of these groups. It was found that the groups (a) to (d) were agreeing in plotting directions with groups 1, 2, 4 and 9 respectively. And also, the pattern of forest cover change in group (a) to (d) was similar to that of group 1, 2, 4 and 9. This shows us that the changes explain by each group in Table 2 are true representations of the actual changes that have being occurred in the field. Therefore, the D1 and D2 images can be used to identify the different changes and their trend in the area of interest.

Means and standard deviation were calculated for the above collected groups, (a) to (d), and parallelepiped classification algorithm was used to classify the D1 and D2 images to change classes. The resulting image is shown in Fig. 7. The image was visually checked with existing maps and aerial photographs, and the major changes described earlier were possible to identify in the image also.

5. Conclusion

Based on the results obtained, the Normalized Difference Vegetation Index could be used to classify satellite data into land cover classes. In all the cases the accuracy of Landsat classification was about 73% when compared with photo-interpreted maps. It may not be possible to achieve very higher agreement due to the subjective nature of photo-interpretation. The accuracy of mapping the severity of fire damage and regeneration is considered high enough to emphasize the validity of the NDVI in forest biomass estimation by satellite data. It is worthy to note that the index has a near linear relationship with the solar energy intercepted by the vegetative cover.

The large volume of data involved in the temporal analysis of satellite data could be reduced while keeping the accuracy of the estimation in a reliable order by using NDVI.

The NDVI values computed separately for images acquired on different dates are capable of depicting the nature and the pattern of the changes in forest cover.
References


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