Inference of landslide susceptible areas by Landsat Thematic Mapper data

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Abstract Geological structure and the exceptional water retention characteristic of soil, said to be the major factors that causes landslide in the upper basin of the Yoshino river in Shikoku Island, Japan. An indirect approach to estimate landslide susceptible areas in this river basin was investigated using Landsat Thematic Mapper (TM) data. Inference of landslide potential areas was made by investigating moisture status in forest canopy deduced by Landsat TM data. Choosing suitable TM data sets, attempt was made to estimate the forest cover that represents relatively high moisture concentration in two different seasons; just after a long spell of rainfall and following a considerable dry period. The scene acquired in September belonged to the wet season of 1986, and November scene represented a dry season of the same year. Forest cover that has been subjected to seasonal changes during the two dates was excluded from the study by comparing Normalized Difference Vegetation Index (NDVI) of the two dates. Subsequently, samples were randomly selected over the forest cover estimated as unchanged, and corresponding digital counts of TM band 3, 4, and 5 of both dates were extracted. Factor analysis was carried out using the two dates band ratios 4/3 and 4/5 of the selected samples. Physical meaning of the resultant factors were interpreted according to the spectral properties of the bands that showed high correlation with respective factors. Subsequently, factor score scatter diagram of the samples was plotted and the samples that represented relatively high moisture in both the dates were extracted. These samples were utilized in separating relatively high moisture areas within the river basin using Landsat data. The extrapolation of training results was based upon a maximum likelihood classifier. The above estimated high moisture areas were compared with the existing landslides map of the area, and it was found that most of the landslides were concentrated over the estimated high moisture areas. This showed that the areas with relatively high moisture in both dates are more susceptible for landslides than other areas. Therefore, it could be said that the Landsat data acquired in rainy and dry season can be used for preliminary investigation of landslides susceptible areas as well as to monitor landslides in an area.

INTRODUCTION

An ideal land and water management plan should account and take care of the surface parameters and their changes in time scale. Landslide is one of the phenomenon that account for land degradation, which could cause mass destruction to life and property. Remotely sensed data has been used in land and water resources management since early sixties. Through wide range of scientific and application research works, it has been demonstrated that satellite technology can effectively be used in observing spatial parameters like surface water, land use, snow cover, surface temperature, etc. Estimation and monitoring of landslides is becoming an active field of remote sensing technology, but the appropriateness in practical application is yet to be assessed.

Landslide is a phenomenon that causes mass movement of earth due to factors such as geology, ground water, land cover. In fractured or volcanic altered zones, presence of excess ground water could influence landslides by transforming soil into soft clay. It has been shown that ground water in these geologically altered areas influences the generation of landslide (Takagi & Murai, 1991). Direct measurement of ground water in a large area is practically not viable, therefore prediction through indirect approaches have to be developed. Fractured zones in the bedrock may show high water content in the soil, and this may be detected by luxuriant plant growth in that area. This could

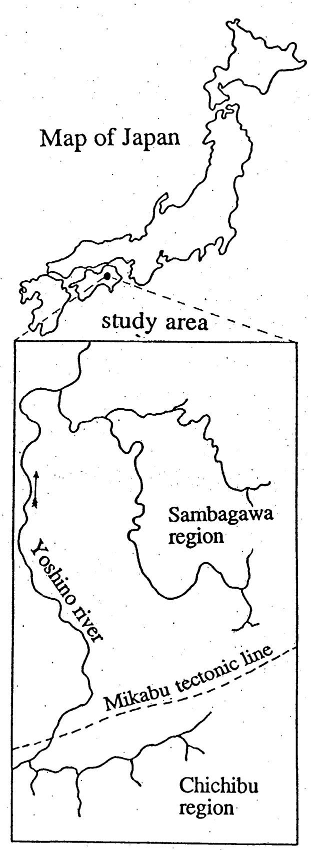

Fig. 1 Location of the study area.

easily be observed by remotely sensed data, and could be utilized in predicting the state of ground water. This follows that investigation on canopy moisture content could lead to understand the ground water distribution, hence landslide proven areas. Also, spatial limitations and the difficulty of continuous investigations could be answered with the development of remote sensing techniques.

Tucker reported (Tucker, 1977) that 0.63 to 0.69 Mm is the best spectral region for estimating low level of chlorophyll and leaf water content, and spectral response of this region has an inverse relationship with chlorophyll and leaf moisture. Tucker demonstrated (Tucker, 1980) that, 1.55-1.75 Mm spectral window is superior than the other spectral transmission windows in 0.7-2.5 Mm spectral region in monitoring moisture stress in plant canopy by satellite remote sensing. Cohen illustrated (Cohen, 1991) that leaf water potential is highly correlated with vegetation indices than any single Landsat Thematic Mapper band, and the middle-infrared to near-infrared ratio with the highest correlation. Thematic Mapper band 4 has the lowest response, and band 5 has the highest response to change in leaf water content.

These are some of the research works that show the possible use of spectral investigations in detecting moisture stress in vegetation. In this study, attempt was made to estimate the spatial locations of vegetation that have relatively high moisture level irrespective of seasonal changes using Landsat Thematic Mapper (TM) data, and their correlation with landslide areas mapped by other means. The research concept was developed on following assumptions:

(a) After a lengthy rainy period the vegetational cover moisture density will be relatively high due to presence of excess soil moisture.
(b) A prolonged dry season could lower ground water table, hence reducing moisture in the soil, which could induce water stress in vegetation.
(c) The areas that have excess ground water may not develop appreciable water deficiency with annual precipitation patterns.

MATERIAL AND STUDY AREA

Investigation was carried out in the upper stream of Yoshino river basin in Shikoku island, Japan. The total catchment area of the river basin is about 3750 km^2. A study area with about 1000 km^2 was selected for the present study as depicted in Fig. 1. Geology of the river basin is notified by the Median tectonic line and the Mikabu tectonic line. The area between Median and Mikabu tectonic lines are designated as Sanbagawa region, and the area to the south of Mikabu tectonic line is referred to as Chichibu region, as shown in Fig. 1. The most important lithologies in the Sanbagawa area are crystalline schist including black, green and quarts, and in the Chichibu region is Mikabu green schist. All of these bedrocks contain several weak places due to influence of tectonic movements, and this area is identified as one of the Japanese top fracture zones. Landslides have been in active in this area for centuries and presently under active landslides prevention projects. It is said that the course for the landslides in this area is mainly due to water retention characteristic of the soil. The mean annual rainfall of the area is about 2500 mm. The land cover types of the study area are dominated by forests, paddy fields, crop lands, orchards and few water bodies. According to published land use maps, the forest cover of the study area is about 85% of the total area.

Rainfall data of the area from 1984 to 1990, and information of TM data available for the same period was studied to select two scenes that meets the requirements of the research concept. The scene acquired on 3 September 1986, which was after a considerable rainy period, and 6 November 1986, which was in the dry season, were selected for the analysis. Table 1 shows rainfall within the study area for the year, 1986.

Black and white photographs acquired in 1985 were obtained for selection of reference data, and to verify satellite data classification results. Also, landslide map of the area was acquired for assessment of classification accuracy.

IMAGE REGISTRATION AND GEOCODING

1:50 000 topographical maps were acquired and used as base-maps for georeferencing satellite data. This was carried out in two steps. Initially the two scenes were overlaid

Table 1 Precipitation observed within the study area during 1986.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1					11.0					22.0		
2				9.5	6.5		0.5	18.0				
3	35.5				21.0		1.0		▧		7.0	
4					2.0		12.5					
5					22.0		6.5		5.5			
6		0.5			17.0		4.5				▧	
7							8.0					
8							6.0		16.5			
9			6.5	105.0					22.0		17.5	2.0
10			6.5	5.0			2.5	2.0	11.0	8.5		7.0
11			1.5	0.5			209.0					
12	0.5	0.5					31.0		35.0			
13		3.5	37.5		28.5			5.0				4.0
14			8.5	45.0	67.0		35.5		6.0		0.5	22.5
15				15.5		3.0	6.0	30.5	15.0			0.5
16						153.0	9.5		30.0			
17		2.5		17.0		136.5	3.5	17.5	8.0			
18		67.5	1.0	7.5					23.0			96.0
19					70.0		0.5		10.5			1.0
20									109.5			
21		1.5		20.0		1.0			35.0	9.0		0.5
22			30.0	5.0		29.0		6.5				
23	1.5		9.0			10.0		2.5				
24	0.5		7.5			5.5	2.0			0.5	10.0	
25			0.5			26.5		0.5				
26				2.5						8.0		
27			13.5	21.0		1.5		4.5				5.0
28			25.0	6.0				161.5				2.0
29			1.0		19.5	59.5				2.5		3.5
30			6.5	0.5								2.0
31												1.5
Total	38.0	76.0	154.0	260.0	264.5	436.5	339.0	248.5	327.0	50.5	35.0	147.5

▧ Represents the dates that Landsat TM data acquired for the study by taking September scene as the master image. This was followed by the georeferencing of master image with topographical maps. Subsequently, the November image, which was transformed onto September scene in earlier step also registered over the same base-map. A bilinear polynomial using least square adjustment was used for geometric transformation, and pixels in both of the scenes were resampled into 30 × 30 m pixels using the nearest neighborhood method. The standard error for the prediction of control points of map from September image was less than 10 m in both of the arbitrary selected *X* and *Y* directions.

METHOD OF ANALYSIS

NDVI images of the georeferenced TM data sets were generated using the bands given in the following formula:

$$\text{NDVI} = (\text{band4} - \text{band3})/(\text{band4} + \text{band3})$$

The TM band 3 and 4 in the above equation belongs to the red and nearinfrared regions in the electromagnetic spectrum, respectively. Subsequently, a new image was created with the difference of NDVI images of two dates to extract the ***unchanged*** forest cover in both of the dates. The term ***unchanged*** stands for forest cover with uniform aerial coverage in both dates, and that have not subjected to any seasonal changes. Sensible comparison of two dates satellite data for any phenological or moisture change can be carried out if the above mentioned factors remain same. The NDVI was used here as it reduces the influence of the background on the canopy composite reflectance (Clevers, 1988), and partly compensate for illumination conditions and atmospheric effects (Kanemasu *et al.*, 1979 & Tucker *et al.*, 1979). Samples were chosen randomly over the unchanged forest land, and digital counts of Landsat TM band 3, 4 and 5 of both dates were extracted. These samples were analyzed by factor analysis, which identifies a relatively small number of factors that can be used to represent relationship among a set of many interrelated variables (Davis, 1973). Also, this helps to identify underlying factors and permits a way to understand what the data are really measuring. Instead of digital counts itself, band ratios 4/5 and 4/3 of both of the dates were used in factor analysis to minimize atmospheric effect, illumination differences on temporal images, and to enhance the interpretation of the condition of vegetation. On the results of factor analysis the selected samples were grouped into two; high moisture in both dates and relative deficit in moisture, in the following manner.

(a) The physical meaning of the most significant two factors were interpreted according to the factor loadings and spectral characteristics of the TM bands used.

(b) Having determined the physical meaning of each factor, the positions of each sample on the factor score plot were examined and grouped into above mentioned classes concerning the physical representation of the factors.

The statistical parameters of the estimated classes were used to classify whole area into high moisture forest cover using maximum likelihood technique. Finally, distribution of high moisture areas were compared with available landslides maps of the area.

RESULTS AND DISCUSSION

Rainfall data in Table 1 shows that there were more rainy days than clear skies for about two months before the acquisition of the September scene. Specially 162 mm. precipitation five days before the satellite pass would have effectively contributed to soil moisture and ground water in the study area. From September 22 to November 6 there was no effective rainfall except for less intensive and sporadic rainfall. Therefore, it would be reasonable to assume that this period could have introduced an appreciable water deficiency in soil as well as in forest canopy.

Theoretically, the difference of two dates NDVI values of the unchanged land cover should be zero. The resultant image showed a deviation from this expectation. This could be due to variation in atmospheric condition and difference in illumination in two dates, which may not have fully compensated using NDVI. Therefore, referring to aerial photographs samples were selected, and probable range of the NDVI of unchanged forest cover was established. Applying this range, unchanged forest cover was established and random samples were selected for further analysis.

The factor loadings for the randomly selected samples over unchanged forest cover is shown in Table 2. It shows ratio 4/3 of both dates has a high contribution to factor 1. Ratio 4/5 of both dates has a high correlation with factor 2. Figure 2 shows

Table 2 Factor loading and the distribution of Eigen values for the first two factors.

	Factor 1	Factor 2
September 4/5	0.0541	0.5931
September 4/3	0.7163	0.0850
November 4/5	0.5089	0.4208
November 4/3	0.9243	0.0878
Eigen value	2.3940	0.9870

a laboratory experiment conducted on maize leaves (Woolley, 1971). It can be deduced from this figure that ratio 4/5 decreases with reduction of leaf water. This gives the behavior of red reflectance with near-infrared reflectance and canopy leaf area index. Also, it can be deduce that ratio 4/3 is sensitive to leaf area index or the presence of green biomass. On these explanation and properties of ratio 4/5 and 4/3 the factor axes of this research could be interpreted as follows:

Factor 1: Correlation with green biomass or amount of leaf cover.

Factor 2: Represents moisture in two dates. High value depicts relatively high moisture in both dates.

The factor scatter diagram of the samples is shown in Fig. 3. On the above interpretations the samples in quadrant 1 and 2 could be interpreted as samples from areas with relatively high moisture in both dates when compared to samples in third and fourth quadrants. Samples in first and fourth quadrants are high in leaf cover than samples in other two quadrants. Therefore, samples in first quadrant could be classified

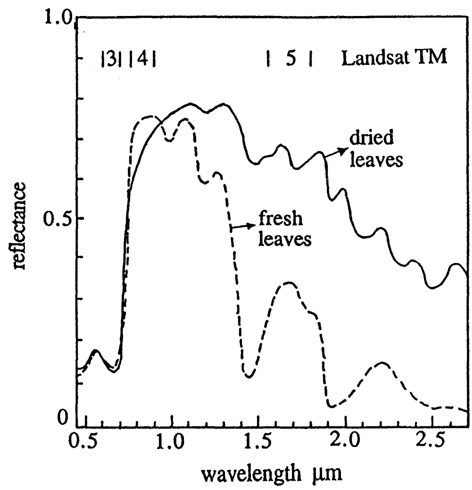

Fig. 2 Reflectance characteristics of fresh and dried Maize leaves on a laboratory experiment (modified from Woolley, 1971).

as relatively high in moisture and leaf cover. Samples in second quadrant could be identified as high in moisture but relatively low leaf cover than samples in first quadrant. On this interpretation the study area was classified into high moisture areas in two dates using the statistics of samples in first and second quadrants. The classification was carried out using maximum likelihood method. In the classification stage samples in two quadrants were not combined into one group to avoid possible multimodel distribution of training samples.

The resultant image of high moisture areas was compared with the landslides map of the area produced by Ministry of Construction upon field surveys. The surveys have been confined only to areas where the destruction has a severe impact on inhabitant of the area. The comparison found that most of the estimated high moisture areas by satellite data interpretation were distributed over landslides proven areas. Therefore,

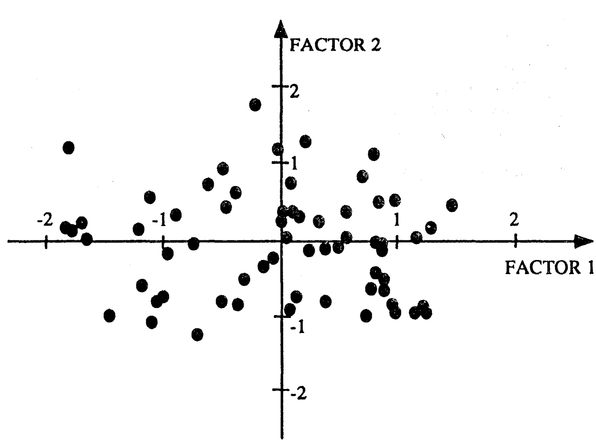

Fig. 3 Factor score scatter diagram of the random samples selected over the unchanged forest cover in the study area.

it could be said, areas that indicated high moisture could be landslide hazard regions, or the potential of occurring landslides in estimated high moisture areas is greater than other areas.

CONCLUSION

In this study it was found that satellite data could be used to estimate soil moisture through interpreting the state of the vegetation. As there is a high correlation of soil moisture to ground water in landslide proven areas in the Yoshino river basin, this facilitates an indirect approach to estimate landslide susceptible regions. Classification result of this study was centered on factor analysis, which gives relative characteristics of the sampled being used. Therefore, it is important to choose samples that have similar land cover to detect moisture differences. This research was carried out on unchanged forest cover in both dates, which could be considered as coniferous forest, but selecting suitable satellite images other areas could be analyzed by the same procedure. The observed high moisture areas in this study will assist in easy location of sites for detailed field investigation for identifying areas that are highly susceptible for landslides. Finally, it could be said that this method could be used as a preliminary approach in landslide studies where the detailed investigation could be restricted to a confined area.

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