Methods for Detecting Landslide within Mountainous Area Using Multitemporal SPOT HRV Imageries : A Case Study in Niigata, Japan

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Summary

This study examined the use of multitemporal SPOT imageries for detecting landslides that occurred in Niigata Prefecture on July 13th, 2004. Two methods were proposed, i.e., the multitemporal principal component (MPC) and the vegetation index differencing (VIDN). In general, the study results show that the MPC method provides the best landslides detection than the VIDN method. The synthetic images derived from stable greenness, delta greenness and delta brightness of MPC provide accuracy of 88% for Teradomari and 91% for Tochio and Shitada Mura, while the VIDN method provides relatively lower accuracies, i.e., only 62.5% for Teradomari and 64% for Tochio and Shitada Mura. The study found that most of the landslides occurred in the steeply sloped areas, particularly near the roads and or stream networks. The study also found that the minimum size of the landsides that could be detected should be at least equal to the size of spatial resolution of the applied SPOT imagery, i.e. 10 m x 10 m. The study concludes that detecting landslides using SPOT imagery is relatively more efficient than using only terrestrial survey, providing a relative efficiency of 2.4.

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Key words: : Multitemporal principal component analysis, vegetation index differencing, stable greenness, delta greenness and delta brightness

The excessive precipitation occurred on July 13th, 2004 in Niigata Prefectures had caused large flood that destroyed residential areas and major infrastructure such as roads, dams as well as rice field in many parts of Niigata Prefecture. This triggering mechanism had upset the natural stability of the slope, resulting in falling, sliding or flowing of landmass under gravity. Landslides are abrupt geomorphic events that constitute the rapid downward motion of soil and rock materials occurring in sloping terrains.

Collecting information on landslide occurrence and activity over wide areas is a crucial task for landslide hazard assessment. Detecting landslides based solely on field observation techniques, despite being very precise, are usually not sufficient to give overall views because they provide point-based measurement. They also do not provide information on the displacement fields or surface changes due to land-sliding in a wider area. Moreover, their application to preliminary investigations of unstable areas may sometimes not be cost effective.

Conventionally, the visual interpretation of aerial photographs has been used extensively to characterize landslides and to produce landslide inventory maps, particularly because of their stereo viewing capability and high spatial resolution. However, the shortcoming of this method is the unavailability of real time photographs expressing the land conditions immediately after the disaster. This technique, although still useful, does not automatically and geometrically precisely determine the evolution of landslide features.

Now, the advent of the satellite technology having various spatial resolutions provides a new opportunity to develop more rapid and reliable method. Optical (visible-infrared) remotely sensed imagery acquired at different dates and at high spatial resolution can be considered as an effective complementary tool for field techniques to derive such information. Developing new satellite-based techniques to identify and character of landslides will assist in the current national landslide inventory and hazard mapping programs. The significance of identifying landslide features is that they provide clues on the nature of motion and therefore indicate potential hazards along transportation routes and where protective measures are necessary.

In this study, an image-processing method to map and monitor landslide occurrence using multitemporal optical imagery is proposed. The method entails automatic change detection of suitably pre-processed (geometrically registered and radiometrically normalized) sequential images, followed by thresholding into landslide-related change pixels. This

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method is examined in 2 study areas in Niigata Prefecture, Niigata, Japan. It has focused on detecting landslides that occurred in July 2004. Although the method has been devised for optical remote sensing imagery in general, the study particularly used the SPOT 2 and SPOT 5 HRV having resolution 20 m x 20 m and 10 m x 10 m.

In this study, two main objectives are outlined, i.e., (1) to detect the distribution and size of the landslides occurred using multitemporal satellite imageries (2) to find out the effective quantitative method to detect landslides using satellite imagery.

METHODS

Study areas

The study was performed in Teradomari, Shitada Mura, Tochio and their vicinity, Niigata Prefecture, Japan. The Teradomari area is located between 128°43' 31.07" and 138°50' 31.95" East Longitude and between 37°42' 22.30" and 37°34' 01.09" North latitude. LU, while Shitada Mura and Tochio are located between 138°54' 54,54" and 139°13' 37,80" East Longitude and between 37°36' 40,25" and 37°21' 54,71" North Latitude. In general, the configurations of the Teradomari areas are ranging from flat to moderately sloped areas. Only small parts of the area have steep areas. In contrast, the Tochio and Shitada Mura areas predominantly have moderately to steeply sloped areas (particularly in mountainous areas).

Image and supporting Data

The study used the following images and supporting data:

- SPOT 2 acquired on August, 15th, 2001, representing the condition prior to landslides. This multispectral image data have three bands, i.e., green, red and near-infrared bands and 20m x 20m spatial resolution.
- SPOT 5 acquired on July 24th, 2004, expressing the condition immediately after the landslides. The multispectral bands of this image have 10 m x 10 m spatial resolution.
- Digital contour map having interval of 50 m.
- Road map at a scale of 1 : 50,000
- Landslide occurence report map.
- Ground checking data.

Software and Hardware

The image processing and spatial analysis were carried out using Erdas Imagine version 8.7, ArcView version 3.3 and ArcInfo version 7.2.1. This software was installed on the personal computer (desk top).

Methods

In this study, the following 2 methods were examined:

<u>Synthetic Image creation</u>

1. *Multitemporal Principal Component (MPC) Analysis*

This technique use compression data techniques frequently referred to as principal component analysis. This technique frequently referred to as is also referred to Hotelling Transformation or Karhunen-Loeve (K-L) transformation method, to select the variance that has low correlation in their linear combination. Three bands of SPOT 2, 2001 were merged with three bands of SPOT 5, 2004, and then this three-plus-three SPOT data were treated as a single multitemporal data set. The 6 new synthetic images provided were then evaluated using brightness and greenness concepts.

The decrease in vegetation cover caused by landslides is accompanied by a decrease in near-infrared (SPOT band 3), while an increase in visible band (SPOT band 1 and 2). This change has led to the identification of vegetation indices that summarize vegetation changes. The following are four indices that evaluated in this method:

(1) *Stable brightness* is the index when the eigenvector (weight) of all six SPOT bands are positive and relatively equal. This index is frequently identified in the first component.

(2) *Stable greenness*, is identified when red and near infrared bands have an opposite algebraic signs each other, either when red band is negative while the near infrared band is positive, or when red band is positive while near infrared is negative. The algebraic sign of the red and near infrared bands in two dates are the same

(3) *Delta brightness*, is characterized either by (a) negative algebraic sign for all bands in one date and positive algebraic signs for the other date, or (b) positive algebraic sign for all bands in one date and negative algebraic signs for the other date,

(4) *Delta greenness* is characterized by opposite algebraic signs of red and near infrared bands between two dates. This indices is found either when (a) red is negative and near infrared is positive in one date, while red is positive and near infrared is negative in the other date, or (b) red is positive and near infrared is negative in one date, while red is negative and near infrared is positive in the other date.

2. *Vegetation Index Differencing*

The vegetation index differencing examined in this study was performed by subtracting the values of NDVI from one date to another. This method is then referred to as VID-NDVI (VIDN) method that derived using the following formula:

$$VIDN = \frac{NIR - RED}{NIR + RED}(year\ 2004) - \frac{NIR - RED}{NIR + RED}(year\ 2001)$$

With this formula, the values of VIDN will range from -2 to 2. The negative values express the decreasing biomes or green vegetation and may be an indicator of landslides occurrence. This method had been implemented by Nelson (1983) to detect leaf defoliation caused by "*gypsy moth*" attack. Banner and Lynham (1982) in Singh (1989) had also implemented this method for detecting land clearing location.

Thresholding

To localize the land slides location within the study area, the study then performed thresholding. The upper and lower bound thresholds were selected based on the training area is pixel that extracted from the landslide location. The value within the thresholds that expressing the landslides were then encoded into 1 value, otherwise to 0.

Filtering and Masking

To reduce noise caused by some inherit errors such as misregistration and difference in spatial resolution as well as atmospheric condition between two dates, then the authors performed filtering and masking. The filtering was intended to reduce salt-and-peeper noise that actually is not landslide. Forest gaps may also cause this noise. In dynamically changed areas, particularly in agricultural areas such as in Teradomari areas, the change in cultivation phases, fallow periods may cause much confusion in detecting landslides. In this case, the author then masked out the agricultural areas from the area of interest. The area having slopes less than 15% is encoded to 0, while the areas having slopes higher than 15% is encoded into 1.

Separability and Accuracy analysis

To evaluate the capability of the SPOT to detect the landslides statistically, the author performed the separability and accuracy analysis. The separability was performed using *Transformed Divergence measure*, while for the accuracy measurement was evaluated by establishing confusion matrix.

RESULTS AND DISCUSSIONS

Teradomari Area

Multitemporal Principal Component (MPC) and Vegetation Index Differencing

Based on the evaluation of the eigenvectors of each component, some indices are identified:

a) *Stable greenness* is found in PC1 having variance of 80%. This index summarizes the information related to brightness of images that expresses unchanged areas.
b) *Stable brightness* is found in PC2 having 16.8% variance. This index is related to the unchanged green biomass.
c) *Delta greenness* is found in PC3 having 1.6% variance. This index summarizes the changes of green biomass. The vegetation cover changes caused by landslides should be summed up in this index.
d) *Delta brightness* is found in PC5 having only 0.4% variance. This index expresses the changes in brightness. Hence, the landslides that occurred in open area could be summed up in this index.

As shown in **Table 1**, the indices of MPC that express stable greenness, greenness and delta brightness are respectively identified in PC2, PC3 and PC5. From these three indices as well as from VIDN, the authors then observe the threshold values of the landslide (**Table 2**).

In **Table 1**, it is shown that the eigenvector of near infrared band in PC2 (stable greenness) are strongly weighted with negative values in both dates. In PC3, positive greenness changes are summed up, in which the near infrared weight is changed from -0.3824 to 0.8546, while the red weight changes from 0.1703 to -0.1865. In PC5 where the change of brightness is taking place, there is an increase in brightness value (algebraic sign increase from negative to positive). In this axis, the landslides are also summarized.

Base on the pixel values explored from training sites,

Table 1. Eigenvector of Principal Component Axes for Teradomari Area

Multitemporal Band	Component axes					
	PC1	PC2	PC3	PC4	PC5	PC6
G-2001	0.5806	0.2618	−0.1965	−0.3110	0.6667	−0.1204
R-2001	0.6157	0.3368	0.1703	−0.1444	−0.6727	0.0711
N-2001	0.4134	−0.8142	−0.3824	0.0400	−0.1349	−0.0028
G-2004	0.1238	0.1234	−0.1449	0.3991	0.1454	0.8764
R-2004	0.1790	0.2200	−0.1865	0.8200	0.0021	−0.4609
N-2004	0.2559	−0.3024	0.8546	0.2218	0.2521	0.0049
Variance (%)	80.4088	16.3539	1.6078	1.2460	0.3449	0.0385
Cum. Var. (%)	80.4	96.8	98.4	99.6	100.0	100.0
Indices	*Stable brightness*	*Stable greenness*	*Delta greenness*		*Delta brightness*	

Table 2. Threshold values of PC2, PC3, PC5 and VIDN of SPOT Imagery for Teradomari area

Indices	Lower bound threshold (Tl)	Upper bound threshold (Tu)
Stable greenness (PC2)	− 106.6	−34.3
Delta greenness (PC3)	− 49.4	−19.3
Delta brightness (PC5)	33.9	42.2
VIDN	− 1.0239	− 0.3517

the threshold values expressing the landslides in each index were determined. As displayed in **Table 2**, the landslides values from stable greenness are ranging from -106.6 to -34.3. In PC3 (delta greenness), the pixel values of landslide are also negative, ranging from -49.4 to -19.3, while in PC5 (delta brightness), the landslide value is positive, ranging from 33.9 to 42.2. Using these threshold values the landslide detection map was then established using Boolean logic with AND logical connector. After all processing methods were performed including filtering and masking, the study recognized that almost all landslides having size larger than 10m x 10m could be detected using both methods. Significant confusion was particularly found in the areas where dynamic land changes occurred, such as agricultural areas, settlement or residential in urban or sub-urban areas. Land preparations for crop planting, infrastructure establishment, house development have very similar spectral or brightness values to landslides. However, this source of confusion could be alleviated by applying masking technique.

Using the VIDN method, the threshold values of landslides obtained is ranging from -1.0239 and -0.3517. As presumed before, the negative value of VIDN express a decrease in green biomes. Hence, the landslides should have a negative value in the VIDN image.

Accuracy analysis of MPC and VIDN methods.

To evaluate the success of this landslide detection, the author perform field visit on 13 sites. From this visit, the study found that 5 small size landslides having size smaller than 10 m x 10 m could not be detected. However, of 8 large size landslides, 7 locations (88%) were well identified on the map produced using the MPC method. Only one site is confused with the soil digging areas.

The accuracy of the VIDN method is slightly lower than that derived from MPC method, having only 62.5% accuracy. This method is less sensitive to the landslides occurred in open areas. The landslides that occurred in open areas could not be well detected using the VIDN method. This method is only suitable to detect large landslide that occurred in the forested areas. This is reasonable because the VIDN is theoretically measure the change of reflectance caused by the change of biomes. The change of land or soil brightness is not formulated in the VIDN equation.

Tochio and Shitada Mura Areas

1. *Multitemporal Principal Component (MPC) and Vegetation Index Differencing*

The eigenvector and eigenvalues of MPC for Tochio and Shitada Mura are tabulated in **Table 3**. Based on the eigenvector characteristics, 3 indices are found, i.e., *stable greenness* on PC2, *delta greenness* on PC3 and delta *brightness* on PC6. The PC2 covers variance of 26.24%; the PC3 covers 5.12% variance, while the PC6 only has 0.1% variance. Furthermore, from the training areas examined, the threshold values of landslides in PC2, PC3, PC6 and VIDN are tabulated in **Table 4**.

Accuracy analysis of MPC and VIDN methods.

For evaluating the accuracy assessment in Tochio and Shitada Mura areas, 13 landslide locations were visited. Of these 13 locations, only 2 locations are small size landslides (smaller than 10 m x 10 m), while the rest are large landslides. The study found that MPC method could detect landslides accurately providing 91% accuracy. Of the 11 locations, 10 locations were well detected; only 1 location could not be detected due to its location in the slopped areas and affected by topographic shadow. Two small landslides

Table 3. Eigenvector of Principal Component Axes for Tochio and Shitada Mura Areas

Multitemporal Band	Component axes					
	PC1	PC2	PC3	PC4	PC5	PC6
G 2001	0.7024	0.1642	0.0862	−0.1037	−0.6768	0.0592
R 2001	0.6254	0.2038	0.2310	0.1089	0.7051	-0.0698
N 2001	0.3129	−0.8876	−0.2865	−0.1516	0.0961	-0.0018
G 2004	0.0752	0.1686	−0.5360	0.1626	−0.0448	-0.8064
R 2004	0.1065	0.2594	−0.7394	0.1585	0.1059	0.5817
N 2004	0.0243	−0.2192	0.1523	0.9502	−0.1493	0.0552
Variance (%)	66.56	26.24	5.12	1.28	0.72	0.08
Cum. var (%)	66.56	92.80	97.92	99.20	99.92	100.00
Indices		Stable greenness	Delta greenness			Delta brightness

Table 4. Threshold values of PC2, PC3, PC6 and VIDN of SPOT Imagery for Tochio and Shitada Mura Areas

Indices	Lower bound threshold (Tl)	Upper bound threshold (Tu)
Stable greenness (PC2)	−137.99	−55.64
Delta greenness PC3	−196.99	−150.21
Delta brightness PC6 (DB)	−41.24	−31.90
VIDN	−0.4564	−0.2799

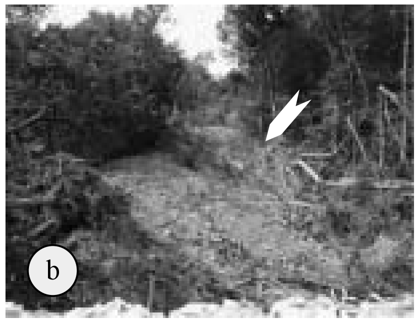
could not be detected too. The ground condition of landslides that could be detected is shown in **Fig. 1**. In persepective view., distribution of detected landslide is depected in **Fig. 2**.

Similar to as the results obtained in the Teradomari area, the VIDN method in Tochio and Shitada Mura Area also shows lower accuracy than the MPC method. The VIDN method only detects large landslides in 7 locations (64%), while 5 locations could not be detected. In this study sites, the VIDN could not detect the landslides in open areas.

Using the MPC method, it was found that the detected landslides are more clear and compact. Using the VIDN method, the map of identified land slide contains much noise than that provided using the MPC method. Misclassification was frequently found along the river, where soil erosions were identified as landslides.

From the ground observation and accuracy analysis of the examined methods, the following are findings that could be summed up from the study:

a) Landslides that having size more than 10 m x 10 m could be well detected using the MPC method.
b) The landslides occurred in the residential areas are more difficult do be detected.



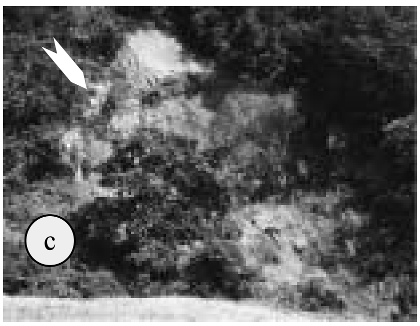


Fig. 1. Ground condition of landslides observed in the field: (a) Landslides having size 15 m x 100 m (Teradomari areas); (b) Landslides having size 15 m x 150 m and (c) Landslides in the cliff having size 60 m x 45 m (Tochio-Shitada Mura areas).

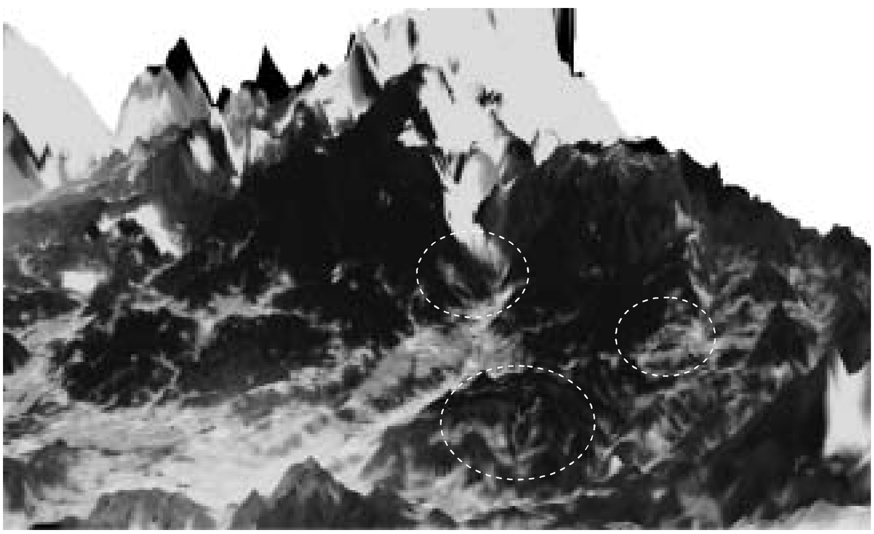


Fig. 2. An Example of Detected Landslides (shown in red color) that superimposed over original SPOT image in Tochio-Shitada Mura area.

c) Filtering is absolutely needed to reduce the unexpected noise caused by misregistration.
d) The study should also mask out the areas having very low landslides possibilities such as flat areas, agricultural areas, residential or urban/sub-urban areas.
e) To reduce the misclassification, judicious decision should be performed, particularly in detecting landslides within the river or river sides. In the river areas, erosion caused by strong river flow during the flood could be detected as landslides.
f) The MPC provides better performance in comparison with the VIDN method.
g) The VIDN is less sensitive to detect the landslides occurred in the open areas or areas without vegetation or areas with very sparse vegetation.
h) The method using SPOT imageries could produce real-time detection map and providing accurate detection (88% ~ 90%)
i) The method could map the extent, form and distribution of landslides in speedy manner.
j) The results could be also used to create vulnerability of landslides occurrence.
k) The method could be used to compare the landcover condition prior to and after landslides occurrence.

Relative Efficiency (RE)

To evaluate the efficiency of using SPOT imagery in comparison with ground-based observation, the authors then compute the relative efficiency (RE). The RE was computed by comparing the total cost needed for landslides detection using SPOT imagery (Cs) and the total cost without SPOT imagery (Cf). In this analysis, all cost components for landslides detection either using SPOT imagery or without SPOT imagery in the field such as data preprocessing, processing, spatial analysis, image purchase and ground observation costs were included. By considering the coverage of SPOT imagery is 60 km x 60 km per scene or approximately 3600 square kilometer and number of ground checking plots using SPOT is 5% from the total landslides, the author computes the cost component as follows:

1. Cost components using SPOT imageries (Cs) USD per sq km

1.1.	Purchasing two-date SPOT data: 2 scenes x USD 4000/ Scene	= 2.221
1.2.	Cost for image processing 7 days x USD100	= 0.194
1.3.	Cost for renting hardware/software USD 1000	= 0.278
1.4.	Lump sum Ground visit for 40 locations x 6 days x 2 persons x USD100	= 0.333
	Total cost per sq km	= 3.026

2. Cost component without SPOT imageries (Cf) USD per sq km

2.1.	Lump sump for ground visiting all landslides locations	= 6.667
2.2.	Mapping all landslides locations, 12 days x USD 100	= 0.333
2.3.	Cost for renting hardware/software USD 1000	= 0.278
	Total cost per sq km	= 7.278

From the cost component above, the RE between using SPOT 2-5 and ground-based observation is:

$$RE = \frac{7.278}{3.026} = 2.4$$

Based on the RE analysis, the study found that the landsides detection based upon solely on ground-based observation is significantly more expensive than using the combination between SPOT and ground checking. The cost of the round-based observation is 2.4 times as much as the cost using SPOT and ground checking.

CONCLUSION

From the foregoing results and discussions, the following are several conclusion derived:
a) The landslides are predominantly occurred in the steeply sloped areas such as in Tochio and Shitada Mura areas.
b) The size of landslides that could be detected using multitemporal SPOT 2 and SPOT 5 is should be larger than or equal to their spatial resolution, i.e., 10 m x 10 m.
c) The MPC method accurately detects the landslides having accuracy of 88% for Teradomari and 90% for Tochio and Shitada Mura.
d) For the MPC method, the landslides information is effectively summarized in some indices, namely, *stable greenness, delta greenness and delta brightness*.
e) The VIDN method provides less accurate landslide detection than MPC method, providing only 62.5% for Teradomari and 64% for Tochio and Shitada Mura.
f) Landslides detection using SPOT imagery and ground-check is relatively more efficient than solely based on ground-based observation, providing the cost of only 1/2.4 as much as the cost of ground-based observation.

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多時期のSPOT衛星データを利用した山崩れ箇所の抽出

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要　約

2004年7月13日の水害では、五十嵐川、刈谷田川が決壊し、寺泊町、三条市、中之島町、栃尾市、下田村管内に大きな被害をもたらした。この時の雨量で、山地でも山崩れが発生し、多くの被害が発生した。2時期のSPOT衛星データを利用して、山地内の山崩れがどの程度、抽出可能なのかを解析した。用いた衛星データは、2001年8月15日撮影のSPOT2号と2004年7月24日のシーンを用いた。2時点のシーンを重ね合わせ、植生指数の差を取り、一定以上示した箇所を変化箇所とした。現地踏査の結果、寺泊町では1ピクセル (10m ×10m) より大きい山崩れ箇所は８８％抽出できた。栃尾市と下田村管内では、1ピクセルより大きい山崩れ箇所は91％抽出できた。このように、２時点の画像を重ねることで、山崩れ箇所の抽出は非常に効果的であると考えられた。

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