International Journal of GEOMATE, March., 2018 Vol.14, Issue 43, pp.118-124
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2018.43.3593 ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

STUDY ON LANDSLIDE CATEGORY BASE ON TEMPORAL-SPATIAL CHARACTERISTIC DISTRIBUTION IN NORTHERN VIETNAM USING SATELLITE IMAGES

*Thuy Thi Thanh LE[1] and Seiki Kawagoe[1]

[1]Department of Symbiotic Systems Science, Fukushima University.

*Corresponding Author, Received: 14 Nov. 2017, Revised: 27 Nov. 2017, Accepted: 27 Dec. 2017

ABSTRACT: North Vietnam has a lot of landslide-prone regions due to heavy rainfall or tropical storms, steep slopes on mountainous sides and human activities such as road or house constructions. Heavy rainfall events are estimated by climate change in the future. Therefore, it is necessary to understand landslide characteristic due to rainfall variation. This paper applied Landsat satellite images and calculated NDIs (Normalized Difference Indexes) to evaluate the condition of vegetation, soil and water and detected 43 landslide points in North Vietnam. Landslide points are then evaluated to compare digital geographic information data to divide landslide type. As result, three typical types of landslides are classified as landslide caused by rainfall on construction (road etc..) sites (Type 1), landslide caused by rainfall on natural slopes (Type 2), and landslide caused by rainfall and water drawdown on banks of reservoirs or streams (Type 3). Considering the Landsat result Type 2 and Type 3 consist larger proportions compared to those in historical data. This means that many landslide would occur in mountainous areas that far from residential or road areas (Type1).

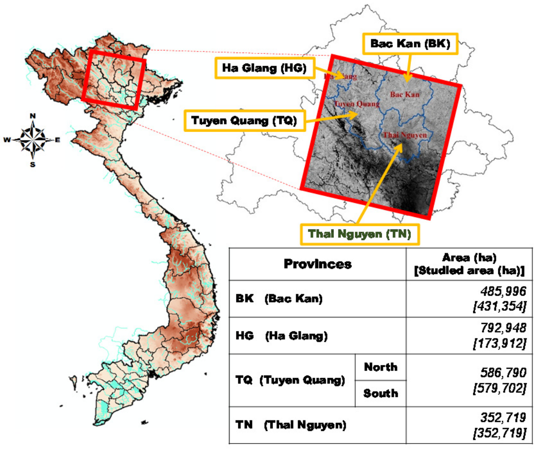
Keywords: Landslide type, Landsat 8, Digital geographic information, Climate change

1. INTRODUCTION

Vietnam belongs to tropical climate area that is often hit by several typhoons and tropical cyclones. As the influence of climate change, abnormal weather phenomenon such as cyclones and severe typhoons have been occurring with more frequencies and higher intensities. During the period from 2014 to 2016 many strong tropical storms and heavy rains occurred in Vietnam. According to a national study of the Vietnam Geography academy study in 2004 [1], North Vietnam is the most prone region to landslide. Sixteen provinces are listed as obtaining high hazard of landslide occurrences. In accordance with topographic and geology condition, landslides in this area often occur under the influences of heavy rainfall or tropical storms, steep slopes on mountainous sides and human activities such as road or house constructions. Detecting landslides occurrences thus becomes necessary approach for landslide susceptibility regions there.

According to Dieu[2] and Metternicht et al[3] , four major classes for landslide susceptibilities are inventory, statistical, deterministic and heuristic approaches. Inventory map is based on satellite images, ground survey and historical database of landslide occurrence. It would give spatial distribution of past landslides and does not provide prediction of landslide susceptible areas. Statistical method would provide prediction of landslide in region that might not have landslide in the past basing on statistical analysis of landslide ground characteristics. However, it needs a large amounts of data collection and suitable for medium scale prediction. Deterministic approach requires physical processes. However, since the data availability is one of the difficulties, the limitation of this approach is shown. Heuristic, which requires long-term landside data and causative parameters, estimates potential landslide from preparatory variables. It is an expert driven approach that depends on the knowledge and experiences of scientists in deciding degree and type of landslide risks. The report of Bui Tien Dieu[4] in 2012 also pointed that landslide inventory maps provide great importance input data in landslide hazard and susceptibility analysis. The inventories can be divided into two sub classes including historical landslide inventories and landslides with triggering factors. The application of inventory thus would give information of locations, types and causative factors of past landslides.

In case of Vietnam, lacking of continuous information about past occurrences of landslide hinders the landslide assessment. It also leads to difficulties in data integration with land use plan and management task in landslide hazard regions. As a one of the most vulnerable nation to climate change, such external hazard risk is estimated to increase significantly in Vietnam. It therefore requires substantial demand in acquiring comprehensive information of landslide in order to obtain adequately adaptive measurements and mitigations for landslide prone areas. Considering the data unavailability (long-term landslide data and its related factors), in this paper, we apply the inventory approach to assess the landslide map based on the satellite images in a relationship with historical database of landslide occurrences [3], [5]. We also utilized Landsat satellite images and calculated NDIs to evaluate the condition of vegetation, soil and water in the North Vietnam. And, landslide points are evaluated to compare digital geographic information data to divide landslide type. The outcomes would support further study on the landslide hazard prediction under the influence of climate change.



Provinces		Area (ha) [Studied area (ha)]
BK (Bac Kan)		485,996 [431,354]
HG (Ha Giang)		792,948 [173,912]
TQ (Tuyen Quang)	North	586,790 [579,702]
	South	
TN (Thai Nguyen)		352,719 [352,719]

Fig.1 Study area map

2. STUDY AREA

Study areas are Bac Kan (BK), Thai Nguyen (TN) and Tuyen Quang (TQ), and Ha Giang (HG) in North Vietnam (Fig.1). These four provinces are considered as having hazard of landslide occurrence in the North Vietnam. The elevation in this studied area varies from 0 to 2958 m covering both mountainous and midland regions with complicated terrain characteristics. There are two major types of directions in mountain ranges.

According to report of Vietnam academy of Water Resources Planning about monthly rainfall [7] from 1960 to 2015 in TQ and from 1960 to 2011 in other provinces, this area has considerably high annual rainfall with the ranges from 2467 to 4735 mm in HG and from 1342 mm (BK) to 1988 mm (TN) in others. Rainy season in this area often starts in late April and ends in October with average precipitation from 300 to 750 mm in HG and from 150 to 300 mm in BK, TN and TQ (Fig.2(1)). June to August is the heaviest rainfall time in rainy season with the maximum daily rainfall is greater than 100mm [8].

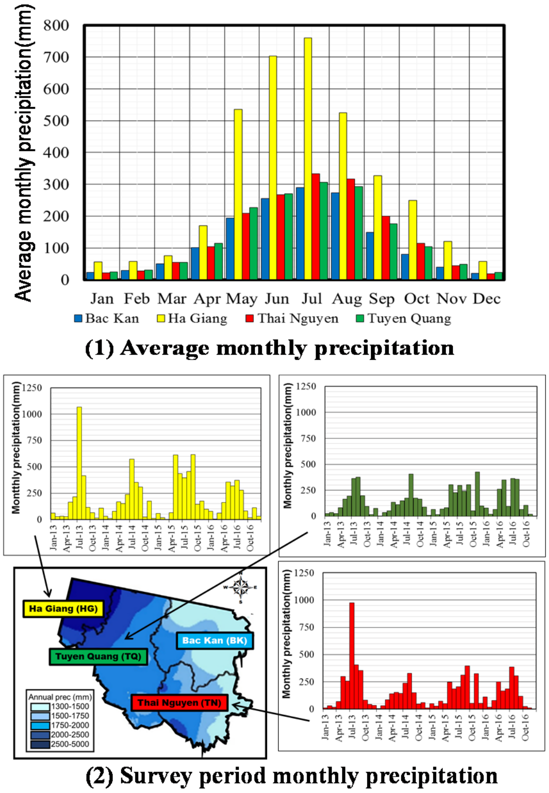


Fig.2 Trend of precipitation in North Vietnam

3. DATABASE AND METHODOLOGY

3.1 Database

We tried to obtain landslide points by using satellite image. Landslide characteristic are often classified using geomorphic information and rainfall condition. Therefore, we utilized actual landslide distribution for landslide analysis. Satellite images and landslide history data were used to obtain landslide distribution characteristics. Geomorphic digital information was also applied to evaluate and confirm causative factors of landslide. Rainfall data was analyzed to provide timely incitement as temporal event characteristics.

a) Satellite image

We utilized Landsat 8 satellite images from USGS website (http://earthexplorer.usgs.gov/) to examine the land surface changes in area of four given provinces in northeast Vietnam. The Landsat 8 released the first image in the research site on 2013/04/22. It is used as the base image to compare the changes in surface condition in this area. With the 16-day-circle, from April 2013 to March 2017 among 94 images, the number of good quality images in 2013, 2014, 2015 and 2016 are 2, 3, 3 and 2, respectively. Looking at the rainfall data from 2013 to 2016 in some stations, we found that the year 2015 obtained the heavier monthly rainfall

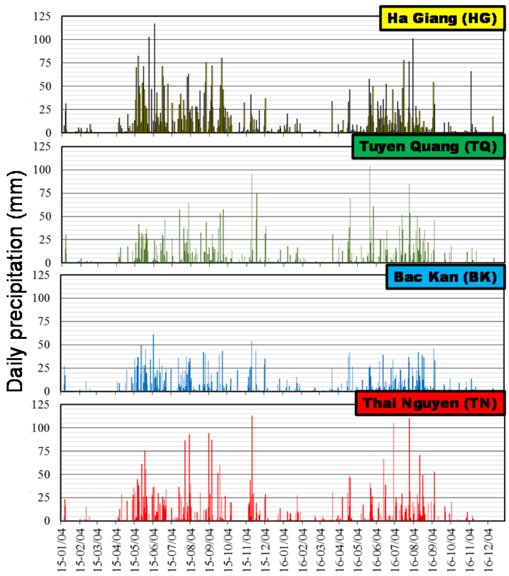


Fig.3 Daily precipitation in North Vietnam (2015-2016)

than that in 2014 and 2016 (Fig.2(2)). Comparing daily rainfall data in the last two years, we found that the number of rainy days in 2015 are higher than those in 2016 (Fig.3). As rainfall is one of the most important triggering factor of landslide occurrence, in this paper, we choose year 2015 as the computing year to evaluate the changes of land surface in this studied region. Regarding to the image quality as well as the occurrence of heavy rainfall, we select the Landsat 8 data on 2015/07/01 as the comparative image for land degradation analysis (land surface changes due to landslides, erosion, and human activities).

b) Landslide history data

In 2012, the government released the national project "Investigation, assessment and zonation of landslide hazards in mountainous area in Vietnam". Phase I (2012-2015) conducted in 13 provinces in the north and 1 province in the north central Vietnam. Twenty-three remaining provinces in the north (4) and other areas (19) will be investigated in the second phase from 2016-2020. The output of this project is the landslide occurrences regarding to investigate time. In this study area, 1049 landslide points in three provinces BK, HG and TQ were recorded with brief information of observed locations, estimated sliding volume and repeated time. The observation routes were implemented along road lines and near residential areas in 2013

c) Other data

Rainfall data in this paper was adopted from the Academy of Water Resources Planning [7] (monthly rainfall from 1960-2011), the Directorate of Water Resources [11] (daily rainfall 2015-2016) and from the Institute of Meteorology in Vietnam (daily rainfall data at some stations). The terrain data was extracted from a digital elevation model (DEM) from the Open Mekong Development [6] with the grid cell size of 30m × 30m. Geology information data was collected from US Geological Survey (USGS). Land use data was extracted from Japan Aerospace Exploration Agency (JAXA) [12] with the resolution of 15m × 15m in north area in 2015.

3.2 Methodology

a) Landsat dataset

Based on the land cover mapping, the Landsat images would support the inventory of land degradation. It would visualize and map the past degradation of land surface including soil erosion, landslide, vegetation removal or land use changes [14]. We obtained NDIs information by using landsat analysis. In order to evaluate the changes in vegetation state and density by the satellite image instruments, a vegetation index is often utilized. This index describes the greenness of surface throughout the reflection of light waves by land surface. Among wavelengths of light being gathered from satellite sensors, the red light's wave-lengths (VIS) are strongly absorbed by photo-synthetically active leaves, and the leaves reflect strongly the near-infrared (NIR) light's wave-lengths. In cases of death or stressed vegetation and non-vegetated surfaces they reflect less near-infrared light and more red light. The near-infrared and red light waves thus are applied to transform raw satellite data into Normalized Difference Vegetation Index (NDVI) (Equation 1).

$$NDVI = \frac{NIR - VIS}{NIR + VIS} \qquad (1)$$

Unlike vegetation factor, water has stronger absorption capacity within the NIR wave range. It also has lower reflectance regarding to the higher wavelength. The Normalized Difference Water Index (NDWI), which is calculated basing on the NIR and Short wave infrared (SWIR) in order to evaluate the water amount in vegetation canopies, can therefore distinguish the vegetation and water [15] (Equation 2).

$$NDWI = \frac{VIS - SWIR}{VIS + SWIR} \qquad (2)$$

In addition, the condition of soil moisture on the ground surface could be observed by applying the SWIR wavelength. The Normalized Difference Soil Index (NDSI) therefore would reflect the soil water content when using SWIR as a spectral signature in a relationship with the NIR wavelength (Equation 3).

$$NDSI = \frac{VSWIR - NIR}{VSWIR + NIR} \quad (3)$$

b) Landslide inventory approach

The occurrence of landslide is often in a close relationship with two main factors namely triggering and conditioning factors. According to Dieu [4], triggering factors include heavy rainfall events, snow and earthquakes. States of slope, soil, geology and land use are some examples of conditioning factors. The former factors could lead to quick changes of slope condition while the latter factors refer to slowly processes. In this study, we consider four main conditioning parameters: slope, elevation, geology and land use. Historical landslide data and Landsat 8 calculated data are thus mapped and combined with DEM, slope, geology and land use data.

4. RESULTS

4.1 Landsat analysis result

With the purpose of determining threshold value for land use change area, we first calculated the NDVI in pre event (2013/09/29) and post event (2015/07/01) (Fig.4(1)) and difference of NDVI between those two periods. The NDVI differences between pre and post event are grouped into 11 major land use categories, which are adopted from USGS database. They are Evergreen Broadleaf Forest (EBF), Mixed Forests (MF), Closed Shrub lands (CS), Open Shrub lands (OS), Woodley Savannas (WS), Savannas (Sa), Grassland (Gr), Permanent Wetland (PW), Croplands (Cr), Urban and Build-up (UB) and Cropland/Natural Vegetation on Mosaic (Cr/VM). The average ΔNDVI value in each land use type varies from -0.2875 to 0.0759. Standard deviations and its multiple values (said 2SD and 3SD) were calculated and subtracted from average values to obtain threshold ΔNDVI values. ΔNDVI values that above the given base lines are mapped as the first trial of land surface changes detection in the studied area (Fig.5).

In case of land degradation, especially in the forest related area, the application of NDSI and NDWI would support the detection of soil-exposed area in post event. The NDSI thus will increase when it illustrates the changes in water content (absorption of SWIR) and chlorophyll of leaves (reflection of NIR). In addition, NDWI is a vital index that reflects liquid water content. Positive NDWI values typically present in open water area and negative ones refer to non-water region. According to Gao [15], most bare soil provides negative NDWI values. Study of Takeuchi in 2004 [16] showed the results of NDVI, NDSI and NDWI

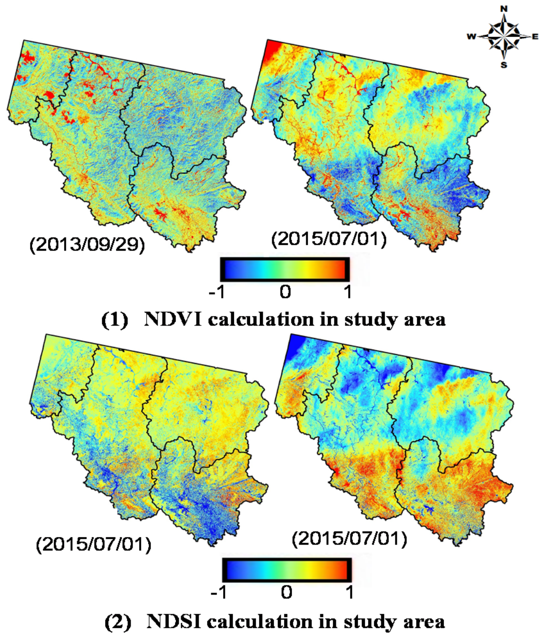


Fig.4 NDIs results map in North Vietnam

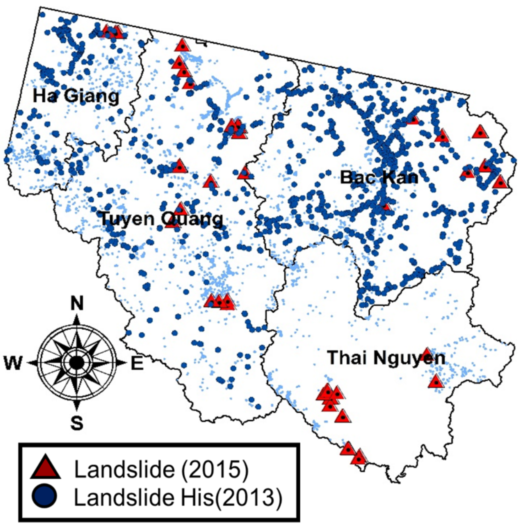


Fig.5 Land use change area and land degradation areas detecting from Landsat calculation

values for eleven land cover types (Fig.4(2). The results point that NDWI obtains the lowest values in conifers (-0.6), broadleaf forest (-0.64) and grass (-0.65) and varies from -0.34 to -0.12 in soil. Water and snow provide positive values. NDSI increases from vegetation cover type (-0.47 to -0.35) to soil cover group (-0.11 to 0.11). In the study of Deng et al. in 2015 [17] , they tested the potential band combination of Landsat TM5 to calculate NDSI. The NDSI output show the critically low value of around -0.37 for vegetation surface for the combination of Shortwave infrared band (SWIR1) and Near Infrared band (NIR) while positive values are shown in impervious surface area and soil surface for all other band combinations (0.06 for soil with the SWIR1 and NIR combination).

In this study, we calculated and set up the relationship between NDVI, NDSI and NDWI in the selected pixels in the first trial map to evaluate the threshold for landslide detecting areas. In case of dead weak or removal of vegetation during the landslide occurrence, the soil will be exposed as a result. The NDSI and NDWI hence would increase comparing to the case of vegetation cover to the positive or near positive values (around zero). The results show the ranges of NDSI and NDWI are from 0.32 to 0.08 and from -0.32 to 0.12, respectively. Since positive NDWI values come with low NDSI data in post even, and it may refer to water or cloudy condition. The threshold of 0 therefore is primary set for NDWI value. NDSI bellowing -0.28 obtains NDVI values of around 0.4 and above. It also refers to vegetation cover area. Low values of vegetation index (reduction in green surface area) locate in the NDSI range from -0.2 and above. In this case, -0.2 is set as NDSI threshold value. We will locate pixels obtaining NDSI that is higher than -0.2 and NDWI that is lower than 0 as land degradation area. In this detecting area, average values of NDVI, NDSI and NDWI are 0.23 (from 0.04 to 0.36), -0.12 (from -0.2 to 0.08), and -0.13 (from -0.32 to -0.02), respectively.

4.2 Inventory approach

In this part, we applied the land use map, which was released by JAXA in September 2016 to demonstrate land cover situation in North Vietnam in the year 2015. In this version, land use cover includes 9 categories namely: (1) water site, (2) urban and built up, (3) rice paddy, (4) crops, (5) grassland, (6) orchards, (7) bare land, (8) forest and (9) mangrove (Fig.6). There are 9 main geology categories in this study area: (1) Carboniferous /Permian(CP), (2) Cambrian/Ordovician(CmO), (3) Devonian(D), (4) Jurassic/Cretaceous (JK), (5) Ordovician/Silurian(OS), (6) Permian/Triassic (PTr), (7) Proterozoic/Cambrian (PtCm), (8) Quaternary(undivided)(Q), and (9) Silurian/ Devonian (SD) (Fig.7). The slope angle were divided into six sub-classes: (1) <10°, (2) 10-20°, (3) 20-30°, (4) 30-40°, (5) 40-50°, (6) >50°. The elevation is also grouped into six subclasses: (1) <100 m, (2) 100 m- 200 m, (3) 200 m – 300 m, (4) 300 m – 400 m, (5) 400 m – 500 m and (6) >500 m.

a) Landslides and its causative factors

We analyses 1049 historical landslide events in 2013 when combining with causative factors such as slope angle (Fig. 8(1)), elevation(Fig.(2)), geology and land use(Fig.8(3)). The analysis results show that landslide density is the highest (27.5%) in the slope class iii (20-30°), following by class ii (25.8%) and class iv (21.9%). The numbers of

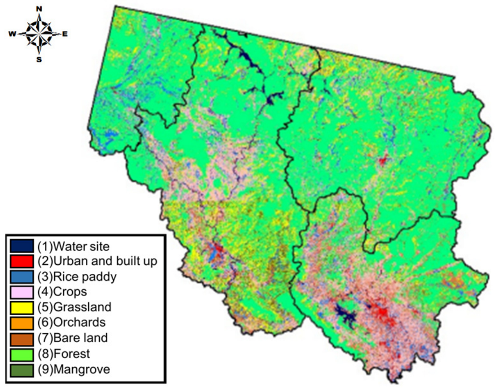


Fig.6 Land use map in North Vietnam

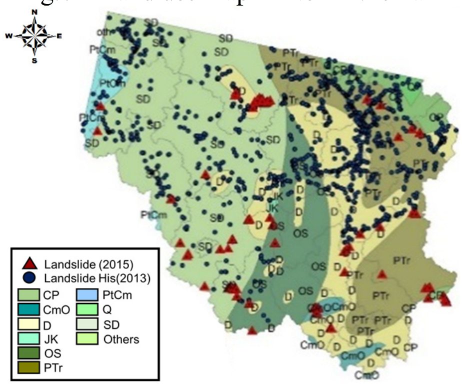


Fig.7 Geology map in North Vietnam

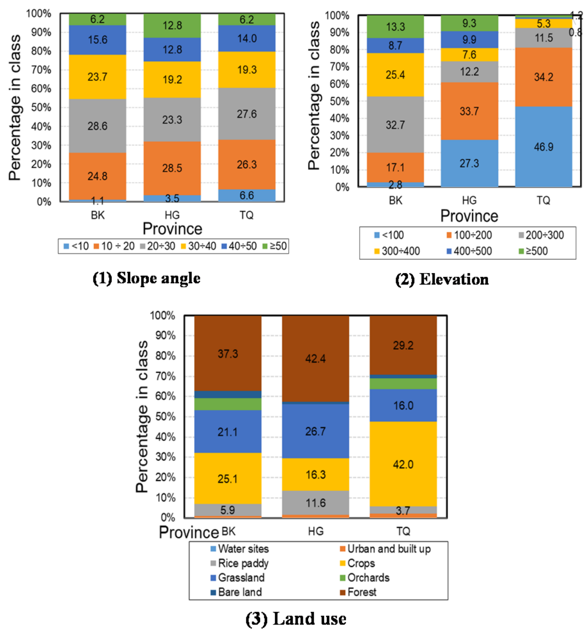


Fig.8 Category results with causative factors

landslide events decrease when the slope angle increase from group iii (20-30°) to group 6 (>50°). This overall trend is similar in all three provinces BK, HG and TQ. In general, landslide

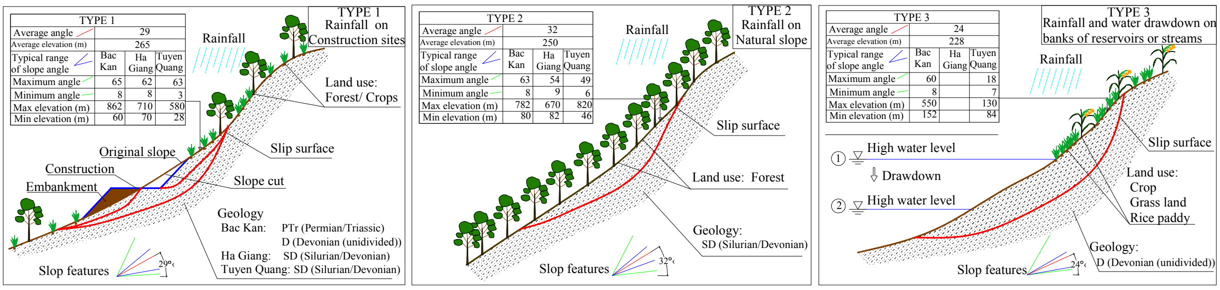


Fig.9 Illustration of three landslide types

landslide density concentrates in the elevation range from 100m–300m (48.23%). The most common elevation class in landslide occurrence site in BK, HG and TQ is iii (200m-300m), ii (100m-200m) and i (<100m) in respectively. The susceptible geology type in landslide sites in BK area D and PTr while Devon dominates landslide areas in HG and TQ. Among 9 land use classes, historical landslides occurs mainly in forest (BK and HG) and crops (TQ). In all area, grassland also performs in intermediate level (16-26%).

b) Landslide classification

According to Chandrasekaran, et al [18] . Internal and external causes are two main types of landslide causes. Internal causes include seepage erosion, weathering and progressive failure. Some illustrations of external causes are slope geometry changes, slope toe under loading, slope crest loading, water regime changes or drawdown as well as vibrations and shocks. The external causes can also be divided into two sub categories: natural cause and human cause. For the case of North Vietnam, regarding to the external mechanism, the natural cause for landslide often relate to slope undercutting by wave strength and stream erosion, heavy and prolonged rainfall events, critical groundwater fluctuation and upper slope loading by dense vegetation. The human cause can be seen from some main activities such as slope overloading, slope cutting activities for houses and road constructions, cultivation activities (vegetation removal) and quarrying or mining activities. Our study in 2016 about the regional precipitation distribution in Vietnam [8] showed that an average annual rainfall in the studied site (1975-2006) is about 1997 mm (1762 mm in the North). Rainfall fluctuates significantly around the year. Approximately 80% of total rainfall occurs during summer time. This area has high dense of streams and rivers. The main river systems in North Vietnam [19] appear high density. With regards to geomorphic condition, mountain regions in this area are heavily divided and eroded by thick dense of tributaries so that erosion and sliding activities become more seriously, especially under the influence of heavy rainfall the main landslide triggering factor here. Considering the climatic, hydrological and geomorphic conditions as well as human-related activities in North Vietnam, in this study, we divide the landslides into three major causing types: i) Type 1: Rainfall on construction sites, ii) Type 2: rainfall on natural slope, and iii) Type 3: Rainfall and water drawdown on banks of reservoirs or streams (Fig.9). Type 1 refers to landslide on artificial slopes that are resulted mainly from road and house constructions after heavy or prolonged rainfall events. Type 2 belongs to the case that slopes are not significantly modified by human activities [20] [21] under the influences of rainfall triggering factors. In type 3, water fluctuation especially rapid drawdown in a relationship with rainfall event thus are major attributions to landslides that occur on the slope facing water sites such as rivers, ponds and reservoirs. Regarding to historical landslide data in 2013, only 1.34 % and 7.54% of landslide events are classified in type 3 and type 2, respectively. Type 1 dominates in all three provinces (from 83.7 % in HG to 94% in BK).

5. DISCUSSIONS AND CONCLUSIONS

Above discussions lead to our consideration for further study on the landslide issues in upper stream regions in Vietnam. However lacking information of landslide scales (height, depth and area) throughout surveys are main limitations of this study. Outputs of this paper, which are mainly based on historical data in a relationship with Landsat instrument, would be considered as initial assessment results of landslide issue in those four provinces in North Vietnam. Further studies should be implemented with requirements of site surveys for position and scale verification and landslide hazard mapping as well as training model for rainfall induced landslide and water level simulations.

ACKNOWLEDGMENT: This research was supported by the Social Implementation Program on Climate Change Adaptation Technology (SI-CAT) of MEXT, Japan.

REFERENCES

[1] Hue, T. T.: Research on crack and subsidence hazards in mountainous region in North Vietnam, Vietnam Geogr Acad., 2004.

[2] Tien. Bui. D, Owe, L., Inge, R. and Dick, O.: Landslide susceptibility analysis in the Hoa Binh province of Vietnam using statistical index and logistic regression, Nat Hazards. , Vol. 59, pp. 1413-1444, 2011.

[3] Metternicht, G., Hurni, L. and Gogu, R.: Remote sensing of landslides: An analysis of the potential contribution to geo-spatial systems for hazard assessment in mountainous environments, Remote Sens Environ., Vol. 98, No. 2-3, pp. 284-303, 2005.

[4] Dieu, T. B.: Modeling of rainfall-induced landslide hazard for the Hoa Binh province of Vietnam, Nor Univ Life Sci. , 2012.

[5] Behling, R., Roessner, S., Golovko, D. and Kleinschmit, B.: Derivation of long-term spatiotemporal landslide activity-A multi-sensor time series approach, Remote Sens Environ. , Vol. 186, pp. 88-104, 2016.

[6] ODM.: Digital Elevation Model (DEM) of Vietnam, Open Dev Mekong., 2016, Available at https://data.opendevelopmentmekong.net/vi/dataset/digital-elevation-model-dem

[7] AWRP.: Monthly rainfall in North Vietnam, Acad Water Resour Planning, Minist Agric Rural Dev Vietnam, 2016.

[8] Thuy, T. T. Le, Kawagoe, S. and Suzuki, K.: Study on the variation of regional precipitation characteristics based on meteorological spatial data in Vietnam: Relationship between GCMs output and historical data, Vietnam-Japan Work Estuaries, Coasts, Rivers 2016, Ho Chi Minh City, Vietnam, 2016.

[9] RCFEE.: Forest ecological stratification in Vietnam, Res Cent For Ecol Environ Vietnam., 2011.

[10] USGS.: Landsat 8, US Geol Surv., 2015. Available at http://landsat.usgs.gov/landsat8.php

[11] DWR.: Management of Hydraulic system in Vietnam, Dir Water Resour Minist Vietnam Agric Rural Dev, 2016.

[12] JAXA.: High- Resolution Land Use and Land Cover Map of Northern Region of Vietnam (Released in Sep.2016/Version 16.09), Adv L Obs Satell – ALOS Res Appl Proj EORC, JAXA., Available at http://www.eorc.jaxa.jp/ALOS/en/lulc/lulc_vnm.htm

[13] Broxton, P. D., Zeng, X., Sulla, M. D. and Troch, P. A.: A Global Land Cover Climatology Using MODIS Data, J Appl Meteorol Climatol., Vol. 53, No. 6, pp. 1593-1605, 2014.

[14] Mwaniki, M. W., Agutu, N. O., Mbaka, J. G., Ngigi, T. G. and Waithaka, E. H.: Landslide scar/soil erodibility mapping using Landsat TM/ETM+ bands 7 and 3 Normalised Difference Index: A case study of central region of Kenya, Appl Geogr., Vol. 64, pp. 108-120, 2015.

[15] Gao, B. C.: NDWI - A normalized difference water index for remote sensing of vegetation liquid water from space, Remote Sens Environ., Vol. 58, No. 3, pp. 257-266, 1996.

[16] Takeuchi, W. and Yasuoka, Y.: Development of normalized Vegetation, soil and water indices derived from satellite remote sensing data, J Japan Soc Photogramm Remote Sens. , Vol. 43, No. 6, pp. 7-19, 2004.

[17] Deng, Y., Wu, C., Li, M. and Chen, R.: RNDSI: A ratio normalized difference soil index for remote sensing of urban/suburban environments, Int J Appl Earth Obs Geoinf. , Vol. 39, pp. 40-48, 2015.

[18] Chandrasekaran, S. S., Senthilkumar, V. and Maji, V. B.: Landslides in Nigiris: Causal factors and remedial measures, Indian Geotech Conf IGC 2016, 2016.

[19] Hue, T. T.: Research on evaluation of the river bank sliding hazard in mountainous region in the North Vietnam, Vietnam Geogr Acad, 2004.

[20] Ko, F. W. Y. and Lo, F. L. C.: Rainfall-based landslide susceptibility analysis for natural terrain in Hong Kong - A direct stock-taking approach, Eng Geol. Vol. 215, pp. 95-107, 2016.

[21] VIGMR.: Geology hazard and natural disaster warning program, Vietnam Inst Geosci Miner Resour, 2014.