

Simulation of Flash–Muddy Flash Flooding and Inundation of Western Tamdao Mountain Region, Vinh Phuc Province, Viet Nam using Hydro-geomorphology

Thach, N. N. and Canh, P. X.

Faculty of Geography, University of science, Ha Noi (HUS), Vietnam National University (VNU)
334 NguyenTrai, Thanh Xuan, Ha Noi, Vietnam, E-mail: nguyenngothachus@gmail.com

Abstract

The performance of the concept was evaluated using statistical hydrological and geomorphological methods to assess the model's capability in simulating the phenomena of flash flood, muddy flood in sloping regions of the study area, located in Western Tam Dao mountain, Vinh Phuc province. By using ArcGIS 9.3 software, the processing steps are as follows: From DEM, extracting vertical eroded, watershed and stream accumulated, separating the watershed into a number of sub-basins, and then calculating the average slope value for each sub-basin; From SPOT image, making land use, land cover, and the topographical wetness index of the study area. An important layer is geomorphology, which was created by doing interpretation of topographic maps, SPOT image and ground truth. Each class has been evaluated for the potential of accumulated water. From the statistics of rainfall data of 30 years, average and maximum rainfall layers were also created. These factors are overlaid and then the integrated layer is reclassified as the result layer with the Flash Flood Potential Index (FFPI). Result is the FFPI map with five levels of flood risk. The result is useful referenced for regional planning of the Vinh Phuc province.

1. Study Area

Vinh Phuc province has the total area of 1373.2 sq. km and population of 1,180, 400 (2006), located in the north of Vietnam, around the latitude of 21° 01' N and the longitude of 105° 52' E (Figure 1). With its location in the plains and midland, the North Vietnam, Vinh Phuc is surrounded by Tuyen Quang and Thai Nguyen in the north, Hanoi in the east, Ha Tay in the south, and Phu Tho province in the west. The province has diverse topography including the midland, low hill and plain. There are four large rivers flowing through the province namely Hong (Red), Lo, Pho Day, and Ca Lo. In the north, Tam Dao mountain range is the natural borderline between Thai Nguyen and Vinh Phuc. In the south, the Hong (Red) River separates Vinh Phuc and Ha Tay. Tam Dao is the highest mountain in the province. Mountains in Vinh Phuc have the highest peak of 1500 meters above the sea level, running in Northwest - Southeast direction. At the base of mountain, elevation is differenced only from 8 to 10 meters; it is the reason for slope change quickly from base of mountain to upper. From 40-years statistics data, the maximum value of precipitation is 3000 mm. These natural conditions are causing flash flood and muddy flood happening along the

old valley that fills system and deposits cones plains, located at the base of Tam Dao mountain regions. For environmental planning, hazard mapping of flash and muddy flood is an essential task.

2. Geomorphological Signatures of Flash Flood

2.1 Classification of Flash Flood

Flash flood is a phenomenon of rapidly water accumulation from mountain to low-lying areas depending on characteristic of the watershed. It may be caused by heavy rain associated with a storm, hurricane, or tropical storm in the tropical region or by melt-water from ice or snow flowing over ice sheets or snowfields in the temperature zone. In some case, flash floods may occur after the collapse of nature debris dam or a human structure such as a man-made dam. Flash floods are distinguished from a regular flood by a timescale less than several hours or even less. A. (Abeyta, 2009) and due to very high speed of water flow. Usually, flash flood is the result of intense rainfall and distributed over a relatively small area (Bentley, 2011). Due to these characteristics, no

advance warning methods are existing for flash flood.

2.2 Characteristics of Flash Flood

Different from inundation in lowland areas where flood happens slowly, flash flood occurs when precipitation is highly intense on saturated or dry soil that has poor absorption ability. The runoff collects in low-lying areas and rapidly flows downhill. Flash floods occurs mostly in dry areas that have received precipitation recently, but can be seen anywhere downstream from the source of the precipitation, even many miles far from the source. In mountainous areas, flash floods are known to

occur in the high mountain ranges. One of the reasons that makes flash floods most dangerous is that water destroy structures and roads, living areas (Truong, 2005), (Science and Environment Department of Vinh Phuc province, 2008, 2009, 2010, 2011 Annual report). It namely sparse population and poverty, damages house or kills people. In fact, in some areas that small roads cross dry rivers without bridges, flash flood occurrence potential is always high. Though occurring in small areas, flash flood's damage is so profound as well as risky. Risks include people death, damage of infrastructure, housing, cultivation and changing the environment to negative direction.

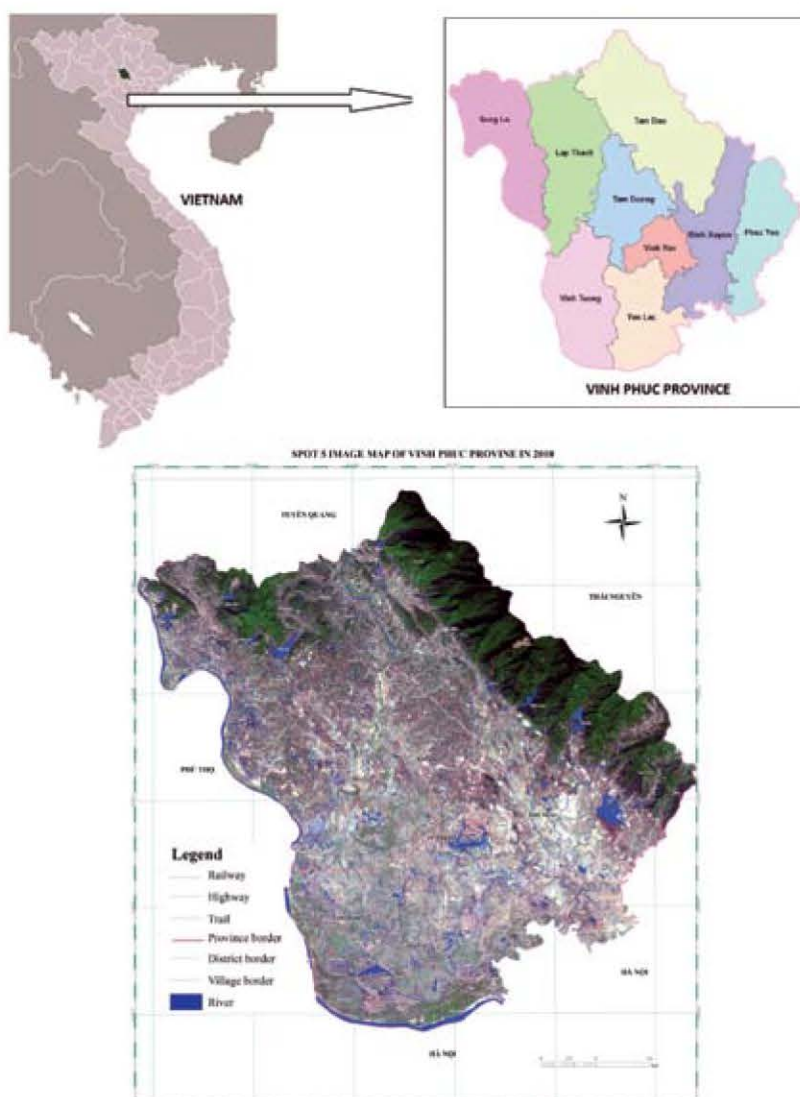


Figure 1: Study area location and SPOT image (2010)

2.3 Flash Flood Analysis

Flash flood and muddy flood are the open system with many factors. Severity of flood (strength, danger) is characterized by its kinetic energy $P = mv^2/2$ (P : kinetic energy of the flood; m : ratio of the flow [ton/m³]; v : velocity [m/s]) (Bentley, 2011). Dominant factor is the strength related to the flash flood as: rainfall, river slope, weathered cover, vegetation cover, (Abeyta, 2009). Based on the specific conditions of the study area, five following key factors are identified to calculate the risk of flash flood and muddy flood:

Maximum daily rainfall: is the direct cause and necessary prerequisite conditions to create flash flood.

Landslide and erosion potential: is the ability to form the essential and structural material of flood flow. This information will be the integration of multiple related parameters but the process may create classes of independent information in flash flood study.

The average slope of the sub-basins: a representative parameter for a sub basin, are in direct ratio to the speed of the flash flood. The buffers of first, second and third orders of drainage network, where flash – muddy flood often occur after raining. In the Geographical aspect, these buffers are same locations of valley fills types V-shape and U-shape.

Vegetation cover or land use: is the related information to the ability to store water, limiting the energy of flash flood.

Topographical Wetness Index: the layer is the significance of the capacity of water accumulated on the land surface. Depending on the difference between the slope and the width of valleys stretch, surface water can be distributed differently in the three dimensions spatially.

Geomorphological landforms: some landforms are typical signature to recognize the trace of flash flood such as valley fill, accumulated fan, and old river terraces. However, in this small case study, extent of those factors is too large compared with the contour of flash risk hazard location. In this study, the buffer zone of stream orders is sufficient instead of geomorphological factors.

2.4 Modeling for Flash Flood Mapping

In the basin, to build flash flood - muddy flood risk maps, five factors mentioned above are considered as input layers of the model analysis. Following diagram illustrates the model for risk flash flood mapping with difference Flash Flood Potential Index (FFPI) (Bentley, 2011) (Figure 2).

In the Figure 2, weighted model, derived layers from GIS processing with the basic input data becomes component factor maps. The landslide risk map is an input layer which will be processed by a separate model (figure 4). These derived layers were allocated corresponding with flash flood sensitive levels. The final work is integrating build flash flood and obtaining the flash flood potential index. Creating a “Flash Flood Potential Index (FFPI)” will help to represent how “flashy” the land is in certain areas and useful for planning purpose with the aspect of reducing damage by the flash flood.

3. Flash Flood Mapping

3.1 Mathematic Equation for Integration

Flash-muddy flood risk map is built based on spatial analysis tools in ArcGIS software environment. In this model, five possible factors of flash flood-muddy flood are calculated according to this formula:

$$F = 1/m \sum_1^n (\alpha A + \delta B + \gamma C...)$$

Equation 1

Where: F : flash flood risk map (FFPI map), m : Ranking of index value (from 1- m), 1..... n : Information layers (from 1- n), α , δ , γ ...: Weighted values for separated layer, A , B , C ...: Score of separated mapping unit.

4.2 Creating Layer for the Model and Assessment

The analysis layers are digitized, encoded, processed individually or extracted from integrated process. Following are these layers and assessment for them in the relationship with flash flood potential by the expert score (Thach, 2012) (Figure 3).

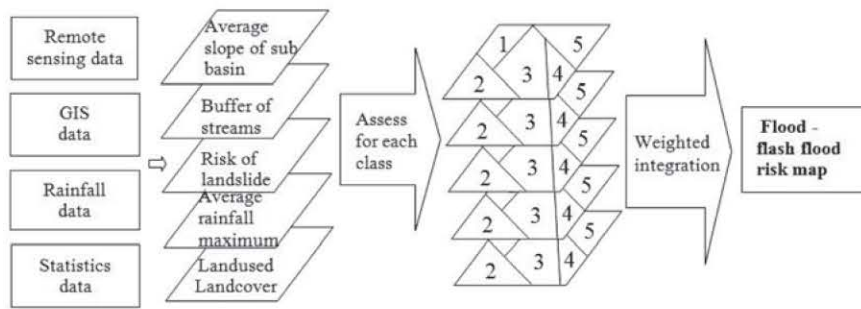


Figure 2: Weighted model diagram mapping the risk of muddy - flash flood in Vinh Phuc

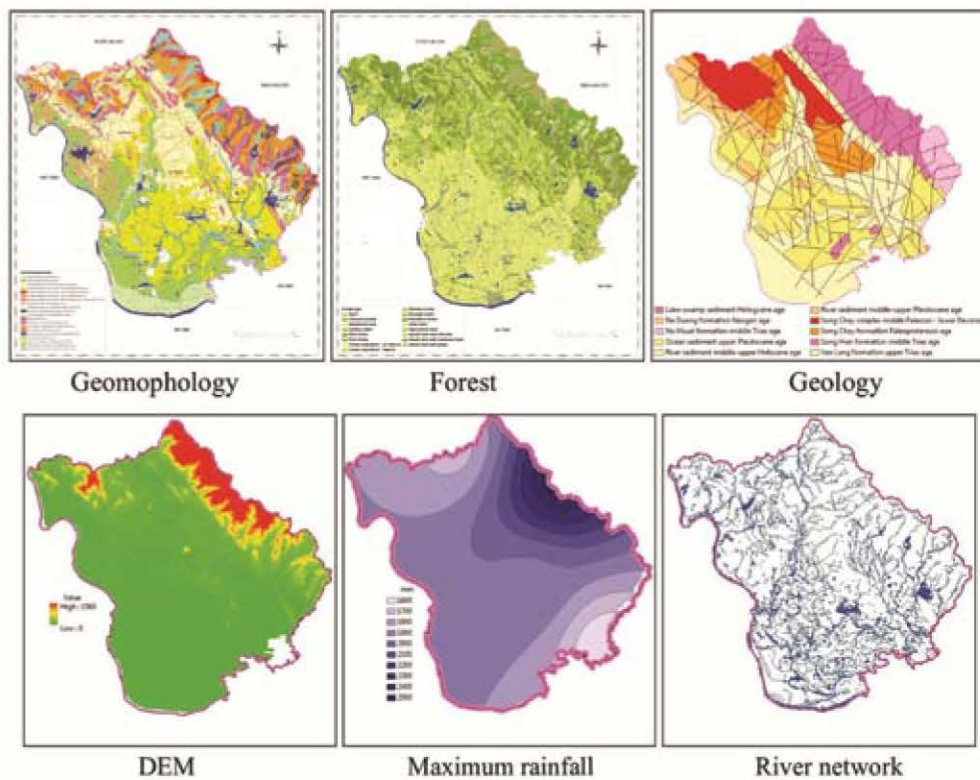


Figure 3: Data base for the model with five major layers

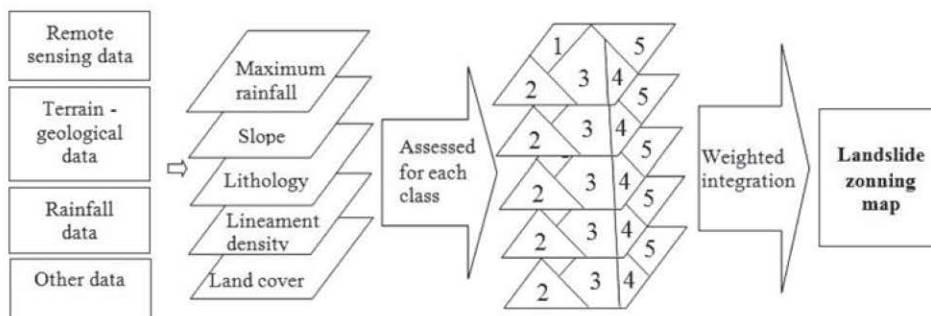


Figure 4: Create layers for landslide risk map

4.2.1 Landslide risk factor

represents the sum of many factors affecting the flash flood - muddy flood like side slope, average annual rainfall, geology - petrography, lineament density, land cover, slope, road buffer, landslide risk map of the study area will be established by means of weights model (Westen, 1996) (figure 6) (Figure 4).

4.2.2 The buffer zones of stream orders

Stream buffer zones are polygons on both sides of the stream with the same distance of 20 to 30 meters depending on the stream's slope. These areas are dry but they can be filled by surface water during flash flood.

4.2.3 The average slope of the sub-basins factor

These basins are divided into sub basins based on the division of the rivers and streams. Average slope value of the basins plays an important role in the formation of flash flood-muddy flood disaster on the catchment area.

4.2.4 The forest cover or land cover

The capacity of forests to reduce the incidence and severity of downstream flooding associated with major rainfall events may be more limited than common thoughts. Nevertheless, maintaining natural vegetation in catchments and riparian zones can reduce flash floods and flood peaks through the sponge effect of standing forests, and diminish the damaging impacts of local floods by blocking the path of the water with tree trunks, branches and other forest litter.

4.2.5 Topographical Wetness index

This index calculates wetness index which is a function of natural logarithm of ratio of local upslope contributing area and slope. The Topographic Wetness Index (TWI) is frequently used to simulate the soil moisture conditions in a watershed quantitatively, and it is the most commonly used indicator for static soil moisture content as well. Therefore, it plays an important role in the research of soil erosion and distributed hydrological model in watersheds, etc.

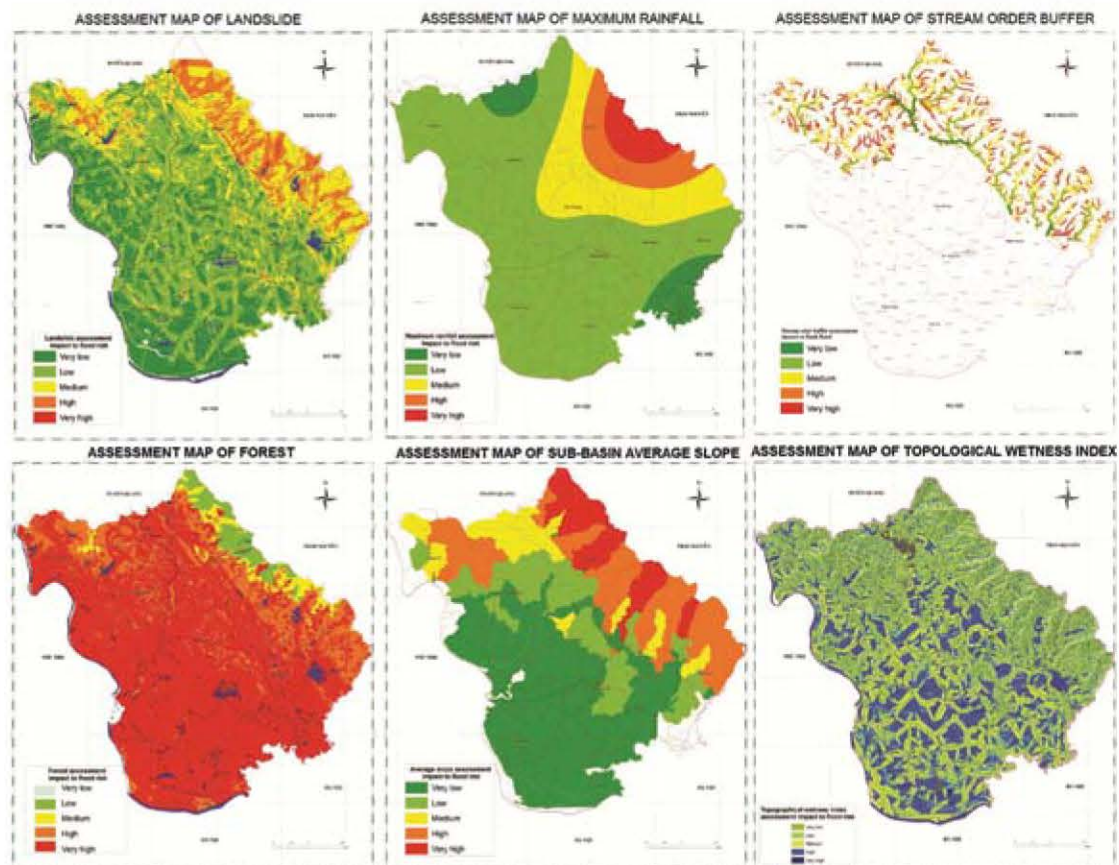


Figure 5: Separate layer assessment impact to flash flood

Table 1: Assessment separate layer for flash flood

Land slide sensitivity assessment impact to flash flood		
N^o	Land slide sensitivity level	score
	Very low	1
	Low	2
	Medium	3
	High	4
	Very high	5
Total annual rainfall assessment impact to flash flood		
N^o	annual rainfall level	score
	<1800mm	1
	1800-200mm	2
	2000-2200mm	3
	2200-2400mm	4
	>2400mm	5
Buffer of stream order assessment impact to flash flood		
N^o	Buffer of stream order	score
1	Branch 1	4
2	Branch 2	5
3	Branch 3	3
4	Branch 4	2
4	Branch 5	1
Average slope of sub basin assessment impact to flash flood		
N^o	Average slope of sub basin level	score
1	<5°	1
2	5° – 10°	2
3	10° – 15°	3
4	15° – 20°	4
5	>20°	5
Forest assessment impact to flash flood		
N^o	Forest type	score
1	Rich forest	1
2	Medium forest	1
3	Poor forest	2
4	Regrow forest no reserves	3
5	Regenerated forest no reserves	2
6	Bamboo mix wood forest	2
7	Plantation	2
8	Specialties forest	3
9	Grass land	3
10	Grass land with brush	4
11	Grass land with wood tree	3
12	Forest garden	3
13	Industrial forest, orchard (tree, orchard...)	4
14	Agriculture land	4
15	Resident areas	5
16	Sand bar	5
17	Water	5
18	Other land	5
Topographical wetness index assessment impact to flash flood		
N^o	Topographical wetness index	score
1	< -0.7	4
2	0.7 – 1.3	5
3	1.3 – 2.7	3
4	2.7 – 4.8	2
5	>4.8	1

Additionally, the index was generally extracted from Digital Elevation Model (DEM), and the formula is: $w = \ln (A_s / \tan\beta)$, where A_s means the specific catchment area (catchment area divided by the cell width in slope direction); β means the local slope in the steepest down slope direction of the terrain in degrees. Then $\tan\beta$ is the local slope angle of the specific grid, which is used to replace approximately the local hydraulic gradient under

steady state conditions (Ma, 2010) (Table 1 and Figure 5).

4.2.6 Mask for space of flash risk region

Based on the statistics of 30 years, the space of flash risk occurrence is located in mountain region with elevation from 50 m and higher. By this data, the mask for space of flash risk region is created from DEM, which cover all areas having flash flood hazard (Figure 6).

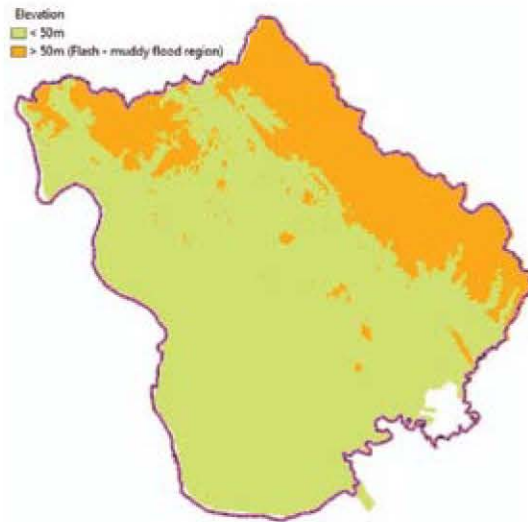


Figure 6: Building Mask for space of flash risk region



Figure 7: Final map for flash-muddy flood risk map with FFPI ranking from 1 to 5 Flash - muddy

4.3 Weights Calculation for Separated Layer

The Analytic Hierarchy Process (AHP) is applied for weighing calculation for separated layers (Abeyta, 2010). This method is widely used now in the geoscience. The AHP (Saaty, 1980, 1983, 1990, and 1994) is based on decomposing a complex MCDM problem into a system of hierarchies (Saaty, 1980). The final step in the AHP deals with the structure of an $M \times N$ matrix (where M is the number of alternatives and N is the number of criteria). This matrix is constructed by using the relative importance of the alternatives in terms of each criterion. The vector ($ai_1, ai_2, ai_3, \dots, ai_N$) for each i is the principal eigenvector of an $N \times N$ reciprocal matrix which is determined by pair wise comparisons of the impact of the M alternatives on the i -th criterion. Some evidence is presented in Saaty's (1980), which supports the technique for eliciting numerical evaluations of qualitative phenomena from experts and decision makers. However, we are not concerned about the possible advantages and disadvantages of the use of pair wise comparisons and the eigenvector method for determining values for the ai_j 's.

Instead, we examine the method used in AHP to process the ai_j values after they have been determined (Tables 2, 3, 4).

4.4 Integration by ARC/GIS Software

In ARC/GIS software, an equation is written as follows: $F = 1/6$ (**0.416***Assessment for max daily rainfall + **0.161***Assessment for average slope of the sub-basins **0.120***Topographical wetness index assessment + **0.269***Assessment for buffer of stream orders+ **0.035***Assessment for land use + **0.046***Landslide risk) (Figure 7).

4.3 Accuracy Assessment

Comparing with historical data, flash muddy flood has been occurred in many places of the study area. Locations of it are inside the piedmont alluvial plain which running along the west –south side of the Tam Dao Mountain. Historical flash flood has occurred in several villages like Tam Tien, Tan Phu, Xa Huong (Dao Tru community), Dong Quan, Ngoc ly (Yen Duong community), Son Dinh (Dai Dinh Community), Dong Que, Ngoc My, Bac Binh, Quang Son communities...(Annual report).

Table 2 : Scale for comparison (Saaty and Vargas, 1991)

Scale	Degree of preference
1	Equal importance
3	Moderate importance of one factor over another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Values for inverse comparison

Table 3: Criteria and pair wise comparison

C.I. Value = 0.0431775	Max daily rainfall (R)	Average slope of the sub-basins (A)	Topographical wetness index (T)	Buffer of stream orders (B)	Land use /land cover (L)	Landslide a (Ls)
R	1	3	4	2	8	9
A	1/3	1	2	1/3	6	5
T	1/4	1/2	1	1/2	5	2
B	1/2	3	2	1	7	6
L	1/8	1/6	1/5	1/7	1	1/2
Ls	1/9	1/5	1/2	1/6	2	1
Sum	167/72	118/15	97/10	29/7	29	47/2

Table 4: Pair wise comparison and average weigh for each criterion

	R	A	T	B	L	Ls	Sum	Average weights
R	0.453	0.391	0.435	0.503	0.296	0.383	2.078	0.416
A	0.151	0.130	0.217	0.084	0.222	0.213	0.805	0.161
T	0.113	0.065	0.109	0.126	0.185	0.085	0.598	0.120
B	0.226	0.391	0.217	0.251	0.259	0.255	1.346	0.269
L	0.057	0.022	0.022	0.036	0.037	0.021	0.173	0.035
Ls	0.048	0.025	0.052	0.040	0.069	0.043	0.277	0.046

Traces of these muddy flash flood flows existed inside buffer zone of stream network with various water levels corresponding to the FFPI. The traces of high value of FFPI are usually located at the first and second orders.

5. Conclusion

The studies have solved the questions of mapping muddy –flash flood in mountainous areas, not a fresh but a much disputed topic. With the GIS and Geomorphological concept, muddy –flash flood can be established following the procedure. With the climate change aspect, rainfall cannot follow the normal rule of annual statistic so it is necessary to have hydrological station and rain forecasting network. This work is useful for creating an early flash –muddy flood warning system. Local government can apply the result of the study for regional planning purpose, such as the planting of protection forests, assorted agricultural and hydraulic techniques based on general management of river basins, above all, the proper planning on land use for sustainable development, which shall serve as the most economical and effective measures to be applied in the study area and also for other parts of Vietnam. Depending on the detail of elevation contours, stream network can be differenced, so the results will be established with difference accuracy. Based on the results of the study, in the model 5 parameters were used for the calculation of Flash Flood Potential Index (FFPI), topographical wetness index and stream buffers can be used as the most important layers for study at medium and small scale. Among these parameters, only rainfall factor is flexible and changed seasonally and yearly. Accuracy enhancements can be achieved by employing the long duration statistics data

Acknowledgment

Special thanks to the scientific project between Vietnam and India, titled “*Bilateral R&D India-Vietnam project on institutional capabilities reinforcement of Hanoi University of Science in education and research in Remote sensing and GIS applied to monitoring and management of natural resources and environment, case study in Vinh Phuc and Bac Kan provinces*” for providing the all

necessary data which are required to execute this work as well as I appreciate the support from the Vietnam National University, Hanoi in this work during conducting.

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