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Simulate landslide activities during flood season 2020 - 2021 in Phong Nha - Ke Bang National Park

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Thien Quang Do[1], Duong Hai La[2,*], Hoang Tung Ho[3], Thi Thanh Nhan Nguyen[1], Thanh Nhan Tran[1], Avirut Chinkulkijniwat[4]

[1] Department of Engineering geology and Hydrogeology, University of Sciences, Hue University, Thua Thien Hue 52000, Vietnam
[2] Faculty of Civil Engineering and Technology, Dong A University, Da Nang 55000, Vietnam
[3] Department of Thua Thien Hue Transport, Thua Thien Hue 52000, Vietnam
[4] School of Civil Engineering, Suranaree University of Technology, Thailand

[*] Corresponding author's e-mail: haild@donga.edu.vn

Abstract. Research highlights in study area, there are various small-scale landslide points occurred and located surround from major landslide point with already 42 field-investigated points. The core zone of study area has the gravity displacement coefficient (Kg) by 0.0006, the buffer zone has Kg by 0.0033, all of them are weak and relative stable. The core zone of the National Park has more than 60 landslide points with total area of 81.19 hectares, and total landslide soil volume is over 2.6 mil m^3. The largest landslide volume in study area is about 2.4 mil m^3, with added 14 large-scale lanslide volume from 1,000 to 65,000 m^3. In particular, a number of slopes occurred consecutively during flood seasons in years of 2020 - 2021. Landslide activities strongly affecting the integrity and aesthetic value of Phong Nha – Ke Bang (PNKB) National Park with calculation results, for the largest landside point during rainny season in October, 2020, show that the sliding soil blocks have displaced more than 130 m, with low factor of safety (FS) by 0.32 and the total sliding soil volume is 2.1 million m^3, also consistent with field monitoring data and analysis of remote sensing images (2.4 mil m^3).

1. Introduction

The historic flood in October 2020 in the area of PNKB National Park, there were 3 floods with rainfall up to 700 mm, rainfall intensity ranging from 92-240 mm/day has caused flooding, landslides - mud and rock floods, destroying ecosystems and improving the environment. geomorphological field, as well as infrastructure of Phong Nha – Ke Bang (PNKB) National Park. In which, some slopes have consecutive landslides in the two flood seasons of 2020-2021 and serious changes in the geomorphological environment, threatening the integrity and aesthetic values of the PNKB heritage.

In the world nowadays, the landslide hazard warning map has three levels: (1) The map of landslide hazard zoning in space (susceptibility); (2) Disaster level map, warning in both space and time (hazard); (3) Map of the level of risk zoning in space, time and level of damage (risk). However, currently, in Vietnam, only maps of landslide risk zoning are built in space (susceptibility), the maps are too small scale (the largest is usually at 1/50,000 scale). Mostly maps based on historical figures (static maps), only warning about spatial aspect, not estiamate in real-time and not detailed enough to warn the correct location of the landslide. Moreover, these maps are built based on traditional methods such as expert method and weighted method which have large errors due to dependence on subjective factors and expert's experience. Detailed, highly accurate and up-to-date landslide disaster warning maps are essential for residential planning, construction and disaster management. Besides, the use of monitoring systems to control the evolution of landslides is increasingly common . The process of urbanization and the development of population area, combined with climate change, has increased the risk of landslides and significantly affected the socio-economic and living of people [1,2]. With many different approaches to mitigating the impact of landslides such as developing landslide hazard maps, re-planning residential areas and building early warning systems…The most common and effective is the use of monitoring and support systems for local authorities to make urgent decisions in cases involving landslides due to slope instability.

Over the years, landslide warning systems have been studied quite thoroughly. At the workshop on landslides on April 27th, 2012, Prof. Hirojasu Otshu (Thailand) introduced a monitoring system supported by radar equipment to monitor surface runoff, the infiltration of rainwater into the soil layers of the country slope, from which to calculate the possibility of slope and propose measures to prevent and minimize damage from landslides. In Italy, an early landslide warning system is installed on the mountainside, in order to warn the vehicles below, including steel and a number of sensors and cameras to calculate, thus giving the scene. early notice. When a landslide is imminent, the system will activate roadside barriers to block vehicles that are about to enter the danger zone. Complex networks have been perfected to control the development of landslides such as Ancona, Montaguto, Mt.de La Saxe, Rotolon, and Ruinon [3-6]. In other countries, similar methods have been applied to monitor landslide complexes such as Randa (Switzerland) [7], La Vallette (France), Super Sauze (France) [8,9], Sado Island (Japan) [10], and Slumgullion (USA) [11]. However, based on the parameters representing the process, three types of warning systems landslides can be divided: (1) Direct warning based on the direct measurement of the displacement of the sliding mass, (2) Early warning based on “thresholds” for landslides : pore water pressure, humidity and precipitation, (3) Combination of the two above systems.

The warning system is based on the direct measurement of the displacement of the sliding mass highlighted by the work of Angeli et al. [12], including all existing technologies such as GPS (Global Positioning System), RTS (Automation Total Station), GB-InSAR (Ground-Based Synthetic Aperture Radar) and robotized spot inclinometer [13-17]. Allasia et al. and Frigerio et al. presented the capabilities and approaches to managing and processing such data sets [5,17]. The system usually has a high degree of reliability due to the direct determination of the slip mass displacement, but being expensive and is only used for stable monitoring of dams and other important structures. The early warning system (EWS) is based on real-time measurements of parameters that directly affect the landslide process [18,19]. They are an optimal solution that can assist in the correct management of landslide development stages. Usually, the EWS system includes parameters affecting the formation and displacement of the sliding mass. The term “threshold” is the most important and pivotal term of the landslide monitoring system in this regard. However, there is not a common threshold for all sliding blocks, thresholds are determined by slope stability problems based on detailed studies of soil structures, geotechnical properties, and groundwater. as well as the hydro-meteorological conditions of the slide itself . Experience gained during the development of monitoring data landslide management software called ADVICE, Daniele Giordan, Aleksandra Wrzesniak and Paolo Allasia argue that bringing in the monitoring results Closer to the community is best on a dedicated website [17,20-23].

Vietnam is one of the regions heavily affected by natural disasters, so in the past time, many projects, projects and tasks have been implemented, making significant contributions to the prevention, avoidance and control of natural disasters. As for mitigating damage caused by sliding, landslides, mud and debris flow, pipe floods, flash floods. Most of the research works focus on assessing the status, zoning risks and proposing prevention solutions. It can be mentioned that two major projects have been implemented: Flash flood zoning project chaired by the Institute of Meteorology, Hydrology and Climate Change, mainly making 14 Northern mountainous provinces billions of dollars. ratio 1:100.000; flash flood risk for 23 main river basins, 19 central provinces - Central Highlands, ratio 1:50.000. Landslide zoning project chaired by Institute of Geosciences and Minerals, scale 1:50,000 in 25 provinces from the Northern mountainous region to Quang Ngai, scale 1:10.000 for 64 key communes. There are not many warning systems for flash floods and landslides, except for the system of the International Mekong River Commission; The system of two institutes of Science, Geosciences, Geometries and Geodesy and Mineral Geology is being implemented. The General Department of Hydrometeorology is using these systems to perform the warning of flash floods and landslides. In addition, some provinces such as Ha Giang, Son La, Mu Cang Chai, Hoa Binh, Lao Cai have been supported to pilot early warning works systems for 1-3 high-risk communes.

Directly related to the warning system of slips and landslides, the topic "Study on the scientific basis, establish an automatic slide warning monitoring system in some key urban areas in the Central Highlands", code TN18/T13, under the Central Highlands Program 2016 - 2020. The project has established two models of landslide monitoring system for the scope of the study area and for the specific sliding block location in accordance with the actual conditions and needs in the locality based on the scientific research on the landslide monitoring system at home and abroad; combine data collection, analysis and evaluation of the topic in the implementation process.

The automatic landslide warning monitoring system at the sliding block location using modern automatic monitoring technology equipment, has high accuracy in large-scale sliding block monitoring with deeply developed sliding surface applied worldwide. The monitoring parameters of horizontal displacement, pore water pressure, and rainfall are updated online on the website, continuously every 2 hours/day. From there, establish the relationship between rainfall - pore water pressure - displacement at the monitoring slip block for warning of landslide development. In the work "Design and construction of an early warning system for landslides caused by rain" by Gian Quoc Anh et al. [24], it was proposed and implemented early warning and monitoring system against landslides caused by rainfall (named EWMRIL) with a case study at Nam Dan landslide (Nghe An). The test results at Nam Dan in August-September 2016 proved the validity of the EWMRIL system. In addition, the author's research group has also had a lot of research on both theoretical (classification of processes on slopes and surface flows) and experimentally on landslide and flash flood risk zoning - mud and rock floods, assessment of landslide activity intensity and stability of slopes along mountain roads in the climate change period [25-31]. Therefore, this study will provide an overview picture of the current status and evaluate the landslide dynamics, from which to simulate a large sliding block to compare with the actual results to assess the impact of this process on geological environment serving the early warning of the study area.

2. Methodologies

In this study, we choose both traditional and modern landslide hazard research methods to assess this kind of geohazard as below:

Methods of Data collecting, analyzing and summarizing: Annual statistics on landslides and damages in the research area is the base for works analyzing and establishing the scale, occurrence frequency and magnitude of the increase of landslides in the next period. The collected data helps the researcher to have an overview of the current situation of landslides, damage consequences and recovery. In addition, the analysis of these data is also the base of the oriented process in the next research content.

Methods of analyzing remote sensing image analysis and spatial models: This method will clear the history and current status of landslides, and determine the causes of impact factors (geology - tectonics, active fault zones, topography - geomorphology, hydrological conditions, forestry coverage, land use situation...) giving rise to landslide. Utilizing remote sensing image analysis technique not only allows us to determine the location and characteristics of the sliding blocks, soil fractures and active faults but also allows us to determine the characteristics of the factors affecting the development of landslides such as geomorphology, geology, young tectonics and human socio-economic activities based on geomorphological deformations.

Field survey method combined with Unmanned Aerial Vehicle (UAV) technology: Investigating, surveying and researching in the field allows to collect data on the current status, preliminary assessment of causes and damage caused by landslides in the study area. In addition to the investigation and collection of information on the location, scale, and situation of damage caused by landslides in the past;

In the field, the sliding blocks, soil cracks are measured and drawn in detail, determining the characteristics of location (geographic coordinates), size (length, width, depth of sliding block; length, width, depth, direction of the crack), classification of the time of appearance and damage. Survey and evaluate the role of each factor affecting each specific sliding block. Besides, the application of UAV technology to collect data and survey the current state of landslides (sliding block size, volume of soil and rock sliding, location and type of landslide...), especially this technology has the ability to continue provides good access to areas where traditional surveying cannot implement, and provides researchers with high-resolution images and video [25, 26].

Method of evaluating dynamics and scale of the sliding mass: On the basis of the above research methods, the authors evaluate the dynamics and scale of the sliding mass by the landslide coefficient K_g (which is the ratio between the total landslide mass and the area of the slope studied). : $K_g = \sum f/F$ (1), f: is the area of the landslide blocks (m^2), F: is the area of the studied slope (m^2), at the same time determine the landslide scale according to the volume of the sliding block suggested by the authors (Table 1) [25].

Table 1. Regional landslide dynamics hierarchy

Gravity displacement coef. (Kg)	Dynamics of landslides	Volume of landslide (m^3)	Scale oflandslide
< 0,1	Weak and pretty stable sliding	≤ 100	Small
0,1 - 0,25	Medium and stable sliding	100 - 1.000	Moderate
0,25 - 0,40	Strong and unstable sliding	1.000 - 5.000	Wide
0,40 - 0,55	Very strong and very unstable sliding	≥ 5.000	Very wide

Slope stability analysis method via using Plaxis 3D: Because PLAXIS 3D is quite popular, in order to condense the information, the authors do not present it again. However, in practice, it is found that the natural slope angle is one of the prerequisite factors for the development of landslides in the study area. To simulate the slope stability, the authors calibrate some other sizes of the sliding block to ensure the slope is constant, using the computational grid (MESH) in the rough size of mesh (Coarse) to fit and simulate the actual size of the slope. Precipitation is simulated through groundwater level in 2 cases: (a) water level at the footing of the slope (BASIC) and (b) water level rise 2 m above the slope surface (RISE). For case (a) to simulate the rain process from October 6-21, 2020 causing landslides and rocks in the landslide area PN34, case (b) to predict the sliding stability in the condition that the rainfall exceeds and threshold during Oct. 2020 [28, 30].

3. Results and discussion

The landslide-debris flow in research area occurred strongly at curshing debris geological layer which have high thickness, low cohesion and caused significantly to geology-geomorphology environment and asthetic values of PNKB National Park.

The results of the study of geo-disaster after the rainy season in 2020 and 2021 shown in Figure 1 and Table 2 show that in addition to the locations where landslides, flash floods, and debris flows, there were also some landslides, flash floods, and debris flows with small scale appearing around the main sliding block throughout PNKB National Park. The happened of landslides not only occur on natural slopes (PN3, PN5, PN7-10, PN17, 21, PN33, PN34, PN41) but also destroy artificial slopes of road constructions already built. There are several prevention workson Ho Chi Minh road west branch (35 points), road 20 (14 points) and many other small -scale landslides distributed in both the core and buffer zone of PNKB National Park.

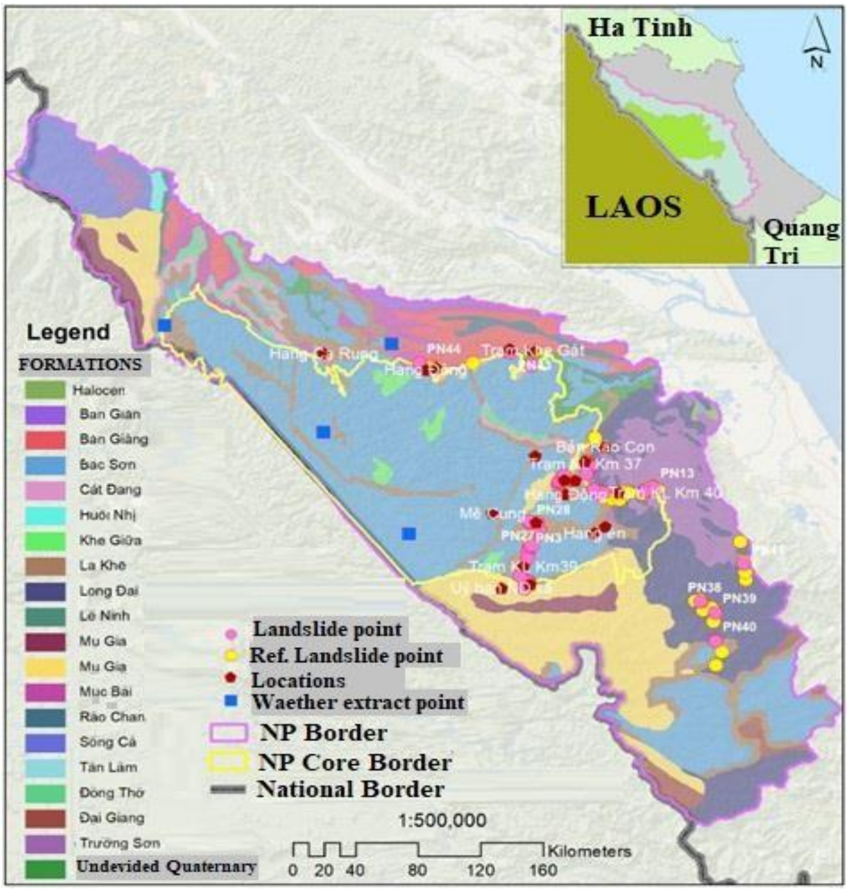

Figure 1. The Location map of geo-disasters upon different geological strata in PNKB National Park.

The landslide sites surveyed and collected are concentrated in the southeast region of the core zone, the northern boundary of the core zone and the buffer zone. Particularly, landslides in the buffer zone occurred mainly in Truong Son commune, Quang Ninh district. From a regional perspective, the core zone has a gravity displacement coefficient of $K_g = 0.0017$, the buffer zone (including 26 landslide points) has $K_g = 0.0033$, with the regional geodynamic intensity of the medium and medium stable types.

Table 2. Statistic the landslides, flash flood and debris flow in PNKB National Park.

Sym.	Lon.	Lat.	Slope (^{0})	Widthof slope top (m)	Width of slopetoe (m)	Slope height(m)	Slope body length (m)	Avg. Slope thickness (m)	Volume of slope sliding (m^3)	Times	Occurred time
PN3	106.2204	17.41158	20	10	15	7	10	3	200	1	19/10/2020
PN4	106.2569	17.49493	40	7	20	7	12	3	300	2	19/10/2020
PN5	106.2573	17.49836	40	6	15	4	10	2	100	1	19/10/2020
PN6	106.2633	17.50425	45	8	15	10	30	1.5	300	1	19/10/2020
PN7	106.2152	17.36648	40	3	5	3	4	2	40	1	19/10/2020

PN8	106.2152	17.36648	45	5	15	10	12	2	250	1	19/10/2020
PN9	106.2203	17.37452	30	4	8	3	5	2	30	1	19/10/2020
PN10	106.2192	17.37517	30	3	5	4	3	1	30		19/10/2020
PN11	106.2918	17.50980	50	20	50	12	15	3	1000	2	2020, 2021
PN12	106.3057	17.4837	60	90	97	10	15	3	3000	2	2020, 2021
PN13	106.3710	17.49104	60	7	15	10	13	2	200	2	2020, 2021
PN14	106.3607	17.48614	45	15	25	17	23	3	100	2	2020, 2021
PN15	106.2192	17.37517	30	3	5	4	3	1	30		19/10/2020
PN16	106.2933	17.52129	40	5	15	6	50	1	300	1	19/10/2020
PN17	106.2949	17.51717	45	7	8	21	30	3	400	2	2020, 2021
PN18	106.2951	17.51636	60	9	19	10	15	2	300	1	19/10/2020
PN19	106.2937	17.51324	60	11	20	7	12	3	300	2	2020, 2021
PN20	106.3120	17.48451	20	5	15	10	20	3	300	1	19/10/2020
PN21	106.2109	17.38174	50	3	5	4	7	1	30	1	19/10/2020
PN22	106.2195	17.40417	30	10	17	5	7	2	60	1	19/10/2020
PN23	106.2229	17.41783	30	10	5	2	8	1	30	1	19/10/2020
PN24	106.2244	17.41976	25	15	20	5	30	3	1500	1	19/10/2020
PN25	106.2337	17.43919	40	5	7	3	6	2	130	1	19/10/2020
PN26	106.2315	17.44867	30	10	12	3	20	1	300	1	19/10/2020
PN27	106.2221	17.44853	30	12	17	5	70	2	1400	1	19/10/2020
PN28	106.2218	17.44962	30	15	18	10	10	2	500	1	19/10/2020
PN29	106.2579	17.49852	30	20	25	10	80	2	3600	1	19/10/2020
PN30	106.2580	17.4995	30	110	25	150	250	4	65000	1	19/10/2020
PN31	106.2631	17.50382	45	15	20	15	60	3	1800	1	19/10/2020
PN32	106.2641	17.50608	45	12	15	10	60	2	1600	1	19/10/2020

PN33	106.2932	17.52135	30	80	15	30	130	4	26000	1	19/10/2020
PN34	106.2956	17.51911	40	1000	300	150	2000	2	2,4 mils.	1	19/10/2020
PN35	106.2950	17.51714	30	4	8	4	20	1	120	1	19/10/2020
PN36	106.2912	17.50804	35	20	30	7	25	3	1800	1	19/10/2020
PN37	106.3000	17.48861	35	20	30	10	100	2	5000		19/10/2020
PN38	106.4265	17.34847	50	15	25	5	30	1	400	1	19/10/2020
PN39	106.4444	17.33471	40	10	20	5	25	2	800	1	19/10/2020
PN40	106.4443	17.29969	50	20	30	5	40	2	2000	1	19/10/2020
PN41	106.4791	17.39476	30	200	60	50	500	1	65000	-	19/10/2020
PN42	106.2256	17.64367	-	-	-	-	-	-	-	-	19/10/2020
PN43	106.2005	17.65934	-	-	-	-	-	-	-	-	19/10/2020
PN44	106.0914	17.64705	30	30	70	100	165	1	8200	1	19/10/2020

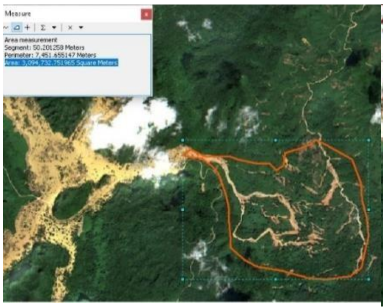

Figure 2. Large-scale landslide at km 23 of Ho Chi Minh road in West Branch

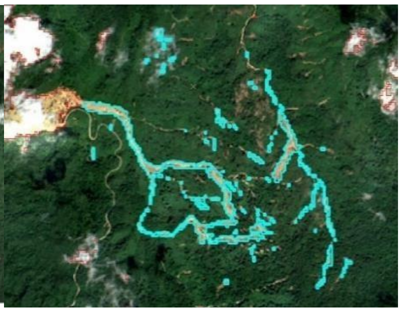

Figure 3. A series of small sliding blocks that lose their gravity balancefall after the main sliding blocks move

Figure 4. Main sliding block at km23 of Ho ChiMinh road in West Branch

The results of determining Kg in the sub-zones and subdivisions in Table 2 also show that landslides, flash floods - mud and rock floods have affected 2/3 of the subdivisions of PNKB national park, which in the strict protection zone with the largest landslide area (10,112 ha), this area of geodynamical active protection forest is also common with an area of 10.385 ha. The sub-zones with the most landslides are subdivision no. 265 (3.407 ha) and no. 266 (4.51 ha). However, the intensity of landslide dynamics of each subdivision and sub-zone is still moderate and stable condition. Some typical sliding points of large to very large scale include a series of slide blocks in the protected forest area at km23 of the HCM road west branch with K_g = 0,12. Next is a series of sliding blocks occurring from km 28 to km 30 of Ho Chi Minh Road West branch, especially the landslide area near Truong Son Commune People's Committee with a landslide area of 753,594 m^2, the volume of landslides up to 10,000 m^3. Landslide is mainly mixed clay containing fine crushed stone, boulders, some places are mud mixed with clay, sand, crushed stone... in the form of mudflow or flash flood-debris flow (PN28, PN29, PN30, PN42). Most of the blocks slides, leaving the sliding surface as the original bedrock. The solutions to prevent landslides in the PNKB National Park are mainly retaining walls, lowering steps, cutting slope for lower angle, surface water drainage and some other measuring methods, but all of them have been destroyed by the landslide process and caused severe damage (Figure 2-7).

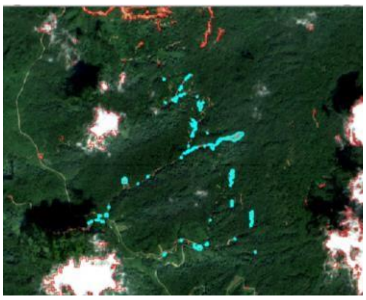

Figure 5. Sliding blocks occur from km28 to km30 of the HCM in West Branch

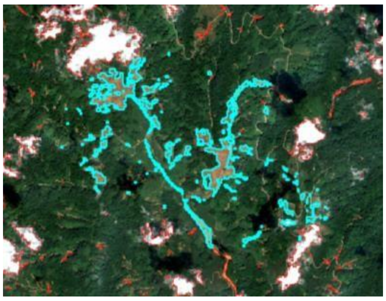

Figure 6. Landslide near Truong Son Commune People's Committee

Figure 7. The landslide covered many sections of the route no.20

Table 3. Gravity displacement coefficient of subdivision and division of PNKB National Park.

No.	Zone	Sector	Area	Landslide area (ha)	Kg
1	Sticky guarded subdivision		100296	10.112	0.0001
2	Recovered Eco subdivision		19619	0.08	0.0000
3	Protection forests		3411	10.385	0.0030
4	253	1	1153	0.0017	0.0017
5	254	1	1131	0.0006	0.0006
6	265	1	787	0.0043	0.0043
7	266	1.4	731	0.0062	0.0062
8	269	1	1222	0.0018	0.0018
9	594	2	1215	0.0006	0.0006
10	599	1	1254	0.0020	0.0020
11	600	3	532	0.0003	0.0003
12	622	10	1085	0.0000	0.0000
13	629	3.5.7	1544	0.0013	0.0013
14	635	9.10	1556	0.0001	0.0001
15	636	2.3	1128	0.0012	0.0012
16	645	2.4	1301	0.0005	0.0005
17	288B	2.3	369	0.0001	0.0001
18	288D	10	1341	0.0000	0.0000

Table 3 shows nearly 60 landslide sites with an area of 20,577 ha and the total volume of landslides in the entire PNKB National Park up to 2.6 million m^3. which, the sliding point with a very large scale has a landslide volume of 2.4 million m^3 (PN34), 14 sliding blocks with large to very large scale (from 1,000 - 65,000 m^3), the remaining sliding blocks with small to medium size (Figure 14). There are many slopes with consecutive landslides in the 2 flood seasons of 2020 and 2021 (PN 11-14, PN17, PN19) destroying of natural forests (shrubs, reeds, trees...), many bridges, roads, etc. Roads were buried and blocked the flow of rivers and streams, changing the appearance of the heritage and the karst landscape, and strongly affecting the geomorphological environment of PNKB National Park. In particular, there are many serious landslides on the route between Dan Hoa Forest Protection Station (from km123 to National Highway No. 12A) and U Bo Ranger Station, Thuong Trach, Km 40 on the Ho Chi Minh in the West branch route, many landslide sections and causing traffic disruption, isolating the Thuong Hoa Forest Protection Station.

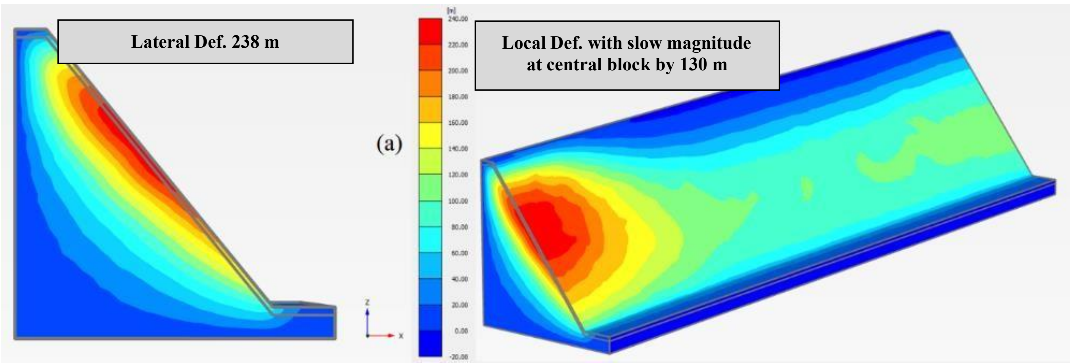

Figure 8. Lateral deformation of sliding block in case 1 for BASIC condition with (a) side view; (b) 3D.

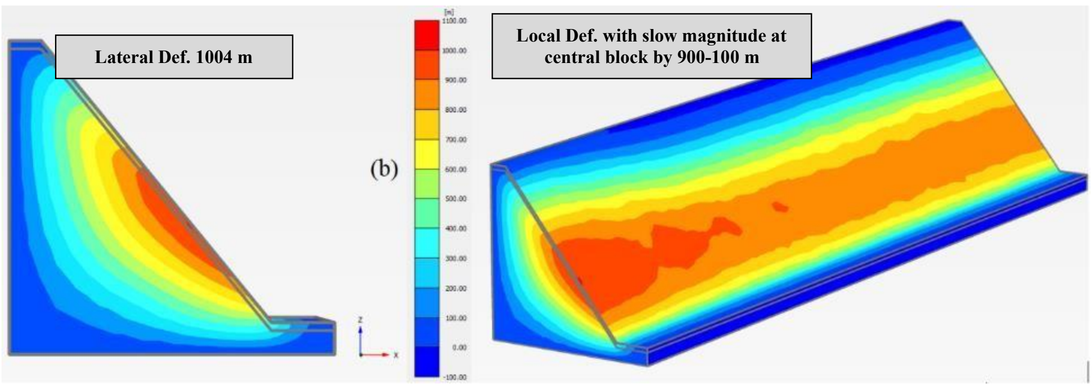

Figure 9. Lateral deformation of sliding block in case 2 for BASIC condition with (a) side view; (b) 3D.

Plaxis 3D was used as environmental for simulating the landslide. The 15-nodes of calculating mesh were applied for these cases with coarse meshing generating. The rainfall was simulated via the rise of water level during modelling. The boundary conditions were set as fixed bottom boundary, fixed y-axis boundary, free upper boundary, and fixed x-axis boundary. There are 3 scenarios for simuation as initial (no landslide), basic (with low slide), rise (with the maximum sliding block).

Simulation of the largest sliding block (PN34) occurred at Phong Nha – Ke Bang (PNKB) National partk on Oct 19th, 2020. The results of simulation of sliding block displacement (strain deformation) with the case of BASIC and RISE are shown in Figure 8 and Figure 9, together with the graph of shear deformation in all directions and the landslide, the factor of safety (FoS) according to the the scenarios shown in Figure 10. The initial case is indicated without any landslide at PKNB national park.

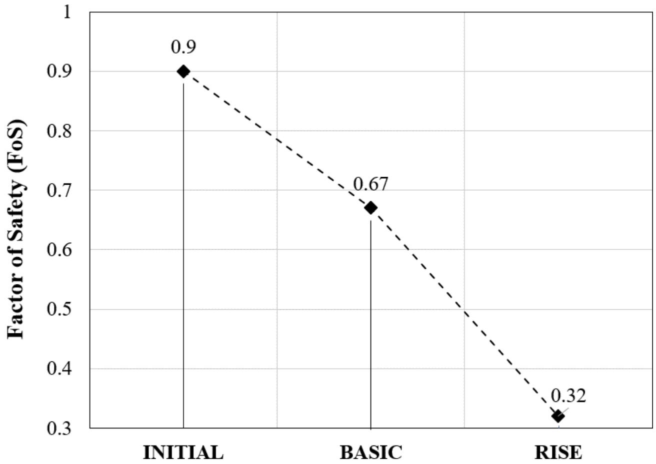

Figure 10. Reduction of FoS for 3 simulated conditions as initial, basic and rise.

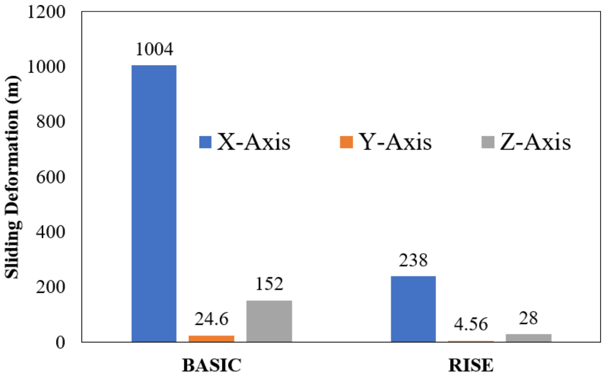

Figure 11. Sliding displacement chart in x, y, z direction from simulation scenarios.

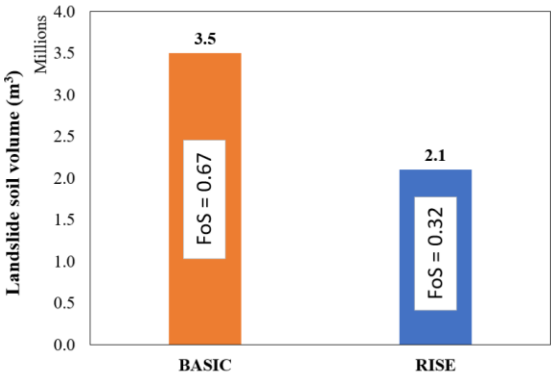

Figure 12. Landslide volume chart and factor of safety (FoS) according to simulation scenarios.

In case1 (initial, simulated by the Oct. 2020 rainfall), the sliding block moves slowly and locally, in the center of the side surface of the sliding block moves 130 mm, the total horizontal deformation of the sliding block is 238 m, the low factor of safety (FoS) by 0.32 and the landslide volume is 2.1 mil. m^3, which is quite consistent with the field measurement data and remote sensing image analysis (2.4 mil. m^3) via Fig 11 and 12.

For case 2 (dangerous, rainfall intensity exceeds the threshold in Oct. 2020, the groundwater level rises by 2 meters), the horizontal displacement of the sliding block develops very quickly over the entire sliding surface from 900 - 1000 m, the boundary the displacement of the sliding block is 1,004 m, the FoS is rapidly decreasing (FoS = 0.32), the sliding block is very unstable and there is a risk of landslides with the volume of soil and rock is 3.5 mil. m^3 (for the sliding block) in Figure 11. The deformation along axis y and z directions are not significant, so it is not considered. The displacement of rock masses on the slope is very large when increasing the groundwater level with a displacement amplitude of more than 1000m on the slope surface, nearly 4 times higher than case 1. The curve represents the sliding arc along the slope. The theory in scenario 2 has a large area and occupies more than 2/3 of the entire slope compared to case 1. This shows a strong decrease in the safety factor SF of the slope in scenario 2 (FoS = 0.32) in Figure 12. This is 2 times lower than scenario 1 (FoS = 0.67) and therefore the risk of landslides is very high if the rainfall exceeds the Oct. 2020 threshold, increasing the groundwater level in the soil body.

4. Conclusions

Landslide in PNKB National Park not only occurs on natural slopes but also destroys road slopes have built prevention works on Ho Chi Minh Road - West branch and Road No.20, along with many other small-scale landslides appear around the main slide in both core and buffer zones.

The phenomenon of landslide occurs strongly and is common in the coarse debris layer witha large thickness of the Long Dai, Muc Bai, La Khe formations and the Truong Son complex with a slope angle of 30 - 60 degrees. In near streams or water basin, rocks are often saturated with water, cohesion is reduced, so the risk of landslides and falling rocks increases.

The core zone has K_g = 0.0006 (medium and stable low-grade soil type) with more than 60 landslide sites with an area of 81.19 hectares and the total volume of landslides is over 2.6 million m^3. The largest slide has a volume of about 2.4 million m^3 and has up to 14 sliding blocks with large to very large scale (1.000 – 65.000 m^3). In particular, a number of landslides occurred consecutively in the two flood seasons of the years 2020 and 2021. Buffer zone with K_g = 0.0033 with 26 landslide points, belonging to medium gravity displacement and medium stability.

Simulation results of the largest sliding block (PN34) according to the October 2020 rainfall show that the total landslide volume is 2.1 million m^3, the displacement amplitude of the sliding block is 130 m and the safety factor is very low 0.32, quite suitable for field measurements, UAV flight and remote sensing image analysis (2.4 million m^3).

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