Secondary Processes Associated with Landslides in Vietnam

Pham Van Tien[1(✉)], Le Hong Luong[2], Tran Thanh Nhan[3], Do Minh Duc[1,4], Dinh Thi Quynh[1], Nguyen Chau Lan[5], Nguyen Quoc Phi[6], Do Canh Hao[7], Nguyen Huu Ha[4,8], Dang Thi Thuy[1], and Vu Ba Thao[9]

[1] Institute of Geotechnology and Environment, Hanoi, Vietnam
Phamtiengtvt@gmail.com
[2] Institute of Transport Science and Technology, Hanoi, Vietnam
[3] University of Sciences, Hue University, Hue City, Vietnam
[4] VNU University of Science, Vietnam National University, Hanoi, Vietnam
[5] University of Transport and Communication, Hanoi, Vietnam
[6] University of Mining and Geology, Hanoi, Vietnam
[7] Institute of Training and Science Application, Thuyloi University, Ninh Thuan, Vietnam
[8] Department of Science and Technology, 208 Dien Hong, Quy Nhon, Binh Dinh, Vietnam
[9] Academy for Water Resources, Hydraulic Construction Institute, Hanoi, Vietnam

Abstract. Landslides are one of the most dangerous geohazards in tropical monsoon countries. Various impacts of landslides on lives and property not only result from the destruction of the down movement itself but is also due to secondary effects including the formation of landslide-dammed lakes and the generation of tsunami-like waves. This paper presents a study on secondary processes associated with landslides hazards in Vietnam through site surveys, air photos, and data collection and analysis. First, the paper reports a comprehensive investigation of the study on landslides and their consequential hazards in recent 30 year. Then, three typical cases of landslides in the Van Hoi reservoir, Khanh waterfall, and Song Bung hydropower reservoir are characterized in terms of geological features, causes, and sliding mechanisms. Besides, landslide hazard assessment for disaster risk reduction is briefly discussed. Study results significantly indicate that heavy rainfall is the main trigger for landslides and its cascading effects (i.e., river damming and dam breach, and landslide-generated waves). While the geological structures of high fractured, deformed, and weathered rocks are the main preparatory factor of the landslides. Landslides associated with secondary hazards has been rarely analyzed in Vietnam, this study will, therefore, bring a significant understanding for planning and management of multiple disaster risk in the river-hillslope system.

Keywords: Landslides · Secondary processes · Dam reservoir · Cause · Mechanism · Vietnam

D. Tien Bui et al. (Eds.): *Proceedings of the International Conference on Innovations for Sustainable and Responsible Mining*, LNCE 108, pp. 192–209, 2021.
https://doi.org/10.1007/978-3-030-60269-7_10

1 Introduction

Landslide phenomena are globally one of the most frequent natural hazards that cause a lot of significant damage to people and properties [1, 2, 3]. The human and economic losses result from the destruction of the mass movement of earth materials itself and the potential effects of its secondary processes that include the dam formation due to river blockage and the generation of tsunami-like waves [4–6, 7, 8]. The cascading effects to upstream and downstream areas due to the secondary hazards are presented in detail by Korup [8]. In river valleys, the large amount of the sliding materials can completely or partially fill the rivers to create natural reservoirs behind the landslide dams [4–8]. If the water table due to the impoundment process increases; the landslide dam may be highly vulnerable to instability or breaching because of various phenomena of upstream inundation, dam erosion phenomena, and the continuous effects overtopping and piping failures [6, 8]. The landslide dam breach associated with debris flows and outburst flood will pose serious hazards to downstream communities. While upstream reservoir bank slopes saturated by impounded water are prone to the failure to generate impulse waves and overtop that may cause cascading effects [4–6]. Several historical records of catastrophic landslides associated with secondary processes, including dam formation, landslide-generated waves and flash floods, are presented in Table 1.

Table 1. Historical records of catastrophic landslides associated with its secondary effects over the world

No	Event	Time	Country	Casualties	Ref
1	The overtopping and flooding due to the landslide dam failure	1786	China	100,000	[9]
2	The failures of three landslide-dammed lakes and its flooding	1933	China	20,000	[10]
3	Landslide lake outburst flooding and landslide dam failures in Uttarakhand	2013	India	5,000	[11]
4	The landslide induced waves in the Vajont reservoir	1963	Italy	2,000	[12]
5	The Shiaolin landslide dam and severe outburst flood event	2009	Taiwan	400	[13]
6	The Jure landslide dam and its dam overtopping and failures	2014	Nepal	156	[14]
7	The large-scale landslide in the Canelles reservoir	2006	Spain	-	[15]
8	The Qianjiangping landslide in the Three Gorge Reservoir (TGR)	2003	China	24	[16]
9	The large-scale deep-seated landslide in the Aratozawa reservoir	2008	Japan	-	[17]
10	The Shuping and Outang landslides in the TGR	Active	China	-	[18]

Specifically, rainfall triggered the Truong Giang landslide and Khanh waterfall landslide are very extreme.

Tsunami-like waves generated in the Truong river and Van Hoi reservoir are specific and uncommon in Vietnam. In this study, three cases of landslides in association with secondary hazards, e.g., of dam formation (at Khanh waterfall and in Song Bung No. 5 reservoir) and landslide-generated waves (in Van Hoi reservoir), are briefly presented through site investigations, aerial photos, and data analysis. The problems of landslides and their hazards in dam reservoirs have been outlined as an increasingly considerable challenge during the building and operation periods. However, this kind of research topic has still been under development, particularly the investigation of its sliding mechanisms has not been conducted. Therefore, it is imperative to study the initiation mechanism and processes as well as to assess the landslide hazards in Vietnam. The understanding of the mechanisms and processes of landslides and its secondary hazards are very crucial for safely planning and managing the dams and their reservoirs.

Acknowledgement. This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 105.08–2019.14.

References

1. Dai, F.C., Lee, C.F., Ngai, Y.Y.: Landslide risk assessment and management: an overview. Eng. Geol. **64**, 65–87 (2002)
2. Nadim, F., Kjekstad, O., Peduzzi, P., Herold, C., Jaedicke, C.: Global landslide and avalanche hotspots. Landslides **3**, 159–173 (2006)
3. Petley, D.: Global patterns of loss of life from landslides. Geology **40**(10), 927–930 (2012)
4. Costa, J.E., Schuster, R.L.: The Formation and Failure of Natural Dams, pp. 87–392. US Geological Survey, Open-File Report (1987)
5. Dal Sasso, S.F., Sole, A., Pascale, S., Sdao, F., Bateman Pinzón, A., Medina, V.: Assessment methodology for the prediction of landslide dam hazard. Natural Hazards Earth Syst. Sci. **14**, 557–567 (2014)
6. Evans, S.G.: The formation and failure of landslide dams: an approach to risk assessment. Ital. J. Eng. Geol. Environ. 1 (2006)
7. Korup, O.: Recent research on landslide dams – a literature review with special attention to New Zealand. Progress Phys. Geogr. **26**(2), 206–235 (2002)
8. Korup, O.: Geomorphic hazard assessment of landslide dams in South Westland, New Zealand: fundamental problems and approaches. Geomorphology **66**, 67–188 (2005)
9. Dai, F.C., Lee, C.F., Deng, J.H., Tham, L.G.: The 1786 earthquake-triggered landslide dam and subsequent dam-break flood on the Dadu River, southwestern China. Geomorphology **65**(3–4), 205–221 (2005)
10. Xu, F.G., Yang, X.G., Zhou, J.W.: Experimental study of the impact factors of natural dam failure introduced by a landslide surge. Environ Earth Sci. **74**, 4075–4087 (2013)
11. Ray, P.K.C., Chattoraj, S.L., Bisht, M.P.S., Kannaujiya, S., Pandey, K., Goswami, A.: (2016) Kedarnath disaster 2013: causes and consequences using remote sensing inputs. Nat. Hazards **81**, 227–243 (2016)
12. Genevois, R., Ghirotti, M.: The 1963 Vajont landslide. Giornale di Geologia Applicata **1**, 41–52 (2005)

13. Tsou, C.Y., Feng, Z.Y., Chigira, M.: Catastrophic landslide induced by Typhoon Morakot, Shiaolin. Taiwan. Geomorphology **127**, 166–178 (2011)
14. MOI.: Report on Jure landslide, Mankha VDC, Sindhupalchowk district. Nepal Government Ministry of Irrigation (MOI), 2071/06/05 BS, 29 p. (2014)
15. Pinyol, N.M., Alonso, E.E., Corominas, J., Moya, J.: Canelles landslide: modelling rapid drawdown and fast potential sliding. Landslides **9**(1), 33–51 (2012)
16. Wang, F., Zhang, Y., Huo, Z., Peng, X.M.: Mechanism for the rapid motion of the Qianjiangping landslide during reactivation by the first impoundment of the Three Gorges Dam reservoir. China. Landslides **5**(4), 379–386 (2008)
17. Setiawan, H.: Landslide Hazard Assessment on the Upstream of Dam Reservoir. PhD thesis, Kyoto University (2017)
18. Yin, Y., Huang, B., Wang, W., Wei, Y., Ma, X., Zhao, C.: Reservoir-induced landslides and risk control in Three Gorges Project on Yangtze River, China. J. Rock Mech. Geotech. Eng. **8**(2016), 577–595 (2016)
19. Ermini, L., Casagli, N.: Prediction of the behaviour of landslide dams using a geomorphological dimensionless index. Earth Surf. Proc. Land. **28**, 31–47 (2003)
20. Fan, X., van Westen, C.J., Xu, Q., Gorum, T., Dai, F.: Analysis of landslide dams induced by the 2008 Wenchuan earthquake. J. Asian Earth Sci. **57**, 25–37 (2012)
21. Fan, X., van Westen, C.J., Korup, O., Gorum, T., Xu, Q., Dai, F., Huang, R., Wang, G.: Transient water and sediment storage of the decaying landslide dams induced by the 2008 Wenchuan earthquake. China. Geomorphology **171**, 58–68 (2012)
22. Fan, X., Tang, C.X., Van Westen, C.J., Alkema, D.: Simulating dam-breach flood scenarios of the Tangjiashan landslide dam induced by the Wenchuan Earthquake. Nat Hazards Earth Syst Sci **12**, 3031–3044 (2012)
23. Hermanns, R.L.: Landslide dam. In: Bobrowsky, P.T. (ed.) Encyclopedia of earth sciences series, pp. 602–605. Springer, Dordrecht (2013)
24. Korup, O.: Geomorphometric characteristics of New Zealand landslide dams. Eng. Geol. **73**(1), 13–35 (2004)
25. Peng, M., Zhang, L.M.: Breaching parameters of landslide dams. Landslides **9**(1), 13–31 (2012)
26. Stefanelli, C.T., Segoni, S., Casagli, N., Catani F.: Assessing landslide dams evolution: a methodology review. Advancing Culture of Living with Landslides, pp. 253–258 (2017)
27. Stefanelli, C.T., Catani, F., Casagli, N.: Geomorphological investigations on landslide dams. Geoenviron. Disasters **2**, 21 (2015)
28. Tien, P.V.: Mechanisms and Hazard Assessment of Rainfall-Induced Landslide Dams. PhD thesis, Kyoto University (2018)
29. Sako, Y., Mori, T., Nakamura, H., Kamee, K., Hanaoka, M., Yusa, N., Fukuda, M., Ohno, R.: Estimating the shape of a landslide dam (river blockage), attributed to a deep catastrophic landslide, using the LSFLOW model. In: Proceedings of the Interpraevent International Symposium 2014 in Nara Prefecture, Japan (2014)
30. Li, X., He, S., Luo, Y., Wu, Y.: Simulation of the sliding process of Donghekou landslide triggered by the Wenchuan earthquake using a distinct element method". Environ. Earth Sci. **65**(4), 1049–1054 (2012)
31. Yang, Q., Ye, Z., Ding, W., Gao, Y.: Impact of water level fluctuation on the reservoir landslide stability. In: Sassa, K., et al. (eds.) Landslide Science for a Safer Geoenvironment, vol. 3 (2014)
32. Tien, P.V., Luong, L.H.: Landslide Dam's Hazard assessment: a literature review. In: VACI2019 Conference Proceedings. pp. 178–188 (2019). ISBN: 978-604-67-1216-9
33. Kofler, C., Comiti, F., Gems, B., Thiebes, B., Schneiderbauer, S., Schlögel, R.: Assessment of Rockslide Dam Scenarios at Catchment Scale in the Context of Cascading Hazards. Advancing Culture of Living with Landslides, pp. 685–691 (2017)

34. Tien, P.V., Sassa, K., Takara, K., Fukuoka, H., Khang, D., Shibasaki, T., Hendy, S., Ha, N.D., Loi, D.H.: Formation process of two massive dams following rainfall-induced deep-seated rapid landslide failures in the Kii Peninsula of Japan. Landslides (2018)
35. Panizzo, A., Girolamo, P., De Risio, M., Di Maistri, A., Petaccia, A.: Great landslide events in Italian artificial reservoirs. Nat. Hazards Earth Syst. Sci. **5**, 733–740 (2005)
36. Biscarini, C.: Computational fluid dynamics modelling of landslide generated water waves. Landslides **7**(2), 117–124 (2010)
37. Ataie-Ashtiani, B., Yavari-Ramshe, S.: Numerical simulation of wave generated by landslide incidents in dam reservoirs. Landslides **8**(4), 417–432 (2011)
38. Glimsdal, S., L'Heureux, J.S., Harbitz, C.B.: The 29th January 2014 submarine landslide at Statland, Norway—landslide dynamics, tsunami generation, and run-up. Landslides **13**(6), 1435–1444 (2016)
39. Kranzer, H.C., Keller, J.B.: Water waves produced by explosions. J. Appl. Phys. 30, 398–407 (1960)
40. Walder, J.S., Watts, P., Sorensen, O.E., Janssen, K.: Water waves generated by subaerial mass flows. J. Geophys. Res. **108**(5), 2236–2255 (2003)
41. Hanes, D.M., Inman, D.L.: Experimental evaluation of a dynamic yield criterion for granular fluid flows. J Geophys Res **90**(B5), 3670–3674 (1985)
42. Heinrich, P.: Nonlinear water waves generated by submarine and aerial landslides. ASCE J. Waterways Port Coastal Oc. Eng. **118**, 249–266 (1992)
43. Srex.: The Vietnam special report on managing the risks of extreme events on disasters to advance climate change adaptation. IMHEN and UNDP (2015)
44. Dieu, T.B., Binh, T.P., Phi, Q.N., Nhat, H.D.: Spatial prediction of rainfall-induced shallow landslides using hybrid integration approach of Least-Squares Support Vector Machines and differential evolution optimization: a case study in Central Vietnam. International Journal of Digital Earth **9**, 1077–1097 (2016)
45. Duc, D.M.: Rainfall-triggered large landslides on 15 December 2005 in Van Canh district, Binh Dinh province. Vietnam. Landslides **10**, 219–230 (2013)
46. Lan, C.N., Tien, P.V., Do, T.N.: Deep-seated rainfall-induced landslides on a new expressway: a case study in Vietnam. Landslides **17**(2), 395–407 (2019)
47. Thục, T., Ha, L.T.: Flashfloods-Background and methodologies. Publisher of Natural Science and Technology in Hanoi (2012)
48. Tam, D.M.: Flooding and landslides at the highways of Vietnam. In: Proceedings of the International Workshop on "Saving Our Water and Protecting Our Land", Hanoi, 20–22 October, 2001, pp. 18–27 (2001)
49. Vietnam Disaster Management Authority (VDMA) Flash floods and landslides in Vietnam. A presentation report, Scientific Meeting on October 2019, Hanoi, Vietnam (2019)
50. Tu, T.V., Duc, D.M., Tung, N.M., Cong, V.D.: Preliminary assessments of debris flow hazard in relation to geological environment changes in mountainous regions, North Vietnam. Vietnam J. Earth Sci. **38**(3), 277–286 (2016)
51. Minh, V.C., Chuong, P.D., Minh, T., Thang, T., Tu, D.V., Tu, T.V., Dan, N.L., Can, N., Chat, V.V., Hai, T.Q., Kha, T.V., Hoan, N.T., Linh, P.D., Hai, N.P., Cuc, L.T., Nhan, P.T.: Report on the assessment of landslides and debris flows and the proposals of countermeasures in Lai Chau. Institute of Geological Sciences - Vietnam Academy of Science and Technology (1997)
52. SFLP: Report on landslides in Laocai, the State-Funded Landslide Project (SFLP) for Investigation, assessment and warning zonation for landslides in the mountainous regions of Vietnam (2014)
53. Nghi, H.Q., Khuong, D.V., Linh, N.M.: An application of GIS for landslides and flash floods hazard forecast maps in Son La. Journal of Water Resources Science and Technology, Vietnam Academy for Water Resources (2012)

54. Nga, P.T.T., Duy, N., Archana, R.S., Matthias, G.: Vulnerability assessment of households to flash floods and landslides in the poor upland regions of Vietnam. Clim. Risk Manage. **28**, 100215 (2020)
55. Nhandan Online News. https://www.nhandan.com.vn
56. Radio The Voice of Vietnam (VOV) (2012). https://vov.vn/xa-hoi/hinh-anh-sat-lo-nui-chan-dong-suoi-coc-tai-lao-cai-226451.vov
57. Hoa Binh Online News. https://www.baohoabinh.com.vn/274/119827/Tro-lai-noi-xay-ra-lo-dat-kinh-hoang-xom-Khanh.htm
58. Lao Dong Online News. https://laodong.vn/xa-hoi/can-canh-thac-khanh-truoc-khi-sat-lo-chon-lap-18-nguoi-o-hoa-binh-570142.ldo
59. Duc, D.M., Khang, D., Duc, D.M., Ngoc, D.M., Quynh, D.Q., Thuy, D.T., Giang, N.K.H., Tien, P.V., Ha, N.H.: Analysis and modeling of a landslide-induced tsunami-like wave across the Truong river in Quang Nam province, Vietnam. Landslides (2020)
60. Sassa, K., Nagai, O., Solidum, R., Yamazaki, Y., Ohta, H.: An integrated model simulating the initiation and motion of earthquake and rain induced rapid landslides and its application to the 2006 Leyte landslide. Landslide **7**(3), 219–236 (2010)
61. Sassa, K., Dang, K., Yanagisawa, H., He, B.: A new landslide-induced tsunami simulation model and its application to the 1792 Unzen-Mayuyama landslide-and-tsunami disaster. Landslides **13**(6), 1405–1419 (2016)
62. Tan Lac Radio and Television: A published video on Khanh village before and after the landslide disaster (2017)
63. Lao Dong Online News. https://laodong.vn/xa-hoi/tai-nan-hy-huu-sat-nui-ben-kia-song-xoa-so-lang-ben-nay-574774.ldo
64. Binh Dinh Irrigation Works Operation Limited Company. A report on Landslides in Van Hoi reservoir released on 19 September 2016 (No. 150/BC-KTCTTL). https://khaithacthuyloibinhdinh.com.vn
65. Department of Geology and Mineral Resources (DGM) Geological and mineral resources map of Vietnam on 1: 200,000 (1999)
66. Luong, L.H.: Large scale landslide risk evaluation by aerial photograph interpretation and integrated ahp approach for humid tropical region based on Japan and Viet nam field surveys. Ph.D. thesis. Tohoku Gakuin University (2016)