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Community Empowerment in Landslide Management in Sonyo Hamlet

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ABSTRACT

Soyo Hamlet is led by Mr. Suranto as the head of the hamlet. The hamlet itself consists of eight RTs with 173 family heads. The hamlet is located in a mountainous area in the Kulon Progo district. Soyono Hamlet is bordered by Sidomulyo Hamlet and Mount Kelir Hamlet. Soyo Hamlet, which is located in a mountainous area, has many problems. One of the problems that have come to our attention is the problem of vulnerability to natural disasters. Natural disasters that often occur in the village are landslides. It is feared that in the rainy season like today, heavy rains can cause landslides. Based on the above problems, this community service designs and implements a landslide early warning tool. This tool is made using the main component is a microcontroller which is used as a data processor, a sensor uses a potentiometer to detect ground movement, and a siren. In addition to installing landslide equipment, this community service also provides lessons on landslide recovery

KEYWORDS
Early Warning System;
Landslide;
Microcontroller;
Sono Village

1. Introduction

Dukuh Sonyo itself consists of eight RTs with 173 family heads. Based on the information our team got from Mr. Suranto as the head of the hamlet. Pedukuhan Sonyo has several groups of informal community organizations such as youth organizations, PKK women. Soyono Hamlet is bordered by Sidomulyo Hamlet and Mount Kelir Hamlet. The majority of the population of Sonyo Hamlet are Muslim and have a livelihood as laborers, but there are also those who work as entrepreneurs because the geographical location of Sonyo Hamlet is located in the highlands. Dukuh Soyo area is a mountainous area located in Kulon Progo district. The area has the potential to be prone to natural disasters. During the rainy season, the Sonyo Hamlet area often experiences landslides. Although this natural disaster did not cause loss of life and property, we must overcome this natural disaster. Research on landslide disaster mitigation is a reference in this community service. Clayey's Viscous Behavior Modeling Using a Single Mechanical Analog Model was investigated by Mohd Nazer [1]. IoT-based hydrological monitoring of water-induced landslides: a case study in Norway under investigation by Oguz [2]. Exploring the potential for reanalysis of ERA5 to support landslide investigations: a test case from the Campania Region (Southern Italy) studied by Reder [3]. Empirical Based Rainfall Threshold for Landslide Event in Cameron Highlands, Malaysia studied by Maturidi [4].

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The monitoring strategy for a local landslide early warning system was investigated by Pecoraro [5]. Regional re-analysis of landslide events using the TRIGRS model and rainfall threshold: an approach to estimating landslide hazard for Kodagu, India studied by Rana [6]. Landslide Forecasting Using Mobility Functions: A Case Study from Idukki District, India researched by Abraham [7]. An algorithm for intelligent prediction of landslide displacement was investigated by [8]. The formulation of a landslide risk scenario using underground monitoring data and numerical models: a conceptual approach, analysis, and evolution of a case study in Southern Italy researched by Segalini [9]. A double tree reinforcement framework for estimating the warning level of rainfall-induced landslides was investigated by Pham [10]. Trigger factors and critical thresholds for landslides in Rio de Janeiro-RJ, Brazil were investigated by Ehrlich [11]. The application of intelligent algorithms in the prevention and early warning of mass landslides was investigated by Yan [12]. Application-based intelligent landslide monitoring system design and operation: the case of the Three Gorges Reservoir Area was studied by Tao [13]. The prediction of groundwater level based on the combined intelligence method for the Sifangbei landslide in the Three Gorges Reservoir Area was studied by Zeng [14]. Landslide prediction based on enhanced principal component analysis and least squares of mixed kernel functions supports the vector regression model studied by Li [15]. Selection of rain gauges and rainfall parameters in estimating intensity-duration thresholds for landslide events: A case study from Wayanad (India) investigated by Abraham [16].

Towards setting a rainfall threshold for a real-time landslide early warning system in Sikkim, India was researched by Harilal [17]. The present rainfall model for an early warning system applied to the case in Central Italy was investigated by De Luca [18]. The advantages of an IoT-based geotechnical monitoring system that integrates automated procedures for data acquisition and elaboration were investigated by Carri [19]. A landslide early warning system with a gsm modem based on a microcontroller using rain sensors, soil shift and accelerometer was investigated by Suryadi [20]. Modeling of the 2018 Collapse of Anak Krakatau and the Tsunami: The Effect of Landslide Failure Mechanisms and Dynamics on Tsunami Generation studied by Zengaffinen [21]. The evaluation of processes and potential for landslides in the Shenmu sub-watershed, Taiwan is being investigated by Lin [22]. An experimental investigation on the process of formation of a landslide dam and criteria for river blockage was investigated by Nian [23]. Characteristics, mechanisms, and post-disaster lessons of delayed semi-diagenetic landslides in Hanyuan, Sichuan, China were studied by Hou [24]. Improving the reliability of landslide early warning systems with machine learning was investigated by Thirugnanam [25]. Towards a shiftable rainfall vulnerability threshold approach for landslides was investigated by Monsieurs [26]. A proposed Sri Lankan warning system update for east and west coast tsunamis was investigated by Wickramaratne [27]. Landslides were captured in the seismic network and satellite radar investigated by Manconi [28].

The assessment of temporal probabilities and their use in mapping landslide susceptibility for Eastern Bhutan was investigated by Dikshit [29]. Simultaneous state-parameter estimation of rainfall-induced landslide displacement using data assimilation was investigated by Wang [30]. Research on monitoring cracks on trailing edge landslides based on image processing was investigated by Wang [31]. A Cost-Effective Single Frequency GPS Network as a Landslide Monitoring Tool was investigated by [32]. The Estimation of Landslide Risk Threshold in the Three Gorges Reservoir based on the KDE-Copula-VaR Approach was studied by Zhang [33]. Landslide Estimation Due to Rainfall Using the TRIGRS Model was investigated by Dikshit [34]. A rock landslide early warning system that combines slope stability analysis, two-stage monitoring, and case-based reasoning: a case study researched by Liu [35]. Avalanche Warning Model Hybrid Coupling Vulnerability Zoning and Rainfall studied by Sun [36]. Machine Learning: New Potential for Current Broadcasting of Local and Regional Landslides researched by [37]. The development of a community-based landslide early warning system in the Nepal Himalayan earthquake affected area was investigated by Thapa [38]. A new displacement prediction method using a gate repeating unit model with time series analysis on the Erdaohe landslide was investigated by Zhang [39]. Using ensemble quantitative rainfall forecasts for prediction of shallow landslides caused by rainfall

was investigated by Ho [40]. The integration of the observed groundwater level and derived from the model in the landslide threshold model in Rwanda was investigated by Uwihirwe [41]. Combining Site Characterization, Monitoring, and Hydromechanical Modeling to Assess Slope Stability was investigated by Moradi [42].

The standard for assessing the performance of the territorial landslide early warning system was investigated by Piciullo [43]. Applying the Series and Parallel Models and the Bayesian Networks Model to Generate a Disaster Chain Vulnerability Map in the Changbai Mountain area, China was researched by Han [44]. Rainfall assessment of landslides in Fengjie County, Three Gorge reservoir area, China was studied by Wang [45]. From this reference, we can overcome the problems that exist in Sunyo Hamlet. The problem in Soyono Hamlet that has caught our attention is the problem of the vulnerability of natural disasters, because Soyo Hamlet is located on a mountain slope and there are many towering trees. landslides or other natural disasters will occur. The problem that occurs in Soyono Hamlet is that when the rainy season occurs, Soyono Hamlet has the potential to be prone to Landslide Disasters. From these problems, this community service contributed to implementing landslide early warning tools in the village.

2. Method

The activity plans in order to implement the solutions offered, in detail are:

1) Manufacture of Landslide Early Warning Tool

This activity aims to make a landslide detection tool. The manufacture was carried out in a workshop majoring in electrical engineering, University of Muhammadiyah Yogyakarta, involving several students and technicians.

2) Installation

The installation of landslide detection is assisted by KKN students and civil engineering lecturers who have knowledge of landslides. In addition to installing these tools, we provide solutions for landslide prevention.

3. Results and Discussion

This community service activity program involves partners in Sonyi hamlet. The first step in this program is an initial site survey whose purpose is to find out the problems and potentials that exist in Soyo Village. The initial site survey was carried out on January 2, 2020 and was attended by the entire service team, and the UMY Community Service Team as shown in Fig. 1.

Fig. 1. Initial Location Survey

From the picture, it can be seen that Soyo hamlet has the potential for a very terrible natural disaster. It can be seen from the picture that there is a landslide in the Sonyo area. After the problem has been identified, the next step is to coordinate with partners regarding the socialization of landslide natural disasters in Sonyo Hamlet, Girimulyo District, Kulon Progo Regency. In this coordination, a mutual agreement has been reached to carry out community service activities according to the process and time of implementation. This agreement is an important commitment for the success of community service activities with the superior product "making landslide detection equipment" in Kulon Progo Regency. The landslide hazard counseling was carried out on January 20, 2020 and was attended by the entire community service team, partners, KKN UMY team and village heads as shown in Fig. 2. Hamlet Sonyo.

Fig. 2. Survey Starting Location

After the socialization activity, it was continued with the installation on January 23, 2020 and was attended by the entire community service team, partners, KKN UMY team and village heads. The implementation of the installation of landslide detection equipment in the Partner Group is shown in Fig. 3.

Fig. 3. Tool Installation

This activity in counseling and socializing the installation of landslide detection equipment in Dusun Sonyo, Girimulyo District, Kulonprogo Regency has been published in the mass media. Socialization activities and training activities have been published by the mass media at Trimbun Jogja, Thursday Pon 27 February 2020.

4. Conclusion

The conclusions that can be drawn from PKM activities for community empowerment in preventing landslides in Soyono Hamlet are as follows: (1) The initial site survey was carried out on January 2, 2020 and was attended by the entire community service team, and the UMY Community Service Team as shown in Figure 1. (2) Coordination with partners regarding the socialization of landslide natural disasters in Sonyo Hamlet, Girimulyo District, Kulon Progo Regency. (3) After the Socialization activity, it was continued with the installation on January 23, 2020 and was attended by the entire service team, partners, KKN UMY team and village heads. Implementation of the installation of landslide detection tools in the Partner Group. The output of the activity is a landslide detection tool. Suggestions for the next activity are monitoring and evaluating the sustainability of the Salak Pondok coffee powder business unit, ensuring product quality standards from instant coffee produced, improving product packaging and labeling and expanding retail-based marketing networks.

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Author Contribution

All authors contributed equally to the main contributor to this paper. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] N. S. Mohd Nazer, "Modelling Viscous Behaviour of Clayey Geomaterials using Single Mechanical- Analogue Model," *Sains Malaysiana*, vol. 48, no. 11, pp. 2521–2528, Nov. 2019, doi: 10.17576/jsm-2019-4811-22.

[2] E. A. Oguz, I. Depina, B. Myhre, G. Devoli, H. Rustad, and V. Thakur, "IoT-based hydrological monitoring of water-induced landslides: a case study in central Norway," *Bull. Eng. Geol. Environ.*, vol. 81, no. 5, p. 217, May 2022, doi: 10.1007/s10064-022-02721-z.

[3] A. Reder and G. Rianna, "Exploring ERA5 reanalysis potentialities for supporting landslide investigations: a test case from Campania Region (Southern Italy)," *Landslides*, vol. 18, no. 5, pp. 1909–1924, May 2021, doi: 10.1007/s10346-020-01610-4.

[4] A. M. A. M. Maturidi, N. Kasim, K. A. Taib, W. N. A. W. Azahar, and H. A. Tajuddin, "Empirically Based Rainfall Threshold for Landslides Occurrence in Cameron Highlands, Malaysia," *Civ. Eng. Archit.*, vol. 8, no. 6, pp. 1481–1490, Dec. 2020, doi: 10.13189/cea.2020.080629.

[5] G. Pecoraro, M. Calvello, and L. Piciullo, "Monitoring strategies for local landslide early warning systems," *Landslides*, vol. 16, no. 2, pp. 213–231, Feb. 2019, doi: 10.1007/s10346-018-1068-z.

[6] H. Rana and G. L. S. Babu, "Regional back analysis of landslide events using TRIGRS model and rainfall threshold: an approach to estimate landslide hazard for Kodagu, India," *Bull. Eng. Geol. Environ.*, vol. 81, no. 4, p. 160, Apr. 2022, doi: 10.1007/s10064-022-02660-9.

[7] M. T. Abraham, N. Satyam, and B. Pradhan, "Forecasting Landslides Using Mobility Functions: A Case Study from Idukki District, India," *Indian Geotech. J.*, vol. 51, no. 4, pp. 684–693, Aug. 2021, doi: 10.1007/s40098-020-00490-8.

[8] Z. Liu, D. Guo, S. Lacasse, J. Li, B. Yang, and J. Choi, "Algorithms for intelligent prediction of landslide displacements," *J. Zhejiang Univ. A*, vol. 21, no. 6, pp. 412–429, Jun. 2020, doi: 10.1631/jzus.A2000005.

[9] A. Segalini, A. Carri, C. Grignaffini, and G. Capparelli, "Formulation of landslide risk scenarios using underground monitoring data and numerical models: conceptual approach, analysis, and evolution of a case study in Southern Italy," *Landslides*, vol. 16, no. 5, pp. 1043–1053, May 2019, doi: 10.1007/s10346-019-01137-3.

[10] K. Pham, D. Kim, C. V. Le, and H. Choi, "Dual tree-boosting framework for estimating warning levels of rainfall-induced landslides," *Landslides*, vol. 19, no. 9, pp. 2249–2262, Sep. 2022, doi: 10.1007/s10346-022-01894-8.

[11] M. Ehrlich, B. J. Luiz, C. G. Mendes, and W. A. Lacerda, "Triggering factors and critical thresholds for landslides in Rio de Janeiro-RJ, Brazil," *Nat. Hazards*, vol. 107, no. 1, pp. 937–952, May 2021, doi: 10.1007/s11069-021-04616-w.

[12] Y. Yan and M. A. Ashraf, "The application of the intelligent algorithm in the prevention and early warning of mountain mass landslide disaster," *Arab. J. Geosci.*, vol. 13, no. 2, p. 79, Jan. 2020, doi: 10.1007/s12517-020-5116-3.

[13] Z. Tao, H. Zhang, C. Zhu, Z. Hao, X. Zhang, and X. Hu, "Design and operation of App-based intelligent landslide monitoring system: the case of Three Gorges Reservoir Region," *Geomatics, Nat. Hazards Risk*, vol. 10, no. 1, pp. 1209–1226, Jan. 2019, doi: 10.1080/19475705.2019.1568312.

[14] T. Zeng, K. Yin, H. Jiang, X. Liu, Z. Guo, and D. Peduto, "Groundwater level prediction based on a combined intelligence method for the Sifangbei landslide in the Three Gorges Reservoir Area," *Sci. Rep.*, vol. 12, no. 1, p. 11108, Dec. 2022, doi: 10.1038/s41598-022-14037-9.

[15] L. Li, S. Cheng, and Z. Wen, "Landslide prediction based on improved principal component analysis and mixed kernel function least squares support vector regression model," *J. Mt. Sci.*, vol. 18, no. 8, pp. 2130–2142, Aug. 2021, doi: 10.1007/s11629-020-6396-5.

[16] M. T. Abraham, N. Satyam, A. Rosi, B. Pradhan, and S. Segoni, "The Selection of Rain Gauges and Rainfall Parameters in Estimating Intensity-Duration Thresholds for Landslide Occurrence: Case Study from Wayanad (India)," *Water*, vol. 12, no. 4, p. 1000, Apr. 2020, doi: 10.3390/w12041000.

[17] G. T. Harilal, D. Madhu, M. V. Ramesh, and D. Pullarkatt, "Towards establishing rainfall thresholds for a real-time landslide early warning system in Sikkim, India," *Landslides*, vol. 16, no. 12, pp. 2395–2408, Dec. 2019, doi: 10.1007/s10346-019-01244-1.

[18] D. L. De Luca and G. Capparelli, "Rainfall nowcasting model for early warning systems applied to a case over Central Italy," *Nat. Hazards*, vol. 112, no. 1, pp. 501–520, May 2022, doi: 10.1007/s11069-021-05191-w.

[19] A. Carri, A. Valletta, E. Cavalca, R. Savi, and A. Segalini, "Advantages of IoT-Based Geotechnical Monitoring Systems Integrating Automatic Procedures for Data Acquisition and Elaboration," *Sensors*, vol. 21, no. 6, p. 2249, Mar. 2021, doi: 10.3390/s21062249.

[20] Suryadi, M. Yuliza, A. Chandranata, and Yulindon, "LANDSLIDES EARLY WARNING SYSTEM WITH GSM MODEM BASED ON MICROCONTROLLER USING RAIN, SOIL SHIFT AND ACCELEROMETER SENSORS," *Int. J. GEOMATE*, vol. 19, no. 71, pp. 137–144, Jul. 2020, doi: 10.21660/2020.71.00949.

[21] T. Zengaffinen, F. Løvholt, G. K. Pedersen, and A. Muhari, "Modelling 2018 Anak Krakatoa Flank Collapse and Tsunami: Effect of Landslide Failure Mechanism and Dynamics on Tsunami Generation," *Pure Appl. Geophys.*, vol. 177, no. 6, pp. 2493–2516, Jun. 2020, doi: 10.1007/s00024-020-02489-x.

[22] B.-S. Lin, K. Thomas, C.-K. Chen, and H.-C. Ho, "Evaluation of landslides process and potential in Shenmu sub-watersheds, central Taiwan," *Landslides*, vol. 16, no. 3, pp. 551–570, Mar. 2019, doi: 10.1007/s10346-018-1109-7.

[23] T. Nian, H. Wu, D. Li, W. Zhao, K. Takara, and D. Zheng, "Experimental investigation on the formation process of landslide dams and a criterion of river blockage," *Landslides*, vol. 17, no. 11, pp. 2547–2562, Nov. 2020, doi: 10.1007/s10346-020-01494-4.

[24] R. Hou, N. Chen, G. Hu, Z. Han, and E. Liu, "Characteristics, mechanisms, and post-disaster lessons of the delayed semi-diagenetic landslide in Hanyuan, Sichuan, China," *Landslides*, vol. 19, no. 2, pp. 437–449, Feb. 2022, doi: 10.1007/s10346-021-01751-0.

[25] H. Thirugnanam, M. V. Ramesh, and V. P. Rangan, "Enhancing the reliability of landslide early warning systems by machine learning," *Landslides*, vol. 17, no. 9, pp. 2231–2246, Sep. 2020, doi: 10.1007/s10346-020-01453-z.

[26] Monsieurs, Dewitte, Depicker, and Demoulin, "Towards a Transferable Antecedent Rainfall—Susceptibility Threshold Approach for Landsliding," *Water*, vol. 11, no. 11, p. 2202, Oct. 2019, doi: 10.3390/w11112202.

[27] S. Wickramaratne, S. C. Wirasinghe, and J. Ruwanpura, "An update of proposed Sri Lanka warning system for east and west coast tsunamis," *Int. J. Disaster Resil. Built Environ.*, vol. 11, no. 2, pp. 169–186, Dec. 2019, doi: 10.1108/IJDRBE-08-2019-0052.

[28] A. Manconi and A. C. Mondini, "Landslides caught on seismic networks and satellite radars," *Nat. Hazards Earth Syst. Sci.*, vol. 22, no. 5, pp. 1655–1664, May 2022, doi: 10.5194/nhess-22-1655-2022.

[29] A. Dikshit, R. Sarkar, B. Pradhan, R. Jena, D. Drukpa, and A. M. Alamri, "Temporal Probability Assessment and Its Use in Landslide Susceptibility Mapping for Eastern Bhutan," *Water*, vol. 12, no. 1, p. 267, Jan. 2020, doi: 10.3390/w12010267.

[30] J. Wang, G. Nie, S. Gao, and C. Xue, "Simultaneous state–parameter estimation of rainfall-induced landslide displacement using data assimilation," *Nat. Hazards Earth Syst. Sci.*, vol. 19, no. 7, pp. 1387–1398, Jul. 2019, doi: 10.5194/nhess-19-1387-2019.

[31] H. Wang, D. Nie, X. Tuo, and Y. Zhong, "Research on crack monitoring at the trailing edge of landslides based on image processing," *Landslides*, vol. 17, no. 4, pp. 985–1007, Apr. 2020, doi: 10.1007/s10346-019-01335-z.

[32] D. Zuliani, L. Tunini, F. Di Traglia, M. Chersich, and D. Curone, "Cost-Effective, Single-Frequency GPS Network as a Tool for Landslide Monitoring," *Sensors*, vol. 22, no. 9, p. 3526, May 2022, doi: 10.3390/s22093526.

[33] S. Zhang, J. Ma, and H. Tang, "Estimation of Risk Thresholds for a Landslide in the Three Gorges Reservoir Based on a KDE-Copula-VaR Approach," *Geofluids*, vol. 2020, pp. 1–13, Jun. 2020, doi: 10.1155/2020/8030264.

[34] A. Dikshit, N. Satyam, and B. Pradhan, "Estimation of Rainfall-Induced Landslides Using the TRIGRS Model," *Earth Syst. Environ.*, vol. 3, no. 3, pp. 575–584, Dec. 2019, doi: 10.1007/s41748-019-00125-w.

[35] F. Liu et al., "Rock landslide early warning system combining slope stability analysis, two-stage monitoring, and case-based reasoning: a case study," *Bull. Eng. Geol. Environ.*, vol. 80, no. 11, pp. 8433–8451, Nov. 2021, doi: 10.1007/s10064-021-02461-6.

[36] D. Sun, Q. Gu, H. Wen, S. Shi, C. Mi, and F. Zhang, "A Hybrid Landslide Warning Model Coupling Susceptibility Zoning and Precipitation," *Forests*, vol. 13, no. 6, p. 827, May 2022, doi: 10.3390/f13060827.

[37] A. L. van Natijne, R. C. Lindenbergh, and T. A. Bogaard, "Machine Learning: New Potential for Local and Regional Deep-Seated Landslide Nowcasting," *Sensors*, vol. 20, no. 5, p. 1425, Mar. 2020, doi: 10.3390/s20051425.

[38] P. S. Thapa and B. R. Adhikari, "Development of community-based landslide early warning system in the earthquake-affected areas of Nepal Himalaya," *J. Mt. Sci.*, vol. 16, no. 12, pp. 2701–2713, Dec. 2019, doi: 10.1007/s11629-019-5586-5.

[39] Y. Zhang, J. Tang, Z. He, J. Tan, and C. Li, "A novel displacement prediction method using gated recurrent unit model with time series analysis in the Erdaohe landslide," *Nat. Hazards*, vol. 105, no. 1, pp. 783–813, Jan. 2021, doi: 10.1007/s11069-020-04337-6.

[40] J.-Y. Ho, C.-H. Liu, W.-B. Chen, C.-H. Chang, and K. T. Lee, "Using ensemble quantitative precipitation forecast for rainfall-induced shallow landslide predictions," *Geosci. Lett.*, vol. 9, no. 1, p. 22, Dec. 2022, doi: 10.1186/s40562-022-00231-0.

[41] J. Uwihirwe, M. Hrachowitz, and T. Bogaard, "Integration of observed and model-derived groundwater levels in landslide threshold models in Rwanda," *Nat. Hazards Earth Syst. Sci.*, vol. 22, no. 5, pp. 1723–1742, May 2022, doi: 10.5194/nhess-22-1723-2022.

[42] S. Moradi, T. Heinze, J. Budler, T. Gunatilake, A. Kemna, and J. A. Huisman, "Combining Site Characterization, Monitoring and Hydromechanical Modeling for Assessing Slope Stability," *Land*, vol. 10, no. 4, p. 423, Apr. 2021, doi: 10.3390/land10040423.

[43] L. Piciullo, D. Tiranti, G. Pecoraro, J. M. Cepeda, and M. Calvello, "Standards for the performance assessment of territorial landslide early warning systems," *Landslides*, vol. 17, no. 11, pp. 2533–2546, Nov. 2020, doi: 10.1007/s10346-020-01486-4.

[44] L. Han, J. Zhang, Y. Zhang, and Q. Lang, "Applying a Series and Parallel Model and a Bayesian Networks Model to Produce Disaster Chain Susceptibility Maps in the Changbai Mountain area, China," *Water*, vol. 11, no. 10, p. 2144, Oct. 2019, doi: 10.3390/w11102144.

[45] K. Wang and S. Zhang, "Rainfall-induced landslides assessment in the Fengjie County, Three-Gorge reservoir area, China," *Nat. Hazards*, vol. 108, no. 1, pp. 451–478, Aug. 2021, doi: 10.1007/s11069-021-04691-z.