Review: "Cost estimation for the monitoring instrumentalization of Landslide Early Warning Systems" by Sapena et al.

RC1: 'Comment on nhess-2023-41', Anonymous Referee #1

The manuscript entitled "Cost estimation for the monitoring instrumentalization of Landslide Early Warning Systems" develops a cost-effective method for low-cost and easy-to-use EWS instrumentalization in landslide-prone areas identified based on data-driven methods. In general, the manuscript contains an interesting topic that is considered one of the important stages in landslide mechanism assessment; but there are several modifications that have to be considered. In this regard, the following comments are requested to be addressed by the authors:

We greatly appreciate the positive feedback. We would like to express our gratitude for your valuable comments and suggestions. We acknowledge the importance of addressing the modifications highlighted and assure you that we will incorporate the feedback into our work. Please find other comment-by-comment feedback in detail below.

Comment 1: The English of the paper is readable; however, I would suggest the authors have it checked, preferably by a native English-speaking person, to avoid any mistakes.

Answer 1: We agree with the reviewer that the English can be improved. We will proceed as suggested and carefully check and improve the readability of the English style by an English-speaking person.

Comment 2: The necessity & novelty of the manuscript should be presented and stressed in the "Introduction" section.

Answer 2: Thank you for highlighting this. Indeed, we believe that emphasizing the need and novelty of our study will contribute to the enhancement of our manuscript.

We will emphasize that landslide early warning systems (LEWSs) play a vital role in reducing the risk associated with landslides by providing timely information, enabling proactive measures, enhancing public awareness and education, and facilitating better planning and decision-making. Moreover, LEWSs collect data that can be used for scientific research, monitoring, and analyzing landslide behavior. This improves the understanding of landslides, their triggers, and their impacts, leading to better predictive models and more effective LEWSs [1-3].

LEWSs also provide significant economic benefits by reducing damage and loss, facilitating cost-effective planning and response, preserving economic activities, and saving costs in emergency response operations [4]. These economic advantages make investing in early warning systems (EWSs) a prudent choice. However, the cost of implementing a LEWS can vary significantly depending on various factors such as the size and complexity of the area to be monitored, the technology and infrastructure used, and the level of sophistication of the system.

As of today, estimating the costs of implementing LEWSs remains challenging due to various factors influencing the overall expenses. The implementation of a comprehensive LEWS entails substantial investments, encompassing equipment costs, infrastructure development, ongoing maintenance, and personnel expenses. Recognizing this knowledge gap, this study takes a significant leap forward by providing cost estimations for the instrumentalization of a low-cost, local, and site-specific LEWS. Furthermore, we identify highly exposed landslide-prone areas that are candidates for the installation of LEWSs in the city of Medellín. To assist decision-makers in their prioritization efforts, we offer valuable recommendations based on different cost-effectiveness scenarios. Our ultimate goal is to provide decision-makers with a comprehensive assessment that facilitates the strategic implementation of LEWSs, ensuring maximum impact and cost-efficiency.

[1] Guzzetti, F., Gariano, S. L., Peruccacci, S., Brunetti, M. T., Marchesini, I., Rossi, M., & Melillo, M. (2020). Geographical landslide early warning systems. Earth-Science Reviews, 200, 102973.

[2] WMO (2018). Multi-Hazard Early Warning Systems: A Checklist. Report. url: https://library.wmo.int/doc_num.php?explnum_id=4463. Accessed 24/05/2023.

[3] Segoni, S., Serengil, Y. & Aydin, F. A prototype landslide early warning system in Rize (Turkey): analyzing recent impacts to design a safer future. Landslides20, 683–694 (2023). Doi:10.1007/s10346-022-01988-3

[4] Rogers, D., Tsirkunov, V. (2011). Costs and benefits of early warning systems. Global assessment rep.

Comment 3: Provide a literature of the methods developed/applied on landslide mechanism assessment and modeling in "Introduction". The use of a table to demonstrate the advantage-disadvantage of these methods can be useful. Towards the end, mention the superiority & repeat the novelty of your work.

Answer 3: Thank you for your comment. In this paper, our focus was not on comparing various methods for mapping landslide susceptibility, as extensive research has already been conducted in this area [5-11]. Instead, we chose to implement a robust and validated method, specifically random forest, due to its proven accuracy in mapping landslide susceptibility, especially in Colombia when compared to other methods [7]. However, we acknowledge the importance of providing a more comprehensive overview of the existing methods in the introduction. Consequently, we will enhance the paragraph concerning the introduction of data-driven methods for mapping landslide susceptibility using EO data.

We propose to enhance the introduction with a paragraph such as:

"*Landslide susceptibility modeling has witnessed an increase in popularity due to the advancements in remote sensing, and statistical and machine learning models. Data-driven approaches have demonstrated significant potential in effectively mapping areas prone to landslides, particularly in situations where the availability of comprehensive geotechnical data required for physically-based methods are lacking. Some of the most common data-driven methods include Random forest [6-9], Logistic regression [8], Convolutional and Artificial Neuronal Networks [5,7,8], Gradient Boosted Regression Trees [7], Weight of Evidence [7], Supported Vector Machine [5,8], K-Nearest Neighbor [5,9], Naïve Bayes [9], and Linear discriminant analysis [11]. It is worth noting that, currently, there is no definitive method established as the optimal choice for empirical susceptibility modeling. In recent literature, various methods have been employed, compared, and their accuracies and suitability have shown regional variations. In this study, we implement the Random Forest method due to its demonstrated high accuracy in Colombia [7]. Additionally, this method offers the advantage of being non-parametric, allowing for the inclusion of non-normalized conditioning factors, and it is relatively straightforward to implement*".

[5] Nikoobakht, S.; Azarafza, M.; Akgün, H.; Derakhshani, R. Landslide Susceptibility Assessment by Using Convolutional Neural Network. Appl. Sci. 2022, 12, 5992. https://doi.org/10.3390/app12125992

[6] Taalab, K., Cheng, T., Zhang, Y. (2018) Mapping landslide susceptibility and types using Random Forest, Big Earth Data, 2:2, 159-178, Doi: 10.1080/20964471.2018.1472392

[7] Calderón-Guevara, W., Sánchez-Silva, M., Nitescu, B. et al. Comparative review of data-driven landslide susceptibility models: case study in the Eastern Andes mountain range of Colombia. Nat Hazards 113, 1105–1132 (2022). Doi: 10.1007/s11069-022-05339-2

[8] Ado, M.; Amitab, K.; Maji, A.K.; Jasi´nska, E.; Gono, R.; Leonowicz, Z.; Jasi´nski, M. Landslide Susceptibility Mapping Using Machine Learning: A Literature Survey. Remote Sens. 2022, 14, 3029. Doi: 10.3390/rs14133029

[9] Abu El-Magd, S.A., Ali, S.A. & Pham, Q.B. Spatial modeling and susceptibility zonation of landslides using random forest, naïve bayes and K-nearest neighbor in a complicated terrain. Earth Sci Inform 14, 1227–1243 (2021). Doi:10.1007/s12145-021-00653-y

[10] Azarafza, M., Azarafza, M., Akgün, H., Atkinson, P. M., and Derakhshani, R.: Deep learning-based landslide susceptibility mapping, Sci Rep, 11, 24112, Doi:10.1038/s41598-021-03585-1, 2021.

[11] Eiras, C. G. S., Souza, J. R. G. de, Freitas, R. D. A. de, Barella, C. F., and Pereira, T. M.: Discriminant analysis as an efficient method for landslide susceptibility assessment in cities with the scarcity of predisposition data, Nat Hazards, 107, 1427–1442, https://doi.org/10.1007/s11069-021-04638-4, 2021.

Comment 4: Please add a subsection clearly articulating the main limitations, wider applicability of your methods, and findings in the "Discussion" section.

Answer 4: Thank you for your suggestion. We appreciate your feedback regarding the discussion section of our study. In the current version of the manuscript, we focused on discussing the challenges associated with training a random forest model using different data sources and how it impacted the accuracy of mapping landslide susceptibility. We also mentioned the selection of suitable exposed sites and the need for adaptation in different regions. Additionally, we reflected on the uncertainties surrounding the cost function and the exclusion of certain costs related to maintenance, warning elements, safety signs, social work, and operating the LEWSs.

However, we recognize the importance of addressing the limitations more explicitly. In the revised version of the manuscript, we will provide a more detailed discussion of the limitations. For instance, we will delve into how the specific model applied for mapping landslide susceptibility, along with the assigned thresholds, may have influenced the identification of exposed suitable sites in Medellín. We acknowledge that these factors could impact the size, complexity, and overall accuracy of the identified sites, which in turn affect the cost estimation. Nevertheless, we would like to emphasize that our selection of 32 sites covers a significant portion of highly-populated exposed locations in Medellín, encompassing a diverse range of sizes and complexities. This allows for comparability in cost estimation across different sites.

Furthermore, we would like to acknowledge in the discussion that our cost estimation was based solely on a previous LEWS implemented in a specific neighborhood of Medellín, which exhibits certain unique characteristics such as being an informal settlement, highly vulnerable due to its low-quality building structures, with medium building density, steep slopes, and ample open spaces. We provided the cost of instruments and working hours for this specific case and used it as a basis to estimate costs in other areas, aiming to extrapolate the costs to other neighborhoods. However, we agree that it is crucial to clearly state this limitation in the manuscript, e.g. that different conditions than in our sample case may hold some hidden costs that cannot be assessed with current knowledge.

Furthermore, we recognize the importance of clearly stating the applicability of our workflow to improve the impact of our study. Therefore, we intend to incorporate a new paragraph in the discussion that highlights how our approach can be applied to other regions. For example:

"*In recent years, there has been a significant increase in the utilization of data-driven methods and EO-derived data for mapping landslide susceptibility [5-11] and generating finer-grained population distribution maps [12-13]. These advancements make it possible to identify highly exposed and landslide-prone areas in different regions worldwide. In our study, we proposed a workflow that can be applied to identify exposed sites suitable for implementing low-cost LEWSs and developed a function to estimate the cost of instrumentalization based on area, susceptibility, and building density. This approach allows for the assessment and comparison of estimated costs across multiple sites. We believe that this open and transparent cost estimation for LEWS is one of the key contributions of our study, serving as a valuable reference for other regions*."

Regarding the findings of our study, we recognize the need to provide a concise paragraph that summarizes the key outcomes beyond what has already been discussed in the initial part of the discussion. For instance:

"*Through the application of our proposed workflow, we successfully identified critical locations characterized by high exposure, high vulnerability, and susceptibility to landslides. These locations can be assessed by the municipality of Medellín to implement LEWSs based on their available budget. Implementing LEWSs in these areas has the potential to enhance the resilience of thousands of individuals residing in various parts of the city. Moreover, by utilizing the developed cost function, we were able to suggest cost-effectiveness scenarios that align with the financial resources allocated for risk management. As a result, our study provides valuable decision-making support on where to proceed with LEWS implementation following the successful deployment in Bello Oriente [14].*"

By highlighting the significance of our findings in identifying critical locations, considering cost-effectiveness, and supporting decision-making, we aim to effectively communicate the practical implications and contributions of our study.

[12] Metzger, N., Vargas-Muñoz, J.E., Daudt, R.C. et al. (2022) Fine-grained population mapping from coarse census counts and open geodata. Sci Rep 12, 20085. Doi:10.1038/s41598-022-24495-w

[13] Sapena, M., Kühnl, M., Wurm, M., Patino, J. E., Duque, J. C., and Taubenböck, H. (2022). Empiric recommendations for population disaggregation under different data scenarios, PLoS ONE, 17, e0274504, Doi:10.1371/journal.pone.0274504.

[14] Werthmann, C., Sapena, M., Kühnl, M., Singer, J., Garcia, C., Menschik, B., Schäfer, H., Schröck, S., Seiler, L., Thuro, K., and Taubenböck, H.: Inform@Risk. The Development of a Prototype for an Integrated Landslide Early Warning System in an Informal Settlement: the Case of Bello Oriente in Medellín, Colombia, Nat. Hazards Earth Syst. Sci. Discuss. [preprint], Doi:10.5194/nhess-2023-53, in review, 2023.

Comment 5: The authors should deepen the discussion.

Answer 5: By considering the answer to the previous comment and incorporating the proposed changes, alongside our willingness to address any concerns together with the changes we plan to make based on RC2 comments, we believe that this enhances and deepens the discussion.

Comment 6: As a suggestion, the following articles could be useful for improving this manuscript.

1. Nikoobakht, S., Azarafza, M., Akgün, H., & Derakhshani, R. (2022). Landslide susceptibility assessment by using convolutional neural network. Applied Sciences, 12(12), 5992. https://doi.org/10.3390/app12125992
2. Fathani, T.F., Karnawati, D., Wilopo, W., Setiawan, H. (2023). Strengthening the Resilience by Implementing a Standard for Landslide Early Warning System. In: Sassa, K., Konagai, K., Tiwari, B., Arbanas, Ž., Sassa, S. (eds) Progress in Landslide Research and Technology, Volume 1 Issue 1, 2022. Progress in Landslide Research and Technology. Springer, Cham. https://doi.org/10.1007/978-3-031-16898-7_20
3. Nanehkaran, Y. A., Licai, Z., Chengyong, J., Chen, J., Anwar, S., Azarafza, M., & Derakhshani, R. (2023). Comparative Analysis for Slope Stability by Using Machine Learning Methods. Applied Sciences, 13(3), 1555. https://doi.org/10.3390/app13031555
4. Yang, F.-Y.; Zhuo, L.; Xiao, M.-L.; Xie, H.-Q.; Liu, H.-Z.; He, J.-D. A Statistical Risk Assessment Model of the Hazard Chain Induced by Landslides and Its Application to the Baige Landslide. *Appl. Sci.*2023, *13*, 3577. https://doi.org/10.3390/app13063577
5. Gariano, S.L., Melillo, M., Brunetti, M.T., Kumar, S., Mathiyalagan, R., Peruccacci, S. (2023). Challenges in Defining Frequentist Rainfall Thresholds to Be Implemented in a Landslide Early Warning System in India. In: Sassa, K., Konagai, K., Tiwari, B., Arbanas, Ž., Sassa, S. (eds) Progress in Landslide Research and Technology, Volume 1 Issue 1, 2022. Progress in Landslide Research and Technology. Springer, Cham. https://doi.org/10.1007/978-3-031-16898-7_27

6. Segoni, S., Serengil, Y. & Aydin, F. A prototype landslide early warning system in Rize (Turkey): analyzing recent impacts to design a safer future. *Landslides*20, 683–694 (2023). https://doi.org/10.1007/s10346-022-01988-3
7. Han, Min, et al. "An Early Warning System for Landslide Risks in Ion-Adsorption Rare Earth Mines: Based on Real-Time Monitoring of Water Level Changes in Slopes." *Minerals*13.2 (2023): 265. https://doi.org/10.3390/min13020265

Thank you very much for the suggestion of these references. As suggested, we have extended the literature review for the introduction using some of these and more references, as can be seen in the answers to the first and second comments. With it, we hope we can provide a more comprehensive view on the status quo.

We express our gratitude for your valuable input, and we assure you that all of your comments and concerns will be carefully considered and incorporated into the revised manuscript.