Thank you for taking the time to review and comment on our manuscript entitled “Risk-based analysis of monitoring time intervals for landslide prevention” submitted to the journal *Natural Hazards and Earth System Sciences*. Our replies to your comments and corrections are listed below point by point.

*** Note : the revised sentences in the attached manuscript are marked in blue, and the sentences marked in red are sentences revised according to the comments of Referee #1.*

[Comments 1] Your paper "Risk-based analysis of monitoring time intervals for landslide prevention" aims at demonstrating that different monitoring time intervals would reduce the landslide risk over wide areas. In this respect, “an optimized set of landslide monitoring time intervals for low temporal resolution methods, such as piezometer or inclinometer, was analysed”. The thesis at the base of the paper, as well as the title, look awkward.

How to manage the risk of landslides with limited resources is an important issue faced by local governments in geographically large areas with frequent landslides. Methods for ensuring safety in a cost-efficient manner through a risk-based approach have been studied in various fields. As described in our manuscript, Su et al. (2012) presented differences in the time-average probability of system failure by reinforcement interval in a search for an optimized earth dam reinforcement strategy. In addition, Stewart (2001) discussed the possibility of updating the reliability of ageing bridges after an inspection for relative risk purposes, including prioritization in risk management. In the field of process industry, risk-based inspection (RBI) and reliability-centered maintenance (RCM) are used to operate systems safely with the purpose of cost-saving over 30 years (Bertolini et al., 2009), and these techniques help to minimize the risk from failures by developing cost-effective maintenance strategies involving prioritization of equipment maintenance (Selvik and Aven, 2011). Monitoring activities are a crucial part of mitigation measures for landslide prevention. Dai et al. (2002) stated that monitoring and warning systems can substitute for expensive engineering solutions to prevent losses from landslides over large areas. A risk-based analysis of monitoring time intervals can help to achieve the goal of cost-efficient management, thereby minimizing the risks posed by landslides in a way suitable for limited-resource settings. Thus, we believe that our study is meaningful because it suggests a method to differentiate monitoring time intervals quantitatively, expecting the same level of risk reduction with discrete grades of landslide hazard.

<u>References used in this response:</u>

Bertolini, M., Bevilacqua, M., Ciarapica, F. E., and Giacchetta, G.: Development of Risk-Based Inspection and Maintenance procedures for an oil refinery, J. Loss Prev. Process Ind., 22, 244-253, 10.1016/j.jlp.2009.01.003, 2009.

Dai, F. C., Lee, C. F., and Ngai, Y. Y.: Landslide risk assessment and management: An overview, Engineering Geology, 64, 65-87, doi:10.1016/S0013-7952(01)00093-X, 2002.

Selvik, J. T., and Aven, T.: A framework for reliability and risk centered maintenance, Reliab Eng Syst Saf, 96, 324-331, 10.1016/j.ress.2010.08.001, 2011.

Stewart, M. G.: Reliability-based assessment of ageing bridges using risk ranking and life cycle cost decision analyses, Reliab Eng Syst Saf, 74, 263-273, 10.1016/S0951-8320(01)00079-5, 2001.

Su, H. Z., Hu, J., and Wen, Z. P.: Optimization of reinforcement strategies for dangerous dams considering time-average system failure probability and benefit–cost ratio using a life quality index, Nat. Hazards, 65, 799-817, 10.1007/s11069-012-0394-z, 2012.

[Comment 2] It is not really clear how different monitoring time intervals may reduce the level of risk. Following the risk formula provided by Varnes 1984, (R = H x V x E) the risk can be evaluated as a function of the hazard, element at risk and vulnerability.

Thank you for your comment. We are aware of the risk formula provided by Varnes (1984) in his study of landslide hazard zonation, which has been cited in many other studies. In our manuscript, the definition of risk was briefly addressed in “2.5 Frequency of landslide occurrence” before a statement about the calculation of probability of landslide occurrence based on the estimation of frequency, with a citation from another reference. Varnes (1984) proposed the definition of total risk (Rt) as the expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon as:

$$Rt = E \times Rs = E \times (H \times V)$$

where, natural hazard (H) refers to the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon, vulnerability (V) denotes the degree of loss to a given element at risk resulting from the occurrence of a natural phenomenon of a given magnitude, specific risk (Rs) refers to the expected degree of loss due to a particular natural phenomenon (the product of H times V), and element at risk (E) denotes the population, properties, and economic activities, including public services, that are at risk.

In Varnes’ description of the meaning of natural hazard (H), the probability of occurrence is one of the variables in the risk definition. Therefore, the level of risk can be reduced by decreasing the probability of occurrence. To clarify this implication, we inserted the following additional sentences and included Varnes’ study in the references. Please see Lines 17-19 on Page 7. To decrease the probability of occurrence, appropriate mitigation is required. Monitoring activities can significantly decrease the probability of landslide occurrence if the detection signal is well communicated to an authority that can take proper mitigation measures. Then, the question arises of how frequently it is necessary to monitor the numerous vulnerable areas where the landslide hazard grades are different. Monitoring at the same intervals for all areas of concern would result in excessive risk reduction for areas with a low landslide hazard grade in comparison to other areas with higher grades.

The main purpose of our manuscript is to suggest a solution to this problem by analysing monitoring time intervals with cost-effective low temporal resolution methods based on the concept of reliability. In the manuscript, we show that Eq.(10) for unreliability ($F(t)$) and Eq.(13) for the average probability of failure on demand ($PFDavg$), which are derived from the concept of reliability, can be used to calculate the probability of landslide occurrence and the monitoring time intervals.

$$F(t) = 1 - e^{-\lambda t} \qquad \text{Eq.(10)}$$

$$PFDavg = \frac{1}{TI}\int_0^{TI} 1 - e^{-\lambda t} \; dt \qquad \text{Eq.(13)}$$

In particular, Varnes (1984) mentioned "within a specified period of time and within a given area" when describing natural hazards (H) and suggested that spatial and temporal probabilities should be taken into account in assessing risk. Using the method shown in the manuscript, it is possible to reflect the temporal probability by quantifying the probability of landslide occurrence dependent on the time (t). Of course, it is crucial to quantify the other variables, vulnerability (V) and element at risk (E), in the risk formula in order to complete the quantitative representation; however, the focus in our study is on the analysis of probability of landslide occurrence. We agree that further research should incorporate other variables into the risk analysis. Please see Lines 21-23 on Page 16.

[Page 7, Lines 17-19] Varnes (1984) expressed landslide risk in an equation that includes the probability of occurrence multiplied by the degree of loss to a given element at risk of a landslide. In the risk equation, the probability of occurrence is considered as one of the variables related to natural hazard. Thus, the level of risk can be reduced by decreasing the probability of occurrence.

[Page 16, Lines 21-23] However, this task requires the consideration of the vulnerability (V) and the element at risk (E) in the risk formula proposed by Varnes (1984) for complete risk analysis. The accumulation of sufficient landslide inventory data is also required for the task.

References used in this response:

Varnes, D. J. and IAEG Commission on Landslides and other Mass Movements: Landslide hazard zonation: a review of principles and practice. UNESCO Press, Paris, 63, 1984.

[Comment 3] Of course in landslide prediction the monitoring phase is fundamental, but, mainly the aim is to gather information on variables responsible for landslides triggering in order to define reliable thresholds or to reduce the number of incorrect predictions in landslide early warning systems (LEWS).

This point is correct. However, we believe that monitoring activities not only gather information for LEWS, but also prevent unwanted loss by landslides because low temporal resolution instruments such as manually read inclinometers or piezometers can provide in-situ warning signals in areas where landslide occurrence is expected. Monitoring and warning systems can substitute for expensive stabilization works or engineering solutions to prevent losses from landslides over large areas (Dai et al., 2002). Various combinations of monitoring techniques and instruments are employed to acquire complete information regarding landslide triggering factors and mechanisms (Dixon et al., 2015). However, pore water pressure, displacement, and deformation have been identified as crucial parameters for landslide monitoring and early warning in previous studies (Baroň and Supper, 2013; Uhlemann et al., 2016). Manually read monitoring methods with a low temporal resolution, such as conventional inclinometers that detect subsurface deformation and piezometers that monitor pore water pressure, can be effective solutions (Uhlemann et al., 2016). Nevertheless, the monitoring activities cannot always be performed continuously for all areas of concern, so it is necessary to consider ways to conduct periodic monitoring efficiently at low cost. Further information can be found in "2.8 Landslide monitoring with low temporal resolution" in the manuscript.

References used in this response:

Baroň, I., and Supper, R.: Application and reliability of techniques for landslide site investigation, monitoring and early warning – outcomes from a questionnaire study, Natural Hazards and Earth System Science, 13, 3157-3168, doi: 10.5194/nhess-13-3157-2013, 2013.

Dai, F. C., Lee, C. F., and Ngai, Y. Y.: Landslide risk assessment and management: An overview, Engineering Geology, 64, 65 87, doi:10.1016/S0013-7952(01)00093-X, 2002.

Dixon, N., Smith, A., Spriggs, M., Ridley, A., Meldrum, P., and Haslam, E.: Stability monitoring of a rail slope using acoustic emission, Proceedings of the Institution of Civil Engineers: Geotechnical Engineering, 168, 373-384, doi: 10.1680/geng.14.00152, 2015.

Uhlemann, S., Smith, A., Chambers, J., Dixon, N., Dijkstra, T., Haslam, E., Meldrum, P., Merritt, A., Gunn, D., and Mackay, J.: Assessment of ground-based monitoring techniques applied to landslide investigations, Geomorphology, 253, 438-451, doi:10.1016/j.geomorph.2015.10.027, 2016.

[Comment 4] : Moreover the authors are analysing the occurrence of rainfall-induced landslides in a wide spread area (Pyeongchang County, South Korea), supposing to be fast slope movements (it is not clearly defined in the text), how these phenomena can be monitored using inclinometers?

We agree with your opinion that fast slope movement is difficult to detect using low temporal resolution methods, but we believe that it is possible to prevent a certain portion of fast slope movement events if significant displacement or deformation can be found by the inclinometers in advance. If an inventory of data regarding landslides triggered by prolonged intense rainfall events is available, the analysis of that data would yield insights into the ability of low temporal resolution monitoring methods to predict slower types of landslides. Unfortunately, continuous landslide inventory data are not currently available for the study area. National-level inventory data based on multiple weather events are not provided to individual researchers in South Korea due to potential implications for property values. We believe that it is necessary to construct an open information system for a continuous landslide inventory on the national level in the future.
However, in other regions where a continuous data inventory is maintained, the probability of landslide occurrence can be estimated more accurately, and the method suggested in the manuscript to reduce the risk with low temporal resolution monitoring instruments would be more applicable. The focus in our work was to suggest a quantitative method for determining the most suitable monitoring time interval for efficiently managing the risk from landsides. We acknowledge that further research should examine the rainfall threshold based on continuous landslide inventories of multiple weather events. Therefore, we want to make it clear that the analysis of our study is limited to an extreme weather event that may have resulted in fast slope movements. Please see Lines 24-26 on Page 2 and Lines 26-28 on Page 17. In addition, please refer to Lines 12-15 on Page 18 to see the additional sentences addressing the requirement of changing the monitoring instruments to detect fast slope movements.

[Page 2, Line 24-26] Due to the lack of an accumulated inventory of landslide data in the study region, the frequency of landslide occurrence limited to an extreme weather event was estimated by establishing a rainfall threshold. The criteria for the rainfall threshold setting were determined by referring to local research results.

[Page 17, Line 26-28] Due to the lack of an accumulated inventory of landslide data in the study region, the estimation of landslide frequency was limited to an extreme weather event that may have resulted in fast slope movements in our study.

[Page 18, Lines 12-15] In addition to regular pore water pressure monitoring and deformation monitoring, efforts should be made to increase monitoring activities in the rainy season. Installing monitoring equipment capable of continuous logging and transmitting will also be required to protect core vulnerable areas against landslides involving fast slope movements.

[Comment 5] In this regard, it is important to have in mind the different scales of analysis we are dealing with. At a regional scale the position and sliding surface of a landslides is not known a priori. On the other hand, at a local scale, we could know the location of the landslide/s and its sliding surface. Thus, as a function of the type of landslide and scale of analysis the monitoring instruments change.

It is correct that different scales of analysis need to be used depending on whether the scope is regional or local. Despite the difficulty of specifying the position and slide surface of landslides at the regional scale, Guzzetti (1999) has pointed out that "regional landslide predictive models generally attempt to identify where landslides may occur over a given region on the basis of a set of relevant environmental characteristics". In fact, since the accuracy of GIS tools and the ability to deal with data computation have improved, it has become possible to estimate the locations of landslides based on fine-resolution maps at the regional scale. If we look at a zoomed-in map from Figure 4 that shows the locations of landslide occurrence on the landslide hazard map (10 m × 10 m resolution) as below, it can be seen that landslides have taken place in the vicinity of the highest hazard grade areas in the catchments.

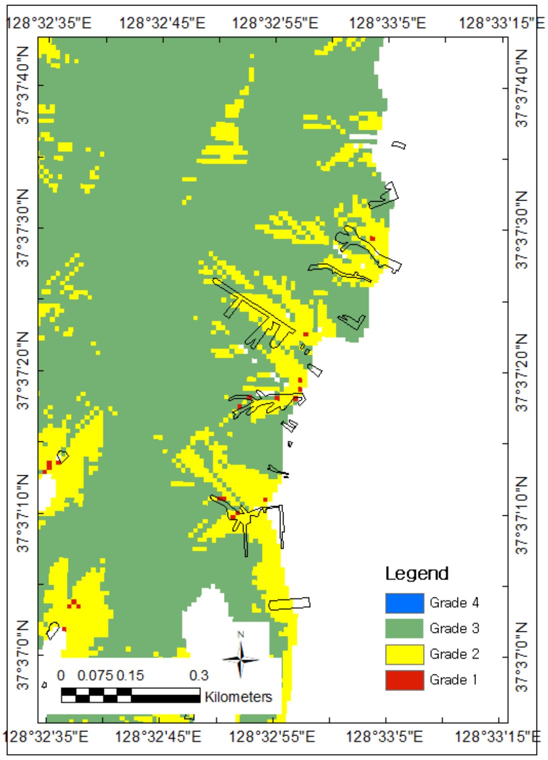

Figure A. A zoomed-in landslide hazard map and the location of landslides from Figure 4 (10 m × 10 m resolution)

By focusing on critical landslide hazard areas such as those near villages or vulnerable infrastructure, it becomes more feasible to identify the location of landslides and to implement appropriate risk management strategies at the regional scale. Thus, we believe that low temporal resolution instruments such as manually read inclinometers or piezometers can perform the function of preventing unwanted losses from landslides by providing in-situ warning signals at the regional scale as well.

[Comment 6] To identity the frequency of landslide occurrence, a unit of relative temporal frequencies was adopted, and it was estimated by establishing rainfall threshold". A crucial point that needed to be clearly explained is how and why the concept of reliability can be applied to evaluate the probability of landslide occurrence. How the assumptions of the method can be generalized and applied to landslide? Which are the similarities? The same questions arise for the definition of the average probability of failure on demand. Is it possible to replace the time interval with the monitoring interval? Why?

One of the definitions of reliability in general terms is the probability that an item will perform a required function without failure under stated conditions for a stated period of time (O'Connor and Kleyner, 2012). The reliability function $R(t)$ and unreliability function $F(t)$ in mathematical terms are expressed as:

$$\mathrm{R(t)} = \frac{\mathrm{Ns(t)}}{\mathrm{N}} \tag{4}$$

$$\mathrm{F(t)} = 1 - \mathrm{R(t)} = \frac{\mathrm{N-Ns(t)}}{\mathrm{N}} \tag{5}$$

where $Ns(t)$ is the number of surviving items in time t, and N is the number of total items.

When a landslide susceptibility map is made using pixels, the number of surviving items and failed items included in the reliability definition can be counted to analyze landslide frequency. Then, the probability of landslide occurrence can be calculated after estimating the frequency, assuming that a pixel unit of GIS-based spatial information is a component for identifying the frequency of landside occurrence.

Please refer to the following figure, which explains the similarity of the reliability concept with that of the estimation of landslide frequency. This figure will be presented as part of a conference paper for ESREL (European Safety and Reliability) 2018 that has been accepted for inclusion in the proceedings (Lee at al., 2018).

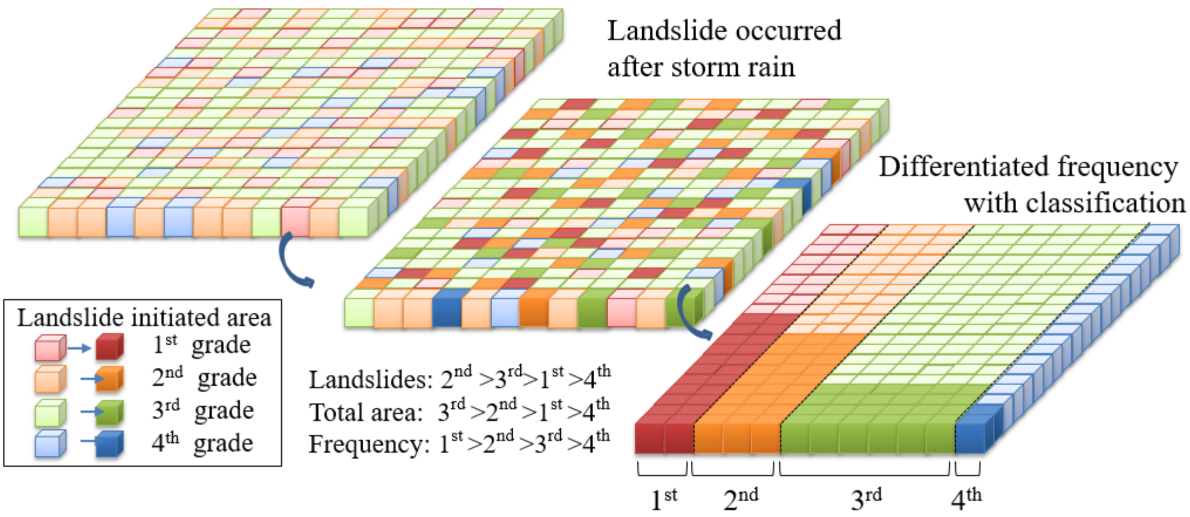

Figure B. The frequency of landslide occurrence based on the concept of reliability.

** Note: This figure is modified from our ESREL 2018 conference paper that has been accepted for inclusion in the proceedings (Lee at al, 2018).

The relative temporal frequency of landslides (F_L) was derived from the unreliability function F(t) in Eq.(5), as the following equation:

$$F_L = (N - Ns) / (Ns \times \Delta t) = \text{landslide event} \times \text{pixel}^{-1} \times \text{year}^{-1} \qquad (11) \text{ and } (12)$$

where *Ns* is the number of surviving items, *N* is the number of total items, and Δ*t* is the probabilistic period of landslide occurrence.

The number of failed items (*N* – *Ns*) was considered as the number of landslide events, *Ns* as the total area, and Δ*t* as the probabilistic return period of landslide occurrence in Eq. (12) in order to derive the relative temporal frequency of landslides from the unreliability function. A further explanation can be found in "2.4.2 Probability model by the concept of reliability" and "2.5 Frequency of landslide occurrence" in the manuscript.
Regarding the average probability of failure on demand (PFDavg), this concept is often used in reliability studies for safety instrumented systems (I.S.A., 2002) and has also been applied to structural safety for earthen dams (Su et al., 2012). Please refer to the answer for Comment 1 above. With this methodology, it becomes possible to calculate the monitoring interval needed to reduce the risk of landslide occurrence below the desired level. Eq.(13) for PFDavg is obtained by integrating the probability of the failure function from time 0 to the proof testing time and dividing by the time interval (I.S.A., 2002). If the proof test time interval (*t*) is replaced with the monitoring time interval for landslide prevention, PFDavg can refer to the time-average probability of landslide occurrence. In other words, the formula shows that the probability of landslide occurrence can be stably managed at a certain level by periodic monitoring in ideal conditions. Please refer to the description in detail in "2.7 Average probability of landslide occurrence". We inserted additional sentences in response to Comment 6. Please see Lines 12-14 on Page 7 and Lines 18-20 on Page 9.

[Page 7, Lines 12-14] When a pixel unit of GIS-based spatial information is considered as a component for identifying the frequency of landside occurrence, the equation for the probability of occurrence can be derived from the definition of reliability.

[Page 9, Lines 18-20] In order to quantitatively estimate the monitoring interval, we adopted the concept of time-average probability of failure. With this method, it becomes possible to calculate the monitoring interval needed to reduce the risk of landslide occurrence below the desired level.

References used in this response:

International Society of Automation : Safety Instrumented Functions (SIF) – Safety Integrity Level (SIL) Evaluation Techniques, ISA-TR84.00.02-2002, 2002.

Lee, J., and Lee, D.K.: Risk management for natural hazards based on reliability analysis: A case study of landslides, ESREL 2018, 2018 (proceeded conference paper)

Su, H. Z., Hu, J., and Wen, Z. P.: Optimization of reinforcement strategies for dangerous dams considering time-average system failure probability and benefit–cost ratio using a life quality index, Nat. Hazards, 65, 799-817, 10.1007/s11069-012-0394-z, 2012.

[Comment 7] Some concerns arise for the rainfall threshold definition and the evaluation of the landslide occurrence frequency, too. For the first, the threshold is defined considering landslides triggered by one extreme rainfall event in 2006 (Typhoon Ewiniar) and the variables considered are dependent, as it possible to notice looking at figure 3. Using different variables would have helped.

Thank you for your comment. This is a critical limitation and should be improved in future research. Unfortunately, the data for the study were limited to the inventory of landslides immediately after Typhoon Ewiniar. No other continuous inventory of data since then is available for study at this moment. The lack of information about landslide occurrence and the difficulty of obtaining a complete or systematic landslide record from the past have been also discussed in previous studies (Jaiswal et al., 2010; van Westen et al., 2006). As discussed in the reply to Comment 4, the purpose of this study was to analyse monitoring time intervals quantitatively based on a risk study and to propose a method for an efficient periodic monitoring plan by considering risk reduction effects. We believe that it will be possible to estimate landslide probability more accurately using the method presented in this study in other regions with a continuous inventory of data. We agree with your opinion that using different variables would have helped to improve the study. Therefore, we added sentences explaining the limitation of using landslide data from only one extreme weather event in the Discussion section. Please see Lines 5-7 on Page 17, Lines 26-27 on Page 17 and Lines 28-29 on Page 18.

[Page 17, Line 5-7] After reliable frequency data for landslide occurrence have been established with continuous inventories and the extent of the area to be analysed is fixed, meaningful calculation results for risk reduction can be obtained.

[Page 17, Line 26-28] Due to the lack of an accumulated inventory of landslide data in the study region, the estimation of landslide frequency was limited to an extreme weather event that may have resulted in fast slope movements in our study.

[Page 18, Line 28-29] Frequency data limited to an extreme weather event were used to calculate the probability of landslide occurrence.

<u>References used in this response:</u>

Jaiswal, P., van Westen, C. J., and Jetten, V.: Quantitative landslide hazard assessment along a transportation corridor in southern India, Engineering Geology, 116, 236-250, doi:10.1016/j.enggeo.2010.09.005, 2010.

van Westen, C. J., van Asch, T. W. J., and Soeters, R.: Landslide hazard and risk zonation - Why is it still so difficult?, Bull. Eng. Geol. Environ., 65, 167-184, doi:10.1007/s10064-005-0023-0, 2006.

[Comment 8] Moreover the threshold defined by the authors (150 mm for daily precipitation and 200 mm for 48-hours) have been exceeded 3 times in 11 years. But it seems that only 1 out of 3 corresponded to landslides occurrence (july 2006, Typhoon Ewiniar), it means that the threshold had 66% of false alerts, which is a quite high error. Then, the probabilistic period of landslide has been evaluated but it is not clearly explained how. However, it looks more as a return period of threshold exceedances than a probabilistic period.

We did not intend to indicate that the threshold had a 66% rate of false alerts, with only 1 out of 3 instances corresponded to landslides occurrence. Due to the lack of accumulated landslide inventory data over the study region, the landslide frequency was estimated by establishing a rainfall threshold. Although no continuous landslide inventory data are available after Ewiniar, the frequency of landslide occurrence was estimated with these cross-sectional data by using the rainfall threshold in the case study. In this respect, it can be assumed that we would find that landslides occurred due to the other 2 extreme weather events in ideal conditions if there was a proper landslide inventory. We acknowledge that this methodology does not fully account for the frequency of landslide occurrence due to the assumptions and the limitations. Further studies with accumulated actual landslide inventory data will enable more accurate estimations of the frequency and the probability of landslide occurrence. In addition, the probabilistic period of landslide occurrence was estimated in our study by establishing the rainfall threshold. This period was called "probabilistic" because the period of landslide occurrence was estimated by assuming landslides will occur in the future with a similar magnitude as in the past. Crovelli (2000) has discussed the estimation of future occurrence of landslides based on historical data using probability formulation of the Poisson model. We agree that this may seem like a return period of threshold exceedance, so we replaced the term with "the probabilistic return period of landslide occurrence". Please see Lines 12-13 on Page 8, Lines 24 on Page 8, and Lines 19-20 on Page 11.

[Page 8, Lines 12-13] Lastly, to estimate the probabilistic return period of landslide occurrence with an equivalent magnitude, rainfall intensity and duration were considered as factors triggering landslide occurrence.

[Page 8, Lines 24] Δt is the probabilistic return period of landslide occurrence estimated by establishing the rainfall threshold

[Page 11, Lines 19-20] Thus, the probabilistic return period of landslide occurrence limited to extreme weather events was estimated as 3.7 years.

References used in this response:

Crovelli, R. A.: Probability models for estimation of number and costs of landslides, United States Geological Survey open file report 00-249, available at : https://pubs.usgs.gov/of/2000/ofr-00-0249/ProbModels.html, 2000.

[Comment 9] Concerning the landslide occurrence frequency in table 1, the values seem to be incorrect. However, it the dimension of a spatial distribution of landslides than a frequency of landslide per each hazard zone. I would have expected a rate of the number of landslides occurred in each hazard zone and the total, in the period of analysis (11years?).

We apologize for the editing error in Table 1 and Table 2. We have corrected all these errors, and the sentences related to this editing error have been reviewed and revised accordingly. Please refer to Table 1 and Table 2 in the revised manuscript, and the spreadsheet used for the calculations is attached as a supplemental file for your review. We have confirmed that the other calculation results shown in the manuscript are correct.

Regarding the rate of landslide occurrence in the total period of analysis (11 years), it should be mentioned again that a continuous inventory of landslide data is not available over the study region, which is a limitation of our study. Due to the lack of an accumulated inventory of landslide data, the landslide frequency was estimated from only one extreme weather event. Please refer to the answer for Comment 4. We completely agree with the referee's comment that including the rate of landslide occurrence in the total period of analysis would improve the study. Further studies using an actual accumulated inventory of landslide data will enable more accurate estimations of the frequency of landslide occurrence.

[Page 14, Lines 1-5]   Table 1. The calculated landslide occurrence frequency

[Page 15, Lines 1-5]   Table 2. Monitoring time intervals yielding the same average probability of landslide occurrence

[Comment 10] Finally, the authors state that different monitoring time intervals reduce the average probability of landslide (Table 2). The table proposes 4 different time intervals (1 – 3,6 – 12,8 – 38,7 years) which seem to be really too wide to me.

The proposed different time intervals expecting the same level of risk reduction may vary depending on the method of grading susceptibility on the landslide hazard map. The landslide hazard map used for the study was made based on a logistic regression analysis (Korea Forest Service, 2013). If the thresholds for the grades used to assess landslide susceptibility are determined differently, the proposed time intervals would be changed. The set of monitoring time intervals is a result of calculations using Eq.(10) and Eq.(13), and it depends on the frequency of landslides (λ), which varies according to the thresholds of landslide susceptibility grades. The ranges would also vary according to the number of classes used to assign landslide susceptibility grades. We would like to clarify that the proposed different time intervals were not intended for preventing loss from landslides, but for yielding the same average probability of landslide occurrence.

<u>References used in this response:</u>

Korea Forestry Service: Integrated management plan for landslide hazard, 2013. (in Korean)

[Comment 11] Depending on the type of landslide, some slopes may require a monitoring frequency well below one year.

Thank you for your helpful advice. We agree that some slopes may require a monitoring frequency of less than one year. Through appropriate decision-making, more frequent monitoring (monthly or weekly) can be planned using the method presented in the manuscript. We have added calculations for monthly and weekly monitoring frequencies, and have inserted a corresponding additional table in the Appendix. Please see Lines 20-21 on Page 14 and Table 3 on Page 19. For significantly higher monitoring frequencies, such as hourly and daily intervals, monitoring equipment capable of continuous logging and transmitting would be required. The possible need for more frequent monitoring has been addressed in the Discussion section. Please see Lines 12-15 on Page 18.

In addition, the methodology presented in the manuscript is focused on monitoring methods with low temporal resolution. Therefore, we have changed the title of the manuscript to "Risk-based analysis of monitoring time intervals for landslide prevention: A case study of low temporal resolution methods". Please see the revised title of the manuscript.

[Page 14, Lines 20-21] The results of setting the monitoring interval for grade 1 to higher frequencies (monthly and weekly) are shown in the Appendix.

[Page 18, Lines 12-15] In addition to regular pore water pressure monitoring and deformation monitoring, efforts should be made to increase monitoring activities in the rainy season. Installing monitoring equipment capable of continuous logging and transmitting will also be required to protect core vulnerable areas against landslides.

[Page 19, Table 3] Table 3. Monitoring time interval sets producing the same average probability of landslide occurrence on a yearly, monthly, and weekly basis.

[Comment 12] Moreover the statement "we have shown that the same level of risk reduction effect can be achieved for lower landslide hazard areas with longer monitoring time intervals compared to the higher landslide hazard areas", reads a bit counter-intuitive.

The statement that we made was more ambiguous than we intended. We have adjusted the text to be clearer. Please see Lines 3-4 on Page 16.

[Page 16, Lines 3-4] Our results show that the same level of risk reduction can be achieved for lower landslide hazard areas with longer monitoring time intervals than are necessary for higher landslide hazard areas.

[Comment 13] Other major issues are represented by the structure of the paper which results confused. A more linear structure would be: Introduction. 2 Method. 3 Case study. 4 Result. 5 Discussion.

We agree that the structure of the paper could appear more linear following the referee's comment, since the study includes a case study. The structure of the paper can be changed upon the editor's decision regarding the final submission of the manuscript.

[Comment 14] The English is difficult to follow, also because the sentences are often too long and not-well articulated.

We have revised the entire manuscript carefully and tried to avoid grammatical errors and long sentences. In addition, a native English speaker and professional editor has checked the English. We believe that the language is now acceptable for the review process.

[Comment 15] Finally the topic of the paper not really fit the aim of the Special Issue.

Planning effective monitoring schedules by allocating limited resources is a realistic problem faced by local governments in geographically wide regions where landslides frequently occur. The objective of this study was to analyse monitoring time intervals for low temporal resolution methods and to propose a plan for periodic landslide monitoring suitable for achieving equivalent risk reductions in areas with different hazard grades. We believe that the methodology shown in our study can contribute to solving this problem. Even though our manuscript may not fit the aims of the Special Issue, it may be suitable for the scope of the NHESS journal overall. As Referee #1 has evaluated our study, the different risk analysis methods for landslides shown in the manuscript will be of interest to readers of NHESS.