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Reply on RC2

Judith Uwihirwe et al.

Author comment on "Integration of observed and model-derived groundwater levels in landslide threshold models in Rwanda" by Judith Uwihirwe et al., Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2021-222-AC2, 2022

Dear Dr. Giulio Castelli,

We are grateful for your overall positive feedback on the manuscript and important suggestions, corrections and comments. Below our responses and proposed way to address the raised issues.

Comment 1: Lines 176-177. The choice of calibrating the model with the later years (instead of the earlier ones) is rather uncommon. Why is this so? Was a proper validation carried out, besides the calibration? What software/methodology was used for the calibration? Which parameters were calibrated?

Response: We used the Transfer Function Noise TFN time series Model that was implemented in Pastas, a new open source Python package for analysis of groundwater time series. The TFN modelling explains an observed time series (here the observed groundwater levels) by one or more other time series (here rainfall and evaporation time series). The TFN model inputs time series “rainfall and evaporation” were available for the entire study period 2006-2018, whereas the observed groundwater level were available for December 2016 to December 2018. We have therefore used the 2 year available groundwater observation time series and these short term data were only used for model calibration and no validation was carried out due to the data limitations. By using the TFN modelling approach, we aim to hind-cast the groundwater levels and get a full time series covering the entire period of the landslide inventory in Rwanda (2006-2018) by using the fully available time series of rainfall and evaporation as model inputs also called model stresses. Each model can have an arbitrary number of hydrological stresses that contribute to the groundwater level changes. These hydrological stresses include rainfall, evaporation, river levels, and groundwater extractions. For our case, however, we used the rainfall and evaporation and assumed runoff and groundwater pumping to be negligible though not accessed in our study area. The impulse groundwater response function to the stresses was fitted with the scaled Gamma distribution function. The calibrated parameters (see equation 3) were A, n, a, d with denoting the scaling factor (-); , are shape parameters (-) and d is a constant or base elevation of the model as summarized in section 3.1.3.

We will make some edits to the M&M section to improve this section.

Comment.2. Lines 184-187. With reference to comment 1 in RC1, I am not fully convinced of the answer given by the Authors. Please state in the M&M section that this is an assumption made given the data scarcity in the area, and provide a justification of the choice, eventually citing suitable references.

Response: We agree with your suggestion to add in the M&M section the information that the assumption was made given the data scarcity in the east African Rift region in general and Rwanda in particular. In the revised manuscript we will add this and will provide additional references (e.g: Monsieurs et al., (2018)).

Comment 3: Lines 195-200: With reference to comment 2, RC 1, I have to say that even here authors should declare that the database has some intrinsic limitations in the M&M section. Kindly cite some papers using the same database to show some example of its usage.

Response: Yes it is true that the used database have some intrinsic limitation and we will add such information in the methodological part and some examples (References) of the previous database use will be provided accordingly (e.g: Nieuwenhuis et al., (2019; Rwanda Water and Forestry Authority, (2017)).

Comment 4: Line 260: It would be useful to understand which is the relative RMSE value, e.g. for example RMSE/mean_groundwater_depth. Moreover, it is not fully clear which was the final value of the calibrated parameter.

Response: The suggestion to add the relative RMSE value is a good one and we agree that it will make the RMSE more meaningful once added for example the RMSE_groundwater level where the relative value here is the groundwater level. We have made a summarised Table indicating the final values of the calibrated parameters and will be appended to the revised manuscript.

Comment 5: Paragraph 4.5: Can the differences in the three watersheds in terms of warning capabilities and thresholds be explained by their geo-morphological differences? How this is related to the comment at line 184-187?

Response: Within the framework of this research study, we defined the landslide empirical hydro-meteorological thresholds using continuous historical precipitations time series and groundwater level time series as proxy for the catchment water storage. We mainly analysed the difference in landslide thresholds and warning capabilities as a result of the differences in catchment water storage, estimated from the groundwater responses to precipitation received in the three study watersheds. The in-deep analysis of the geo-morphological difference between the three catchments and how it could be one of the explanatory factors of the observed difference in landslide thresholds and the warning capabilities was not fully conducted. However, it is generally observed that the catchment with very slow groundwater responding system such as Mukungwa, the warning capability of the groundwater-based thresholds have less performance as compared to the fast groundwater responding systems like Kivu catchment. This is truly due to the catchment specific hydrogeological and geomorphological characteristics. With reference to Figure 1, Mukungwa catchment is characterized by low permeable fractured schist and mica schist and complex aquifer in volcanic rocks and thus being a slow groundwater responding system. The weathering products of volcanic rocks produce a relatively permeable top layer but they tend to form low permeable horizontal layer zones at shallow depth and thus form perched aquifers instead of deep groundwater recharge due to the brecciated or intruded sills of low permeability. Kivu catchment is dominated by fractured granites with overall high transmissivity and recharge and hence a fast groundwater responding system. The weathering products of granites are generally coarse-grained that tend to develop and preserve open joint systems that increase their permeability and thus fast groundwater response. In Kivu catchment therefore, the landslide warning capability of groundwater based thresholds performed higher than precipitation thresholds. The groundwater observation well in Upper Nyabarongo catchment is located in semi permeable fractured schist, mica schist and minor quartzite aquifers less competent in terms of transmissivity and recharge and hence medium groundwater response as compared to Mukungwa and Kivu catchments. The weathering product of schists include clay minerals that tend to fill up the fractures and thus slowing the permeability. Therefore, the warning capability of groundwater-based thresholds in upper Nyabarongo was not as good as in Kivu but higher than Mukungwa catchment.

A point of discussion about these possible effects of the hydrogeology on the observed differences in landslide thresholds and warning capabilities will also be provided in the revised manuscript. The groundwater response curves for each of the three study catchments will be attached to the revised manuscript as a supplement. In the study area section, we will add the general information about the catchment-typical geomorphological characteristics such as landforms and slope in addition to the hydrogeology.