Response letter to MS No: nhess-2022-43- Decision

Entitled "Hazard Assessment of Earthquake –Induced Landslides Based on a Mechanical Slope Unit Extraction Method**"**
15th April.2022

Dear Editor,

We sincerely appreciate the editor's/reviewers time and effort in evaluating our manuscript. We agree with and accept all the comments and suggestions from the Editor and Reviewers. We have carefully and thoroughly revised the manuscript according to the editors/reviewer's questions and comments. In the revised manuscript, changes are shown by using the track changes mode. The point-to-point responses to the comments are detailed as follows:

Editor

Comment: You as the contact author are requested to individually respond to all referee comments (RCs) by posting final author comments (ACs) on behalf of all co-authors no later than 04 Aug 2022 (final response phase).

Response: Thank you for your comment and suggestion.
We agree with your opinion. According to the Reviewers' comments and suggestions, the questions have been answered based on the thoroughly revised manuscript.

Reviewer (Dongliang Huang) (CC)#3

This is a clear, concise, and well-written manuscript; the introduction is relevant and quite theory-based. The procedure and method follows a clear pattern.
The authors methodically dissect the fundamental viewpoint of the meanings of coseismic dislodging, presenting factors that record an infinite slope failure or flexible sliding block failure, as well as proposing a mechanical slope unit extraction method. However, few perspectives are found that need verification or correction.

Comment 1: The manuscript is not adequately organized in style and formatting.

Response: Thank you very much for your constructive comment.
We agree with your comment. Following the reviewer's comments.

After revised: The whole Manuscript

The Manuscript is now adequately formatted by rearranging and restructuring the sentences and figures to suit the Journal's standard. Reference to figures and tables are very consecutive, and captions are informative and self-standing.

Comment 2: The introduction must adequately present the proposed slope unit method and the gap in the displacement method used.

Response: Thank you very much for your constructive comment.
We agree with your comment. Following the reviewer's comments, the introduction has been overhauled to have a balance on the literature and empirical relations available for the calculation of the coseismic displacement and the different solutions for landslide stability analysis, as written below.

After revised: Introduction Page 1 (Line 18-24) and Page 1, (Line 1-35) -Manuscript

Earthquakes are the most dangerous natural hazards, posing the most significant risk to life and property. Since the 1980s, earthquakes-induced landslides have caused many deaths and economic losses. For example, the Chi-Chi earthquake-triggered about 9000 landslides (Tsai et al., 2000), and the Guatemala earthquake triggered 10,000 landslides

(Hamilton, 1997). Landslides mainly occur when acting forces exceed the strength of earth materials that composes a slope, and its evaluation provides general insight into future earthquake-induced landslides based on medium and long-term predictions of earthquake distribution to provide a possible mitigation measure to control its impact on life and properties (Bray et al., 2018; Salunkhe et al., 2017; Tsai & Chien, 2016; Wang & Lin, 2010; Zhang et al., 2019). Statistically-based methods based on historical landslide distribution were typically used in the early days for hazard zonation. However, the engineering approach (i.e., physically-based modeling) with the application of slope stability analysis models has recently been intensively studied and used to analyze landslides (Cencetti & Conversini, 2003; Tsai et al., 2019).

The statistically-based method could be bivariate (Chung & Fabbri, 2012; Chung & Fabbri, 2003; Dai & Lee, 2002; Wubalem, 2020), a multivariate method (Atkinson & Massari, 1998; Polykretis et al., 2019), Artificial Neural Network (ANN) method (Ortiz & Martínez-Graña, 2018; Tsangaratos & Benardos, 2014; Vakhshoori et al., 2019) or Machine Learning Techniques (MLTs) (Tien Bui et al., 2012; Youssef & Pourghasemi, 2021; Kavzoglu et al., 2014). Statistically-based methods assume that landslide controlling factors are conditionally independent of each other (e.g., Youssef et al., 2016). Hazard maps generated by some of these Statistically-based methods are obtained from a combination of maps generated using control points, whose predictive variables suffer from multicollinearity. The multivariate statistically-based methods are also suitable for large and complex areas. However, the method's robustness highly depends on the database used for the analysis. And only conditionally identical to those in the database can be predicted (Tien Bui et al., 2012; H. Y. Tsai et al., 2019). Engineering methods for earthquake-induced landslides and displacement analyses are done using the sliding block displacement method, which is a compromise in complexity between simple pseudo-static analysis and complex numerical simulation engineering methods (Ellen et al., 1998; Jibson & Keefer, 1993; Jibson et al., 2000; Saygili, 2008; Tsai et al., 2019; Wang et al., 2017; Shinoda & Miyata, 2017, Zhang et al., 2021). The sliding block method considers the landslide as a rigid non-deformable plastic body that slides on a plane of continuous dip and friction and only accurately predicts the displacement of an individual sliding body (Jibson, 2011; Tsai et al., 2019). The Newmark's sliding block method produces a stronger correlation between the estimated displacement and the mapping location of the earthquake-triggered landslide, making it a good engineering method suitable for predicting earthquake-induced landslides (Rathje et al., 1998; Tsai et al., 2019; Xie et al., 2003; Zhang et al., 2019). Newmark's sliding block method is the first for seismic-induced landslides' displacement analysis (Jibson, 2011; Newmark, 1965). The Newmark's sliding block method is useful for rapidly predicting a seismic-induced landslide by first diving the study area into numerous grids, especially during regional displacement assessment (Tsai et al., 2019). These grids are assumed to be infinite, hence having definite depth (usually less than 3m) and as well neglect slope geometry in their analysis therefore modelled asrigid blocks (Ellen et al., 1998; Jibson et al., 2000; Xie et al., 2003; Zhang et al., 2019). Rathje & Antonakos, (2011) pointed out that ground motion parameters for displacement analysis on a regional scale can be altered to consider both shallow and deep failure due to their interaction with the sliding soil material. A framework for predicting earthquake-induced displacement is therefore proposed based on Zhang et al., (2019) to overcome the problems of defining slope displacements as an infinite sliding block with shallow depth, to consider it as a finite failure, especially in less cohesive soil materials whiles considering the effect of pore pressure and slope geometry in determining the safety factor F_s to predict an unbiased $k_y(g)$ for the displacement analysis. This framework is based on regional hazard analyses; therefore, the study area must first be divided into sampling units of landslide hazard zones in which every landslide influence factor can be allocated. These landslide hazard zones are mapping units (Ba et al., 2018).

Most popular Mapping units for earthquake-induced landslide displacement analysis include the grid-cell, slope unit, etc. (Schlögel et al., 2018; Tsai et al., 2019; Yu & Chen, 2020). Grid cells are regular square cells with a given size for the unit mapping of landslides and are not closely related to geological environments (Guzzetti et al., 1995). As highlighted by Xie et al., (2003), a limitation of the grid-cell is its inability to represent natural slope topographic boundaries in their natural condition because it uses artificially marked cells of a block to represent the natural landscape event.

According to hydrological theory, a "slope unit" is considered a watershed defined by the ridge and valley lines and is used to divide spaces into smaller regions for easy analysis, making the method more related to the geological environment, hence the best for landslide and displacement analysis (Guzzetti et al., 1995; Wang et al., 2017). Slope unit is more applicable than the grid-cell method because landslides occur on slopes; therefore, the slope unit represents the topographic feature more thoroughly than the grid cell (Wang et al., 2017; Xie et al., 2003). Slope units are usually extracted from the digital elevation model (*DEM*) using geographic information system (*GIS*) software (Wang et al., 2019). The method for the extraction of the slope unit involves delineating a watershed from a

DEM, then reversing the *DEM* to delineate another watershed. The two watersheds are merged to end the extraction of the slope unit (Mesut et al., 2011). This slope unit extraction method is termed the hydrological slope unit extraction method (Fig. 1a)(Mesut et al., 2011). Slope units extracted with the hydrological method are usually based on the surface hydrological process, making it impossible to identify variations in slope gradient beyond the hydrological flow direction, resulting in a sudden change in slope gradient. As such, slope units extracted using the hydrological methods suffer a heterogeneity effect primarily associated with slope units extracted using high-resolution DEM (Guzzetti et al., 1995; Wang et al., 2019, 2020). The hydrological slope unit extraction method again produces irregular boundaries and conjoined slope conditions. This occurs because it barely distinguishes inclined and horizontal planes of deep valleys and high mountainous terrains (Wang et al., 2019). Tedious manual post-extraction corrections are needed to make the slope unit acceptable (Cheng & Zhou, 2018; Wang et al., 2020).

This research proposes a new slope unit extraction method using GIS software for the earthquake-induced displacement framework analysis. The method combines catchment points, hydrological slope unit extraction method, and segmentation to overcome the limitations of the hydrological slope unit extraction method. The application of the slope unit extraction method and displacement framework is validated in Ghana. The prediction result of the slope unit extraction method is compared with the hydrological method. The displacement framework is also compared with the displacement method by Jibson et al., (2000); Tsai et al., (2019). The paper also underlines the possibility of the proposed model for displacement analysis of shallow and deep slope failures considering the pore water pressure during the computation of the factor of safety $F_{S.}$

Comment 3: Eliminating the boundary and heterogeneity effect of the hydrological slope unit extraction method are the main innovations of the newly proposed slope unit extraction method in the manuscript; however, they have not been adequately explained in the manuscript. An explanation of the heterogeneity and boundary effect will sufficiently improve the manuscript.

Response: Thank you very much for your constructive comment.
We agree with your comment. Following the reviewer's comments, We have overhauled the article, restructured it, and added some sentences and figures to enhance clarity on the heterogeneity defect in Fig.4, page 23, and Page 12, (Line 6-16) and 22 of the manuscript and presented it as stated below.

After revised: 1) Slope unit heterogeneity [Fig.4, page 23 and Page 12, (Line 6-16) – Manuscript

Slope angle is a critical factor for consideration in a landslide analysis (Wang et al., 2019). Fig.4 (c) shows the terrain profile line *A'-A* (convex area) with two flat slopes of 30 and 10 degrees, respectively, and a slope toe angle of 45. Fig.4 (a) illustrates a slope unit extracted using the point segmentation method showing line *A'-A* area with three local slope unit regions. Fig.4 (b) is a slope unit map obtained using the hydrological method showing line A'-A (convex area) with two local slope unit regions and two angles. ArcGIS statistical tool is used to compute the slope angle of the slope unit region and profile in Fig.4 (a) and Fig.4 (b). Fig.11 (a) shows the terrain profile of the slope unit region determined using the hydrological method; the terrain shows just two slope angles, with the toe having a 45 angle and a second slope angle of 10 instead of 30 (as was demonstrated in Fig.4 (c)). This indicates that the hydrological method underestimates the slope angles compared to the point segmentation method. The point segmentation method divided the area into three slope units and three angles having the exact sizes and conforming homogenously to the terrain in Fig.4 (c).

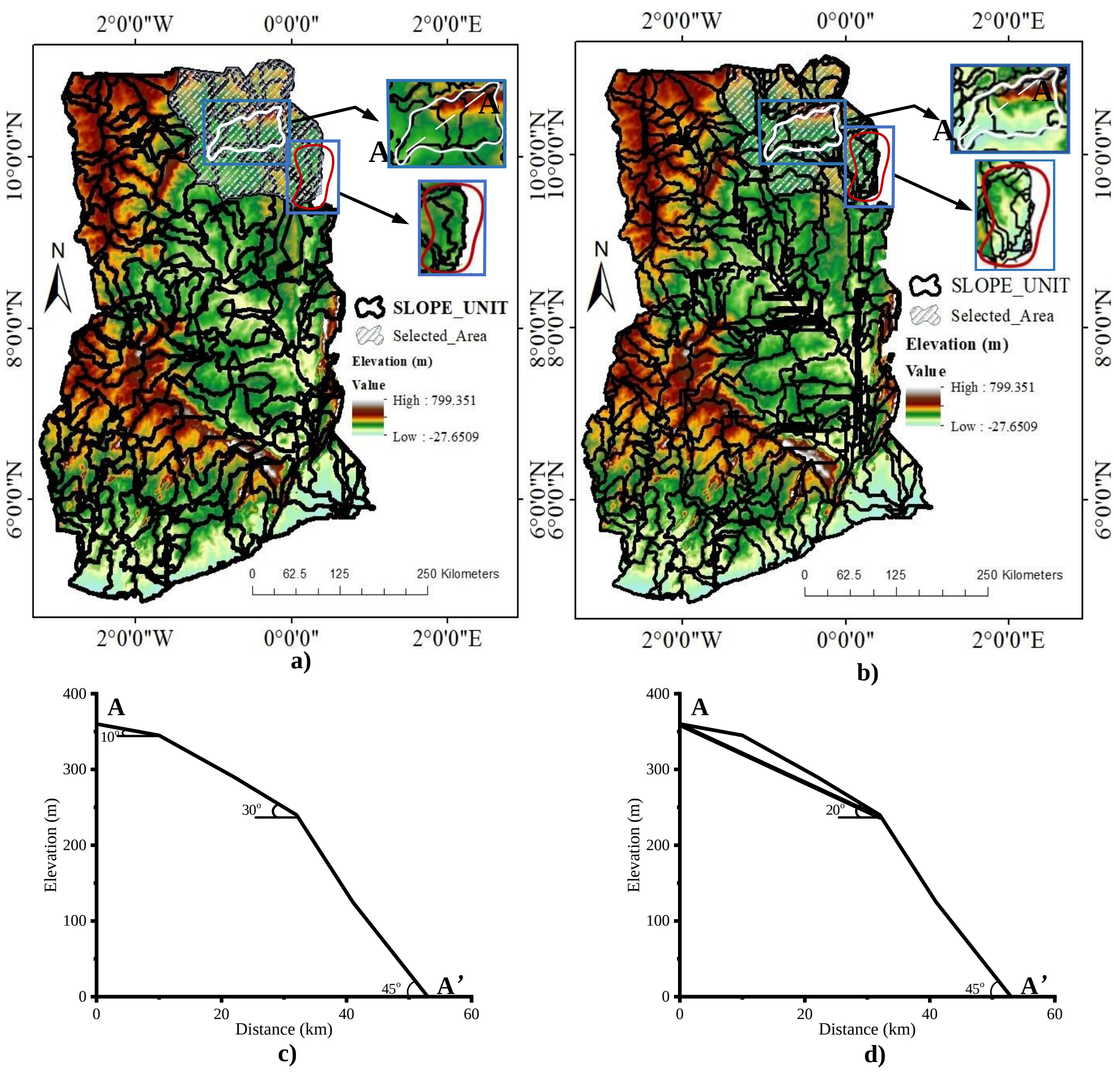

Fig. 4 Slope units of Ghana derived using different methods. a) Results from the point segmentation method b) Result from hydrological method c) Simplified terrain profile along *A”-A*. c) Simplified terrain profile along *A”-A* for hydrological method These slope units are overlain on elevation maps. The region enclosed by red lines indicates how the point segmentation method solves the irregular boundary defect and is further described in the sensitivity section. The region enclosed by white lines in a) and b) also indicates how the point segmentation methods solve the slope unit heterogeneity effect from the hydrological method and is further described in the

sensitivity.

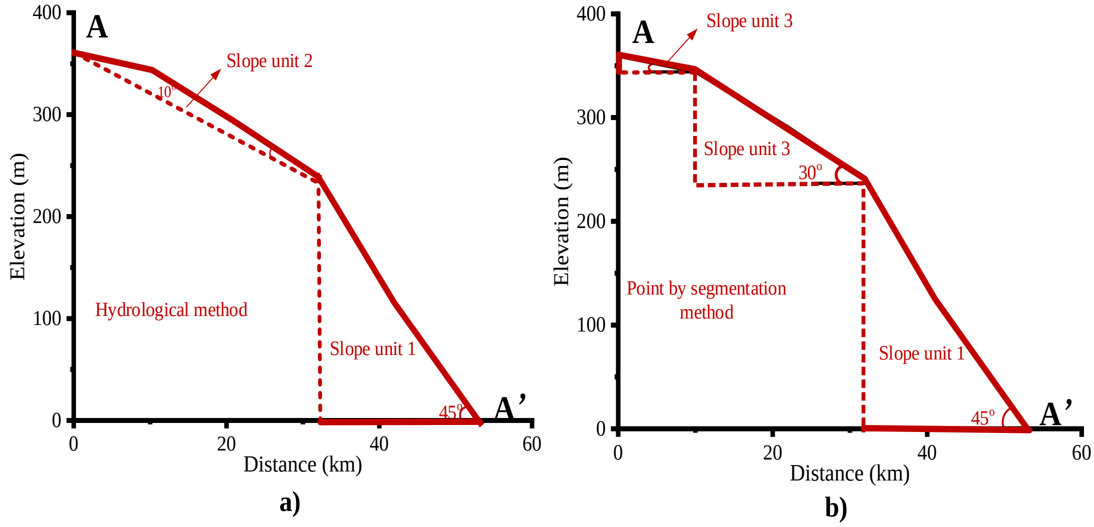

Fig. 1 Profile of slope unit by different methods. a) *A'-A* Slope unit profile determined by the hydrological method and b) *A'-A* Slope unit determined by the point by the segmentation method

After revised: 2) Slope unit heterogeneity Boundary defect

In contrast to slope units delineated using the hydrological technique, those extracted using the point segmentation method (proposed method) (Fig.4a) have regular and smooth bounds that aid in analyses (Fig.4b).

From the red-lined sections in both figures (Fig.4a and Fig.4a), it is clear that Fig.4b has extremely erratic borders that require time-consuming post-extraction adjustments to make them regular. These time-consuming post-extraction adjustments are avoidable using the point segmentation "slope unit" extraction method.

Comment 4: Fig. 4 can be deleted because it is not serving any purpose.

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, Fig.4 has been removed from the revised manuscript

Comment 5: Line 148, The Depth Correction Factor (DCF), should be cited and well written.

Response: Thank you very much for your constructive comment.

The DCF has been well written and referenced based on the review comments on Page 6 (Line 11) of the manuscript as "(Tsai et al., 2019)".

After revised*: *(Page 6, Line 10-14)- Manuscript

$$DCF = \begin{cases} \exp^{(0.4+0.343\tan\varphi)} \times \dfrac{D}{H} - 1.5 \times \left(\dfrac{D}{H}\right) & (\beta \text{-} \alpha \geq 5) \\ 0 & (\beta \text{-} \alpha < 5) \end{cases} \tag{10}$$

Tsai, H. Y., Tsai, C. C., & Chang, W. C. (2019). Slope unit-based approach for assessing regional seismic landslide displacement for deep and shallow failure. Engineering Geology, 248(January 2018), 124–139. https://doi.org/10.1016/j.enggeo.2018.11.015.

Comment 6: Fig.5 should be modified to contain the geological details of the study area (Ghana)

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, then Fig.5 (Now Fig.7) has been adequately modified to show the geological details, major faults, and earthquake epicenters in the study area (Ghana). The new Fig. 7 is located on Page 26 of the manuscript.

After revised*: *(Page 6, Line 10-14)- Manuscript

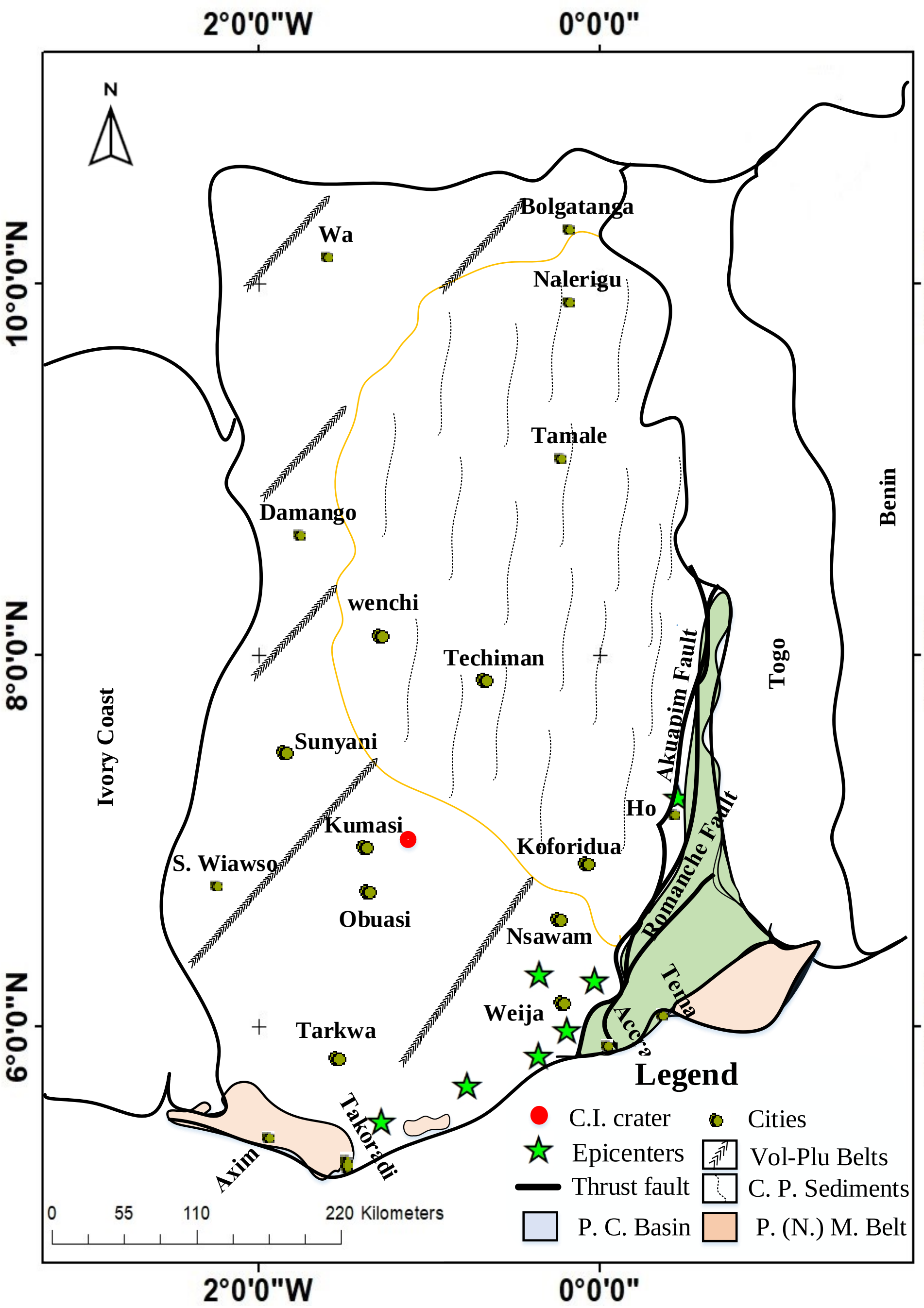

Fig. 7 **Major Lithostratigraphic and Lithotectonic Complexes of Ghana**

Comment 7: The heading "seismic activities of Ghana ", seems to be more focused on seismic activities in Africa rather than Ghana.

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, the opening to the chapter "Seismic activity of Ghana" has been revised to concentrate on Ghana rather than Africa. Page 8 (Line 9-30) of the manuscript.

After revised: (Page 8 Line 9-30) - Manuscript

"Ghana is far away from the major seismic zones of the World. However, the southern part of the country is seismically active and prone to earthquake disasters.

Since the sixteenth century, places like Accra, Axim, Koforidua, and Ho have experienced seismic activities (Table 1).

This seismicity is due to major faults in Ghana (Akwapim fault and Coastal boundary faults zones) connecting with West African continental tectonics (St. Paul and Romanche-transform fracture zone) offshore in the Gulf of Guinea to onshore (Blundell, 1976).

As such, the tectonic activity of the Romanche transform fracture zone reactivates the seismicity on the Coastal boundary fault and causes earthquakes in places like Accra, Kasoa, Awutu-Senya, Weija-Gbawe, McCarthy Hills, and Adenta. Whiles the St. Paul fault activities reactivate seismic activities from the Ivory Coast through Axim and intensify around the Akwapim fault zone through Koforidua and Ho. Ghana recorded its first earthquake in 1615 and the second one in 1636 in Axim, and all other subsequent ones are in Table.1(Amponsah et al., 2009).

Seven severe earthquakes above 5.0 magnitudes have since struck the country in 1636, 1788, 1862,18791906,1907, and 1939. Seismic activities on the St. Paul's fault zone halted in 1879, making the Axim and Akuapim fault zone area free from reactivation of earthquakes. However, movements along the Romanche transform fracture zone fault are still in progress, making Accra and its environs vulnerable to seismic activities and tremors (Kutu, 2013). The western part of Accra (weija), on the junction of the coastal boundary and the Akuapim fault, has experienced most of the earthquakes in Ghana, making it the epicenter of earthquakes (Bates, 1962).

Ghana's landscape has low and high lands, with a rainfall pattern for a minimum of five months per annul. Some periodic earthquakes record has forced GhIG to predict the likelihood of a massive slope landslide in Ghana. The maximum intensity of the earthquake in Ghana is *IX* on the *MSK* Scale, recorded in 1862 (Ambraseys & Adams, 1991). Ghana's highest Peak Ground Acceleration (*PGA*) recorded was at the Accra-Tema seismic zone, estimated at 0.2g and minimized to 0.05g 140 km away from Accra. Ghana's Peak Ground Velocity (*PGV*) ranges from 9.2 to 37.1 cms-1, and the standard PGA ranges from 0.14 to 0.2g (Amponsah et al., 2009). In Ghana, areas with low PGV usually display high PGA (Amponsah et al., 2009)".

Comment 8: Table 2, Table.3, and Table.4 can be merged and summarized because they seem to be repetitive and not very informative.

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments Table 2, Table 3, and Table 4 have been merged. The merged table is now labeled Table 2 (revised manuscript). “Table 2. Detailed geologic Unit, strength parameters and their respective locations in Ghana” is on Page 37 of the manuscript.

After revised: (Page 33) - Manuscript

Table 2 Detailed geologic Unit, strength parameters, and their respective locations in Ghana

Rock Unit	Abb.	Parameters	Fri. Angl. φ(°) medium	High φ(°)	Low φ(°)	Unit wt. (γ) kN/m^3 medium	Coh. MPa	Location	Source
Precambrian	PC	Volcanic plutonic alkaline	50	55	40	26	25	Kumasi, sefwi, brong, central, wassa, some part of the north	Bohne & Frickie 1970
Ordovician - Cambrian	OCM	Sedimentary, Mudstone and Siltstone	45	50	40	25	32	Volta Basin	Hoek & Bray 1989
Water	H20							Volta lake, Kumasi, tarkwa	
Holocene	QE	Granatoids of igneous rocks	45	50	40	28	21.2	Accra	Hoek & Bray 1989
Tertiary	T	Quazite, shales & Granites of Igneous Rocks	45	50	40	28	70	Enchi and its environs.	Goodman 1980
Quaternary & Tertiary	QT	Sand-stones	30	34	27	24	27	Kwahu & volta	Duncan and Norman
Carboniferous & Devonian	CD	Sedimentary Mud and Silt stone	34	39	29	18	21	Takoradi, secondi, axim	Goodman 1980

Comment 9: Fig.6 and Fig .7 should be modified to reflect the actual safety factor and critical acceleration of Ghana.

Response: *Thank you very much for your constructive comment.*

We agree with your comment. Following the reviewer’s comments, Fig.7a (nowFig.6a) “F_s map” has been improved to vividly express the safety factor (F_s) of the slopes. The changes to the F_s also reflected changes to the k_y(g) map and, to a more significant extent, the displacement map. (Page 25-manuscript).

After revised: **(Page 25) - Manuscript**

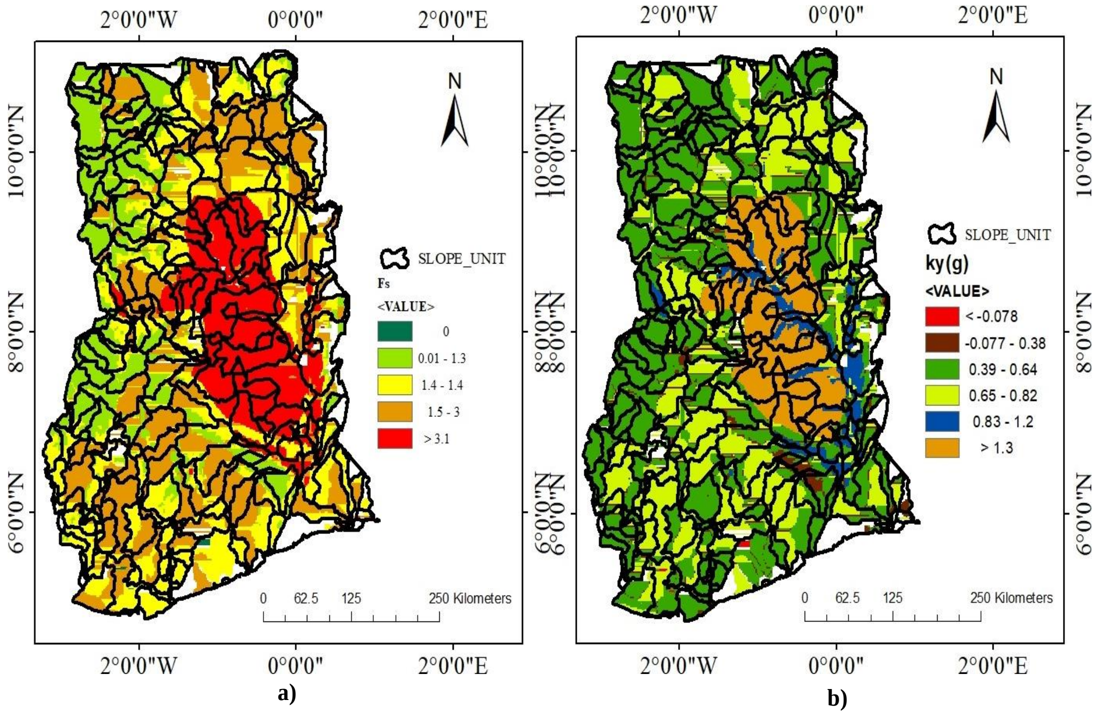

Fig. 6 Automatic generated Maps a) Factor of Safety, F_s, b) Yield acceleration, *ky*(g),

Comment 10: The authors should also check the typing errors in the manuscript, for example, Line 34 and 36, Newmark and not Newark. The authors need to check some of the grammatical errors and correct them.

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, the sentence on Page 2 (Line 18) "Newmark" has been correctly rewritten in the manuscript as *"Newmark."* all other typing errors have also been checked and corrected accordingly.

Comment 11: Fig.16 isn't informative and can be deleted because the highest elevation of the study area is already at line 191 of the manuscript.

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, Fig.16 in the appendix is understood to be uninformative. Therefore, the extracted slope unit *Located on Page 26 of the revised manuscript has been overlaid on the elevation map.*

Abbreviations

F_S: Factor of safety
Val: Value

Pr: Prediction rate

Sym: Symbol

Fr: Failure rate

Fri: Friction

Ang: Angle

C: Cohesion

Wt: Weight

CI. Crater: Cenozoic Impact Crater

CP. Sediments: Cambrian Platform Sediments

P.C. Basin: Phanerozoic Coastal Basin

Vol-Plu Belts: Volcanic Plutonic Belts

Surf: Surface

Mag: Magnitude

References

Analysis, N. (2020). *water Topographic Effects on Three-Dimensional Slope*. 1–24.

Atkinson, P. M., & Massari, R. (1998). Generalized linear modeling of susceptibility to landsliding in the central Apennines, Italy. *Computers and Geosciences*, *24*(4), 373–385. https://doi.org/10.1016/S0098-3004(97)00117-9

Ba, Q., Chen, Y., Deng, S., Yang, J., & Li, H. (2018). A comparison of slope units and grid cells as mapping units for landslide susceptibility assessment. *Earth Science Informatics*, *11*(3), 373–388. https://doi.org/10.1007/s12145-018-0335-9

Bray, J. D., Macedo, J., & Travasarou, T. (2018). Simplified Procedure for Estimating Seismic Slope Displacements for Subduction Zone Earthquakes. *Journal of Geotechnical and Geoenvironmental Engineering*, *144*(3), 04017124. https://doi.org/10.1061/(asce)gt.1943-5606.0001833

Cao, Z., Wang, Y., & Au, S.-K. (2011). GeoRisk 2011 © ASCE 2011 403. *GeoRisk 2011*, 403–410.

Cencetti, C., & Conversini, P. (2003). Slope instability in the Bastardo Basin (Umbria, Central Italy)- The landslide of Barattano. *Natural Hazards and Earth System Science*, *3*(6), 561–568. https://doi.org/10.5194/nhess-3-561-2003

Cheng, L., & Zhou, B. (2018). A new slope unit extraction method based on improved marked watershed. *MATEC Web of Conferences*, *232*, 1–5. https://doi.org/10.1051/matecconf/201823204070

Chung, C. J. F. C. J. F., & Fabbri, A. G. (2012). Systematic Procedures of Landslide Hazard Mapping for Risk Assessment Using Spatial Prediction Models. In *Landslide Hazard and Risk*. https://doi.org/10.1002/9780470012659.ch4

Chung, C. J. F., & Fabbri, A. G. (2003). Validation of spatial prediction models for landslide hazard mapping. *Natural Hazards*, *30*(3), 451–472. https://doi.org/10.1023/B:NHAZ.0000007172.62651.2b

Dai, F. C., & Lee, C. F. (2002). Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong. *Geomorphology*, *42*(3–4), 213–228. https://doi.org/10.1016/S0169-555X(01)00087-3

Ellen, B., Norman, M. R., & Bray, J. D. (1998). *C7·(1)*. *91*(FEBRUARY), 150–159.

Guzzetti, F., Carrara, A., Cardinali, M., & Reichenbach, P. (1995). ; Stern, 1991] and one of the NAVZ (Northern Austral Vol- canic Zone) volcanic events [3010 yr. *Geomorphology*, *13*(6), 1995.

Hamilton, R. (1997). United Nations International Decade for Natural Disaster Reduction IDNDR Early Warning Programme IDNDR Secretariat , Geneva October 1997 EARLY WARNING CAPABILITIES FOR GEOLOGICAL HAZARDS. *Landslides*, *October*.

Jibson, R. W., & Keefer, D. K. (1993). Analysis of the seismic origin of landslides: examples from the New Madrid seismic zone. *Geological Society of America Bulletin*, *105*(4), 521–536. https://doi.org/10.1130/0016-7606(1993)105<0521:AOTSOO>2.3.CO;2

Jibson, Randall W. (2011). Methods for assessing the stability of slopes during earthquakes-A retrospective. *Engineering Geology*, *122*(1–2), 43–50. https://doi.org/10.1016/j.enggeo.2010.09.017

Jibson, Randall W., Harp, E. L., & Michael, J. A. (2000). A method for producing digital probabilistic seismic landslide hazard maps. *Engineering Geology*, *58*(3–4), 271–289. https://doi.org/10.1016/S0013-7952(00)00039-9

Kavzoglu, T., Sahin, E. K., & Colkesen, I. (2014). Landslide susceptibility mapping using GIS-based multi-criteria decision analysis, support vector machines, and logistic regression. *Landslides*, *11*(3), 425–439. https://doi.org/10.1007/s10346-013-0391-7

Mr. Digvijay P. Salunkhe, Assist. Prof. Guruprasd Chvan, Ms. Rupa N. Bartakke, & Ms. Pooja R Kothavale. (2017). An Overview on Methods for Slope Stability Analysis. *International Journal of Engineering Research And*, *V6*(03), 528–535. https://doi.org/10.17577/ijertv6is030496

Newmark, N. M. (1965). Effects of earthquakes on dams and embankments. *Geotechnique*, *15*(2), 139–160. https://doi.org/10.1680/geot.1965.15.2.139

Ortiz, J. A. V., & Martínez-Graña, A. M. (2018). A neural network model applied to landslide susceptibility analysis (Capitanejo, Colombia). *Geomatics, Natural Hazards and Risk*, *9*(1), 1106–1128. https://doi.org/10.1080/19475705.2018.1513083

Polykretis, C., Kalogeropoulos, K., Andreopoulos, P., Faka, A., Tsatsaris, A., & Chalkias, C. (2019). Comparison of statistical analysis models for susceptibility assessment of earthquake-triggered landslides: A case study from 2015 earthquake in Lefkada Island. *Geosciences (Switzerland)*, *9*(8). https://doi.org/10.3390/geosciences9080350

Rathje, E. M., & Antonakos, G. (2011). A unified model for predicting earthquake-induced sliding displacements of rigid and flexible slopes. *Engineering Geology*, *122*(1–2), 51–60. https://doi.org/10.1016/j.enggeo.2010.12.004

Saygili, G. (2008). *A Probabilistic Approach for Evaluating Earthquake-Induced Landslides*.

Schlögel, R., Marchesini, I., Alvioli, M., Reichenbach, P., Rossi, M., & Malet, J. P. (2018). Optimizing landslide susceptibility zonation: Effects of DEM spatial resolution and slope unit delineation on logistic regression models. *Geomorphology*, *301*, 10–20. https://doi.org/10.1016/j.geomorph.2017.10.018

Shinoda, M., & Miyata, Y. (2017). Regional landslide susceptibility following the Mid NIIGATA prefecture earthquake in 2004 with NEWMARK'S sliding block analysis. *Landslides*, *14*(6), 1887–1899. https://doi.org/10.1007/s10346-017-0833-8

Tien Bui, D., Pradhan, B., Lofman, O., & Revhaug, I. (2012). Landslide susceptibility assessment in vietnam using support vector machines, decision tree, and nave bayes models. *Mathematical Problems in Engineering*, *2012*. https://doi.org/10.1155/2012/974638

Tsai, C. C., & Chien, Y. C. (2016). A general model for predicting the earthquake-induced displacements of shallow and deep slope failures. *Engineering Geology*, *206*, 50–59. https://doi.org/10.1016/j.enggeo.2016.03.008

Tsai, H. Y., Tsai, C. C., & Chang, W. C. (2019). Slope unit-based approach for assessing regional seismic landslide displacement for deep and shallow failure. *Engineering Geology*, *248*(January 2018), 124–139. https://doi.org/10.1016/j.enggeo.2018.11.015

Tsai, K. C., Hsiao, C. P., & Bruneau, M. (2000). Overview of building damages in 921 Chi-Chi earthquake. *Earthquake Engineering and Engineering Seismology*, *2*(1), 93–108.

Tsangaratos, P., & Benardos, A. (2014). Estimating landslide susceptibility through a artificial neural network classifier. *Natural Hazards*, *74*(3), 1489–1516. https://doi.org/10.1007/s11069-014-1245-x

Vakhshoori, V., Pourghasemi, H. R., Zare, M., & Blaschke, T. (2019). Landslide susceptibility mapping using GIS-based data mining algorithms. *Water (Switzerland)*, *11*(11), 7–13. https://doi.org/10.3390/w11112292

Wang, F., Xu, P., Wang, C., Wang, N., & Jiang, N. (2017). Application of a gis-based slope unit method for landslide susceptibility mapping along the longzi river, southeastern tibetan plateau, China. *ISPRS International Journal of Geo-Information*, *6*(6). https://doi.org/10.3390/ijgi6060172

Wang, K. L., & Lin, M. L. (2010). Development of shallow seismic landslide potential map based on Newmark's displacement: The case study of Chi-Chi earthquake, Taiwan. *Environmental Earth Sciences*, *60*(4), 775–785. https://doi.org/10.1007/s12665-009-0215-1

Wang, K., Xu, H., Zhang, S., Wei, F., & Xie, W. (2020). Identification and extraction of geomorphological features of landslides using slope units for landslide analysis. *ISPRS International Journal of Geo-Information*, *9*(4). https://doi.org/10.3390/ijgi9040274

Wang, K., Zhang, S., DelgadoTéllez, R., & Wei, F. (2019). A new slope unit extraction method for regional landslide analysis based on morphological image analysis. *Bulletin of Engineering Geology and the*

Environment, *78*(6), 4139–4151. https://doi.org/10.1007/s10064-018-1389-0

Wubalem, A. (2020). *Landslide Susceptibility Mapping using Statistical Methods in Uatzau Catchment Area, Northwestern Ethiopia*. 1–21. https://doi.org/10.21203/rs.3.rs-15731/v2

Xie, M., Esaki, T., Zhou, G., & Mitani, Y. (2003). Geographic Information Systems-Based Three-Dimensional Critical Slope Stability Analysis and Landslide Hazard Assessment. *Journal of Geotechnical and Geoenvironmental Engineering*, *129*(12), 1109–1118. https://doi.org/10.1061/(asce)1090-0241(2003)129:12(1109)

Youssef, A. M., & Pourghasemi, H. R. (2021). Landslide susceptibility mapping using machine learning algorithms and comparison of their performance at Abha Basin, Asir Region, Saudi Arabia. *Geoscience Frontiers*, *12*(2), 639–655. https://doi.org/10.1016/j.gsf.2020.05.010

Youssef, A. M., Pourghasemi, H. R., Pourtaghi, Z. S., & Al-Katheeri, M. M. (2016). Landslide susceptibility mapping using random forest, boosted regression tree, classification and regression tree, and general linear models and comparison of their performance at Wadi Tayyah Basin, Asir Region, Saudi Arabia. *Landslides*, *13*(5), 839–856. https://doi.org/10.1007/s10346-015-0614-1

Yu, C., & Chen, J. (2020). Landslide susceptibility mapping using the slope unit for southeastern Helong city, Jilin province, China: A comparison of ANN and SVM. *Symmetry*, *12*(6), 1–23. https://doi.org/10.3390/sym12061047

Zhang, Y. bin, Xiang, C. lin, Chen, Y. long, Cheng, Q. gong, Xiao, L., Yu, P. cheng, & Chang, Z. wang. (2019). Permanent displacement models of earthquake-induced landslides considering near-fault pulse-like ground motions. *Journal of Mountain Science*, *16*(6), 1244–1257. https://doi.org/10.1007/s11629-018-5067-2