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.

Anonymous Reviewer (RC)#1

The paper would benefit from a deep systematic revision of the presentation of results and proposed approach with respect to the claimed aim before consideration for publication in Natural Hazard and Earth System Science:

Comment 1: The Introduction chapter is unbalanced on the empirical literature relations available for the calculation of the coseismic displacement, and the different solutions for landslide stability analysis with respect to slope units' delineation approaches.

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 balance the literature and empirical relations available for calculating 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 1980*s*, 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, modeled as rigid 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).

The 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). The 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 heterogeneity effects 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 2: The authors stated from line 80 that the main aspect of the model used and proposed has three distinct features compared to the others and include: i) the SU delineation, ii) the consideration of pore water distribution and iii) the GIS computation of F_s and the *ky* (g) to avoid iterative errors: The first important aspect is the SU definition approach that should solve slope heterogeneity defects is not adequately presented and is not clear and easy to understand by the general audience. Secondarily, the role and the areal constraints of pore pressure (hydrostatic) lacks in the whole manuscript. Is it considered parametrically? Does the SF of Fig. 7 account for the r_u pore pressure ratio reported in the methods section? Finally, the areal GIS-based quantification of *SF* and *ky(g)* appears to be a commonly used approach in the scientific community.

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: (i) 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^{o} and 10^{o} respectively, and a slope toe angle of 45^{o}. 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).

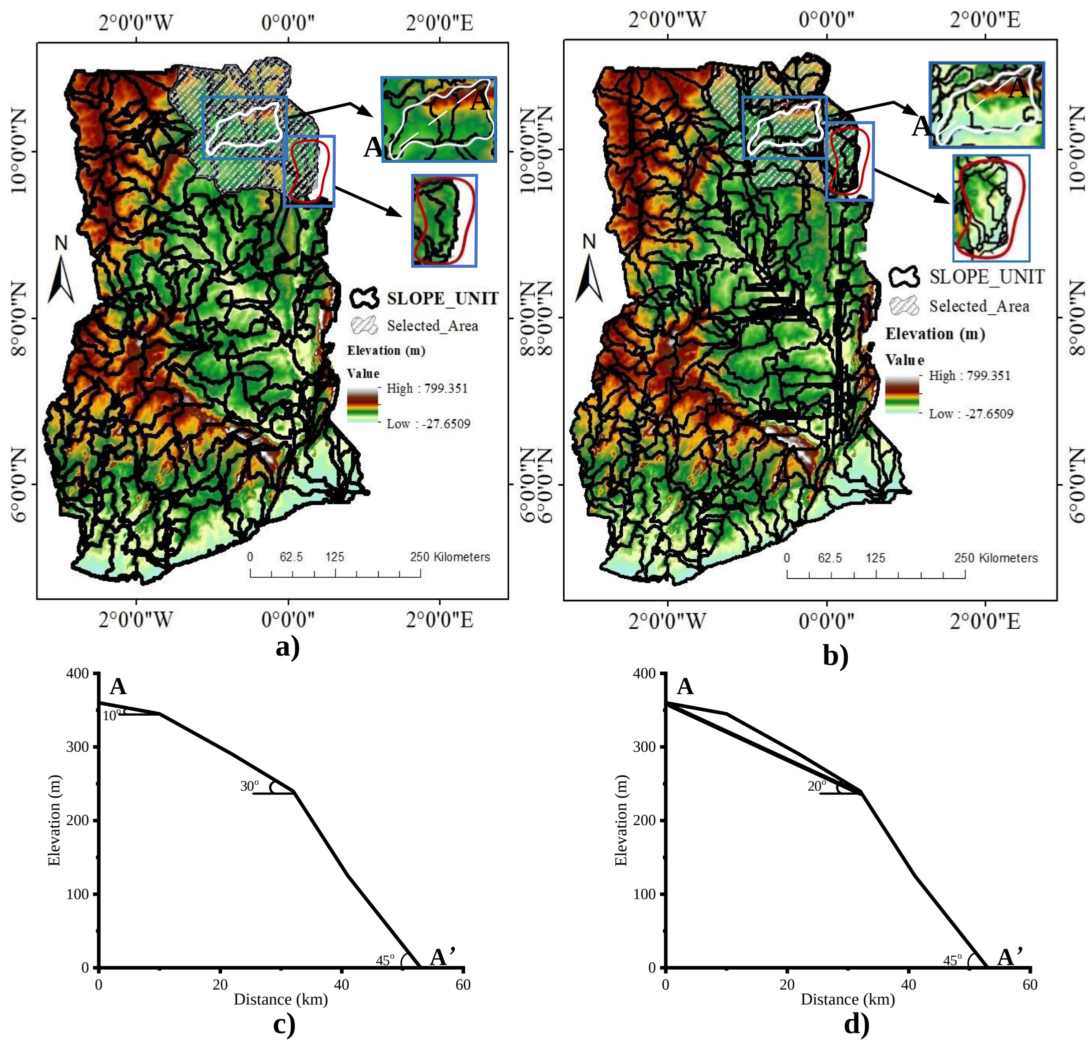

Fig. 4 Slope units of Ghana derived using different methods. a) Results from the point segmentation method b) Result from hydrological method c) Simplified terrain profile along *A"-A*. c) Simplified terrain profile along *A"-A* for hydrological method These slope units are overlain on elevation maps. 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.

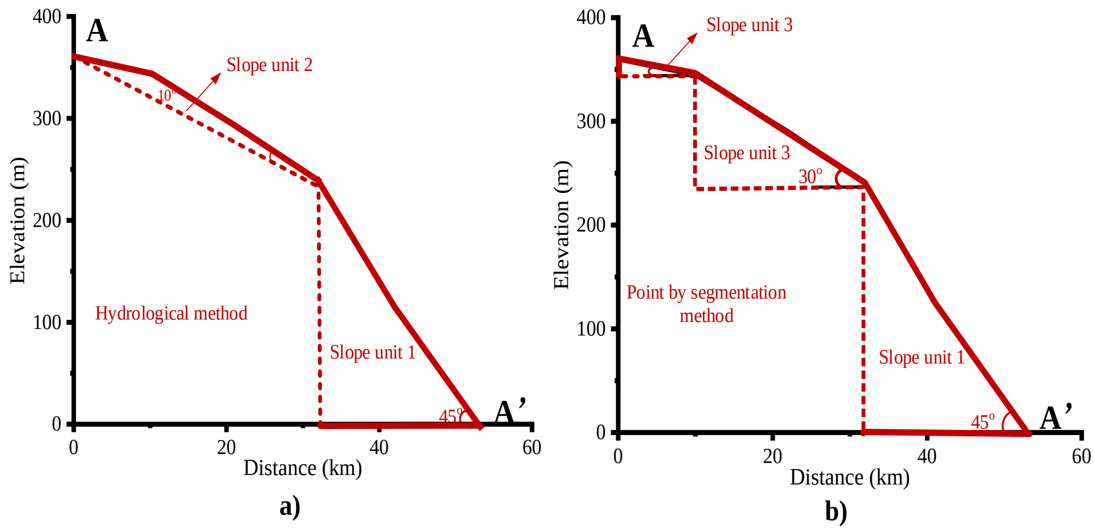

Fig. 1 Profile of slope unit by different methods. a) *A'-A* Slope unit profile determined by the hydrological method and b) *A'-A* Slope unit determined by the point by the segmentation method

After revised: (ii) The effect of pore water pressure has been adequately presented in this manuscript [Page 5, Line 7 -24]

The aspect of the displacement method used has also been reviewed in the manuscript to include the effect of cohesion, however, the influence of pore water pressure remains unchanged and used in the manuscript during the determination of the safety factor,' F_s' Fig.6 (a). It's presented in the manuscript as inscribed below,

Most slope unit methods are typically adopted to estimate the Newmark-type displacement for regional seismic landslide hazard assessment. This procedure is limited to the assumption of infinite slope and rigid block movement, which may be different from the actual behavior of slope exposed to earthquake loading. A new slope unit-based approach is proposed in this study (point segmentation) to estimate earthquake-induced displacements for finite slopes. The method's main advantages are that it considers slope geometry and tends to automatically predict landslide hazards for both finite and infinite slopes. Using the method for finite slope displacement analysis means making considerations for the effect of the pressure associated with underground water that may affect it. Because When pore water pressure is neglected in the strength reduction of a finite slope, it may affect the excess pore water pressure that influences the yield acceleration k_y(g) and underestimate the displacement (Biondi et al., 2007; Sahoo & Shukla, 2019). The effect of pore water pressure at a depth within the soil or underground Hydrostatic consideration has also been adequately presented in this paper for the delineation of an F_s which was used to compute for slope unit displacement and has been mentioned in the research as such Eq. (5) sums up the F_s method used in this study for the delineation of Fig. 6(a).

$$F_s = \frac{c + (\gamma - m\gamma_w) d \cos\beta \tan\varphi}{\gamma d \sin\beta} [1 - r_u] \tag{5}$$

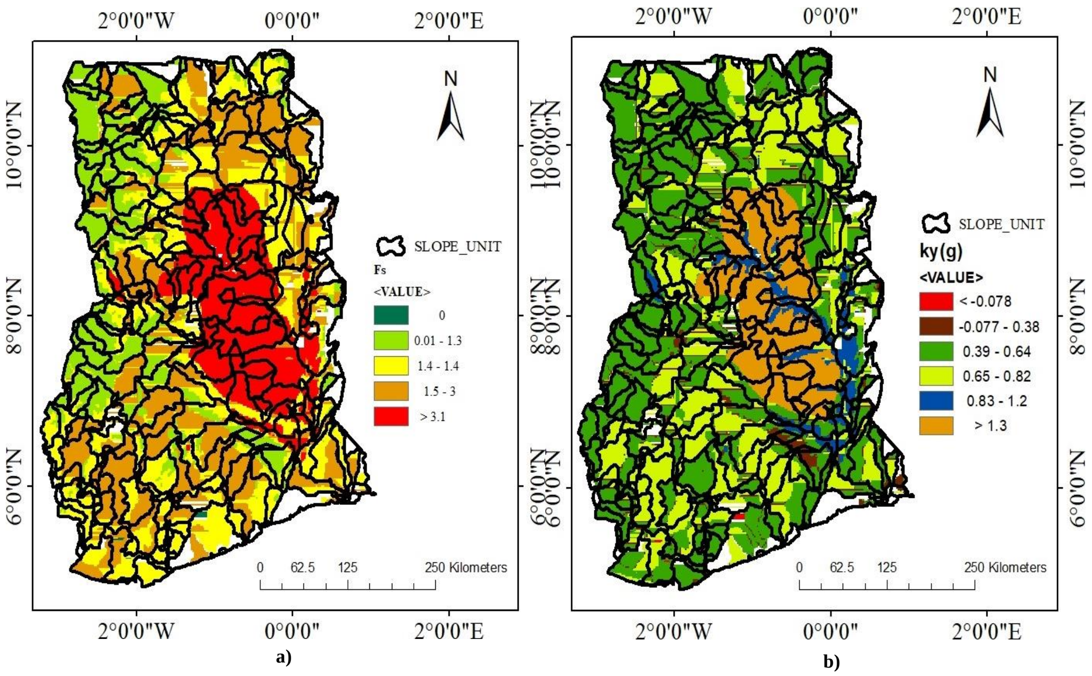

Fig. 6 Automatic generated Maps a) Factor of Safety, F_s, b) Yield acceleration, *ky*,

After revised: (iii) GIS-based quantification of Fs and ky(g), [Page 4 (line 1-8)]

Delineation of the Fs and ky(g) using the GIS approach to eliminate iterative error seems common in some research studies on displacement analysis as stated by the reviewer. As such been changed and thus the distinct aspects of the study have been reviewed on page 4 of the Manuscript as follows,

i) Extraction of slope unit that accurately predicts the watershed and morphology (aspect and gradients) of the study area. 3^D elevation watershed points of the study area were first derived before being used for the extraction of the slope unit. These points helped obtain accurate slope gradients, and ridge and valley lines were used in the extraction of the slope unit to eliminate heterogeneity defects associated, and segmentation is done to solve boundary defects associated with the hydrological method.

ii) The extracted slope unit considers slope geometry and tends to automatically predict landslide hazards for both finite and infinite slopes.

iii) An F_s that considers the effect of pore-water pressure alongside the traditional Newmark's method that considers failure depth *d*.

Comment 3: The rigid and flexible block effect is considered important and treated analytically; however, the contribution of cohesion in earth shallow landslides is considered irrelevant, which are mainly governed by the effect of apparent and mechanical cohesion of unsaturated media. A critical comment about this topic would improve the manuscript. In addition, eq. (8) by Saygili & Rathje, 2009 is dependent on cohesion. Which values have been adopted?

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, the rigid and flexible method has been modified to include cohesion as presented in the manuscript Page 7, (Lines 5-30)]. We initially ignored the effect of cohesion because, according to Biondi et al. (2007), consideration for the effect of pore water pressure during stability analysis of slope is usually done for cohesionless soil materials. As such, this study decided to base the displacement analysis on designing for the worse possible condition. Thus, neglecting the effect of cohesion. However, after further consideration based on the reviewer's comment, the study omitted the idea of neglecting the effect of cohesion in its analysis. And has included the effect of soil cohesion in the determination of the $F_{s,}$ hence including the effect of cohesion in the displacement analysis as stated on page 7 of the manuscript

Comment 4: Are the landslides plotted in Figures seismically induced? In some figures are reported locations of "failure areas and catalog" that are not explained and/or not fully considered in the validation of results.

Response: Thank you very much for your question.

The failure areas and catalog are explained on Page 10 (Line 21-29) of the manuscript as written below,

After revised: i) Failure areas [Page 10 (Line 21-29)-manuscript]

The failure areas and catalogs are explained in the manuscript on page 10 (Line 21-29)of the manuscript.

Because Ghana (the Study area) lacks a strong landslide database that could be utilized to predict failed slopes within the slope unit, the failed regions in this study were predicted using the displacement map alongside the prediction accuracy method by Jibson & Keefer, (1993); Tsai et al., (2019). The method states that the prediction accuracy for slope displacement under seismic loading should depend on the relationship between the threshold and predicted displacements (noting an allowable threshold displacement between 5-10 cm depending on the residual slope). Using the displacement map in Fig.9 (b), areas within the slope units having predicted displacement above 10 cm were selected as the probably failed areas in this study Jibson & Keefer, (1993). The predicted failed areas were consistent with the Landslide susceptibility map of Ghana in Fig.9(a) obtained using the Frequency Ratio F_r method proposed by Buah et al., (2019).

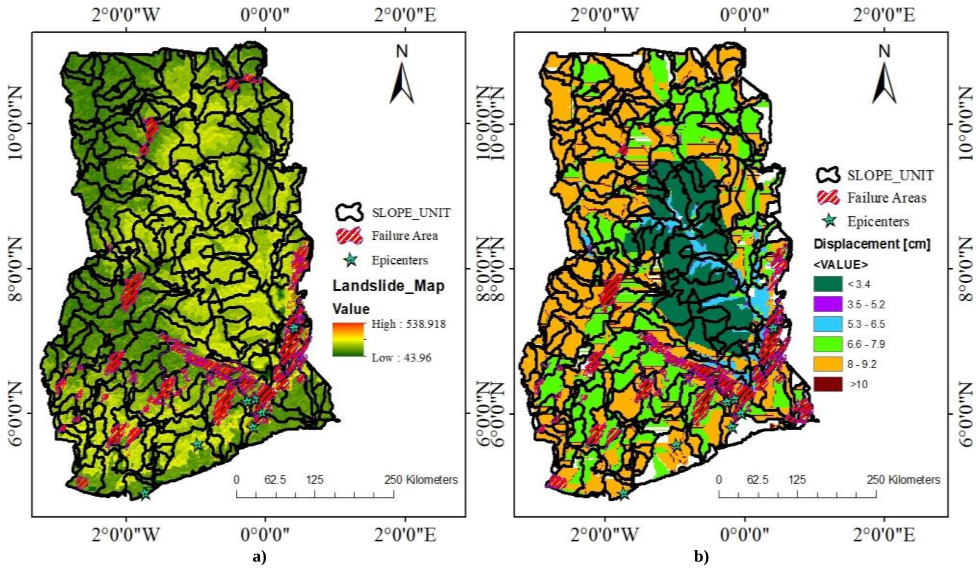

Fig. 9 Displacement: a) T_s/T_m of Slope Unit in Ghana b) Landslide susceptibility Map of Ghana c) Displacement map indicating failure areas and previous landslide catalogs (epicenters)

After revised: ii) Earthquake Epicenters/catalogs (Page 10 and Fig.8 – manuscript)

On the other hand, the major earthquake catalogs /Epicenters considered in this research indicate whether the failure areas on the displacement map coincide with the Earthquake epicenters because the research assumes the displacements of slopes are seismically induced. However, soil properties play a role.

Comment 5: Regarding the Prediction rate, I'd spend more effort discussing the general concept and the meaning of the two curves for the validation of the results. With a few landslides' observations, I supposed the P_r is overbalanced by a large number of negatives. I'll express the success rate as the ratio between the true positive rate and the false-positive rate. Would the success rate for true positives be more informative? What about the effect of strength parameters on the lone True Positives (S_1).

Response: Thank you very much for your suggestion.

The prediction rate (P_r) and Failure proportion (%) have been reviewed and adequately explained on pages Page 11 (line7-22), Table.4, and Fig.10 of the manuscript.

After revised: i) Prediction Rate curves [Page 11 (line7-22), Table.4 and Fig.10 [manuscript]

The P_r and failure proportion curves have been adequately detailed in the manuscript as demanded by the reviewer as such,

The predicted and threshold displacement of the slope subjected to earthquake loading can be used to determine its failure. A threshold displacement of 5-10 cm is deemed reasonable (Jibson & Keefer, 1993; Tsai et al., (2019). In this situation, given a threshold displacement of 10 cm, all areas with slope units having predicted displacements >10cm are indicated as failed areas and used for the validation of the displacement through the prediction rate P_r procedure (Wang & Lin, 2010). P_r is a ratio of the slope units with accurate predictions (true positives) to those with inaccurate predictions (false positives). The true positives encompass slope units containing failure scars and displacement greater than threshold displacement (S_1) and slope units without failure scars with displacement lower than the threshold displacement (S_4). The total number of slope units also includes the incorrect predictions (false positives), which also encompasses slope units without scars but displacement above the threshold (S_2), and those with scars and displacement less than the threshold (S_3) Table.4. The P_r values for all assumed displacements are shown in Fig.10 (a). For the predicted displacement map in Fig.9 (b), the P_r value is 35 %, with 85 accurate predictions out of 241 slope units at a threshold displacement of 5 cm. The Method also presents a 68% P_r value with 164 accurate predictions out of 241 slope units at a threshold displacement of 10 cm. Per Fig.10 (a), the P_r has a maximum value of 68.5 % with 165 correct predictions out of 241 slope units when the threshold displacement of slopes in Ghana is defined as 9 cm, which agrees with the suggestion by Jibson & Keefer, (1993)

$$P_r = \frac{S_1 + S_4}{S_1 + S_2 + S_3 + S_4} \tag{20}$$

Table 4 Displacement prediction parameters S_1, S_2, S_3, and S_4

No	Slope Unit Location identification	Symb	Accurate Prediction	Inaccurate Prediction	Values at 5 cm displacement	Val. at 10 cm displacement
1	With scars and displacement above threshold	S_1	S_1		37	25
2	Without Scar and displacement below threshold	S_4	S_4		48	139
3	Without scars and displacement above threshold	S_2		S_2	114	77
4	With scars and displacement below threshold	S_3		S_3	0	0

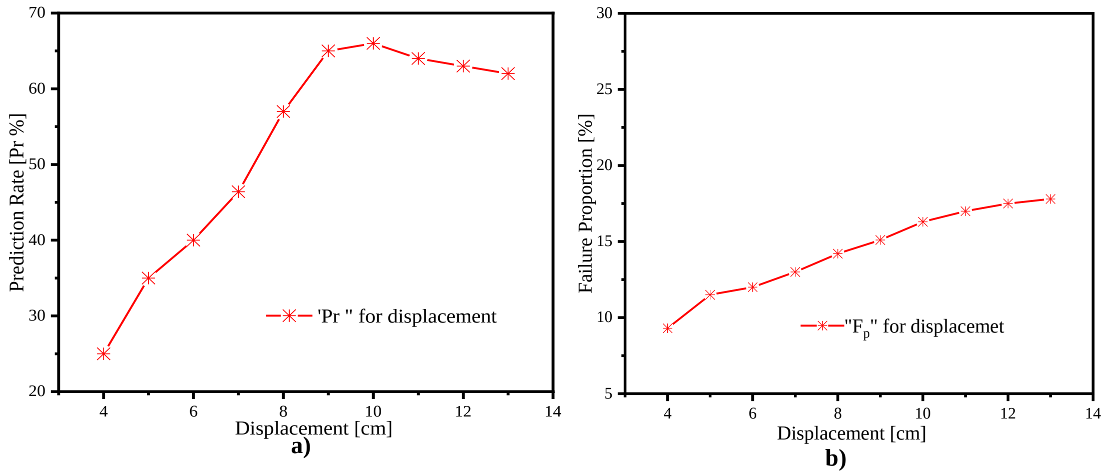

Fig. 2 Displacement analysis for slopes in Ghana. a) Displacement P_r plot showing the maximum P_r value at 68.5% for the threshold displacement of 9cm, b) failure proportion plot showing the least portion of slope to fail in Ghana to be 9.3% and the

After revised: ii) Failure Proportion (%) (page 11(line 24-27), Page 12(line 1-4)- Manuscript

According to (Tsai et al., 2019), a predicted slope failure does not necessarily indicate that the entire slope within a slope unit will fail but rather a portion. Therefore, the proportion of predicted slope failure in Ghana is computed as, the ratio of failure within the slope unit, u, to the slope unit's entire area, an Eq. (21). In comparison to the P_r value, the failure proportion is less affected by threshold displacement. The result from Fig.10 (a) shows that the failure portion value of 9.3 to 17.8% means that even if a slope unit is considered to fail; only 9.3 to 17.8 percent of its area is at risk of failing. The predicted failure rate of slope in Ghana is likely to be between 9.3 to 17.8 percent. Where u is the area of slope unit liable to fail and a is the total area of slope unit.

$$Failure\ Rate\left(F_r\%\right) = \frac{u}{a} \quad (21)$$

After revised: iii) P_r Determination

Thanks for your constructive comments supposing the P_r is overbalanced by a large number of negatives. However, we have an opposing view, because defining the P_r as the ratio between the true positives and the false positives will rather overbalance the results rather than the normal situation where the P_r is a ratio of the true positives and the totality of the slope units. For example, using the 5cm displacement values in Table 4, the true positives sum up to 87 whiles the false positives sum up to 114 whiles the total slope units are 241. So, the normal procedure used for this research gives a P_r of 36%, whiles when the ratio between the true and false positive values is used, a P_r value of 76%, which seems to be too high for 5cm threshold displacement. Therefore, inappropriate to be used.

Comment 6: Concepts expressed in methods are often repeated in the results section. Technical language is often less precise (see Detailed comments). The introduction of the chapter “Seismic activity of Ghana” is mainly focused on African landslides, however, a detailed analysis of the available landslide catalog lacks. I would suggest changing the title or rephrasing the introduction to the chapter.

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer’s comments the introduction of the chapter “Seismic activity of Ghana” has been reviewed to focus on Ghana rather than Africa on Page 8(Line 9-30) of the manuscript.

After revised: [Page 8 (Line 9-30)]

“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 7: The manuscript is not adequately cared for in style and formatting. Figure and not sequentially cited in the text and often placed in the wrong sections. Many of them are not useful or simplistic. Reference to figures and table are not consecutive, captions not informative, and not self-standing. Please consider a detailed review according to Journal standards.

Response: Thank you very much for your constructive comment.
We agree with your comment. Following the reviewer's comments, The Manuscript is now adequately formatted by rearranging and restructuring the sentences and figures to suit the Journal's standard. References to figures and table are very consecutive. Captions are informative and self-standing.

Comment 8: Line 20: Please change the typos sentence that is supposed to be "in order to".

Response: Thank you very much for your constructive comment.
We agree with your comment. Following the reviewer's comments, the sentence has been reviewed on Page 1 (Line 24) of the manuscript. The new sentence reads "earthquake distribution to provide a possible mitigation measure"

Comment 9: Line 36: Newmark instead of Newark.

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".

Comment 10: Line 60: Please deeply explain the limitation in reflecting morphological features.

Response: Thank you very much for your question.
The limitation of the morphological features is explained on page 3 of the manuscript. Morphological features are topographic landforms on the Earth's surface that require high-resolution elevation data to model them.

A slope unit is defined as the geomorphology of an area segmented into smaller mapping units by the ridge and valley lines or right and left-hand sides of a watershed sub-basin. An extracted slope unit must accurately represent the geomorphology of the study areas. A slope unit is as good as the method used in its extraction. If the method used is not suitable, the slope unit extracted wouldn't accurately represent the topographic features. As such, it doesn't reflect the exact geomorphology.

For example, slope units extracted using the hydrological slope unit extraction methods have sudden gradient changes along the flow direction. This affects the boundary of the extracted slope unit and the occurrence of slope unit heterogeneity. The slope unit extracted does not genuinely represent the study area's topography, therefore "not accurately reflecting the study area's geomorphology."

Comment 11: Do the authors referred to river thalweg with the term "crevasses"?

Response: Thank you very much for your correction. The sentence has been corrected on Page 4 (Line 23) of the manuscript and now reads,

After revised: [Page 4 (Line 23)] - Manuscript

"The mountain and river thalweg watersheds obtained are merged and segmented to delineate the boundaries before the morphological ridge and valley lines are determined to end the slope unit extraction".

Comment 12: Line 116: It is not tensile. It corresponds to the shear stress component parallel to the failure surface

Response: Thank you very much for your correction. The Correction has been made on Page 5 (Line 12) of the manuscript and the sentence reads.

After revised: [Page 5 (Line 12)] - Manuscript

"τ" is the shear stress component parallel to the failure surface".

Comment 13: Line 121: “m” should be formatted in italics.

Response: Thank you very much for your correction *“m”* has been italic as indicated by the reviewer on Page 5 (Line 18) of the manuscript.

Comment 14: References are cited twice.

Response: Thank you very much for your correction, one of the references has been removed. (Page 3 (Line 3)of the manuscript) . (Dunn et al., 2011; Terzaghi et al., 1996)

Comment 15: Line 143: Please rephrase the definition of k_y(g).

Response: Thank you very much for your correction, we agree with your comment. Following the reviewer’s comments, k_y(g) has been redefined on Page 6 (Line 6-8) of the manuscript. The newly written k_y(g) is as follows,

After revised: (Page 6, Line 6-8)- Manuscript

Yield acceleration, k_y(g): Permanent displacing of the slope is mainly influenced by its yield acceleration properties, including groundwater level, geometry, material strength, and seismicity. In the sliding block procedure, k_y(g) is defined as the point where sliding failure or permanent displacement of slope initiates (Kan & Taiebat, 2005) Fig. 6(b) using Eq. (9).

Comment 16: Line 190: The list of coordinates can be omitted in the text since they are included in the figures.

Response: Thank you very much for your correction, we agree with your comment. Following the reviewer’s comments, the coordinates of Ghana on Page 8 of the manuscript under the sub-heading Case Study – Ghana (West Africa) have been removed from the sentence.

Comment 17: Line 192, 194: Please use the International System of Units.

Response: Thank you very much for your correction, we agree with your comment. Following the reviewer’s comments, International system units have been given to the rainfall in Ghana by changing the unit from centimeters (cm) to millimeters (mm) on Page 8 (Line 5) of the manuscript. And the sentence is written as,

After revised: (Page 8, Line 5)- Manuscript

“Ghana is tropical and the southern part and eastern part of the Volta Lake experiences the highest rainfall range between 1,400 to 2000 millimeters per year, from April to mid-November”.

Comment 18: Line 148: Reference of DCF is missing. The factor is reported sometimes in subscript, please uniform it.

Response: Thank you very much for your constructive comment, Following the reviewer's comments, The reference to the DCF has been added on Page 6 (Line 11) of the manuscript as "(Tsai et al., 2019)". The factor which was in subscript has been uniformed.

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

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

Comment 19: Line 205: The Romanche Transform fault and earthquake epicenters should be located on Map.

Response: Thank you very much for your constructive comment, Following the reviewer's comments, the Romanche faults and earthquake epicenters have been located on maps (Fig.7). (Page 26)

Comment 20: Line 217: Reference to figure missing.

Response: Thank you very much for your comment, there is no figure on line 217.

Comment 21: Unit weight cannot be considered a strength parameter.

Response: Thank you very much for your constructive comment, Following the reviewer's comments, the unit weight of soil (γ) has been replaced by cohesion as a strength parameter on Page 9 (Line 17) of the manuscript. And the sentence now reads,

After revised: (Page 9, Line 17) – Manuscript

"The required strength parameters used include the c and φ"

Comment 22: Annum

Response: Thank you for pointing this out, Following the reviewer's comments, Annum has been correctly spelt in Table 1, Page 36 of the manuscript. And it's written as,

"Akoto and Anum, 1992, AKO".

Comment 23: Line 323: "Ninety-nine percent correlation is obtained". I missed the presentation

Response: Thank you for your question. The full statement is written on Line 323 of the manuscript (preprint version)

"The study evaluated the strengths of materials' effect on acceleration by establishing a relationship between displacement and k_y(g). Ninety-nine percent correlation is obtained, indicating how strength properties affect the Fs and the k_y(g) but not the P_r of displacement". However, after critical considerations based on the review comments, the statement has been removed from the revised manuscript.

Comment 24: Table 2: In the percentage column 1/3 has been changed to 3/Jan by the corrector.

Response: Thank you for your constructive comments, the previous Table 2 has been removed from the revised manuscript.

Comment 25: Most of the figures are not informative (Esp. Fig. 4 or Fig. 5) and can be deleted.

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, and Fig.5 (now Fig.7) has been improved accordingly to contain the earthquake epicenters in Ghana (Catalogs) and the romance fault. (Page 26- manuscript)

Comment 26: Fig.7a, the red and green color bar looks counterintuitive to express the SF of slopes.

Response: Thank you very much for your constructive comment.
We agree with your comment. Following the reviewer's comments, Previously Fig.7a (now Fig.6a) "F_s map" has been improved to vividly express the safety factor (F_s) of the slopes. (Page 25- manuscript).

After revised: Page 25- Manuscript

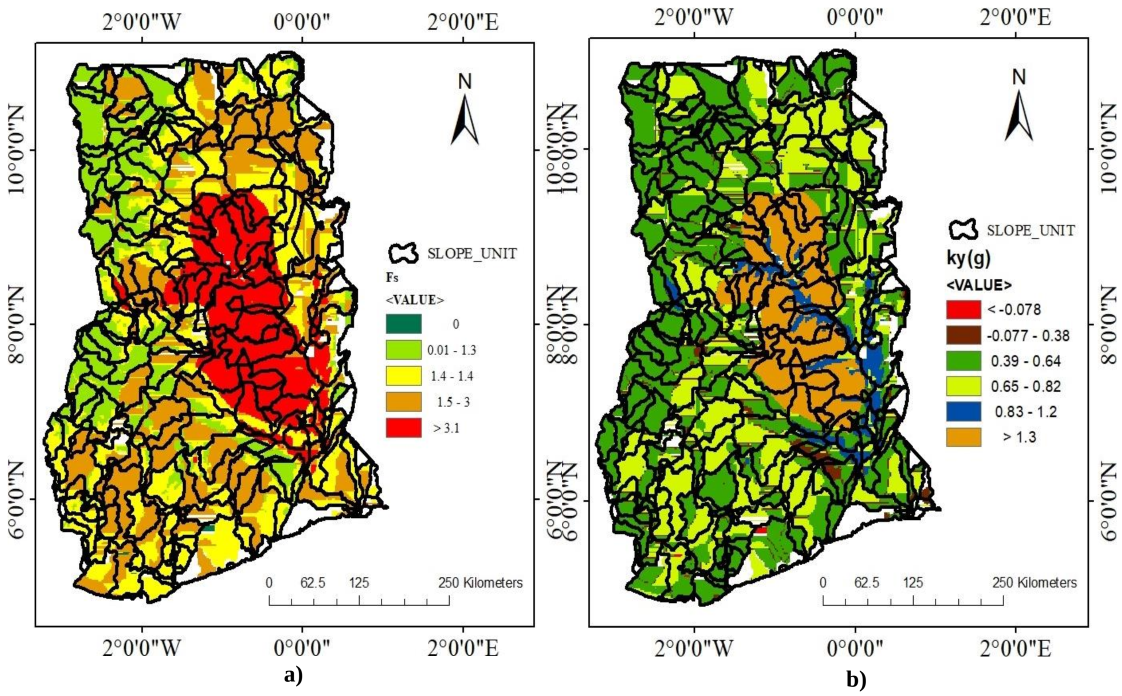

Fig. 6 Automatic generated Maps a) Factor of Safety, F_s, b) Yield acceleration, k_y(g),

Comment 27: Fig. 14 caption is wrong, looks like a repetition of fig 13

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, Caption for **Fig.3** has been reviewed to read "Sensitivity Assessment of point segmentation slope unit extraction method using Zhang et al., (2019) a) Displacement Predicted rate of different strength parameters (P_r) b) failure proportion of different strength parameters." (Page 32 - manuscript)

Caption for ***Fig*. 4** has also been reviewed to read" Comparing different displacement methods a) Displacement Predicted rate of different displacement methods b) Failure proportion of different displacement methods" (Page 33- manuscript).

After revised: Page 33- Manuscript

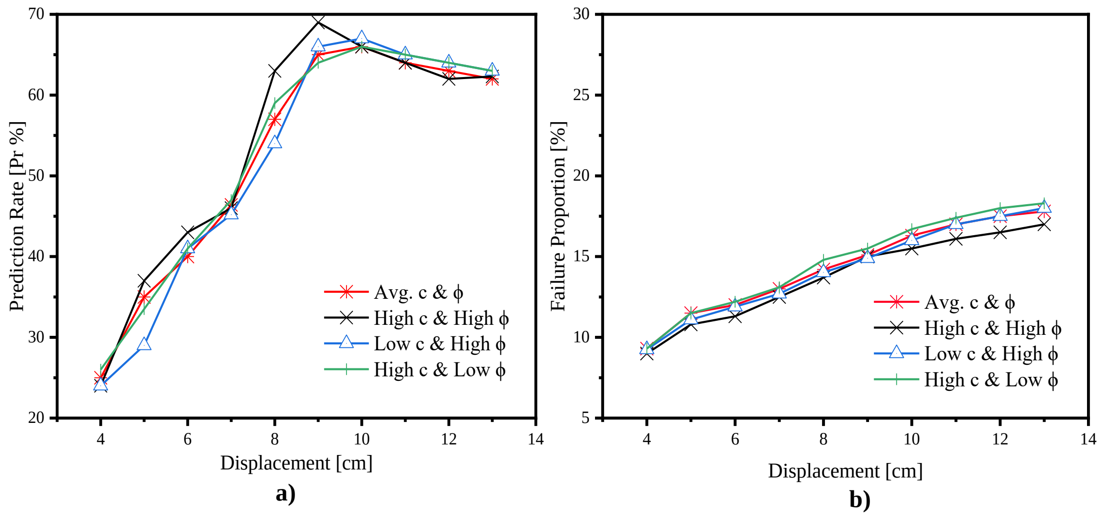

Fig. 5 Sensitivity Assessment of point segmentation slope unit extraction method using Zhang et al., (2019) a) Displacement Predicted rate of different strength parameters (P_r) b) failure proportion of different strength parameters.

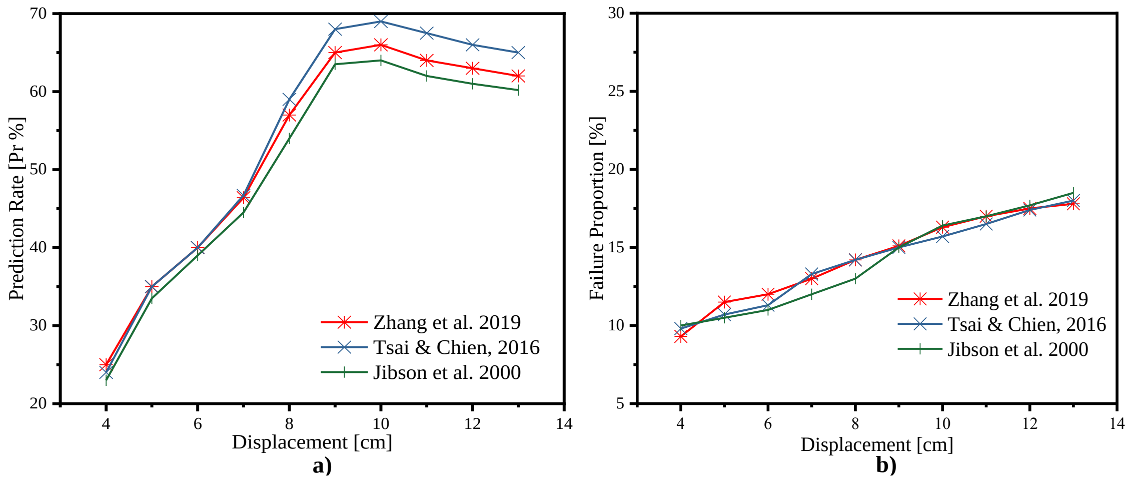

Fig. 6 Comparing different displacement methods a) Displacement Predicted rate of different displacement methods b) Failure proportion of different displacement methods

Comment 28: Table 2 can be merged with Table 3 since it is not informative. The real percentage distribution of the two major complexes is not indicative. I'd report it for the lithological unit in Table 3

Response: Thank you very much for your constructive comment.

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

After revised: Page 37 -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/m³ medium***	***C. 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 29: Fig. 5 can be merged with fig. 6.

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, Fig.5 cannot be merged with Fig.6, because Fig.5 is a locational map while Fig.6 is a Slope Unit Map. Fig.5 (Now Fig.7) has been improved to show the geological details, major faults, and major earthquake epicenters in the study area (Ghana). The new Fig. 7 is located on Page 26 of the manuscript.

After revised: Page 26 -Manuscript

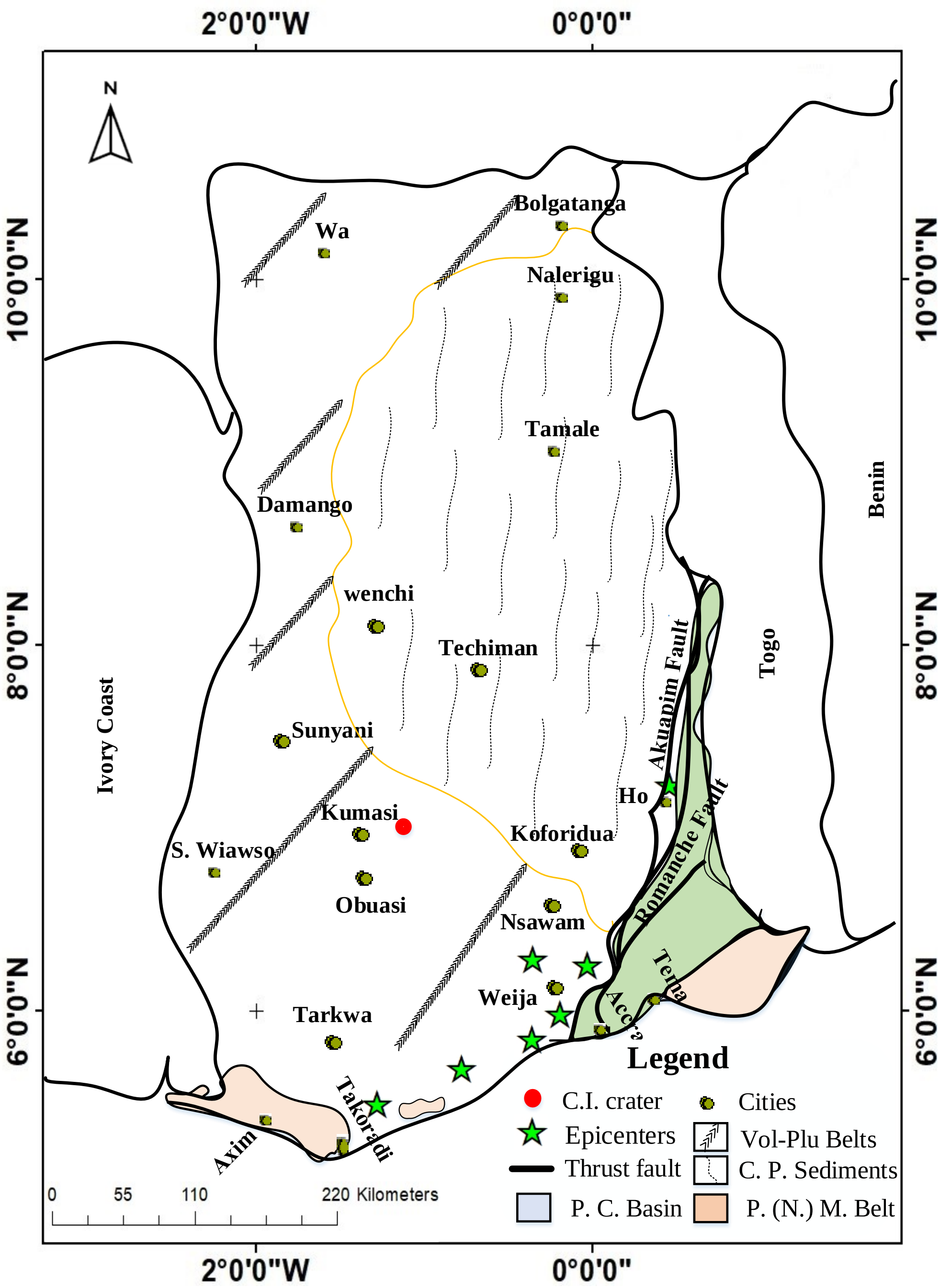

Fig. 7 Major Lithostratigraphic and Lithotectonic Complexes of Ghana

Comment 30: Fig. 6 can be improved including the relief map reported in Appendix Fig. A1.

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, Fig. 6 (now Fig.4) has been revised to include the elevation map in Appendix Fig.A1 and improved as such. An additional feature showing the slope unit profile (Fig.4c) is added and used to explain the slope unit heterogeneity effect. Located on Page 26 of the manuscript.

After revised: **Page 23-Manuscript**

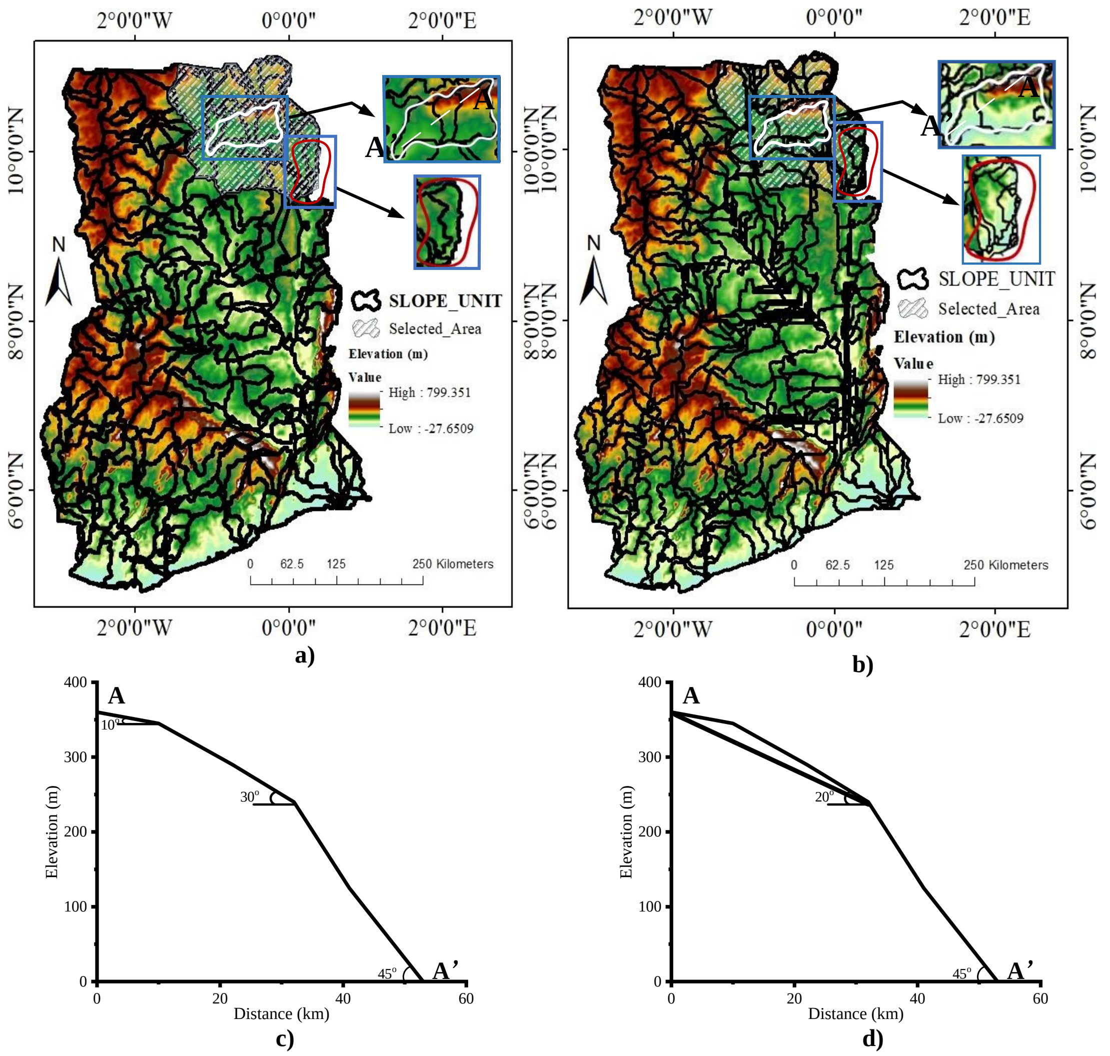

Fig. 4 Slope units of Ghana derived using different methods. a) Results from the point segmentation method b) Result from hydrological method c) Simplified terrain profile along *A"-A*. c) Simplified terrain profile along *A"-A* for hydrological method These slope units are overlain on elevation maps. 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.

Comment 31: It is difficult to appreciate the difference between the three adopted models.

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, the displacement of Ghana generated using different methods has been reviewed to show clearly the difference in the adopted models on Page 27 of the manuscript ("Then Fig.9", now Fig.8). The review is in accordance with the new F_s and k_y(g) map.

After revised: *Page 27 -Manuscript*

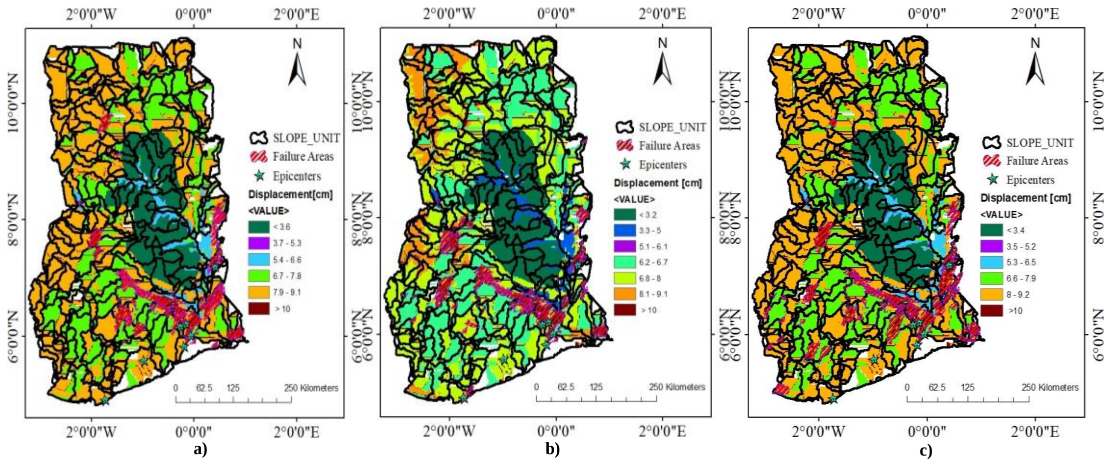

Fig. 8 Displacement maps: a) Tsai & Chien (2016); b) Jibson et al (2000); c) Zhang et a., (2019)

From the figure above it could be seen that the displacement method used for this research (Zhang et al., 2019) produced a displacement map having predicted failure areas in equivalence to the map prepared using the displacement method by Jibson et al., (2000); H. Y. Tsai et al., (2019). This displacement map looks alike with an error margin of about 1% percent. Confirming the accuracy of the prediction method compared with others.

Comment 32: Fig.12 Change "Hydrolical"

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, Caption Hydrolical on *Fig*.12 has been changed to hydrological. And can be found on page 31 of the manuscript.

After revised: Page 31 –Manuscript

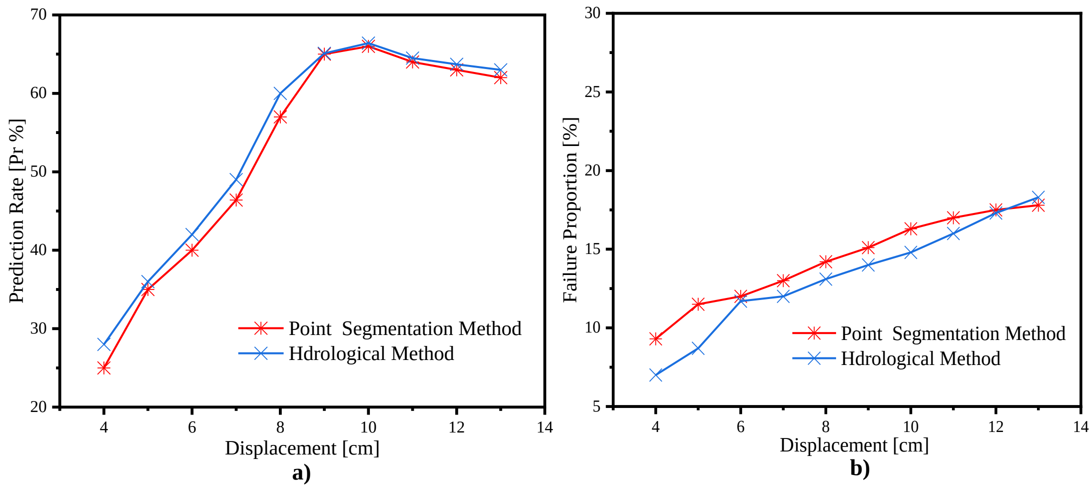

Fig. 7 Comparative Assessment of different slope unit extraction methods, which looks different because different slope unit methods produced different flow accumulations a) Displacement Predicted rate of different slope unit extraction methods. b) Failure proportion of different slope unit extraction methods.

Comment 33: Buah et al. 2019 is not listed in the reference

Response: Thank you very much for your constructive comment.

We agree with your comment. Following the reviewer's comments, Buah et al 2019 have been included in the listed reference.

After revised: **References**

"Buah, P. A., Yingbin, P. Z., Bakah, D. A. Y., Ahiabu, M. K., & Zhibin, L. (2019). Earthquake-Induced Landslide Susceptibility Analysis : The Effect of DEM Resolution. International Conference on Mechatronics, Remote Sensing, Information Systems, and Industrial Information Technologies, ICMRSISIIT 2019. https://doi.org/10.1109/ICMRSISIIT46373.2020.9405915"

References

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

Atkinson, P. M., & Massari, R. (1998). Generalised linear modelling 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