Nat. Hazards Earth Syst. Sci. Discuss., 1, C123–C136, 2013
www.nat-hazards-earth-syst-sci-discuss.net/1/C123/2013/

Natural Hazards and Earth System Sciences
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Discussions

Interactive comment on "Comparing multi-criteria methods for landslide susceptibility mapping in Chania Prefecture, Crete Island, Greece" *by* M. Kouli et al.

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Received and published: 22 April 2013

Reply to comment on "Comparing multi-criteria methods for landslide susceptibility mapping in Chania Prefecture, Crete Island, Greece" by 1) F. Guzzetti, 2) S. Sterlacchini (Referee) and 3) C. Li (Referee).

Dear Dr Guzzetti and Dear Referees, thank you all for your valuable comments. Please find attached our response to your comments as well as a revised manuscript.

(A) Short comment of F. Guzzetti:

Regarding your first comment, Fig.1 provides information on the standard deviation

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associated with the WoE model. The mean value of standard deviation of the susceptibility model is 0.026 and subsequently the average variability i.e. a measure of uncertainty is (2σ) =0.052. Uncertainty associated with the identification and mapping of landslides and with possible mapping and drafting errors of the inventory map must also be taken into account. For these reasons and based on the success rate curves, the prediction rate curves and the ROC curves, presented below, we propose the equality of the prediction efficiency of the two susceptibility methods and we conducted further investigation.

To further investigate the models performances, we prepared Receiver – Operator curves (ROC) (Fig.4). ROC curves plot "sensitivity" vs. "1-specificity", where sensitivity is the proportion of mapping units containing known landslides that are correctly classified as susceptible, and "specificity" is the proportion of mapping units free of landslides that are correctly classified as landslide free. ROC curves were prepared for independent landslide information, in which case they measure the classification prediction skill (Van Den Eeckhaut et al., 2009). In a standard ROC plot, the area under a ROC curve, AUC, is a quantitative measure of the model performance. In contrast to success and prediction rate curves, ROC curves are not sensitive to prevalence (i.e., considerable difference between landslide free and landslide-affected mapping units (Begueria, 2006)). Therefore, ROC curves are considered a more appropriate evaluation and validation tool (Van Den Eeckhaut et al., 2009). Swets (1988) considers AUC>0.90 typical of highly accurate classification models. In our work, WLC ROC curve gave AUC =0.96 while WoE ROC curve gave AUC=0.94.

According to the success rate curves the WoE method shows a better model fitting (success rate of 87.4%) compared to the WLC method (success rate of 84.7%). According to the prediction rate curves (84.4%, 82.4 % and 82% for WofE, WLC and CM respectively) and ROC curves the two methods show equal model performance and prediction efficiency.

The combined model shows 85% success rate and 82% prediction efficiency visually practically refining the large areas of very high and high susceptibility classes of the WLC.

Having in mind the same performance of the two models, we can suggest that the CM succeeded to outline more accurately and strictly the classes of WLC model without missing any of its predicting skills.

During the study four landslide susceptibility maps were initially created; one with distance to roads and one without distance to roads parameter for each one of the two approaches. The susceptibility maps were compared and validated using area under curve (AUC) analysis with the existing landslide locations data that were not used for the training of the model. The rate curves were created and the areas under the curve were calculated for the containing all cases.

The efficiency of prediction using all the casual factors and the WoE method was 88% while the expert-based model showed an accuracy of 85%. In the case of exclusion of roads proximity as a causal factor the WLC model gives area under curve equal to 0.76 while WoE 0.84. The approach taking into account the roads proximity was finally selected due to the following reasons; regarding the landslide inventory, please note that we modified lines 15 to 20. Furthermore, the 108 recorded events of the inventory map is a big number of landslides considering the actual extent of the landslide prone areas in Chania prefecture. In order to collect all these data we conducted an extensive field investigation, we collected all possible old landside studies dating back to the 60s (from IGME, central laboratories of public works, the data bases of universities etc) and at the end, in order to cover the difficult to access areas we scanned the satellite pictures as well as some available aerial photos. Unfortunately, all these data present grate lack of homogeneity considering the data set for each landslide. For that reason we do not know the extent of all the sliding areas and as a result we could not take it under consideration. We decided that the best way to deal with this problem was to introduce the landslides at the inventory map as points and not as polygons. Roads definitely are landslide triggering manmade constructions; this is why we took under consideration the proximity from the roads by introducing a road network buffer zones data layer.

On the other hand we certainly have not collected data only along the road network. In some areas the road network is too dense so practically it is impossible to find a landslide far away from a road. Particularly, most of the trees you see at the south part of the island are olive trees, cultivated at very steep slopes, so the road network is too dense in order to cover the requirements of the farmers. In many cases the roads were constructed after the occurrence of the landslides (like Fig. 3b and 3d) on the other hand certainly some landslides were triggered by the construction works (like Fig. 3a and 3c). Furthermore, there are many landslides (e.g. Fig 3e) that have occurred several hundreds of meters away from the road network and have nothing to do with it. The landslides occurring close to the roads are NOT always related directly or indirectly to the presence of the roads and for sure we did not collected data only along the road network.

Regarding your third comment we must note that the total number of observed landslides in the study area is 108. The weight of evidence (WoE) method was applied using the 80 % of the inventory map landslides (86 landslides) as the training set and the rest 20 % (a number of 22 landslides) for accuracy assessment purposes. According to M. Van Den Eeckhaut et al., 2009 (in NHESS) “success rate and prediction rate curves plot the percentage of the study area in each susceptibility class against the percentage of landslide area in the same class. The difference consists in the considered landslides. Success rate curves are constructed considering the same landslides used to construct the susceptibility model, and hence represent a measure of model fit. Prediction rate curves are built considering independent landslide information (i.e., landslides not used to construct the susceptibility model), and measure the prediction skill of the classification”. The validation procedure of the two susceptibility models initially compared their performance using the total number of the available landslides. For the WLC this gives a measure of prediction efficiency while for WoE a measure of how well the models fits the known distribution of the landslides used to prepare the models but in the same time the ability of the model to properly predict “future” landslides. Moreover, the Areas Under Curves using only the 22 documented - independent landside information not used to construct the susceptibility models (i.e. the rest 20% of the landslides inventory) gave relevant results (Fig.3) with them of Fig 9 (page 37).

(B) Referee comment of S. Sterlacchini:

Regarding your first comment, we agree that we compare two different GIS-based modeling techniques, a knowledge-driven method and a data-driven method. However, this comparison allows the bidirectional control of both methods. The experts experience allows the validation of the data introduced at the WoE method as well as the resulting weights, indicating high probability of landslide occurrence. On the other hand the WoE results can validate/control the subjectiveness of the WLC results. So we think that the comparison contributes on the existing knowledge about the applied modeling techniques.

In order to compare results coming from so different modeling techniques, the Authors are obliged to stop the WoE analysis at the calculation of the Contrasts of the different variable classes used in the analysis instead of concluding the analysis by assessing Post Probability values, as the method can "naturally" provide. This was the method followed in our study. As you can see in page 12 we give the Equation 6, (Kayastha et al., 2012). The final map resulted using the contrast values as rates for the different classes of the causal factors.

Regarding comment 2. As already explained at the reply of the 2nd comment of F. Guzzetti, the use of points for the landslide representation was considered not only the best but also our only choice. Regarding the pixel size, it affects only the scale of the data layers introduced at the GIS environment (e.g. geology, slope, road buffer layers etc) and it has nothing to do with the landslide susceptibility layer.

Regarding comment 3. We do not completely agree with the statement: “From a methodological point of view, the Authors have to build different models for different landslide types, characterized by different degree of activity“ there are several landslide types with similar characteristics. Never the less in our case study we deal mainly with deep seated landslides and secondarily with some rockfalls, only at the areas occupied with calcareous rock, so I think we confront with the comment of the reviewer.

Regarding comment 4. We have created the Receiver-Operator Curves (ROC) for the two different methods and we added them in the revised ms: ROC curves plot “sensitivity” vs. 1-“specificity”, where sensitivity is the proportion of mapping units containing known landslides that are correctly classified as susceptible, and “specificity” is the proportion of mapping units free of landslides that are correctly classified as landslide free. ROC curves were prepared for independent landslide information, in which case they measure the classification prediction skill (Van Den Eeckhaut et al., 2009). In a standard ROC plot, the area under a ROC curve, AUC, is a quantitative measure of the model performance. Swets (1988) considers AUC>0.90 typical of highly accurate classification models. In contrast to success and prediction rate curves, ROC curves are not sensitive to prevalence (i.e., considerable difference between landslide free and landslide-affected mapping units (Begueria, 2006)). Therefore, ROC curves are considered a more appropriate evaluation and validation tool (Van Den Eeckhaut et al., 2009).

Regarding comment 5. Apart from success rate curves we present here (Figs. 3 and 4) and we added them I the revised ms, prediction rate curves and ROC curves.

Regarding comment 6. We definitely acknowledge that WofE is a data-driven method but, from our point of view, we should not as well underestimate the value of the expert’s opinion. As you can understand we do not mix the methods we just tray to interpret/validate the values deriving from the WofE by using the knowledge regarding the landslide susceptibility of the site. As mentioned above we actually think that the comparison made contribute on the existing knowledge about the applied modeling techniques.

Regarding comment 7. This sentence is referred to the two susceptibility maps resulted from the two different methods. We added the following paragraph in the text: "According to the natural breaks classification method, classes are defined based on natural groupings inherent in the data. The break points are identified by picking the class breaks that best group similar values and maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big jumps in the data values."

Regarding comment 8. Please refer to the reply of comment 6.

Reply to "other comments"

Page74 Lines 12-13: We agree with the comment of the reviewer but the abstract focuses only at the techniques applied at the case study. We do not consider it necessary to extend our reference to other techniques within the limits of the abstract.

Lines 22-24: We agree. We rephrased the sentence.

Page 75 Lines 19-20: Thank you for your comment. We have rewrite the sentences as following: Typical multivariate statistical approaches used to map landslide susceptibility are discriminant analysis (Fisher, 1936; Lachenbruch and Goldstein, 1979; Brown, 1998; Van Den Eeckhaut et al., 2009) and the logistic regression method (Wieczorek, 1996; Atkinson and Massari, 1998; Guzzetti et al., 1999; Gorsevski et al., 2000; Lee and Min, 2001; Dai et al., 2001; Dai and Lee, 2002; Ohlmacher and Davis, 2003; Ayalew and Yamagishi, 2005). The Weight of Evidence (WoE) modeling method is a bi-variate, "data-driven" method (Lee et al., 2002; van Westen and Lulie, 2003; Lee et al., 2004a; Thiery et al., 2007; Mathew et al,. 2007; Neuhauser and Terhorst, 2007; Poli and Sterlacchini, 2007; Rezaei Moghaddam et al., 2007; Dahal et al., 2008a; b; Sharma and Kumar, 2008; Barbieri and Cambuli, 2009; Ghosh et al., 2009; Regmi et al., 2010).

Page 76 Line 4: We have adopted here the following references; Ayalew, L., Yamagishi, H., Ugawa, N.: Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, Japan, Landslides 1, pp. 73–81, 2004a Ayalew, L., Yamagishi, H., Watanabe, N., Marui, H.: Landslide susceptibility mapping using a semi-quantitative approach, a case study from Kakuda-Yahiko Mountains, Niigata, Japan In: M. Free and A. Aydin, Editors, Proceedings of the 4th Asian Symposium on Engineering Geology and the Environment, Geological Society of Hong Kong Vol. 7, pp. 99–105, 2004b

Page 77 Lines 3-4: Please, refer to previous reply.

Page 79 Lines 4-9: We rephrased the sentence.

Page 79 Lines 21-22: We rephrased the sentence.

Page 81: paragraph 3.7. a. Regarding the Elevation, as mentioned in the manuscript there is not a general rule, applicable for any case study, relating the landslide occurrence with the elevation but in each case study a different relations can be formalized based on the morphological characteristics and the experts opinion. So we did not force the use of this theme in the analysis we just formalized the individual relation based on the expert‘s opinion. As far as we can understand in our manuscript we explain sufficiently the conditions occurring in our case study “the high relief areas are usually occupied by the most cohesive formations ... can present low to very high landslide frequency“. Anyway, we thank the reviewer for his suggestion regarding the introduction of the Unique Condition Units (UCU) we intent to apply them in a following study.

b. regarding the second notation we definitely have not violated the requested by WofE, unconditional dependence because the formalized relation between elevation and geology was introduced only at the WLC model. Several changes have been made to the 3.7 paragraph in order to improve the text based on the comments of the reviewer.

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Line 18: We rephrased the sentence. When an area is uninhabited two thinks happen a) no human activities take place able to trigger landslides and b) even if a landslide occur due to natural causes no-one notices and records it.

Page 83 Lines 12-13: We mean validation of the model, definition of the predictive power of the model. We have changed the phrase.

Page 83 Lines 21-22: We updated our references.

Page 86 from line 9 on: Please refer to the reply of comment 6.

Page 86 from line 23 on: As stated in a previous reply, we are acknowledged that WofE is a data-driven method but in our opinion its results can still undertake criticism and discussion. We have already mentioned the database problems probably related to WofE.

Page 86 Lines 27-28: These lines make a comparison of the WofE with the WLC approach in which no landslide samples were used.

Page 87 Lines 22-24: We intent to rephrase the lines as: According to the success rate curves the WofE method shows a better model fitting (success rate of 87.4%) compared to the WLC method (success rate of 84.7%)" while according to the prediction rate curves and ROC curves the two methods show equal model performance and prediction efficiency.

Page 88 Lines 9-10: According to the Success rate curves, the prediction efficiency curves (we added them in Fig. 9) and the Operator-Receiver Curves presented herein we insist that both methods provided accurate susceptibility maps. Swets (1988) considers AUC>0.90 typical of highly accurate classification models. In our work, WLC ROC curve gave AUC =0.96 while WoE ROC curve gave AUC=0.94 (we added ROC curves as the Figure 10).

Page 106: Fig. 6: There is no transparency used in this picture. Nevertheless we can improve the quality using more dpis. In case you agree we can add a detail of each

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image as an inset.

Pages 107-108: Fig. 7: Please see the reply of the above comment.

Fig. 8: This figure produced by logistic regression method which does not make the assumption of conditional independence of the evidence with regards to the training sites.

Page 109: Fig. 9: The efficiency curves were created by plotting cumulative sites accumulated from high to low susceptibility value as the Y axis and cumulative area accumulated from high to low susceptibility value as the X axis. If the training dataset is used then efficiency curves give a measure of how well the training sites were classified by the model. If independent landslides (usually a random subset of the initial dataset) are used then we obtain prediction curves which give a measure of the model performance.

Furthermore, the corrections indicated at the“ nhessd-1-C23-2013-supplement“ were incorporated into the manuscript.

(C) Referee comment of C. Li:

Thank you very much for your useful comments. Please see the above answers to the comments.

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/1/C123/2013/nhessd-1-C123-2013-supplement.zip

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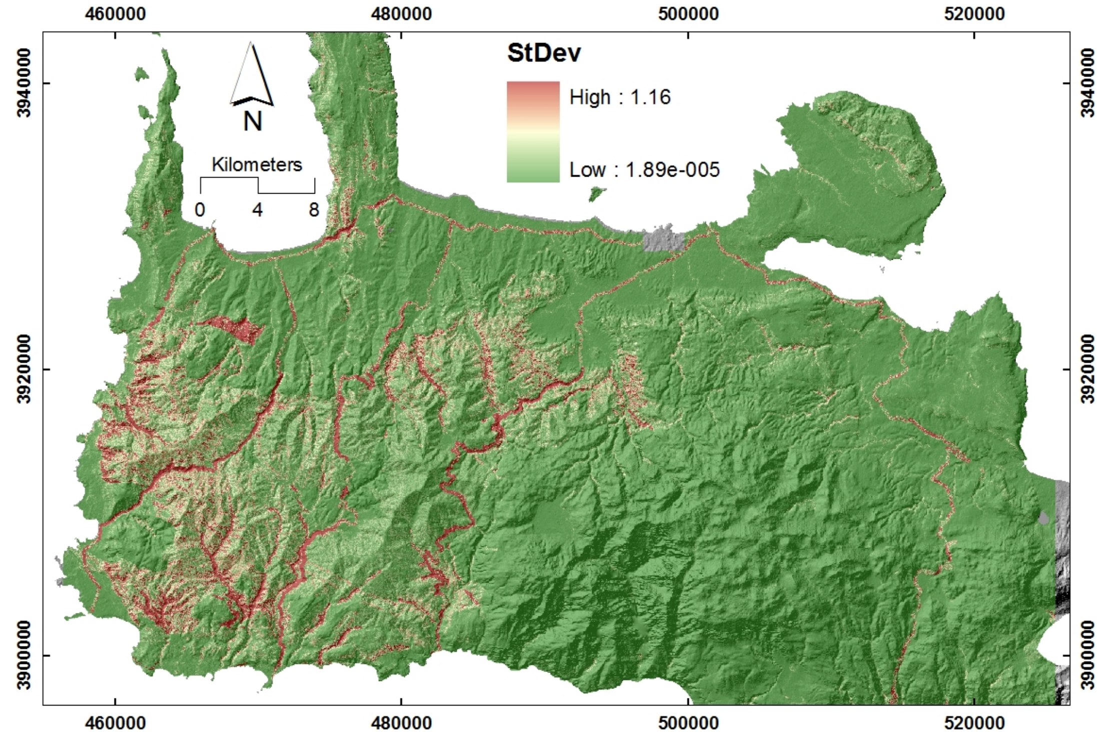

Fig. 1. The standard Deviation map of the WoE susceptibility model shows uncertainty approximately equal to 5%.

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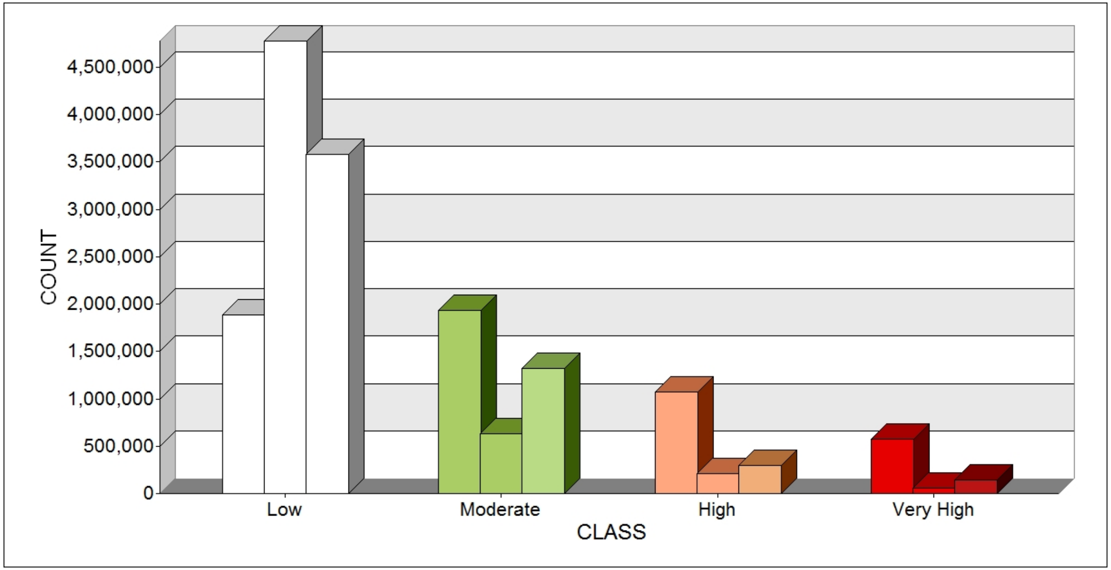

Fig. 2. The four classes of the 3 susceptibility models (WLC, WoE and CM).

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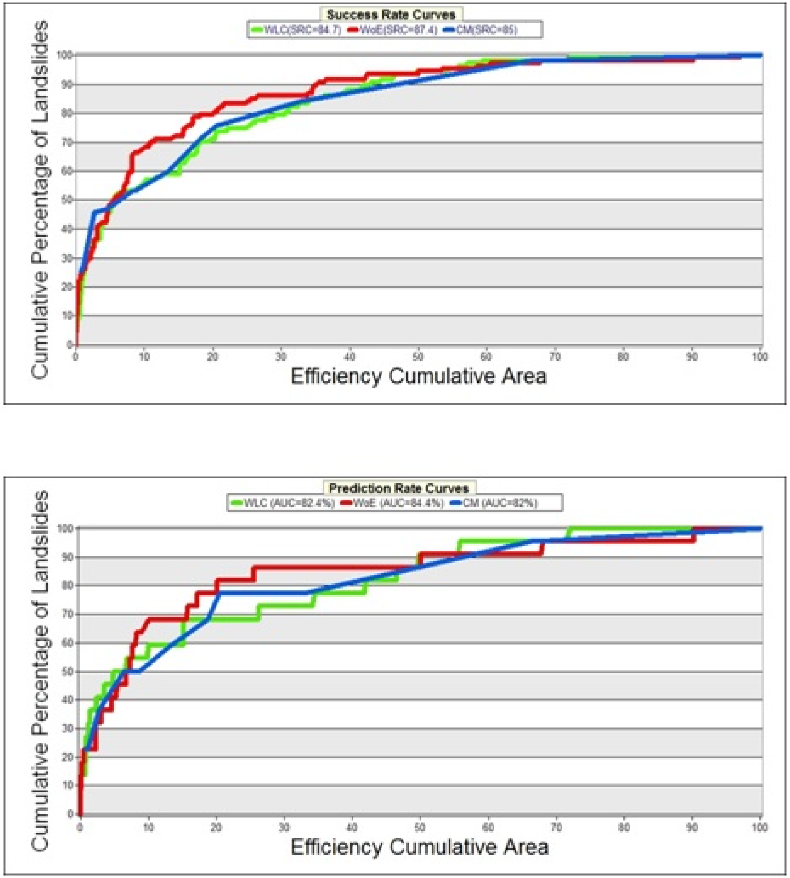

Fig. 3. The Areas Under Curves, using 22 independent landsides (i.e. 20% of the landslides inventory).

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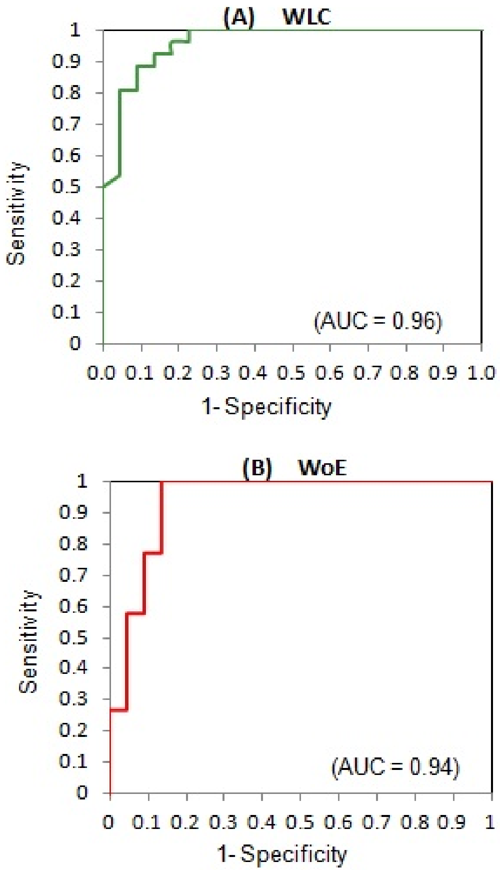

Fig. 4. Receiver operating characteristic (ROC) curves for the two applied models, i.e. the false positive rate (1-Specificity) versus the true positive rate (Sensitivity).

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