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Interactive comment on "Development of a statistical tool for the estimation of riverbank erosion probability" *by* E. A. Varouchakis et al.

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1) The authors present a case study in which they combine the existing BSTEM model with existing regression models. As I am nor familiar with regression techniques, I recommend another reviewer after major revision.

Response#

First, we would like to thank the anonymous reviewer for the time he devoted on reviewing this manuscript and for his useful comments.

We believe that overall the main objective of our work has been misunderstood by the reviewer and is our responsibility to improve this part of the paper. The following

sentence can be added in the text to clarify the proposed methodology and the aim of this work (page 651 end of the introduction section).

"Overall, the concept of this work is to present a statistical model based on LR methodology for the estimation of the erosion probability at specific ungauged riverbank locations where independent secondary explanatory information is available. BSTEM has an auxiliary role to estimate/validate potential eroded riverbank locations by calculating the potential eroded area, using field measurements of hydraulic, hydrologic and geomorphologic variables. These estimations (dependent variables) are then used to set up and validate the statistical model which is then applied to ungauged riverbank points."

To clarify the novelty of the work the following paragraph was added: BSTEM is an existing deterministic model that can be used, among others, to predict eroded riverbank area. In the context of this work, BSTEM is used to produce reliable validation points for the developed statistical model. LR is also an existing statistical model that uses secondary information to calculate probability of an event to occur. LWLR is a new proposition that combines LR and LWR to create a local model that calculates the probability of erosion to occur, based on secondary information (bank slope, river cross section) that are spatially correlated. Therefore, predictions accuracy is improved compared to the global regression model LR. To the best of our knowledge, the combination of deterministic and stochastic models to predict river bank erosion appears for the first time in the scientific literature.

2) My own area of expertise regards bank erosion, and here I have major concerns that lead me to recommending major revision. The paper does not show any validation of the method by showing a comparison between predicted bank erosion and observed bank erosion. No maps of erosion predictions are given.

Response#

The aim and scope of this work is not to present a model that predicts bank erosion under the classical terms of volume or area removed but to predict the probability of a specific bank location to fail or not. Therefore, there is not a potential for the model to provide such maps. BSTEM is applied in order to produce reliable validation points for the developed statistical model.

We have included a methodology flowchart that fully explains the approach followed accompanied by a characteristic photo highlight of the riverbank location (KI) with the most intense observed erosion. Regarding the BSTEM model validation for the predicted erosion (m2), a field investigation was performed at the end of the wet season of the 2013-14 hydrologic year. Photographs were taken at some locations where the 50 cm scaled stick was placed showing the eroded area. The eroded area at each location was successfully predicted as the observed affected area was quite similar. Especially, at location (KI) with the most significant effect, the predicted eroded area (using BSTEM) was equal to 2.043 m2 and the affected area measured at the field (and represented in the modified photo) was roughly 2.08 m2. Similar results were obtained for the other locations. However, as the purpose of this work was to use BSTEM results (at the 12 locations) in accordance with the field inspection to setup the statistical model and to provide validation points, quantified measurements at those points were not performed but, field inspection was used to validate that the BSTEM results are consistent and close to reality. Therefore, only at the point with the most intense erosion a close photo was taken and analysed to quantify the erosion.

Fig 1. Methodology flowchart that presents the combined application of the BSTEM and of the proposed statistical model (SMODEL) based on LR principles.

Fig 2. Photo highlight of the riverbank location (KI) with the most intense observed erosion accompanied by the appropriate scaled tools to provide a rough estimate of the eroded area.

The methodology flowchart (Fig. 1), the photo (Fig. 2) and the above text will be added appropriately in the final manuscript.

The statistical model proposed and applied in this work is a stochastic model that predicts the probability ($0 \leq P \leq 1$) of erosion to occur. Model validation is presented in the submitted manuscript, Page 658 lines 14-18. A more detailed description of the validation method is given below. The 12 measurements of the 2nd field campaign were used to apply LR and LWLR while the 8 locations of the 1st campaign acted as validation points. The first BSTEM application has provided a vulnerability sign at the riverbank sections that these 8 locations assign and to the actual points. The riverbank areas vulnerable to erosion, and therefore the associated locations are characterised as "U" and the non-vulnerable as "S". Correspondingly to the LR and LWLR that deliver probabilities of erosion to occur, $P \geq 0.5$ is interpreted as presence of erosion and is denoted as Unstable "U" and absence of erosion $P<0.5$ as "S". Therefore, the different statistical model forms are validated based on the erosion vulnerability of the 8 locations of the 1st field campaign (Tables 3 and 4). In addition, the proposed model is accompanied by a goodness of fit test estimation (G-statistic) which performs validation of predictions (Section 3.2 in the submitted manuscript and in the discussion section page 658 lines 22-23 and page 659 lines 3-5).

Maps of riverbank erosion predictions cannot be produced using the BSTEM, since it can only deliver the potential erosion presented in a studied river cross section.

Similarly, spatial maps of riverbank erosion predictions cannot be produced by the statistical model since it predicts probability of erosion to occur when a specific couple of geomorphologic secondary variables apply based on the measurements in the specified correlation distance that the model has calculated. The produced 3D figures (figs. 3-5 of the submitted manuscript) actually work as a probability map presenting the erosion probability when a specific couple of secondary variables is met. The concept of the model is to present the probability variability of an event to occur considering secondary explanatory information.

3) The paper also does not provide any information about the values of the input data for BSTEM (flow parameters, bank material parameters, bank vegetation parameters,

bank protection parameters). That makes the work irreproducible and unverifiable.

Response#

The paper is focused on the proposal of a statistical model for the estimation of riverbank erosion probability and that is the reason that the authors did not include extensive information on the BSTEM set up. BSTEM is applied in order to provide reliable validation points for the statistical model. However, we understand the reviewer's concerns and we address the comment with the following information inserted at the methodology section page 652 of the submitted manuscript to update the first paragraph (lines 17-24).

"The riverbank erosion at selected sections and locations along the Koiliaris' riverbanks was assessed using the BSTEM model. Bank geometry, channel and flow parameters, bank material and bank vegetation and protection parameters were used as input to the BSTEM model to calculate the bank eroded area (L2). BSTEM was applied to address riverbank erosion at twelve selected monitoring locations along a river section. In addition, based on model's efficiency and the quality of estimation, the reliability of BSTEM results at eight sections at the same downstream area is evaluated. Channel and bank geometry characteristics were calculated during the field campaigns and are presented later in the text. As far as for the flow parameters, for the 1st BSTEM model application (eight river sections) river water elevation was set to 1.27m for a 48h duration event. The 2nd BSTEM model application (twelve locations) obtain the cumulative riverbank erosion effect of three flash flood events (Fig. 2 of the submitted manuscript). The other parameters were similar for the two models application due to the same river section studied. Therefore, reach slope varied between 0.0042 and 0.11 m/m, the bank material was set after field measurements analysis to "fine rounded sand" with an average medium grain size 0.3 ($\pm$ 0.06) mm and the "geyer willow" was selected from the predefined list to describe the bank vegetation with the assumptions of the plants age of about 100 years and 100% contribution to assemblage. Finally, for the locations where the bank was protected, the "boulders" choice was used to

describe the bank material."

4) Three out of the five figures show predictions for three different regression methods without possibility of comparison with data or inter-comparison.

Response#

Inter-Comparison of estimations is possible as the x and y axis of the plots are at the same scale for the results of the three methods tested and specific discussion is available in page 660 lines 15-26. In addition, we have added the validation point predictions on the plots for easier inter-comparison (Fig. 3 a,b,c below corresponds to Figs. 3,4,5 of the submitted manuscript). Comparison with data is not possible as the model predicts probability of presence or absence of erosion at unmeasured locations. The plots present the probability of bank erosion to occur (z axis) for a specific couple of secondary variables (x and y axes). The model's accuracy has been tested as previously described.

Fig 3. Erosion probability predictions using LR (a), LWLR with the exponential weighting function (b) and LWLR with the tri-cubic weighting function (c) versus independent variables at ungauged Koiliaris' riverbank locations. The black dots indicate the 8 validation points.

5) The main correlation found, i.e. the correlation between new bank erosion and recent bank erosion (= bank angle), is not much more than prediction by extrapolating ongoing trends.

Response#

Regarding ''correlation between new bank erosion and recent bank erosion (= bank angle)", This work does not intend to correlate new with recent bank erosion; it predicts the erosion probability at ungauged locations and validation points, in between of the first and last measurement points, based on the characteristics of the riverbank at the eroded or not measurement locations. Furthermore, correlation is identified on the variability of the secondary information trend and on the predicted erosion probability (page 662 lines 6-8).

LR is a non-linear method. The method's concept is to model binary primary variables that describe the presence or absence of an event and secondary variables to calculate the model's parameters in order to predict the probability of the event to occur when more secondary information becomes available. Therefore, the predictions of LR are "extrapolation" at ungauged river location where the cross river section and bank slope is available based on the parameters calculated from the measurements. This work applies "extrapolation" using two secondary variables that affect significantly the presence or absence of erosion.

However, in LWLR, locality is important; the location of the new couple of secondary variables is used to identify and weight the effect of correlated measurement points in order to calculate the model parameters. The proposed methodology, LWLR, exploits the local information of independent variables and translates it to bank erosion probability. This is not simply a result of ''extrapolating ongoing trends" because the model parameters are calculated each time for the new couple of secondary variables.

"Extrapolation" though is useful and optimal when the model can successfully describe the real event, as it occurs herein with low model deviance and successful validation.

The three plots (Figs 3-5 in the submitted manuscript) show the probability of erosion to occur at the specific riverbanks when a couple of independent values is met. These couples of independent variables are randomly selected among the measurement points from a 3D model of the downstream part of River Koiliaris. In a similar work recently published (Vozinaki 2015), the simple LR model was applied on predicting crop damage curves based on measurements of river flood depth and velocity (secondary data). The secondary data required to develop the probability curves (predictions) were produced by a Monte Carlo simulation in the absence of sufficient measurement data. Herein the selected secondary values come from the 3D river structure model

developed based on a 5m DEM.

Vozinaki, A. E. K., Karatzas, G. P., Sibetheros, I. A., and Varouchakis E. A.: An agricultural flash flood loss estimation methodology: the case study of the Koiliaris basin (Greece), February 2003 flood, Nat. Hazards, 10.1007/s11069-015-1882-8, 2015.

Therefore, probability of erosion to occur at ungauged riverbank locations when significant secondary variables become available, ''extrapolation", through an efficient statistical model based on LR principles is a proposition that can aid riverbank erosion management. A similar model had been developed to identify the most appropriate secondary variables (Atkinson 2003).

Atkinson, P. M., German, S. E., Sear, D. A., and Clark, M. J.: Exploring the relations between riverbank erosion and geomorphological controls using geographically weighted logistic regression, Geogr. Anal., 35, 58–82, 2003

6) The introduction mixes the problems of surficial soil erosion with bank erosion, and fails to list the beneficial effects of bank erosion for fluvial ecosystems.

Response#

The first paragraph of the introduction referred to surficial soil erosion will be removed in order to avoid confusion of the two topics. In addition the following paragraph can be added in the introduction to address the reviewer comment.

"Bank erosion constitutes a significant factor to the functioning of river ecosystems and provides a sediment source that creates riparian habitat. Bank erosion is a key geomorphological mechanism in the fluvial ecosystems since it regulates the diversity of habitats, species and vegetal units. The process provides riparian vegetation succession and develops dynamic habitats vital for fluvial plants and animals. Where bank erosion is of small scale or of local extent then there is no significant influence on the aquatic ecosystem and it is contributing to the ecosystem sustainability. If the opposite occurs the ecosystem is significantly affected while riparian land losses and damages are caused providing areas vulnerable to flooding. The downstream area of River Koiliaris has been characterised as zone of high agricultural productivity while lately the residential development has been increased. Therefore, the protection from floods is a major concern for the local authorities. The latter requires the protection of riverbanks from significant erosion by identifying highly vulnerable areas."

Florsheim, J.,L., Mount, J. F., and Chin A.: Bank Erosion as a Desirable Attribute of Rivers, BioScience, 58, 519-529, 2008.

Piégay, H., Darby, S. E., Mosselman, E., and Surian, N.: A review of techniques available for delimiting the erodible river corridor: a sustainable approach to managing bank erosion, River Res. Appl., 21, 773-789, 2005.

Piégay, H., Cuaz, M., Javelle, E., and Mandier, P.: Bank erosion management based on geomorphological, ecological and economic criteria on the Galaure River, France, Regul. River, 13, 433-448, 1997.

7) A few minor points: (1) Bridge (2009) is referenced but the list of references lists Bridge (2003); (2) At several locations: "the vulnerable to erosion locations" must be "the locations vulnerable to erosion" (similarly for areas vulnerable to erosion); (3) Page 4, line 27: "principals" must be "principles"; (4) Page 8, lines 17-18: This sentence is unintelligible; please rephrase.

Response#

Regarding the minor points referred by the reviewer, the authors have made the appropriate changes to the manuscript in order to address those comments.

(1) Bridge (2009) is referenced but the list of references lists Bridge (2003); Bridge 2003 is the correct, so we have corrected the year. (2) At several locations: "the vulnerable to erosion locations" must be "the locations vulnerable to erosion" (similarly for areas vulnerable to erosion); The authors have corrected the corresponding sentences in the text (3) Page 4, line 27: "principals" must be "principles"; The authors

have corrected the sentence in the text (4) Page 8, lines 17-18: This sentence is unintelligible; please rephrase. The sentence is modified as follows, "Therefore, the proposed statistical model is extended to predict the erosion probability based on spatially correlated independent variables."

Please also note the supplement to this comment:
http://www.soil-discuss.net/2/C494/2015/soild-2-C494-2015-supplement.pdf

Interactive comment on SOIL Discuss., 2, 647, 2015.

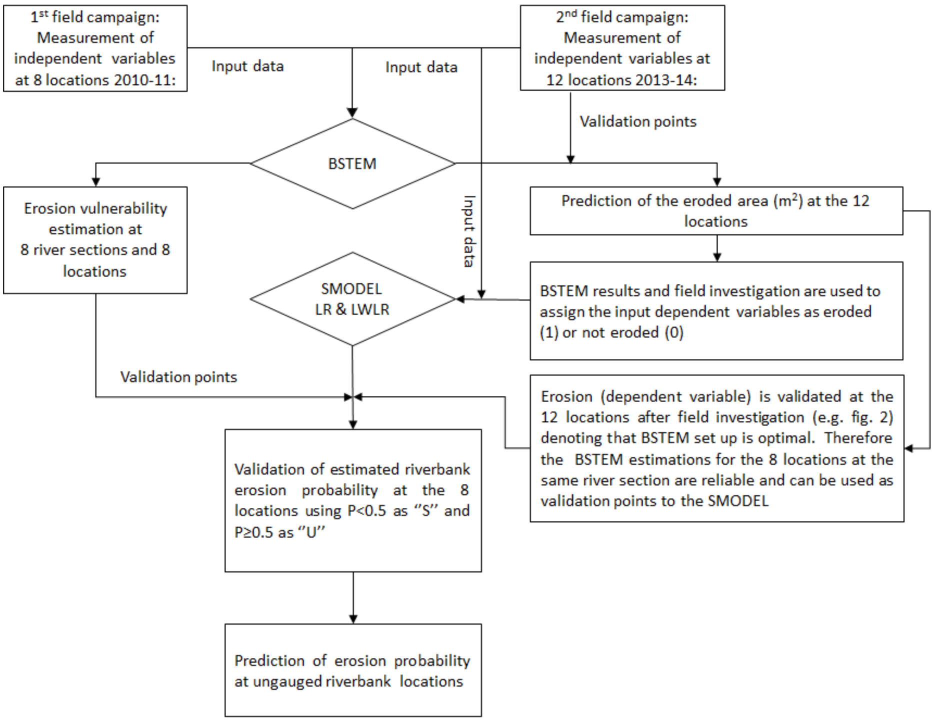

Fig. 1. Methodology flowchart that presents the combined application of the BSTEM and of the proposed statistical model (SMODEL) based on LR principles.

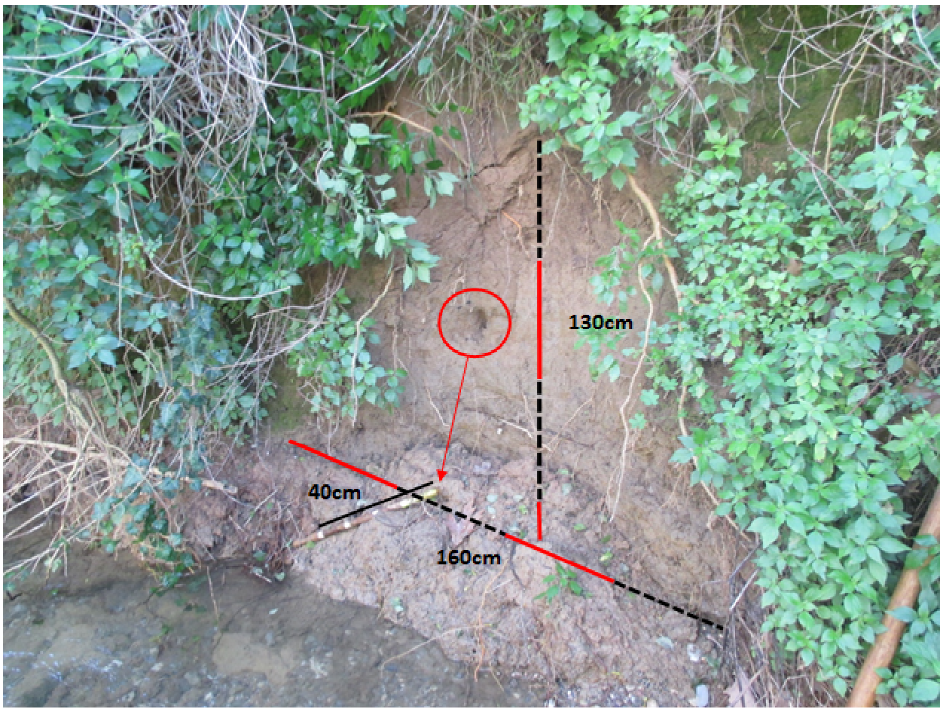

Fig. 2. Photo highlight of the riverbank location (KI) with the most intense observed erosion accompanied by the appropriate scaled tools to provide a rough estimate of the eroded area.

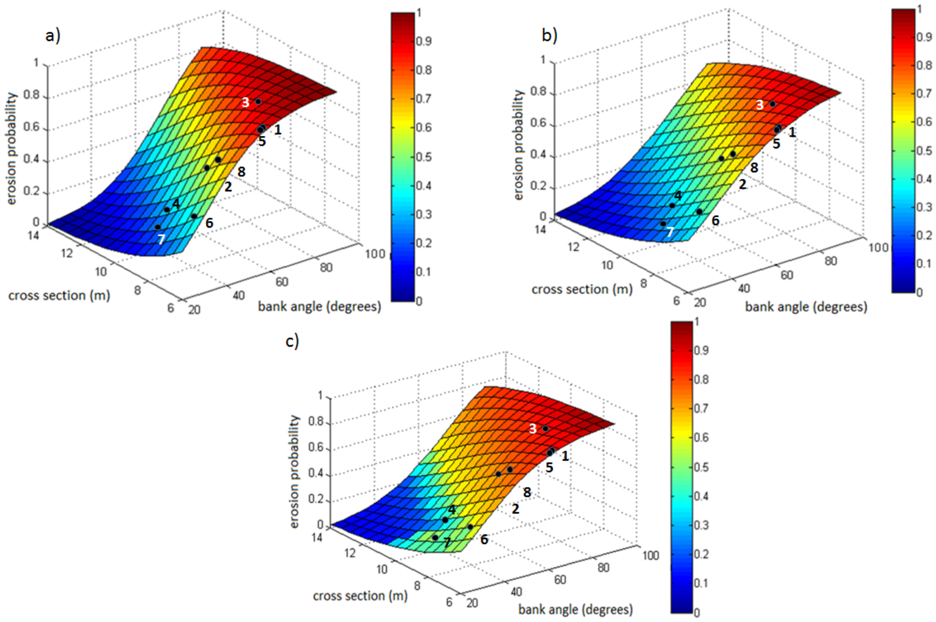

Fig. 3. Erosion probability predictions considering the 8 validation points using LR (a), LWLR with exponential (b) and tricubic (c) weighting function vs independent variables at ungauged riverbank locations