

Human-Enhanced Tsunami Hazard in Large Lakes

Corresponding Author: Mr Muhammad Naveed ZAFAR

This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

The manuscript entitled “Human-Enhanced Tsunami Hazard in Large Lakes” reconstructs two landslide-generated tsunamis that occurred during the Medieval period in Lake Iseo (Northern Italy). Specifically, the authors integrate seismic stratigraphy and sediment core analysis with historical and archaeological evidence to constrain the timing of the two landslide events. They propose that two relatively large earthquakes acted as triggering mechanisms, inducing the collapse of subaqueous sediments in the Oglio River delta.

While the combined use of historical sources, geological data, and numerical modelling is well established in the field of tsunami science and other natural hazard disciplines, applications aimed at identifying past tsunami events in lacustrine environments remain rare in the literature, leading to severe underestimation. Furthermore, this work is framed as a contribution to understanding human-related erosion and its effects on lake morphology, which are significant factors in lacustrine environmental hazards.

The manuscript is original and thorough, with a high degree of interdisciplinarity: its publication would be a great contribution to the field. Nonetheless, we believe that several aspects could be slightly improved to make it even more solid. They are listed and individually discussed in the following.

1. On lines 98-99 the authors state that “landslide volumes were calculated as the difference between the reconstructed and present-day bathymetric surfaces”. This seems to contradict one of the manuscript's most important arguments, namely that the high sedimentation rate causes material deposition in the river delta. The present-day bathymetry cannot be taken as the post-failure morphology, since it is likely to have changed significantly over the last centuries. How was the initial bathymetry reconstructed? Is there evidence of scars along the delta? The reconstructed volumes should also be quantified more precisely, as they are reported only to be within the same order of magnitude as the deposits (line 100).
2. The historical accounts and archaeological findings (in the section starting at line 136) lead the authors to conclude that the river delta collapses were caused by the earthquakes. While we agree that this argument is strong, a quantitative assessment of the instability would improve the discussion. Ideally, a slope stability analysis (e.g., using a limit equilibrium approach) would provide strong support for the authors' conclusion. We realise that such an analysis would represent a significant detour from the paper's discussion, so we suggest at least adding plots of the earthquake effects, e.g., isoseismal or shake maps.
3. The historical and archaeological evidence seems indeed not so strong as mentioned in the manuscript. Is there the possibility to quantify run-up or inundation, for example, by estimating the position of the villages destroyed by the two events? What kind of archaeological evidence has been found from the documents relative to the 1222 event? They deserve to be described, at least briefly, to support the occurrence of such a big tsunami and the results of the simulations.
4. The modelling approach described in the subsection starting at lines 339 and 363, respectively, would benefit from a better description of the coupling between landslide modelling and tsunami generation. In particular, the approach seems to be two-step, where the landslide is modelled first and then used as input to the tsunami simulation, thus ignoring the back-effects of tsunami propagation on the landslide. This approximation is valid and widely used in the literature, but it usually means that some hydrodynamic effects, such as viscous/turbulent drag and added mass, are neglected and should be accounted for before coupling, i.e., in the landslide simulation itself. The discussion on these points should be more explicit. Furthermore, how can we rule out the possibility of a progressive, retrogressive, faster-eroding event, presumably not

tsunamigenic?

5. The modelling section does not explicitly describe how the sliding motion generates the tsunami: how is the mass-wave interaction treated? How much energy is transmitted between the two phenomena? Maybe also computing the Froude number (the ratio of the two velocities) would help quantify the efficiency of this process.

6. The discussion on adimensional numbers at lines 388-393 should include a reference to an explanation of how they are derived and their role, e.g. Mei et al. (1989).

7. Data sources for topo-bathymetrical data should be mentioned for reproducibility. If the data are from public dataset (e.g. Tintaly for the topography) they should be referenced appropriately. If the data are not public, it should be clearly stated.

8. Lake water levels are subject to seasonal and secular variation, which means that the shoreline position at rest can vary with time. In turn, the shoreline's position has a significant impact on tsunami coastal dynamics. How did the authors choose the water level for lakes? If they just assume the level is the same as today, it should be explicitly stated in the text.

Reviewer #2

(Remarks to the Author)

I co-reviewed this manuscript with one of the reviewers who provided the listed reports. This is part of the Nature Communications initiative to facilitate training in peer review and to provide appropriate recognition for Early Career Researchers who co-review manuscripts.

Reviewer #3

(Remarks to the Author)

The presented study is based on a seismic survey of Lake Iseo (northern Italy), which has documented two substantial mass-wasting deposits (MWDs) throughout the lake basin, with the delta of the Oglio River serving as the point of origin. A sediment core extracted from the central basin corroborates these MWDs. The trigger of both MWDs is related to strong historic medieval earthquakes. Subsequent high-resolution rheological modelling calculated the volume of the MWDs, which agree with the results of seismic data and the data of the sediment core. In the next step, a hydrodynamic model for the reconstruction of tsunami run-up heights and inundation distances was utilised. The considerable destruction caused by these tsunamis is in accordance with other historical data, which report significant destruction along the shores of Lake Iseo following these events. However, the search for tsunami-based sediments along the lake shore was unsuccessful, likely attributable to intensive human modification of all near-shore environments. The authors also establish a connection between the examined Lake Iseo and other Alpine lakes, as well as to lakes in tectonically active regions worldwide, which are susceptible to destructive tsunamis triggered by earthquakes. Consequently, efforts should be undertaken to enhance the preparedness of communities, politicians and near-shore inhabitants.

This presented investigation is original, while based on earlier sediment core and seismic studies, which lay the ground for this interpretation. The study presented here has significant implications for a range of other scientific disciplines, including archaeology, history and politics. Accordingly, it makes use of archaeological and historic data to substantiate own results and is requesting awareness from politicians of comparable future hazards like the ones documented as consequence of the medieval earthquakes. Furthermore, the authors point out that the documentation for Lake Iseo is providing local evidence, but that a multitude of other locations worldwide are prone to similar hazards. As accelerated soil erosion over the past centuries is a global phenomenon, with accelerated sediment yields in lakes being a direct consequence, the described geohazards become significant if the lake is located in a tectonically active region that is prone to earthquakes. It is imperative that preparedness for such events should be prioritised on the political agenda, particularly in areas where lake shores are densely populated, as it is the case for Lake Iseo.

The findings of this study are corroborated by all the provided evidence.

The analysis, interpretation and conclusions presented are of an excellent standard. The text is very well written and comprehensible to scientists from outside the field of limnogeology who may have an interest in the outcome of this study. For example, it may be of interest for archaeologists, historians and politicians. Therefore, this manuscript is strongly recommended for publication.

It is asserted that the methods chapter provides all necessary details for the reproduction of the analyses. Moreover, the methodology employed is robust and adheres to the established standards of geoscientific research.

I have two very small suggestions for improvements:

1. Assuming that an independent chronology is available for sediment core SEB18, please add these datings to Extended Data Fig. 1. This has the potential to provide another confirmation for the ages of the two MWDs.
2. The sites where Russian peat cores were utilized should not only be marked in Fig. 3a, b by red dots. These should also be explained in the caption to this figure. Additionally, these "core locations" should be added to Fig. 1c.

Overall, the story is both pleasant to read and scientifically intriguing. It synthesises sedimentological and seismic investigations with modelling of slope failure-related sediment (MWD) thicknesses, as well as modelling of tsunami heights and inundations. The latter are supported by historic data. It is evident that this phenomenon is of societal relevance, insofar

as it has the potential to enhance the preparedness to such hazards for communities located in tectonically active regions worldwide.

Bernd Zolitschka

Reviewer #4

(Remarks to the Author)

The manuscript "Human-Enhanced Tsunami Hazard in Large Lakes", submitted by Muhammad Naveed Zafar et al. for publication in Nature Communications, presents the results of modelling the characteristics and spatial impact of two large tsunami waves that purportedly occurred during medieval times in response to $M_w \geq 6.0$ earthquakes in deep pre-Alpine Lake Iseo, northern Italy. The study is based on comprehensive previous work on the Lake Iseo sediment record, i.e. information on the characteristics of large-scale event deposits in the lake basin derived from sediment core analyses and seismic surveys. This information is used for data-driven modelling of tsunamis that are supposed to have been caused by large, seismically triggered delta collapses that caused the emplacement of the event deposits in the lake basin.

Overall, this is a solid and concisely written manuscript with well-designed figures that illustrate the findings, which, most importantly, add new information on an obviously still underestimated natural risk, namely the occurrence of disastrous tsunamis in lacustrine settings after strong seismic shaking. Moreover, although the study itself is rather local/regional, the authors relate the high tsunami risk mostly to the human-driven increase in allochthonous riverine sediment supply and the consequently rising risk of river delta failures at even lower earthquake magnitudes, a problem that is of global relevance when considering the massive worldwide increase in human-induced erosion.

Given the robust findings of the present study and the important implications at a global scale, I consider the manuscript perfectly suited for publication in Nature Communications and have only a few minor remarks that could be considered in a possible revision.

First of all, the last part of the abstract reads like the recent global synthesis study on the Industrial Era increase in human-driven erosion incorporating 632 lakes is part of the present study, which is actually not the case. I would suggest to re-write this part a little bit, just stating that other studies indicate high present-day sediment supply to deltas and that resulting overloading-driven failures similar to those recorded in the past in Lake Iseo and elsewhere could consequently occur more frequently in the future, also at lower earthquake magnitudes or even spontaneously.

Second, I wonder whether the sediment volume supposedly mobilized by the AD 1222 delta failure can be evaluated somehow against the sediment supply of the Oglio River. I see that the volume of the AD 1222 event deposit is much smaller than that mobilized by the stronger AD 1117 earthquake, which is in general reasonable. But considering that the river delta possibly completely collapsed during the AD 1117 earthquake with no sediment left (mobilization of $\sim 62 \text{ Mm}^3$ of sediment), would the ~ 100 -year period until the AD 1222 earthquake be sufficient to newly accumulate $\sim 10 \text{ Mm}^3$ of sediment in the delta that could be mobilized during this event? Is the sedimentary input of the Oglio River that strong? I would like to see a bit more discussion on this issue, especially if the amount of mobilized sediment is at least in the same magnitude of the amount of sediment that could have been deposited in the delta fan over 100 years given the erosional input rate displayed in Extended Data Fig. 4.

Another question would be why the tsunami modelling has only been carried out for the two events that caused the emplacement of the event deposits MWD 7 and MWD 8, i.e. the AD 1117 and AD 1222 regional earthquakes, but not for the third prominent event, the 6th century earthquake that caused the emplacement of event deposit MWD 6. Given the fact, that this deposit is apparently rather similar to MWD 6 in terms of size/volume and also occurred when erosional input was already relatively high, a comparison with the other two events might be useful. One could maybe learn something about the rate of sediment supply, delta loading and mobilization processes compared to the other two events as well as about possibly different tsunami impacts of the two, in terms of their volume, comparable events MWD 8 vs. MWD 6.

And last but not least, I wonder whether there are some local pollen records available that could be used to sustain the inferences of rising human land use since the Roman Empire period.

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

Dear Editor and Authors,

We have read the revised version of the paper and found it to be substantially improved. Thank you for addressing all our comments. In our view, the manuscript is now much more comprehensive, particularly in the methodological section and in the description of how the landslide sources were built, which were the main weaknesses of the previous version.

We believe that the paper is now ready for publication and represents an important contribution to the study of tsunamis in lakes and enclosed basins.

Reviewer #2

(Remarks to the Author)

I co-reviewed this manuscript with one of the reviewers who provided the listed reports. This is part of the Nature Communications initiative to facilitate training in peer review and to provide appropriate recognition for Early Career Researchers who co-review manuscripts.

Reviewer #3

(Remarks to the Author)

This is the revised version of a study on two mass-wasting deposits (MWDs) in Lake Iseo related to medieval earthquakes. High-resolution rheological modelling supports seismic and sediment-core data allowing the reconstruction of tsunami run-up heights and inundation distances, which caused considerable destruction along the shores of Lake Iseo.

Overall, the manuscript is well written and comprehensible to scientists from outside the field of limnogeology who may have an interest in the outcome of this study, such as archaeologists, historians and politicians. I appreciate the authors' effort in conducting a study combining sedimentological and seismic data with modelling and archaeological data. Particularly, the sections describing the sediment record and the seismic data are well supported and convincing. As accelerated soil erosion over the past centuries is a global phenomenon, with accelerated sediment yields in lakes being a direct consequence, the described geohazards are significant for lakes located in tectonically active regions prone to earthquakes. It is imperative that preparedness for such events should be prioritised on political agendas, particularly in areas where lake shores are densely populated.

Overall, the story is pleasant to read and scientifically intriguing. It synthesises sedimentological and seismic investigations with modelling of slope failure-related sediment thicknesses, as well as modelling of tsunami heights and inundations. The latter are supported by historic data. It is evident that this phenomenon is of societal relevance. Thus, it has the potential to enhance the preparedness to such hazards for communities located in tectonically active regions worldwide.

I reviewed an earlier version of the manuscript and recommended minor revisions. The authors incorporated all my suggestions as well as those of the other two reviewers. Therefore, I suggest accepting the revised version of the manuscript with two minor language modifications:

Line 88-89 reword to: "... following the last delta collapse in the 6th century (extended Data Fig. 3). After the collapse of 1117 CE, ..."

Line 224: delete "and"

Bernd Zolitschka

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Ms. Ref. No. NCOMMS-26-002061-T

Title: Human-Enhanced Tsunami Hazard in Large Lakes

Dear Reviewers, we extend our sincere gratitude to you for your constructive feedback, which have substantially enhanced the quality of our manuscript.

Below, we provide a detailed point-by-point response to your comments. The reviewers' comments are shown in blue, and our responses are provided in black. Each change has been incorporated systematically into the revised version of the manuscript.

Enclosed are a marked-up version of the revised manuscript, with all changes highlighted in red, and a clean, non-highlighted version incorporating all revisions.

(Reviewers # 1 & 2):

1. On lines 98-99 the authors state that “landslide volumes were calculated as the difference between the reconstructed and present-day bathymetric surfaces”. This seems to contradict one of the manuscript's most important arguments, namely that the high sedimentation rate causes material deposition in the river delta. The present-day bathymetry cannot be taken as the post-failure morphology, since it is likely to have changed significantly over the last centuries. How was the initial bathymetry reconstructed? Is there evidence of scars along the delta? The reconstructed volumes should also be quantified more precisely, as they are reported only to be within the same order of magnitude as the deposits (line 100).

*Thank you very much for this important comment. We have revised the manuscript (**lines 102-118**) to better explain the reconstruction approach. The landslide volume is estimated from the mapped mass-wasting deposits identified from the seismic reflection profiles and sediment-core data in the deep basin. We agree that the present-day bathymetry cannot represent the immediate post-failure morphology, as sustained sedimentation following the medieval failures has filled the delta front and obscured landslide scars. Instead, the present-day high-resolution bathymetry was used as a geomorphological analog for the pre-failure delta morphology. This was done assuming that continued sediment delivery after the medieval failures rebuilt the delta along a similar depositional pathway.*

Based on this framework, the post-failure delta morphology was reconstructed in GIS by removing areas of sediment accumulation and restoring a plausible failure-scar morphology. This reconstruction was guided by large-scale bathymetric trends, erosional features, and the present-day morphology of the Oglio Delta front. Landslide source volumes were then estimated as the difference between the reconstructed post-failure surface and the modern bathymetric surface. The reconstruction was iteratively refined until the estimated source volumes were consistent with the volumes derived from geological data (seismic reflection profiles and sediment-core) in the deep basin. This yielded reconstructed source volumes of $6.2 \times 10^7 \text{ m}^3$ for the 1117 CE event and $1.0 \times 10^7 \text{ m}^3$ for the 1222 CE

event. The revised version now explains this process better and in much more detail.

These reconstructed source geometries represent the most plausible scenarios based on the present-day delta morphology. However, to evaluate the sensitivity of tsunami generation to landslide initiation depth, we also tested two additional scenarios S1 and S2 for 1117 CE event, in which the failed mass was initiated from depths of 45 and 75 m along the delta front, respectively. Scenario S1 produced a maximum tsunami height of 22 m, whereas S2 produced a maximum height of 11 m. Details of the landslide initiation depth sensitivity analysis have been added to the Methods section of the manuscript (**Lines 463–469**), and the corresponding results are presented in Extended Data Fig. 6. However, these two scenarios are considered less likely according to slope geometry and morphology of the Oglio River delta. Therefore, the reconstructed source geometries presented in Fig. 2 of the manuscript are considered the preferred and most plausible scenarios

2. The historical accounts and archaeological findings (in the section starting at line 136) lead the authors to conclude that the river delta collapses were caused by the earthquakes. While we agree that this argument is strong, a quantitative assessment of the instability would improve the discussion. Ideally, a slope stability analysis (e.g., using a limit equilibrium approach) would provide strong support for the authors' conclusion. We realise that such an analysis would represent a significant detour from the paper's discussion, so we suggest at least adding plots of the earthquake effects, e.g., isoseismal or shake maps.

Thank you very much for this valuable suggestion. We agree that slope stability analysis could provide additional quantitative support for the interpretation of earthquake-triggered delta collapse. However, as noted by the reviewer, such an analysis would require a dedicated investigation beyond the scope of the present study. In particular, attempting to run a limit-equilibrium model for medieval events introduce highly unconstrained geotechnical variables (such as exact pre-failure pore pressures), thereby making the empirically grounded macroseismic and sedimentological data a much more robust framework for this specific context. Moreover, coarse-grained delta slopes as in Lake Iseo are notoriously difficult to be modeled, in contrast to the well-understood fine-grained lateral slopes (Kremer et al., 2017; Strupler et al., 2017). We therefore followed the reviewer's suggestion and added references to previously published intensity maps for historical earthquakes in northern Italy (<https://shakemap.ingv.it/#archive>) based on the Italian Macroseismic Database, indicating macroseismic intensities in the Lake Iseo region of approximately VI–VII for the 1117 CE Verona earthquake (Oliveti et al., 2023) and V–VI for the 1222 CE Brescia earthquake (Michetti et al., 2012). This information has been added to the revised manuscript (lines 77 - 80).

Furthermore, the interpretation that the delta collapses were triggered by earthquakes is supported not only by historical and archaeological evidence but also by the sedimentological record. The largest mass-wasting deposits identified in seismic reflection profiles and sediment cores from the deep basin chronologically coincide with the 1117 CE and 1222 CE earthquakes (Rapuc et al., 2022).

3. The historical and archaeological evidence seems indeed not so strong as mentioned in the manuscript. Is there the possibility to quantify run-up or inundation, for example, by estimating the position of the villages destroyed by the two events? What kind of archaeological evidence has been found from the documents relative to the 1222 event? They deserve to be described, at least briefly, to support the occurrence of such a big tsunami and the results of the simulations.

Thank you for highlighting this point. We have revised the manuscript by adding additional records and clarifying the limitations of the available evidence (**lines 171-177**). Historical sources, whether textual or archaeological, inevitably contain gaps and uncertainties and therefore do not allow a precise reconstruction of tsunami inundation or a clear distinction between damage caused by seismic shaking and that caused by tsunami waves. Nevertheless, all the available sources describe severe destruction around the shores of Lake Iseo during both the 1117 CE and 1222 CE events, including reports of major lake overflow and catastrophic impacts along the shoreline._

Detailed information regarding individual buildings affected during these events is unfortunately not available. However, archaeological evidence from the pieve (parish) church of Sant'Andrea d'Iseo (Fig. 1, modified from Gallina (2013) provides useful information. The church underwent major reconstruction shortly after the 1117 CE event, both in the lower and upper parts, suggesting significant damage at that time. Whether this damage resulted from seismic shaking, tsunami impact, or a combination of both cannot be determined from the available evidence. However, our numerical simulations indicate that, during the 1117 CE event, a tsunami inundated the Iseo shoreline in front of the church, with a maximum wave height of approximately 3.5 m and an inundation distance of 165 m. This would have been sufficient to flood the area surrounding the Parish Church of Sant'Andrea.

For the 1222 CE event, archaeological evidence primarily indicates reconstruction of the upper part of the bell tower of the Parish Church of Sant'Andrea, suggesting that damage is more likely attributable to earthquake shaking than to direct tsunami impact. This interpretation is also consistent with our numerical simulations, which indicate tsunami wave heights of approximately 1 m, with no inundation in front of the church along the Iseo shoreline during the 1222 CE event. These wave heights were insufficient to inundate the church area.

We have now included the description of the damages, with the relevant reference (Gallina, 2013), in the main text of the manuscript.

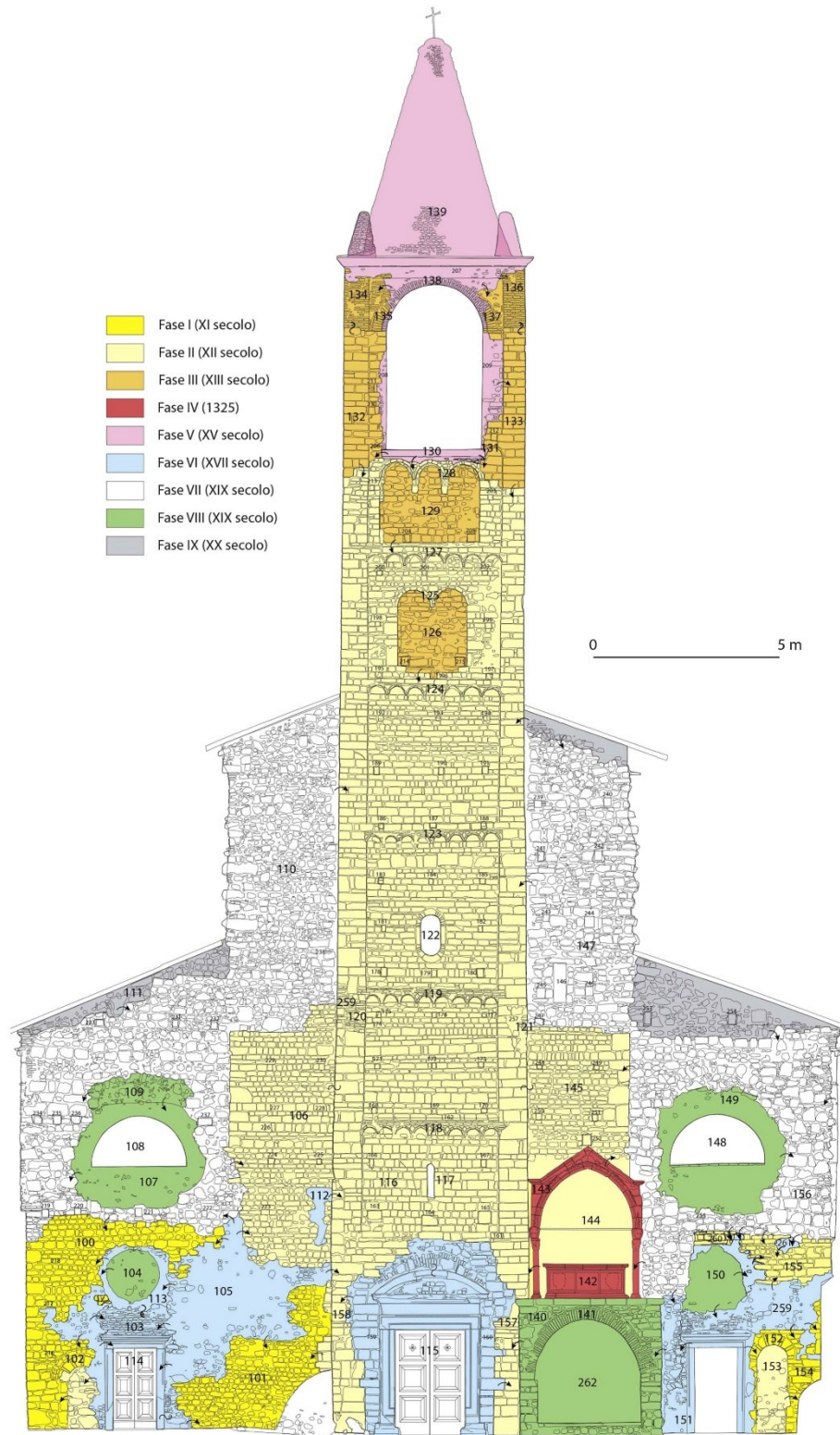


Figure 1: Archaeological reconstruction phases of the Parish Church (Pieve) of Sant'Andrea, Iseo. Modified from Gallina (2013).

4. The modeling approach described in the subsection starting at lines 339 and 363, respectively, would benefit from a better description of the coupling between landslide modeling and tsunami generation. In particular, the approach seems to be two-step, where the landslide is modeled first and then used as input to the tsunami simulation, thus ignoring the back effects of tsunami propagation on the landslide. This approximation is valid and widely used in the literature, but it usually means that some hydrodynamic

effects, such as viscous/turbulent drag and added mass, are neglected and should be accounted for before coupling, i.e., in the landslide simulation itself. The discussion on these points should be more explicit. Furthermore, how can we rule out the possibility of a progressive, retrogressive, faster-eroding event, presumably not tsunamigenic?

*Thank you for highlighting this important point. We have revised the manuscript to clarify the coupling strategy between landslide modeling and tsunami generation (**lines 373 – 383**). We modeled the tsunamis generated by delta collapses in Lake Iseo in two stages using a one-way coupling approach. First, the dynamics and time evolution of the landslide were simulated using the landslide model. Second, the simulated landslide evolution was converted into time-dependent bathymetric changes that served as inputs to the tsunami model. We acknowledge that this approach neglects the feedback of wave propagation on landslide dynamics, as for these specific water depths and landslide kinematics, the dynamic backpressure from the generated surface waves exerts a negligible effect on the dense viscoplastic slide layer. Nevertheless, hydrodynamic effects such as viscous/turbulent drag and added mass are accounted for during the landslide modeling stage prior to coupling with the tsunami model.*

We agree that a retrogressive failure mechanism cannot be entirely excluded, particularly in paleotsunami studies where uncertainties in past landslide dynamics inevitably remain. However, the available sedimentological and historical evidence supports a predominantly rapid, single-event failure mechanism in this case. The sedimentological structure of the event deposits in the deep basin is consistent with rapid deposition. These deposits show an erosive sandy base, interpreted as a high-energy remobilization phase associated with a single upward-fining depositional episode, without evidence for repeated grading or multiple stacked subevents (Rapuc et al., 2022). This unit is overlain by thick homogeneous deposits, interpreted as suspension settling associated with basin-wide seiche oscillations (Zafar et al., 2025), with an upper fine-clay interval reflecting the final stage of suspension settling.

*Additionally, historical accounts describing catastrophic flooding and destructive lake overflow around Lake Iseo, where almost no one survives after such flooding, further support the occurrence of a high-energy event compatible with rapid tsunami generation. Although some degree of retrogressive evolution cannot be fully ruled out, the combined sedimentological, historical, and modeling evidence supports rapid earthquake-triggered slope collapse capable of generating significant tsunami waves. These details about the single-event failure mechanism have been added to the revised manuscript (**Lines 121-128**).*

5. The modelling section does not explicitly describe how the sliding motion generates the tsunami: how is the mass-wave interaction treated? How much energy is transmitted between the two phenomena? Maybe also computing the Froude number (the ratio of the two velocities) would help quantify the efficiency of this process.

Thank you for this valuable suggestion. We have revised the Methods section to explicitly describe how the sliding motion generates the tsunami (**lines 375 – 379**). In the tsunami model, the temporal evolution of the landslide is imposed as time-dependent bathymetric changes. The tsunami model accounts for these time-varying lakebed deformations generated by landslide motion. These bathymetric perturbations are directly transferred to the overlying water column, leading to the generation and propagation of tsunami waves.

Following the reviewer's suggestion, we also calculated the temporal evolution of the Froude number (Fig. 2) to assess tsunami-generation efficiency and incorporated the results into the revised manuscript as a new subsection entitled "Froude number estimation" in the Methods section (**lines 422–437**). The results show that the Froude number reached a maximum of ~ 0.9 (approaching the resonant condition $Fr \approx 1$) during the initial acceleration phase of the delta collapse, indicating efficient energy transfer from the landslide to surface waves and, consequently, the most efficient tsunami generation. After ~ 20 s, Fr rapidly decreased to ~ 0.6 and then gradually declined during runout, reflecting reduced tsunami generation efficiency as the landslide decelerated and propagated into deeper water.

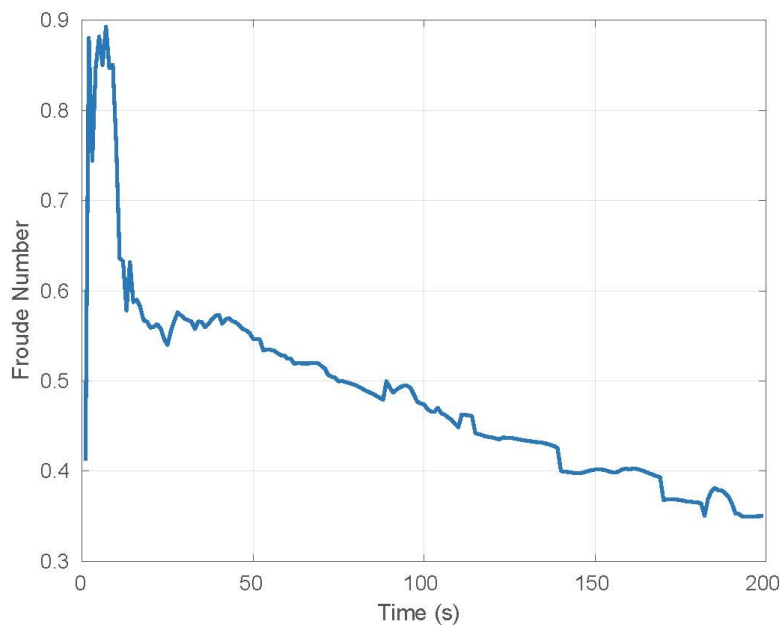


Figure 2: Temporal evolution of the Froude number during the first 200 s for the 1117 CE event.

6. The discussion on a dimensional numbers at lines 388-393 should include a reference to an explanation of how they are derived and their role, e.g. Mei et al. (1989).

Thank you so much; the suggested modifications have been incorporated into the revised manuscript (**lines 452–456**).

7. Data sources for topo-bathymetrical data should be mentioned for reproducibility. If the data are from public dataset (e.g. TinItaly for the topography) they should be referenced appropriately. If the data are not public, it should be clearly stated.

*Thank you for highlighting this point. The topographic and bathymetric datasets used in this study consist of high-resolution LiDAR topography and multibeam bathymetry acquired in 2002 by Regione Lombardia and the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) within the Italian National Geological Mapping Programme (CARG). These details, together with the corresponding references (Bini et al., 2007; Piccin & Coren, 2002), have been added to the revised manuscript (**Lines 105-108**).*

8. Lake water levels are subject to seasonal and secular variation, which means that the shoreline position at rest can vary with time. In turn, the shoreline's position has a significant impact on tsunami coastal dynamics. How did the authors choose the water level for lakes? If they just assume the level is the same as today, it should be explicitly stated in the text.

*Thank you for highlighting this important point. We have now explicitly stated the lake water level assumption in the revised manuscript (**Lines 418-421**). The shoreline position is based on the present-day reference lake level (185.44 m a.s.l.), as there is no evidence of significant lake-level variations during the last ~2 kyr, also considering the nearly constant extent of the marsh area (Torbiere d'Iseo) at the southern edge of Lake Iseo.*

(Reviewer # 3):

1. Assuming that an independent chronology is available for sediment core SEB18, please add these datings to Extended Data Fig. 2. This has the potential to provide another confirmation for the ages of the two MWDs.

Thank you so much for this important suggestion. The Extended Data Fig. 2 has been revised accordingly in the revised manuscript.

2. The sites where Russian peat cores were utilized should not only be marked in Fig. 3a, b by red dots. These should also be explained in the caption to this figure. Additionally, these "core locations" should be added to Fig. 1c.

Thank you for the helpful suggestion. The figures (1c and 3a) and their captions have been revised accordingly in the revised manuscript.

(Reviewer # 4):

1. *First of all, the last part of the abstract reads like the recent global synthesis study on the Industrial Era increase in human-driven erosion incorporating 632 lakes is part of the present study, which is actually not the case. I would suggest to re-write this part a little bit, just stating that other studies indicate high present-day sediment supply to deltas and that resulting overloading-driven failures similar to those recorded in the past in Lake Iso and elsewhere could consequently occur more frequently in the future, also at lower earthquake magnitudes or even spontaneously.*

Thank you for highlighting this and your helpful suggestion. We have revised the manuscript accordingly and incorporated the suggested changes into the abstract (lines 31-34).

2. *Second, I wonder whether the sediment volume supposedly mobilized by the AD 1222 delta failure can be evaluated somehow against the sediment supply of the Oglio River. I see that the volume of the AD 1222 event deposit is much smaller than that mobilized by the stronger AD 1117 earthquake, which is in general reasonable. But considering that the river delta possibly completely collapsed during the AD 1117 earthquake with no sediment left (mobilization of ~62 Mm³ of sediment), would the ~100-year period until the AD 1222 earthquake be sufficient to newly accumulate ~10 Mm³ of sediment in the delta that could be mobilized during this event? Is the sedimentary input of the Oglio River that strong? I would like to see a bit more discussion on this issue, especially if the amount of mobilized sediment is at least in the same magnitude of the amount of sediment that could have been deposited in the delta fan over 100 years given the erosional input rate displayed in Extended Data Fig. 4.*

Thank you so much for raising this important point. We agree that the plausibility of sediment recharge between the 1117 CE and 1222 CE delta failures should be discussed more explicitly. We have revised the manuscript and added the following first-order estimate of sediment accumulation in the deep basin between the two events (lines 92-99).

Direct quantification of sediment accumulation in the proximal Oglio delta is not possible without dedicated new delta cores. However, we can provide a first-order estimate using the deep-basin sedimentation rate. The accumulated sediment volume can be estimated as follows:

$$V = SR \times A \times \Delta t$$

where V is the accumulated sediment volume, SR is the sedimentation rate in the deep basin, A is the depositional area, and Δt is the time interval.

For the 105 years between the 1117 CE and 1222 CE events, using a mean sedimentation rate of 3 mm yr⁻¹ and the deep-basin depositional area below a water depth of 210 m (~18 km²), the accumulated sediment volume is as follows:

$$V = 0.003 \text{ m yr}^{-1} \times 17,975,477 \text{ m}^2 \times 105 \text{ yr}$$

$$V \approx 5.66 \times 10^6 \text{ m}^3 \approx 5.7 \text{ Mm}^3$$

Thus, the deep basin alone could have accumulated approximately 5.7 Mm³ of sediment during the 105 years separating the two medieval events. This value is of the same order of magnitude as the approximately 10 Mm³ mobilized during the 1222 CE delta collapse.

We emphasize that this estimate is conservative because the deep-basin sedimentation record reflects mainly fine suspended sediment deposited in the central basin. It does not fully account for bedload, coarse-grained material, or sediment temporarily stored in the proximal delta front, which are the components most relevant for rebuilding an unstable deltaic sediment wedge. In addition, the accommodation space created by the collapse of the 1117 CE would have enhanced sediment trapping at the delta front during the following century. Therefore, the accumulation of a sediment volume on the order of 10⁷ m³ before the 1222 CE event is physically plausible.

- 3. Another question would be why the tsunami modelling has only been carried out for the two events that caused the emplacement of the event deposits MWD 7 and MWD 6, i.e. the AD 1117 and AD 1222 regional earthquakes, but not for the third prominent event, the 6th century earthquake that caused the emplacement of event deposit MWD 8. Given the fact, that this deposit is apparently rather similar to MWD 6 in terms of size/volume and also occurred when erosional input was already relatively high, a comparison with the other two events might be useful. One could maybe learn something about the rate of sediment supply, delta loading and mobilization processes compared to the other two events as well as about possibly different tsunami impacts of the two, in terms of their volume, comparable events MWD 8 vs. MWD 6.*

Thank you for this important suggestion. We agree that modeling the event associated with MWD8 would be scientifically interesting, especially because it represents one of the largest mass-wasting deposits identified in Lake Iseo. However, we did not include this event in the tsunami simulations because it is significantly less constrained than the 1117 CE and 1222 CE events.

The main limitation is that the volume of MWD8 cannot be independently constrained with sufficient confidence from the available seismic data. MWD8 occurs in the lower part of the recovered sedimentary sequence, and the seismic-data penetration (Extended Data Fig. 1B) does not fully constrain the complete extent and total volume of the deposit. Without reliable estimates of both the total volume and extent of this deposit, the resulting tsunami model would be subject to large uncertainties. In addition, we do not have any historical or archaeological records of tsunami impact that could be used to validate the event.

A second limitation concerns the triggering earthquake itself. Unlike the 1117 CE and 1222 CE events, which are supported by historical documentation and independent evidence of regional destruction, the earthquake associated with MWD8 is constrained only indirectly through the sedimentary record. Consequently, its age, magnitude, and source characteristics remain substantially more uncertain.

For these reasons, tsunami simulations were carried out for only the 1117 CE and 1222 CE events.

- 4. And last but not least, I wonder whether there are some local pollen records available that could be*

used to sustain the inferences of rising human land use since the Roman Empire period.

*Thank you for highlighting this point. Yes, pollen studies are available from the Lake Iseo catchment and surrounding regions and provide evidence of past human activities (e.g. [Pini, 2002](#)). A synthesis of the available evidence on past human impacts in the catchment and surrounding areas has been discussed in [Rapuc et al. \(2021\)](#). We have now added the relevant references to the palynological studies in the revised manuscript (**Line 69**).*

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Response to Reviewers #1 & 2

We thank the reviewers for their positive assessment of the revised manuscript and for their valuable comments and suggestions throughout the review process.

Response to Reviewer #3

We thank the reviewer for their positive assessment of the revised manuscript and for the two minor language suggestions. Both suggestions have been incorporated into the revised manuscript.