EGUSPHERE-2025-5792 | Research article

We thank the reviewer for the positive and constructive assessment of our manuscript. We appreciate the recognition of the multidisciplinary approach adopted in this study, and we also acknowledge the reviewer's concerns regarding clarity, structure, and the depth of the scientific discussion.
In response to these comments, we carefully revised the manuscript to improve its structure, strengthen the discussion of the results, and clarify the presentation of the methods and findings. These revisions have enhanced the overall clarity and coherence of the manuscript while preserving its central contribution: highlighting the interactions between seismic processes, wetland ecology, and disaster risk management in a highly seismic coastal environment. Our detailed responses to each specific comment are provided below.

Comment 1: *The introduction is very long and contains an excessive literature review. It will improve readability if the authors shorten some background discussions and focus more directly on the research gap and objectives.*

We agree that the Introduction can be streamlined to improve readability and better emphasize the main contribution of the study. In the revised manuscript, we have shortened several sections of the literature review and strengthened the presentation of both the research gap and the study objectives. We have also clarified why this topic is particularly relevant in the Peruvian and South American Pacific coastal context, where coastal wetlands are experiencing rapid degradation and loss, while information on the wetland dynamics remains scarce. By refining the Introduction, we aim to more clearly highlight the scientific and practical importance of addressing this knowledge gap and its implications for both wetland conservation and disaster risk management.

Comment 2: *The novelty of the study should be explained more clearly. The manuscript discusses liquefaction and wetlands, but the unique scientific contribution compared to previous studies is not sufficiently highlighted.*

We agree that the novelty of the study should be more clearly articulated, and we have revised the manuscript accordingly: The main contribution of this work is not only the analysis of the relationship between soil liquefaction and coastal wetlands, but also the generation of evidence for a major knowledge gap in the central Pacific coast of South America, a highly seismic region where this relationship has received very limited scientific attention. While coastal wetlands are often recognized for their ecological and landscape value, their role in disaster risk management and as indicators of subsurface conditions susceptible to liquefaction has rarely been considered in this region.

In addition, coastal wetlands in Peru are frequently perceived either as areas to be conserved solely for their environmental value or, conversely, as underutilized lands that can be drained, filled, dredged, or transformed for urban expansion, second-home developments, agro-export activities, and other productive uses. A key aspect that we seek to highlight is the importance of land-use change in these environments. Changes in land use may alter or even eliminate the visible expression of wetlands, but they do not necessarily eliminate the underlying geological and hydrological conditions that contribute to liquefaction susceptibility.

Our results suggest that even when wetlands are degraded, reclaimed, or no longer visible at the surface, the subsurface characteristics associated with them may persist and continue to represent a significant hazard during future earthquakes. We therefore consider that incorporating wetland dynamics and land-use change into territorial planning and disaster risk reduction strategies represents an important and underexplored contribution of this study.

Comment 3: *The methodology section needs more details regarding the DPL-to-SPT correlation procedure. The uncertainty and limitations of using equivalent SPT values should also be discussed.*

We agree that the methodology should provide a clearer description of the DPL-to-SPT correlation procedure and explicitly acknowledge the associated uncertainties and limitations: In the revised manuscript, we have expanded the methodology section to describe that the Light Dynamic Penetration (DPL) tests were conducted in accordance with the DIN 4094 standard, recording the number of blows required for each 10 cm increment of penetration **(**N_{10}**).** To estimate geotechnical parameters from these measurements, a correlation with the Standard Penetration Test (SPT) was applied following the procedure described by Ortiz & Gómez (2020)**,** which was calibrated for sandy and sandy-silty soils along the Peruvian coast.

This correlation provides an equivalent Nspt value derived from the DPL N_{10}**,** accounting for the differences in energy transfer and equipment geometry between the two testing methods. Based on this equivalent Nspt**,** the internal friction angle was estimated using the empirical relationship proposed by Ohsaki (1959, as cited in Ortiz, 2020)**:** $\varphi = 20\sqrt{Nspt}+15$, widely used as a conservative approximation for sandy deposits and therefore suitable for estimating their potential susceptibility to soil liquefaction.

It is important to note that the equivalent Nspt values derived from DPL testing represent indirect estimates and should not be regarded as a substitute for a conventional SPT. The correlation is subject to uncertainties associated with soil variability (grain-size distribution, the presence of gravel or cementation), groundwater saturation conditions, and the manual operation of the DPL equipment. Accordingly, the results were interpreted as indicators of relative liquefaction susceptibility and were evaluated in conjunction with information obtained from test pits, groundwater levels, and the geological and geotechnical characteristics of the study area. This methodological approach has previously been applied in seismic microzonation studies conducted in the Pisco and San Andrés regions. Following the reviewer's suggestion, we have also incorporated the following references into the revised manuscript:

DIN 4094-3:2002-01 (2002). *Subsoil - Geotechnical investigation and testing - Part 3: Dynamic probing*. Berlin: Deutsches Institut für Normung.

Ortiz, S. y Gómez, J. (2020). Estimación de parámetros de resistencia en suelos arenosos empleando el ensayo DPL y su aplicación en los estudios de Zonificación Sísmica Geotécnica - caso Catacaos, Instituto Geofísico del Perú. Retrieved from https://sigrid.cenepred.gob.pe/sigridv3/documento/13872

Comment 4: *The authors should explain why only 26 DPL tests and 5 test pits were considered sufficient for the study area. Some justification on spatial representativeness is needed.*
We appreciate this comment and have added a justification for the number and distribution of tests. The 26 DPL soundings and 5 test pits were strategically located based on geomorphological criteria, historical evidence of liquefaction following the 2007 Pisco earthquake, and the presence of shallow water tables and susceptible sandy deposits within six main coastal wetlands. Additionally, we incorporated prior microzonation studies developed by IGP and INGEMMET for the Pisco and San Andrés area, which provided baseline geotechnical information. While logistical constraints and ground conditions (e.g., compact layers or gravels) limited the number of soundings, the resulting dataset proved sufficient to identify consistent spatial trends in liquefaction susceptibility across the study area, which is the primary objective of this research. We have clarified this in the methodology section.

Comment 5: *The NDVI/SAVI analysis is interesting, but the attribution of vegetation increase solely to earthquake-related processes may be too strong. Other climatic or hydrological factors during 2000–2014 should also be considered.*

We agree that our original discussion placed considerable emphasis on earthquake-related processes as a potential explanation for the observed NDVI and SAVI trends, while giving less attention to other factors that may also influence vegetation dynamics in coastal wetlands. In response, we are revisiting the discussion and incorporating additional literature on the influence of climatic and hydrological drivers, including interannual rainfall variability, wetland hydrological connectivity, and the effects of large-scale climate oscillations such as El Niño–Southern Oscillation (ENSO). These studies suggest that changes in vegetation cover may result from the interaction of multiple environmental factors operating at different temporal and spatial scales.

Accordingly, we have revised the manuscript to present earthquake-related processes as one contributing factor rather than the sole explanation for the observed vegetation changes. We also discuss how climatic and hydrological conditions may have influenced wetland dynamics during the study period and acknowledge the limitations of attributing vegetation trends to a single driver in such complex socio-ecological systems. We have also incorporated the following references into the revised manuscript:

Aponte, H. Ecología y dinámica de humedales costeros del Perú. [In Spanish]. Revista Peruana de Biología 2014, 21, 1–12. doi: 10.15381/rpb.v21i1.8244

Cerna-Arrue, R.; Aponte, H. Dinámica ecológica de humedales costeros y su relación con variabilidad climática y procesos antrópicos [In Spanish]. Ecología Aplicada 2024, 23, 55–71. https://doi.org/10.21704/rea.v23i1.2045

Delgado, L.E.; Marín, V.H.; Tironi, A.; Bachmann-Vargas, P.; Torres-Gómez, M. Fragmentation and ecological degradation of urban wetlands in coastal environments. Landscape and Urban Planning 2017, 164, 43–51. doi: 10.1016/j.landurbplan.2017.03.012

ENFEN. Comunicado Oficial ENFEN N.º 14-2014 [In Spanish]. Comité Multisectorial Encargado del Estudio Nacional del Fenómeno El Niño: Lima, Perú, 2014. Available online: https://www.enfen.gob.pe

ENFEN. Reporte Técnico: Condiciones oceánicas y atmosféricas del Pacífico frente a la costa peruana durante 2014 [In Spanish]. Comité Multisectorial Encargado del Estudio Nacional del Fenómeno El Niño: Lima, Perú, 2014. Available online: https://www.enfen.gob.pe

Comment 6: *The discussion sometimes becomes descriptive rather than analytical. More comparison with previous international studies on post-seismic wetland recovery would strengthen the scientific discussion*.

We thank the reviewer for this observation. We have revised the Discussion section to move beyond description and incorporate analytical comparisons with international studies. Specifically, we now compare our findings with Hill et al. (2024) on human amplification of liquefaction hazards in modified coastal wetlands, including the Christchurch and Tokyo Bay case studies, which show that drained and filled wetlands retain liquefaction susceptibility for decades. We also reference Qiu et al. (2024), who found persistent degradation of alpine wetlands one year after the Maduo earthquake, consistent with our observations of limited post-seismic recovery in the Pisco wetlands. These additions situate our local findings within a broader international context and strengthen the analytical depth of the discussion. Following the reviewer's suggestion, we have also incorporated the following references into the revised manuscript:

Hill, E. M., McCaughey, J. W., Switzer, A. D., Lallemant D., Wang Y. and Sathiakumar, S. (2024). Human amplification of secondary earthquake hazards through environmental modifications. Nature Reviews Earth & Environment, 5, 463–476. doi: 10.1038/s43017-024-00551-z

Qiu, D., Zhang, H., Ren, Y., and Zhu, Y. (2024). The lost biodiversity and degraded alpine wetlands caused by strong earthquake on the Qinghai─Tibet Plateau did not self-restore in the short term. Global Ecology and Conservation. doi: 10.1016/j.gecco.2024.e02830

Comment 7: *The interview-based observations are valuable, but the manuscript should mention possible biases and limitations associated with local memory and perception.*

Thank you for this thoughtful comment. We fully recognize that local memory and perception are subject to potential biases, including selective recall, personal interpretation, and the passage of time. For this reason, the interviews were not intended to serve as the sole source of evidence but rather as an independent line of qualitative information integrated with the geotechnical analyses and remote sensing results.

We agree that these limitations should be explicitly acknowledged in the manuscript, and we have incorporated a discussion of the potential biases associated with interview-based data. Although nearly two decades have elapsed since the 2007 Pisco earthquake, we consider the reliability of the testimonies to be relatively high because of the exceptional magnitude of the event and its long-lasting consequences for local communities (Demirkol et al., 2025). The study area has yet to fully recover, and many of the observed impacts remain part of residents' everyday experience and collective memory (LimaGris, 2022; Infobae 2024). In this context, the interviews provide valuable contextual evidence that supports and enriches the physical observations rather than replacing them, contributing to a more comprehensive interpretation of the post-seismic evolution of these coastal wetlands. Additional references incorporated into the revised manuscript:

Demirkol, H., Ramos-Vera, Cristian, Kaçmaz, E. D., Yilmaz, M. (2025). Post-traumatic growth in adults in Türkiye and Peru after devastating earthquakes at different times: A cross-cultural study. Journal of Death and Dying. doi: 10.1177/00302228251377276

Infobae (2023). El terrible terremoto en Pisco: las cicatrices que dejó este sismo en la zona centro-sur del Perú. Retrieved from: https://www.infobae.com/peru/2023/08/15/a-16 -anos-del-terrible-terremoto-en-pisco-las-cicatrices-que-dejo-este-sismo-en-la-zona-centro-sur-del-peru/

LimaGris (2022). Quince años después del terremoto de Pisco y aún falta mucho para recuperarse. Retrieved from: https://limagris.com/quince-anos-despues-del-terremoto-de-pisco-y-aun-falta-mucho-para-recuperarse/

Comment 8: *The manuscript would benefit from a clearer explanation of the "200 m influence zone" and how this threshold was determined.*

We thank the reviewer for this comment. The 200 m influence zone was determined based on the integration of multiple pieces of evidence specific to the Pisco wetland H-01 and adjacent areas. Post-earthquake field observations following the 2007 Pisco earthquake identified liquefaction features such as sand boils, ground cracking, and subsidence up to approximately 200 m from the wetland boundaries, and geotechnical data from our study together with previous microzonation reports for the Pisco-San Andrés area confirm that sandy, loose, saturated soils susceptible to liquefaction extend to this distance, beyond which the subsurface transitions to gravelly or denser materials. This threshold is consistent with the quantitative buffer distance established by Civico et al. (2015) in the Po River plain (Italy) following the 2012 Emilia earthquake sequence, where high-to-moderate liquefaction susceptibility was found to occur within a buffer distance of 100 to 200 m from mapped fluvial landforms. For the remaining wetlands in our study area, where detailed geotechnical investigations are not available due to their less urbanized character, we consider that a similar approximate buffer may be applicable given the comparable geomorphological and sedimentological conditions; this is also supported by interviews with local residents who reported observed liquefaction effects during the 2007 earthquake at distances consistent with this range.

Our primary basis remains the Liquefaction Potential Maps derived from our own DPL and SPT soundings, which delineate the actual liquefiable zones for each wetland, with the 200 m value serving as a generalized reference for H-01 while acknowledging that other wetlands may exhibit local variations depending on subsurface conditions and the extent of saturated sandy deposits. We will add this clarification in the revised version of the manuscript, specifically in the section describing the study area and the delimitation of the influence zone. We have also incorporated the following reference:

Civico, R., Brunori, C. A., De Martini, P. M., Pucci, S., Cinti, F. R., and Pantosti, D.: Liquefaction susceptibility assessment in fluvial plains using airborne lidar: the case of the 2012 Emilia earthquake sequence area (Italy), Nat. Hazards Earth Syst. Sci., 15, 2473–2483, https://doi.org/10.5194/nhess-15-2473-2015, 2015.

Comment 9: *Several paragraphs in the Discussion section are too long. Shortening and restructuring them would improve readability.*
We agree that some sections of the Discussion benefited from a more concise structure. In the revised manuscript, we reviewed these paragraphs, dividing and shortening them where appropriate to improve readability while preserving the continuity of the scientific arguments and the interpretation of the results.

Comment 10: *The conclusion is good, but some statements appear repetitive. The authors may consider making the conclusions more concise and focused on the main findings.*
We agree that the Conclusions section benefited from being more concise and focused. In the revised manuscript, we carefully reviewed this section to reduce repetition and emphasize the main findings and their broader implications. These revisions provide a clearer synthesis of the study while preserving the key messages regarding the interactions between soil liquefaction, wetland dynamics, and disaster risk management.