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Earth's Future

REPLY
10.1029/2025EF007826

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Addressing the Escalating Impacts of Extreme Heat, Heat Waves, and Urban Heat Islands on Public Health: Vulnerability, Resilience, and Mitigation Strategies

Reply to Comment by Darwish on "Soaring Building Collapses in Southern Mediterranean Coasts: Hydroclimatic Drivers and Adaptive Landscape Mitigations"

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Key Points:

- Misinterpretation of Research Findings: Fouad et al. (2025, https://doi.org/10.1029/2024EF004883) did not solely attribute building collapses to hydroclimatic factors but also considered anthropogenic influences
- Flawed Statistical Analysis: The comment's approach obscures absolute risk by normalizing collapse rates to the total number of buildings
- Misunderstanding of Soil Analysis Methods: The comment conflates shallow isotope mapping for soil relaxation with deep structural assessments for individual buildings

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Citation:
Fouad, S. S., Heggy, E., Amrouni, O., Hzami, A., Nijhuis, S., Mohamed, N., et al. (2026). Reply to comment by Darwish on "Soaring building collapses in southern Mediterranean coasts: Hydroclimatic drivers and adaptive landscape mitigations". *Earth's Future*, *14*, e2025EF007826. https://doi.org/10.1029/2025EF007826

Received 26 NOV 2025
Accepted 9 DEC 2025

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Abstract We are grateful for Darwish's interest in our paper, Fouad et al. (2025, https://doi.org/10.1029/2024EF004883). In this reply, we show that Fouad et al. (2025, https://doi.org/10.1029/2024EF004883) did not attribute building collapses in Alexandria solely to hydroclimatic factors, as stated in the comment. Instead, we emphasize that hydroclimatic drivers are presented as accelerators, with other anthropogenic influences explicitly stated in the original paper. Moreover, our response proves that Darwish (2026, https://doi.org/10.1029/2025ef006885)'s simplistic statistical approach is physically incorrect and obscures absolute risk by normalizing actual building collapse rates to the total number of buildings within a city. Furthermore, our reply shows that the comment conflates the distinct measurement of soil relaxation using shallow isotope mapping at the city scale, as conducted in Fouad et al. (2025, https://doi.org/10.1029/2024EF004883), with deep structural geotechnical assessments for foundation design of individual buildings. The utility and complementarity of both methods are already discussed in Fouad et al. (2025, https://doi.org/10.1029/2024EF004883). We acknowledge that the statement on the "7,000 at-risk buildings" is only mentioned in the abstract and is inadvertently missed in the main text; however, the calculation leading to this result is detailed in our supplementary data set and methods. Accordingly, Darwish (2026, https://doi.org/10.1029/2025ef006885)'s comment, while appreciated, misinterprets Fouad et al. (2025, https://doi.org/10.1029/2024EF004883) and overlooks the contemporary literature on Alexandria's hydrogeological and coastal dynamic contexts and their implications for infrastructure instability.

Plain Language Summary Darwish (2026, https://doi.org/10.1029/2025ef006885)'s comment is appreciated; however, Fouad et al. (2025, https://doi.org/10.1029/2024EF004883) did not solely attribute building collapses to hydroclimatic factors as suggested in Darwish (2026, https://doi.org/10.1029/2025ef006885)'s comment, but rather as accelerators and also considered other anthropogenic influences. Our reply highlights the limitations of Darwish (2026, https://doi.org/10.1029/2025ef006885)'s statistical methodology for assessing urban vulnerability to building collapse, particularly its reliance on ratios of at-risk buildings to the total building population, which obscure absolute risk. Furthermore, our reply clarifies the distinctions between soil relaxation and geotechnical assessments, which Darwish (2026, https://doi.org/10.1029/2025ef006885) conflates. Finally, it provides information on the availability of supplementary data detailing the 7,000 at-risk buildings questioned by Darwish (2026, https://doi.org/10.1029/2025ef006885). Accordingly, Darwish (2026, https://doi.org/10.1029/2025ef006885) misinterprets Fouad et al. (2025, https://doi.org/10.1029/2024EF004883), overlooking the recent advances in scientific literature on the role of hydroclimatic drivers in coastal building collapses in Alexandria.

1. Reply to "Comments Regarding Collapses Due To Foundation Deterioration Solely"

Darwish (2026)'s main critique of Fouad et al. (2025) is that it "singles out" building collapses solely to coastal hydroclimatic drivers, which cause foundation deterioration. For instance, Darwish (2026)'s comment stated that

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"*Although they acknowledge in several places, that the impact of relative sea level rise on building failures is poorly understood and that the origins of increasing building collapses remain speculative, however, they proceed to assume that collapses are solely due to one factor*."

This critique does not reflect the findings of Fouad et al. (2025) for the following reasons:

a. First, Fouad et al. (2025) have never asserted that hydroclimatic factors are the sole cause of building collapse. In contrast, we defined the hydroclimatic drivers as accelerators for building collapse, as explicitly stated in the abstract and reiterated multiple times throughout the text (Fouad et al., 2025, pp. 1, 2, 7, 10, 17).
b. The aforementioned statement is neither part of our results nor our conclusions, nor is it mentioned multiple times, as portrayed in Darwish (2026)'s comment. It is listed only once in the introduction to highlight the gaps in previous studies and the aim and novelty of Fouad et al. (2025). For evidence, this statement was followed in the text by our study aims, as stated: "*Herein, we explore the hydroclimatic and anthropogenic drivers that accelerate building collapse in Alexandria*" (Fouad et al., 2025, p. 2). Hence, we didn't assume that collapses are solely due to one factor in our investigation.

1.1. Reply to "Comments Regarding Deterioration From Bottom Foundation up"

The comment asserts that Fouad et al. (2025) assume that deterioration and potential collapse occur solely from *"groundwater infiltration from the bottom (foundation) up"* and that the manuscript does not highlight other factors, such as rain, exposure, leakage, spills, and lack of maintenance.

This critique overlooks several sections in Fouad et al. (2025) where these drivers are mentioned. Fouad et al. (2025) explicitly discussed multi-source deterioration pathways beyond foundation-driven infiltration, including those mentioned in Darwish (2026)'s comment. For example, in Section 5.2 (Decadal Increase in Coastal Building Collapses), p. 8, we explicitly state that environmental factors, such as air pollution, waterway contamination, and changes in air humidity, can also adversely affect the structural resilience of coastal buildings in the city. Furthermore, current inefficient management strategies are prevalent in Alexandria. We also mentioned different case studies (e.g., Tunisia, Italy, and California) that emphasize the reasons for accelerated building collapses in coastal areas, including inefficient structural design, as mentioned in our study, Fouad et al. (2025, pp. 4–6).

1.2. Reply to "Comments Regarding the Depths of the Surface Soil Tests Used"

Darwish (2026)'s comment asserts that Fouad et al. (2025) used shallow soil sampling at a depth of 5 cm to assess the foundation structure stability, which is, in his view, inappropriate and contradicts the ASM standards for deep geotechnical assessment via well logs.

The above criticism confuses the aim and method in Fouad et al. (2025) as follows:

a. The 5 cm shallow subsurface soil sampling in Fouad et al. (2025) aims to use surface radionuclide (particularly ^{7}Be isotope levels) to create city-scale soil stability maps, and not individual buildings' foundation assessments, as is the case with the ASM standard (ASTM, 2024). This approach, as well as interferometric synthetic aperture radar (inSAR), a widely used in Alexandria and other coastal cities for identifying large-scale soil instability patterns (e.g., Hemeda, 2021; Kurylyk et al., 2025; Mohamadi et al., 2019; Thomas et al., 2025; Wöppelmann et al., 2013), as stated in the original paper in Fouad et al. (2025, p. 5).
b. Fouad et al. (2025) clearly distinguish between the above method and the classical geotechnical assessment suggested by Darwish (2026)'s comment. We emphasize that our radionuclide-based soil profiling is not intended to replace geotechnical subsurface investigations required for foundation design or structural failure assessment, but rather to serve as a complementary tool and an environmental tracer linking hydroclimatic drivers of coastal erosion to ground stability in urbanized coastal zones, as stated in Fouad et al. (2025, Section 5.4, p. 11; and Section 6, pp. 12 and 13).
c. The shallow depth resolution is deliberately chosen to capture the surface soil response to erosion, saltwater intrusion, and moisture fluctuations (e.g., Đokić et al., 2023; Kanivets et al., 2020; Saleh et al., 2024), which are first manifested in the upper soil layers and can progressively undermine near-surface stability over time, as clearly stated in Fouad et al. (2025, Section 5.4, p. 11).

Table 1
Comparison of Building Collapses in Alexandria and Other Cities in Egypt During 2014–2020 (Hilal, 2022), Showing That a Third of National-Scale Collapses Occurred in Alexandria

Governorate (population in millions)	Alexandria (5.6)	Cairo (10.4)	Sohag (5.9)	El Beheira (7)	Asyut (5.2)	Gharbia (5.5)	Dakahlia (7.2)	Giza (9.7)	Minya (6.5)	Aswan (1.7)	Al Qalyubia (6.2)	Menofia (4.8)	Faiyum (4.2)	Total
Number of building collapses 2014-2020	**287**	153	63	58	43	41	40	39	37	29	24	18	14	846
National percentage %	**34**	18	7	7	5	5	5	5	4	3	3	2	2	100

Note. While the cities of Damietta and Port Said, which would have been identified as vulnerable using Darwish (2026)'s approach, have not reported any accidental collapses over the last decade. This suggests that the simplistic statistical approach is flawed. The bold values indicate inhabitants (in millions) of each governorate.

1.3. Reply to "Comments Regarding Building Collapses in Alexandria Relative to Other Egyptian Locations"

Darwish (2026)'s comment suggests that the vulnerability of a given city to building collapses should be defined in terms of the percentage of buildings at risk out of the total inventory, rather than using the actual numbers of collapses. Under this hypothesis, a city with a lower percentage of buildings at risk would be less vulnerable. The comment provides a comparison between building renovation statistics for Alexandria and other cities in Egypt, expressed in terms of percentages relative to the total number of buildings, and suggests that rates are somehow similar among several cities; consequently, it advocates that hydroclimatic drivers are negligible.

While this approach may appear reasonable at first, deep examination of the building renovation data set that existed in the Egypt Statistical Yearbook (2024) demonstrates that this approach suffers from significant statistical and physical deficiencies, as follows:

a. First, the building renovation data set listed in the Egypt Statistical Yearbook (2024) is a single table, located on pages 223–225, that was executed in 2017. While this data can offer some baseline insights into building conditions between 2006 and 2017, it misses the significant increase in total building numbers from 2018 to 2025, which has exceeded ~6 million units (Shawkat & Elmazzahi, 2025). For example, the 2017 census reported 2,489 buildings required for demolition in Alexandria, whereas 2025' official government statements state that this number is ~7,500 buildings (Ahram, 2025; Almahdy, 2025; Fouad & Fahmy, 2025). As such, the 2017 records do not accurately reflect the current state of building vulnerabilities assessed in Fouad et al. (2025) and are inappropriate for validating or invalidating the most recent building status in Egyptian cities.
b. Second, the comment compares the percentages of building renovations in Alexandria and other cities, rather than presenting the absolute numbers mentioned in the Egypt Statistical Yearbook (2024, p. 223), which is based on the 2017 census. This relative approach fails to accurately reflect the magnitude of the phenomenon in each city, as it does not consider urban densities, geological and geotechnical setups, and building geographical distributions, among other physical factors. For example, using the same data set (Egypt Statistical Yearbook, 2024) and approach in Darwish (2026)'s comment for the case of the coastal city of Port Said (~800,000 inhabitants), the second-largest port city after Alexandria (5,600,000 inhabitants), shows that the buildings that do not need renovation are ~58%, compared to ~76.8% in Alexandria. This means that 42% of Port Said's buildings need renovation, compared to 23.2% in Alexandria. Hence, based on Darwish (2026)'s approach, one would expect the number of buildings at risk in Port Said to be much greater than in Alexandria. However, the absolute number of buildings needing demolition in Port Said is 264, compared to 2,489 in Alexandria, as documented in the same reference of the Egypt Statistical Yearbook (2024, p. 223). Furthermore, there have been no reported collapsing buildings in Port Said from 2014 to 2020 (Hilal, 2022), and the city is not known for this phenomenon, unlike Alexandria, which has been a focus of ground subsidence and associated building deterioration studies (e.g., Elneel et al., 2024; Kamal et al., 2021; Mohamadi et al., 2020; Thomas et al., 2025). The Port Said case, among several other examples, demonstrates that the relative approach suggested by Darwish (2026) is physically incorrect and cannot be employed as a measure of vulnerability for a given city, as advocated in the comment.
c. Third, Darwish (2026)'s comment does not compare the actual building collapse numbers in Alexandria to other cities over the last few decades, despite the public availability of these data (Hilal, 2022). As shown in

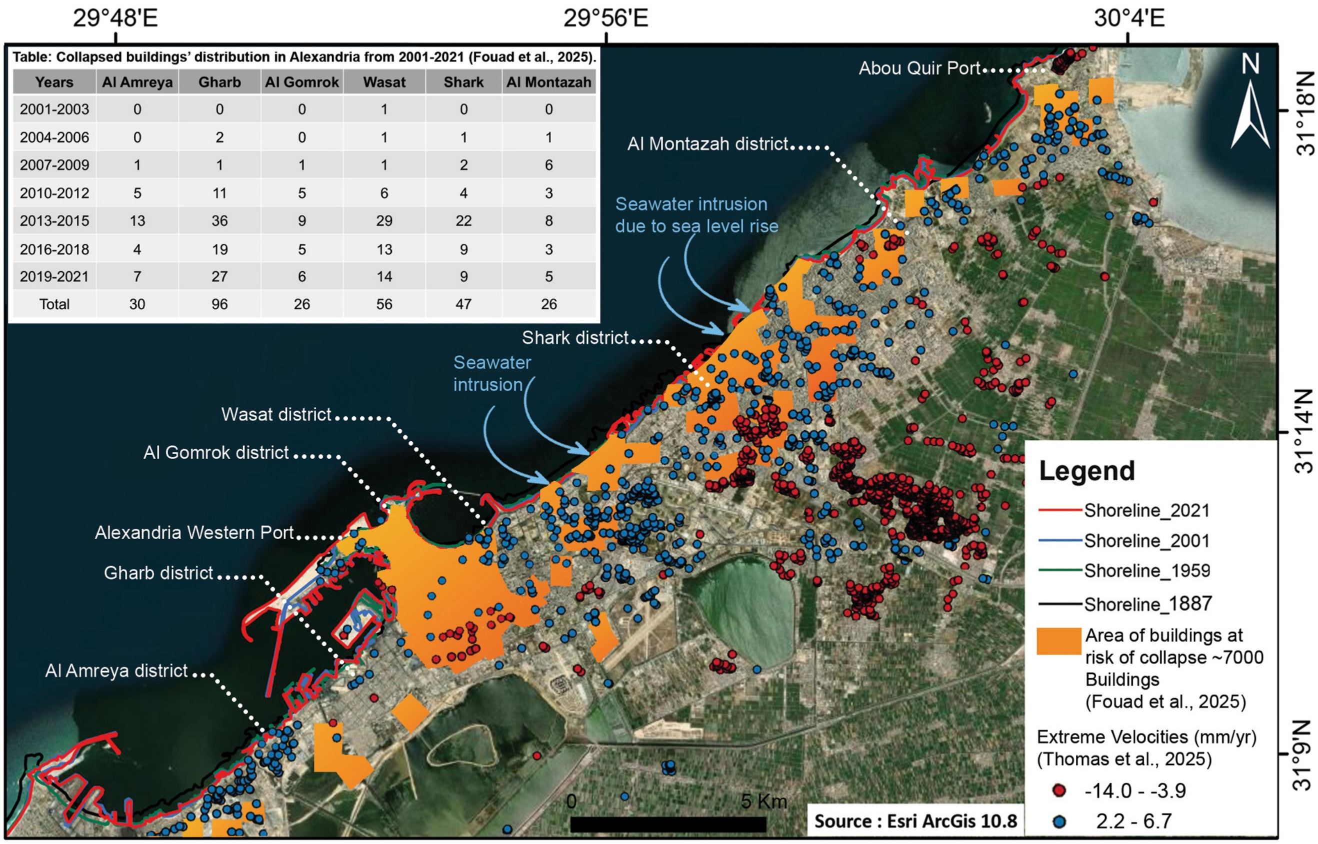

Figure 1. The correlation between the areas containing buildings at risk of collapse reported in Fouad et al. (2025) and those derived from the PS-InSAR data in Thomas et al. (2025). The figure illustrates the high correlation between the instability data from both studies. The areas at risk of building collapse in Fouad et al. (2025) are based on the integration of isotopic results (^{7}Be < 3.9 in Bq/kg), building collapse distribution, governmental reports, field observations, and monitored ground subsidence from Mohamadi et al. (2019, 2020). The figure shows the clustering of buildings at risk, as observed from isotopic and InSAR data, which is unique to Alexandria among Egyptian cities. The figure was created using ArcGIS Pro (2023) and Adobe Photoshop (2019).

Table 1, Alexandria, with its 5.6 million inhabitants and ranks the 9th city in number of inhabitants, tops the Egyptian governorates in terms of building collapses, accounting for 33% of the total in Egypt, surpassing the country's capital, Cairo, with its 18 million inhabitants which ranks as the most populated city, by nearly double (Hilal, 2022). It is important to note that only 25% of the collapsed buildings had received demolition orders (Hilal, 2022). Hence, a key shortcoming of the data used in Darwish (2026)'s comment is that it largely underestimates the number of buildings at risk.

d. Finally, the findings on the impact of hydroclimatic drivers on soil stability in Fouad et al. (2025) are entirely consistent with the results of the recent independent study by Thomas et al. (2025). As shown herein in Figure 1, the distribution of the areas at risk derived from soil analysis and historical building collapse distributions in Fouad et al. (2025) matches the high building displacement rates derived from inSAR satellite observations in Thomas et al. (2025). In addition, Thomas et al. (2025) attributed these ground instabilities to hydroclimatic drivers (e.g., groundwater infiltration and sea level rise), in agreement with the findings of Fouad et al. (2025).

1.4. Reply to "Comment on the Mentioned Number of 7,000 Buildings at Risk of Collapse in Alexandria"

Darwish (2026)'s comment asserts that "the area including 7,000 buildings at risk" mentioned only in the abstract of Fouad et al. (2025) needs justification and clarification. Additionally, the comment questions over what period Fouad et al. (2025) indicate over which period the assumed 7,000 building collapses are expected to occur.

First, we acknowledge that the number of 7,000 buildings at risk is mentioned only in the abstract. However, the method used to assess that number is clearly defined in Section 4, and the full calculation is detailed in the supplementary material of Figure 7 of Fouad et al. (2025). The numbers correspond to building counts in the areas integrating anomalous isotopic values, increased building collapses, and severe shoreline retreat, as shown in Figure 7. Full details of the calculation can be found in the data availability section of Fouad et al. (2025), and for the associated data reproducibility, refer to the file " Figure 7/Count of Buildings in areas prone to future collapses/Susceptible_collapse_buildings_Alexandria.xlsx" in the paper data repository (https://osf.io/98pyu/).

Regarding the temporal scale of when these buildings would collapse, this requires an individual geotechnical assessment of each building's structural specifics and is, therefore, outside the scope of Fouad et al. (2025), which focuses only on assessing the spatial vulnerability across the city of Alexandria.

1.5. Reply to "Comments Regarding Building Collapses in Alexandria's Old Districts"

Darwish (2026)'s comment mentioned that 50%–65% of the buildings in the Gharb and Gomrok districts are over 40 years old, and as such, they are old and prone to failure. The above statement regarding aging buildings in these districts is also found in Fouad et al. (2025) and does not contradict the published results, which indicate that hydroclimatic changes accelerate foundation deterioration, as reported by other studies, such as Thomas et al. (2025). Moreover, Fouad et al. (2025) demonstrate how hydroclimatic stressors compound with existing age-related vulnerabilities through measurable physical processes. For instance, Fouad et al. (2025) stated on pages 10–11 that seawater intrusion accelerates corrosion of steel reinforcements in aging concrete foundations, while rising groundwater levels destabilize soil beneath already-compromised structures (Habel et al., 2024). Additionally, shallow strip footings or pads located near the groundwater table can be affected due to the lack of base-isolation. Furthermore, Fouad et al. (2025) confirm that chemical isotope analysis correlates spatially with both building age and proximity to eroded coastlines, creating convergent risk zones where the Gharb district experiences a 31-m annual shoreline retreat alongside the city's oldest building stock. In addition, the 280 documented collapses over 20 years with clear spatial clustering in the oldest coastal districts illustrate how coastal-driven changes transform manageable aging infrastructure into catastrophic failure scenarios. This is supported by recent official observations that ~7,500 buildings already have demolition orders, and some of these buildings are less than 15 years old (Ahram, 2025; Almahdy, 2025). It is noteworthy that, from a structural point of view, buildings do not simply collapse because they are 40 years old, as suggested in Darwish (2026)'s comment. A combined impact of hydroclimatic, aging, and anthropogenic factors causes these failures, as reported in Fouad et al. (2025).

1.6. Reply to "Comment on the Collapse of the Khalil Hamada Building"

Darwish (2026)'s comment uses this single case to suggest that Fouad et al. (2025)'s analysis lacks empirical foundation, when in fact it demonstrates the value of systematic data collection across multiple failure modes. One building collapse caused by structural modifications, as suggested without any official proof in Darwish (2026)'s comment, does not invalidate the accelerated patterns observed across ~280 failures over two decades. Instead, if valid, it illustrates how different collapse mechanisms can operate simultaneously within the same urban environment, which requires analytical frameworks capable of distinguishing between various contributing factors.

1.7. Reply to "Comment on Wooden Pillars as a Proposed Solution"

Darwish (2026)'s criticism of Fouad et al. (2025)'s proposed wooden pillar solutions as "culturally inappropriate" for Egypt and southern Mediterranean countries overlooks the ongoing efforts to implement coastal nature-based solutions on the North African coast. The wood and palm fences are the typical primary material used in the southern Mediterranean regions to fix the coastal dune, used, for example, on the northern coast in Egypt under the UNDP Climate Change Adaptation funds project entitled "Enhancing Climate Change Adaptation in the Nile Delta and North Coast" (United Nations Development Program, 2018). This wooden mitigation measure has also been implemented in Tunisia in the cities of Mahdia, Jerba, Korba, Nabeul, Sfax, Bizerte and Tabarka, among others, since 1999 and resulted in a positive progression of the sandy beaches (Agence de Protection et d'Aménagement du Littoral (APAL), 2017). The Tunisian Governmental Agency for Littoral Protection (APAL) continues to adopt wooden pillars and local materials along the entire Tunisian coast (Amrouni et al., 2002). Consequently, Darwish (2026) undermines recent scientific advances on coastal mitigation efforts in the southern Mediterranean basin.

1.8. Reply to "Proposed Simple Protection Methods"

Darwish (2026) briefly outlines protective coatings, improved concrete specifications, and enhanced durability measures for foundation elements, which can be applied to both new construction and strategic retrofits. We believe that the solutions mentioned in Darwish (2026)'s comment can be applicable to some specific cases, but cannot replace the nature-based solution suggested by Fouad et al. (2025), as these have severe environmental impacts on groundwater quality that cannot be ignored and require accurate investigations. Fouad et al. (2025)'s landscape mitigation aims to provide broader protection for entire neighborhoods with minimal environmental impact. In addition, Darwish (2026)'s comment acknowledges that his proposed engineering methods "*are primarily applicable to new construction or specific cases involving old buildings*". This clearly highlights the call in Fouad et al. (2025) to adopt landscape-scale approaches to address the tens of thousands of existing structures under hydroclimatic stressors. As such, Fouad et al. (2025) suggested that mitigation policies require both engineering upgrades for priority buildings and landscape interventions for neighborhoods to mitigate the hydroclimatic impacts on the built environment.

2. Conclusion

The recent surge in building collapses in the coastal city of Alexandria has sparked widespread interest in the role that hydroclimatic drivers play in the sustainability of urban infrastructure in the southern Mediterranean Basin (Nazarnia et al., 2020). Darwish (2026)'s comment, while appreciated, has taken multiple statements in Fouad et al. (2025) out of context. The comment claims that Fouad et al. (2025) "singles out" the cause of building collapse in Alexandria as hydroclimatic drivers, which contradicts the original investigation's findings, which define hydroclimatic drivers as accelerators within a multi-causal framework. Furthermore, the comment employs an oversimplified statistical approach to assert that the role of hydroclimatic drivers in building collapses is negligible compared to the effects of building aging and maintenance. Moreover, the comment reiterates others' already addressed drivers in the original paper without incorporating appropriate data analysis or engaging with contemporary observations or literature on Alexandria's hydrogeological context to enrich the ongoing discussion on the resilience of southern Mediterranean coastal urban areas to recent hydroclimatic changes. In contrast, the findings on the impact of hydroclimatic drivers on soil stability in Fouad et al. (2025) are entirely consistent with the results of the recent independent study by Mohamadi et al. (2020) and Thomas et al. (2025).

Finally, in October 2025, the Egyptian prime minister announced a new governmental policy designating Alexandria as a top priority for building collapse mitigation among all Egyptian cities (Almahdy, 2025; SIS, 2025). The latter contradicts Darwish (2026)'s assessment that Alexandria's vulnerability to building collapses is like that of other major cities, such as Cairo and Giza. For all these reasons, the integrated hydroclimatic-anthropogenic perspective advanced in Fouad et al. (2025) remains valid and beneficial to the scientific community and policymakers in supporting future infrastructure resilience studies in Alexandria.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Availability Statement

All data used in this reply to Darwish (2026)'s comment are openly available in Fouad et al. (2025). A copy of all the data, graphs, and statistical analyses used in the manuscript is made available in the Center for Open Science Repository (Fouad, 2025).

Acknowledgments

This research was funded by the Zumberge Research and Innovation Fund of the University of Southern California, which is allocated to the Arid Climates and Water Research Center (AWARE). Part of this work was also funded by the National Aeronautics and Space Administration (NASA) through the NASA Jet Propulsion Laboratory, under the contract (SAA#630). Graduate student Sara Fouad was partially supported for this research by the Alexander von Humboldt Foundation (ID: 1212439) at the Technical University of Munich, Germany.

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