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DISCUSSION

UNEXPECTED FLOODING IN MERSA MATRUH, EGYPT INVESTIGATING CAUSES, HYDROLOGICAL ANALYSIS AND FLOOD RISK ASSESSMENT

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Discusser

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This discussion centres on the recent and pertinent study by EZZ (2025), which delves into the flood hazards confronting Egypt, with particular emphasis on the region of Mersa Matruh. The work has been done following the flood recorded in Mersa Matruh, Egypt, in 2023, where the author offers details that allow an explanation of the unexpected flooding in this region. The discussion objective is to highlight the meteorological description of Mersa Matruh, which determines one of the main causes of flood origin in this area. In addition, great importance has been given to the geomorphological context of the watershed, which can also be one of the natural factors that intervene in determining the flood mechanism and consequently the impacted urban areas.

First, it seems necessary to present a general overview of the climate change impact on the Mediterranean basin. The unexpected floods across this large zone have increased in recent years, causing human and material damage, where climate change has visibly affected areas on both sides of the Mediterranean basin (Hafnaoui et al., 2022; Hafnaoui et al., 2023; Remini, 2023). In Spain and Greece, the intensification of these phenomena is associated with the constant increase in population and urbanization. While in Libya, floods are frequently caused due to infrastructure vulnerability. On the northern Mediterranean side, the flooding of the province of Valencia in Spain is a recent example (Lekkas et al., 2024). On the southern Mediterranean side, another example is the Derna Dam failure in Libya, which was attributed to heavy rains caused by Storm Daniel. This led to the dams reaching their full capacity, then overflowing and collapsing. In such affected areas, an aggravation of flooding in small Mediterranean watersheds occurs. For this, a rich inventory of historical and recent floods is necessary, including the temporal distribution and frequency, the seasonality of floods, periods of high flood frequency and their frequency peaks, as well as the main types of flood-related damage.

It is obvious to note, from a meteorological point of view, in the large Mediterranean area, that cyclones are associated with flooding that passes over (Lionello et al., 2019). Although annual precipitation has decreased considerably in the eastern part of the Mediterranean basin, particularly in Palestine (Hänsel et Zurba, 2015; Yaqob, 2023), Egypt (Abdelaal Ibrahim, 2014), and Lebanon (Merheb et al., 2024), significant precipitation rates are observed in coastal areas (Makké Traboulsi, 2010; Gado, 2023).

In Egypt, the surface circulation is dominated by the inflow of Atlantic water along the North African coast, as well as by the Mersa Matruh anticyclonic gyre (Said et al., 2013) to the west of the Egyptian coast and the El-Arish gyre to the east (Said et al., 2013). The Mersa Matruh gyre exhibits extreme variability between the two seasons, switching from an anticyclonic circulation (winter) to a cyclonic circulation (summer) that can split into two or three eddies at 200 meters (Said et al., 2013). The area is a coastal city where the amount of rainfall is among the highest in Egypt (Hussien, 2021), and the rainfall is concentrated in the winter season until early spring (Ighbareyeh, 2019).

The morphometric Analysis of Mersa Matruh wadi Basins using ASTER (DEM) Data and spatial information techniques is necessary to indicate the basin drainage density. The watershed delineation, well shown in Fig. 6, allows the determination of five basins with a total drainage area of about 600 km^2. It allows having an idea about the bifurcation ratio, where the author is invited to exploit the indications of the bifurcation ratio to have an idea of risk flash flooding in the five basins, noting that a higher bifurcation ratio means a greater probability of flooding. Calculation of this parameter can be used as additional information that allows the assessment of proactive measures in the flood risk management strategy and the construction of sewerage systems. In addition, it is necessary to indicate that higher stream order could be associated with a larger drainage basin. In the case of the Mersa Matruh, it is clear that basin 1, 2 and 5 are the largest drainage basins (Fig.6). Consequently, they should have the largest surface area that captures more precipitation; have a higher peak discharge and a longer lag time as confirmed in Table 4. However, small drainage basin should capture fewer precipitations; have a lower peak discharge and systematically a shorter lag time. This second case can be applicable to basins 4 and 3, which is confirmed by the calculated runoff details given in Table 4.

The rangeland dominates the centre and the northern part. While the bare land and the built area are less important. This suggests that the runoff could be easier from the South to the North, especially since the type of soil is red sandy soil that allows water retention (Hussien, 2021), and the elevation decreases from the south to the north. The runoff hydrograph of the five basins (Fig.7) indicates a logical evolution that is proportional to these basins' surface area (Fig.6).

It is worth mentioning that the spatial planning closely relates to the geomorphology, which changes in time due to the evolution of the Wadis. For this, the hydro-geomorphological diagnosis based on hydro-sedimentary dynamics, the geomorphological trajectory, and the dynamism of a watercourse over time becomes primordial for a flooding modelling study (Hachemi and Benkhaled, 2016; Cherki, 2019; Khebizi, 2024). For this, spatial planning has to be done according to the scale of the spatial analysis, depending on whether it is a watershed, a main channel, or even the wadi bed (Aroua, 2020). During the floods, the runoff causes an increase in the size and volume of the transported sediments and has a direct implication on the agglomerations. The transported sediments create either erosion forms or accumulation forms that cause changes in the geomorphology of the wadi and its course over time, and consequently have a direct impact on current or future urban extensions (Riahi et al., 2020; Chabokpour and Azamathulla, 2025). In addition, the sewerage system may be clogged due to the sandy material being transported by water, which hinders the final delivery of wastewater to the outlet. Consequently, urban areas can be flooded even if the amount of rainfall is not significant due to water drainage problems caused by the blockage of the sewer system. For this, some recommendations seem to be necessary as well:

- The hydro geomorphological diagnosis in the five basins is recommended to quantify both the quantity of water and the quantity of transported sandy material.
- SAR is recommended before and after flooding to enable the determination of the most affected zone by the flood.

Finally, I would like to thank the author for this highly objective academic investigation and encourage him to continue the research on natural flood risks. In addition to this valuable work, I believe that the multidisciplinary approach becomes necessary for establishing vulnerability maps. Developing strategies for new urban expansions has to involve new techniques, including architectural and civil engineering, that can present new urban aspects adapted to population growth while respecting the natural path of water from upstream to downstream. The future studies have to present recommendations that take into account return periods and the contribution of other disciplines of geosciences, notably geology, hydrogeology, and hydro-geomorphology that provide a basis for vulnerability maps.

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REPLY BY THE AUTHOR

I would like to express my sincere gratitude to the discusser for his interest in my article and for providing such a thoughtful and detailed analysis. The insights shared in the discussion are highly valuable and serve to further enhance the understanding of the research findings presented in my study. In response, I wish to offer the following clarifications and additional information to further enrich the discussion.

Concerning the global issue of flooding, which affects countries worldwide, with a particular emphasis on the vulnerability of arid and semi-arid regions, fortunately, numerous studies have proposed a range of effective solutions to mitigate flood risks, each tailored to specific hydrological and geographical contexts. The most prominent approaches are the construction and strategic operation of reservoirs (Mezenner al., 2022; Zegait and Pizzo, 2023; Verma et al., 2023; Mehta et al., 2023; Panchal and Suryanarayana, 2025), flood-duration-frequency modelling (Hachemi and Benkhaled, 2016; Houichi, 2017), and the quality of the prediction of heavy rains that cause flooding (Gassi and Saoudi, 2023), which serve as critical flood control structures by capturing excess runoff during peak rainfall events and gradually releasing it in a controlled manner to prevent downstream flooding. In addition to reservoirs, advanced flood management strategies, flood risk numerical simulation, and better control of the mechanisms and triggering factors (Hountondji et al., 2019; Boulghobra, 2013; Derdour et al., 2017; Benslimane et al., 2020; Do et al., 2025), have been developed, including the implementation of early warning systems, real-time flood monitoring, and the use of hydrodynamic models that simulate flood propagation in river basins.

Regional climate dynamics in the Mediterranean basin

The October 2023 flooding event in Mersa Matruh should be viewed within the broader context of a rapidly evolving Mediterranean climate system. Recent decades have shown a marked increase in the frequency and intensity of short-duration, high-intensity rainfall events across the Mediterranean basin, affecting both northern and southern coasts (Cherki, 2019). On the northern shores, such as in Spain and Greece, flood intensification is often linked to increased urbanization and population density. In contrast, southern coastal nations like Libya and Egypt face infrastructure deficiencies and limited hydrometeorological monitoring, which exacerbate the impact of extreme events.

Catastrophic incidents—such as the Valencia flood in Spain and the Derna dam failure in Libya—underscore the multifactorial nature of Mediterranean flood risks, where climatic shifts interact with geomorphic, infrastructural, and socio-technical vulnerabilities. Cyclonic systems, particularly Mediterranean cyclones, are increasingly associated with these events (Lionello et al., 2019), even as total annual precipitation trends downward in parts of the eastern Mediterranean, including Egypt.

Focus of the study: Explaining a local flooding anomaly

Against this regional backdrop, the primary objective of the Mersa Matruh study was to investigate a distinct local anomaly: a significant flood event on 5 October 2023 despite the rain gauge recording only 6.5 mm of precipitation. This is unusual considering the region has historically endured much higher rainfall events (exceeding 100 mm) without flooding.

- The research sought to explore plausible explanations for this discrepancy, including:
- Possible underrepresentation of rainfall due to gauge limitations or spatial rainfall heterogeneity;
- The absence or malfunctioning of flood protection or drainage systems;
- Elevated antecedent soil moisture and land-use changes reducing infiltration capacity.

By applying the SCS-CN method and simulating a 50-year return period storm in HEC-HMS, the study evaluated the region's hydrological response under extreme but plausible rainfall conditions. The results pointed to significant differences in basin behavior based on drainage area, slope, and land cover.

Hydrological structure: Morphometric relationships and basin behavior

The delineation of five basins, with a combined drainage area of approximately 600 km², enabled a detailed hydrological assessment of surface runoff response under extreme rainfall conditions. As shown in Fig. 1, stream ordering analysis reveals a hierarchical drainage network across the watershed, with stream orders ranging from first to fourth order channels. This spatial structure plays a crucial role in determining the rate and volume of runoff movement through each basin.

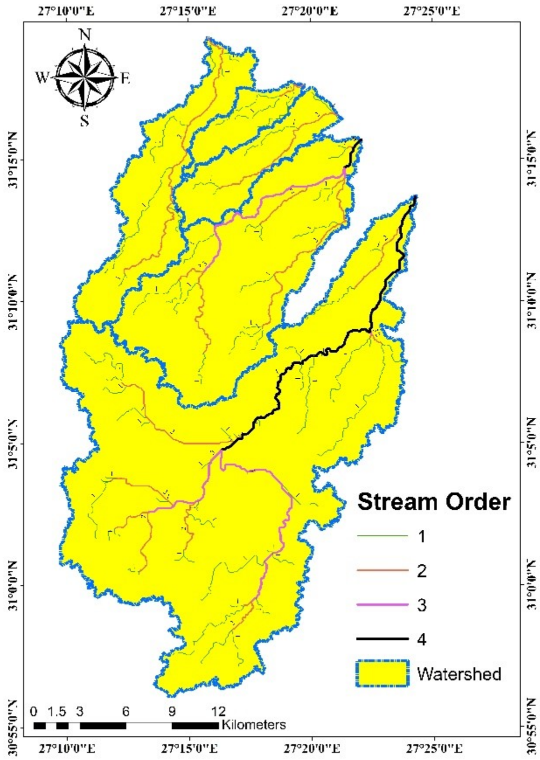

Figure 1: Stream orders for the five basins of the study area

The calculated hydrological response parameters for each basin are summarized in Table 1. The results show that the largest basins—Basin 1 and Basin 2—exhibited the highest peak runoff discharges (782.3 m³/s and 460.4 m³/s, respectively), the longest times to peak (16.5 and 14.5 hours), and the largest runoff volumes, aligning with their stream order (4) and areal extent. Conversely, smaller basins (Basins 3 and 4) responded more quickly and generated lower volumes of runoff, consistent with their lower stream orders and shorter flow paths.

Table 1: Calculated runoff details for the five basins

	Peak Runoff (m^3/s)	Time to peak (hr)	Volume (1000 m^3)	Stream Order	Bifurcation ratio
Basin – 1	782.3	16.50	22414.0	4	2.58
Basin – 2	460.4	14.50	8534.8	4	2.63
Basin – 3	139.6	13.50	1894.0	2	4
Basin – 4	103.7	13.50	1359.8	2	3
Basin – 5	206.7	14.25	3701.1	2	8

Notably, the bifurcation ratio—a key morphometric index reflecting the branching pattern of the drainage network—varies among the basins. A higher bifurcation ratio, such as the value of 8 in Basin 5, suggests greater structural complexity and a potential for faster runoff concentration, which may elevate flash flood susceptibility. While the original study focused on curve number-based hydrological modeling, incorporating stream order and bifurcation ratio analysis into future assessments would provide enhanced insight into drainage efficiency, lag times, and basin-specific flood dynamics.
These morphometric indicators offer valuable tools for prioritizing infrastructure planning, early warning system design, and basin-scale flood mitigation strategies, especially in small Mediterranean catchments where geomorphological controls dominate hydrological behavior.

Land Cover, Soil, and Runoff directionality

The hydrological response of the study area is also shaped by its physical geography. The dominance of rangeland in the central and northern zones, combined with bare soil and sparse built-up areas, supports relatively unimpeded surface runoff—particularly from the elevated southern zones toward the lower-lying north.

Soil characteristics, notably the presence of red sandy soils, contribute to variable infiltration behavior. These soils, while generally permeable, can contribute to flash flooding under saturated conditions or if surface sealing has occurred. The runoff hydrographs presented in the study (Fig. 7) demonstrate a logical progression tied closely to basin size and slope direction, confirming the geomorphic influence on flow dynamics.

The Role of hydro-geomorphological processes and sediment transport

The comment correctly highlights the critical role of hydro-geomorphological dynamics in flood modeling. Floods in semi-arid environments like Mersa Matruh often mobilize substantial sediment loads, which can alter wadi morphology and obstruct sewerage systems. The evolution of sedimentation patterns—through erosion and deposition—can influence flood extent and severity, particularly in areas of rapid urban development.

A comprehensive hydro-geomorphological diagnosis would thus provide valuable complementary data. Monitoring sediment transport and deposition would clarify how floodwater behavior evolves over time and could explain how drainage systems become overwhelmed even during low-precipitation events. This is especially pertinent in cities where unmaintained or undersized infrastructure is common.

Use of remote sensing and SAR for flood extent analysis

The integration of satellite-based tools such as Synthetic Aperture Radar (SAR) offers an effective method for pre- and post-flood analysis, particularly in data-scarce regions. SAR can delineate flood extents, track sediment-rich zones, and validate hazard zones mapped in GIS. It is also crucial for emergency response and infrastructure planning.

Future work should explore multi-temporal SAR datasets to map flood impacts in Mersa Matruh and similar small Mediterranean watersheds. The inclusion of such tools enhances spatial accuracy and improves flood risk communication with planners and decision-makers.

Multidisciplinary approaches and future research directions

Flood risk management in dynamic coastal regions cannot rely solely on hydrological modeling. A multidisciplinary framework is required—encompassing geology, hydrogeology, sedimentology, civil engineering, and urban planning. Such an approach allows the development of integrated vulnerability maps, aligning infrastructure development with natural drainage patterns and long-term geomorphological evolution.

Future research in Mersa Matruh and similar settings should include:

- Return period-specific design recommendations;
- Hydro-sedimentary and geomorphological assessments;
- Remote sensing-based validation of modeled flood extents;
- Urban planning models adapted to natural flow paths.

This integrated perspective ensures that urban expansion, water management, and hazard mitigation efforts are mutually supportive and resilient in the face of evolving climate risks.

CONCLUSION

The October 2023 flood in Mersa Matruh is emblematic of a broader hydrological transformation occurring across the Mediterranean basin—where small watersheds are increasingly prone to flash flooding driven by non-linear interactions between climate anomalies, land use, and infrastructure limitations. By focusing on a localized anomaly, the study contributes a unique case that highlights the importance of both technical hydrological modeling and contextual environmental analysis. Continued interdisciplinary research and enhanced monitoring strategies are essential to safeguarding vulnerable coastal communities against future hydrometeorological threats.

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