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Hurricane Otis Forensic Analysis Effects on Acapulco Bay: Identification of Variables Causing Damage

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Abstract: *The devastating impact of Hurricane Otis, a Category 5 storm that hit Acapulco Bay, Mexico, in October 2023, highlighted the importance of conducting in-depth forensic hydrology analysis. With sustained winds close to 265 km/h, the storm caused rapid urban flooding and landslides exacerbated by an extraordinary 190 mm of rainfall within 4 hours. This event emphasizes the critical link between water dynamics and climate change. By examining the hydrological factors behind such extreme coastal weather events, this study sheds light on the complex interaction of climatic elements like winds, tides, and precipitation. By analyzing these factors, the goal is to develop strategies to mitigate future climate change impacts on water resources. Hurricane Otis serves as a stark reminder of the urgent need to implement sustainable water management practices and resilient climate change adaptation strategies in vulnerable coastal areas.*

Keywords: *Acapulco Bay, Otis, devastation, precipitation, wind speed*

1. Introduction

The geographic position of Mexico leaves it vulnerable to the annual threat of hurricanes originating from both the Pacific and Atlantic Oceans, affecting regions including the Gulf of Mexico and the Caribbean Sea [1] (Jáuregui, 2003). Guerrero State, specifically Acapulco Bay (Figure 1), has witnessed multiple meteorological events causing damages of varying degrees (Figure 2) (Spang et al., 2003, Rojas et al., 2016, Niño-Gutiérrez, 2023, Milenio, 2023) [2,3,4,5].

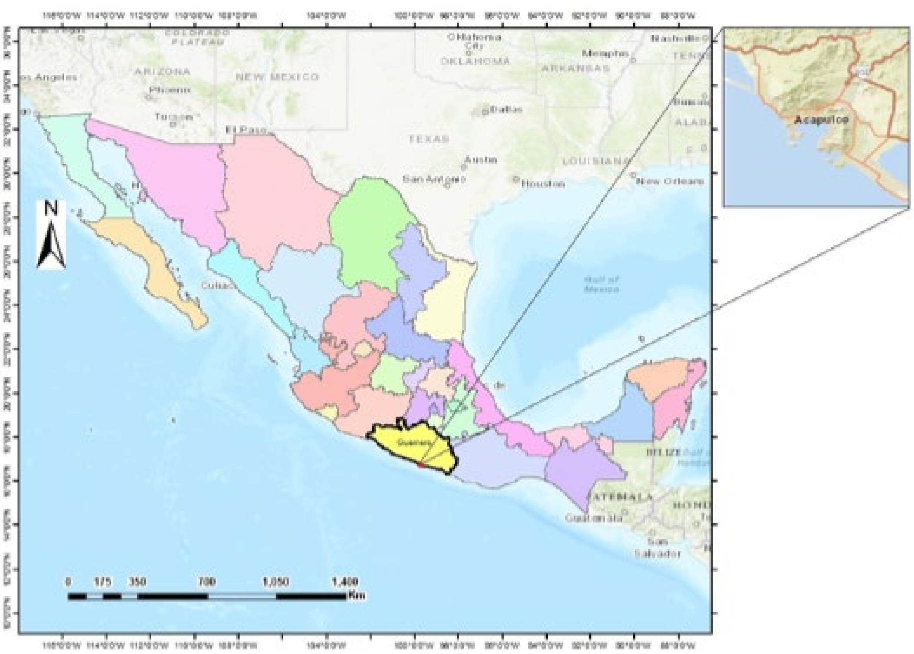


Fig. 1. Acapulco Bay, Mexico. Source: Design with ArcGis ©

On Wednesday, Oct. 25, Hurricane Otis made landfall near Acapulco, on Mexico's southern Pacific coast, at 1:25 a.m. CDT as a Category 5 hurricane with sustained winds of 165 mph (265.54 km/h). The storm had rapidly intensified off the coast, and according to the National Hurricane Center, Otis was the strongest hurricane in the Eastern Pacific to make landfall in the satellite [6,7,8] (NOAA, 2023). Otis caused human losses officially quantified at just over 100 (The Guardian, 2023) [9], but initially estimated at greater than 400, and was also characterized by numerous material losses in the hotel zone of the bay (Verisk Analytics, Inc., 2023, Wolfe et al, 2023) [10,11].

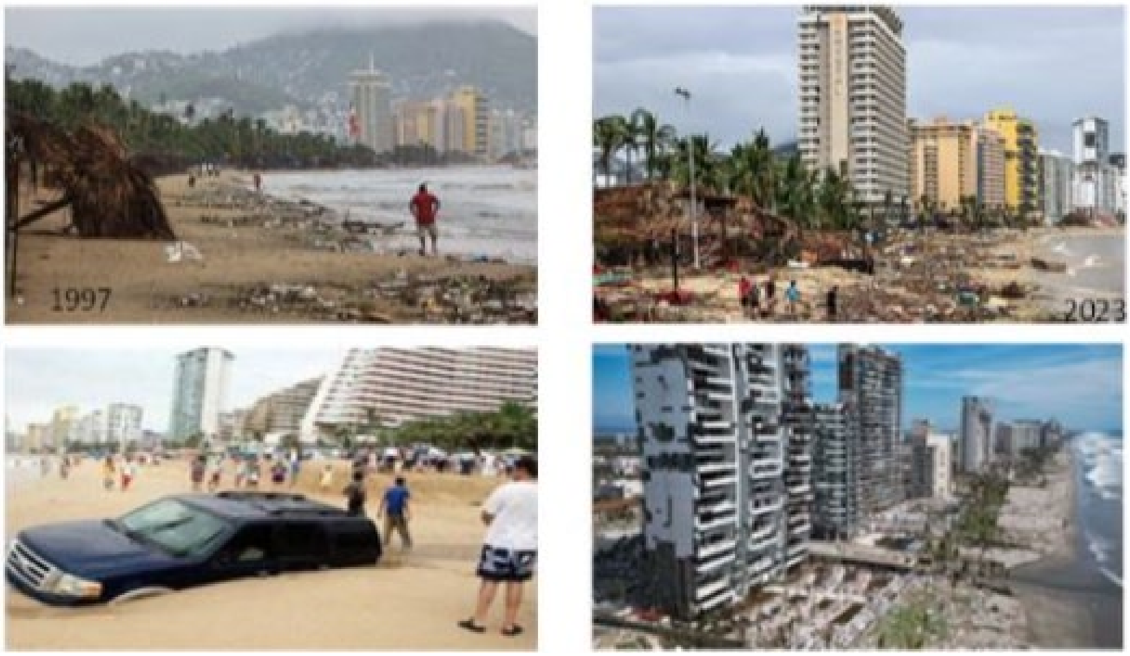


Fig. 2. Effects images for Pauline (Hurricane 1997) and Otis (Hurricane 2023). Source: Google Images©

2. Methods

The methodology applied in this study included various steps such as obtaining information on Hurricane Otis; trajectory from the National Hurricane Center [12], analyzing rainfall data from stations in Acapulco during the hurricane, calculating storm mass curves at measurement stations, estimating return periods for each storm using official isohyets, compiling data on wind speeds reached by the hurricane, tracking the evolution of tides during the event, documenting material damage estimates in dollars, compiling estimates for human losses, researching historical hurricane tracks in the Pacific Ocean near the study site, and gathering historical data on precipitation, wind speed, material damage, and human loss caused by previous hurricanes for comparison with the current event.

2.1 Results

This section delves into the historical trajectories of hurricanes and their cumulative precipitation impacting Guerrero State, Mexico, specifically focusing on Hurricane Otis. It includes a comparison of the recorded trajectories and maximum precipitation data from these hurricanes. The analysis also evaluates and contrasts the tide behavior during Hurricane Otis with the predicted astronomical tide. Furthermore, it compares the peak wind speeds experienced during different hurricanes affecting Acapulco Bay. The examination extends to the total precipitation over 24, 72, and 96 hours attributed to these hurricanes. Additionally, this section quantifies the tragic human casualties and material damages caused by various hurricanes along the Mexican Pacific Ocean. Topics related to forensic hydrology that could be included in this analysis are:
• Hydrological modeling of precipitation patterns
• Analysis of flood dynamics and inundation mapping
• Examination of sediment transport and erosion patterns

• Evaluation of water quality impacts
• Assessment of groundwater interactions
• Study of hydraulic structures and their performance in extreme events.

3. Historical hurricanes trajectory and accumulated precipitation

Figures 3 to 5 illustrate trajectories and maximum precipitation data recorded by hurricane events that occurred between 1959 and 2023, with trajectories that impacted Mexican Republic in places close to or including Acapulco Bay. Figure 5 includes track and total precipitation caused by Hurricane Otis.

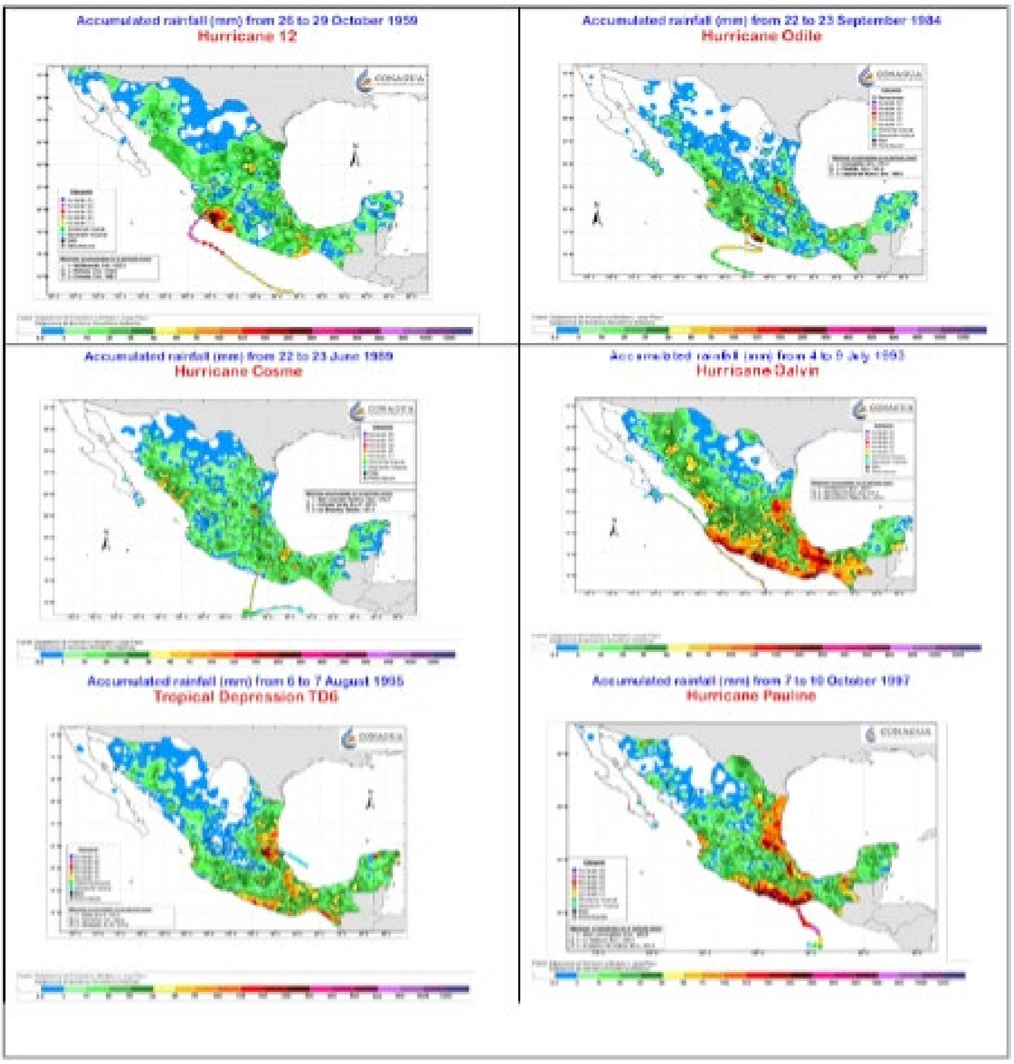


Fig. 3. Trajectory and total precipitation recorded by meteors at Pacific Ocean that have impacted Guerrero State. Cosme, Calvin, Tropical Depression DT6, Pauline. Adapted from [13] CONAGUA, 2023

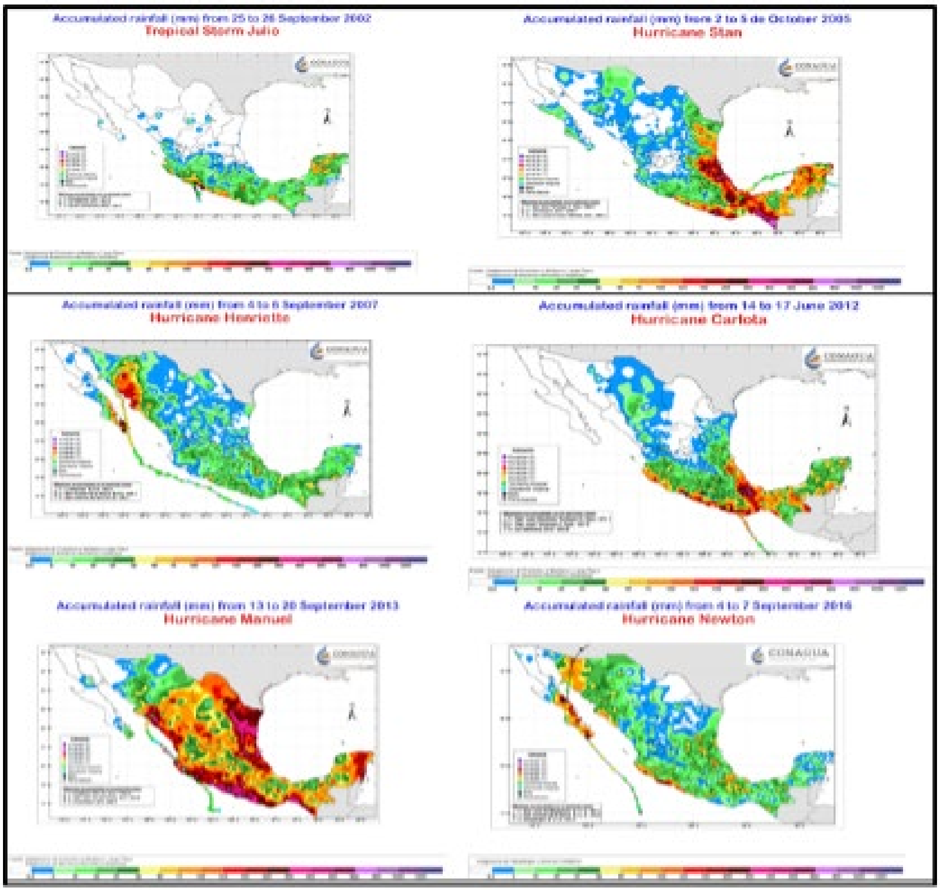


Fig. 4. Trajectory and total precipitation recorded by meteors at Pacific Ocean that have impacted Guerrero State. Tropical Storm TT Julio, Stan, Henriette, Carlota, Manuel, Newton. Adapted from [13] CONAGUA, 2023

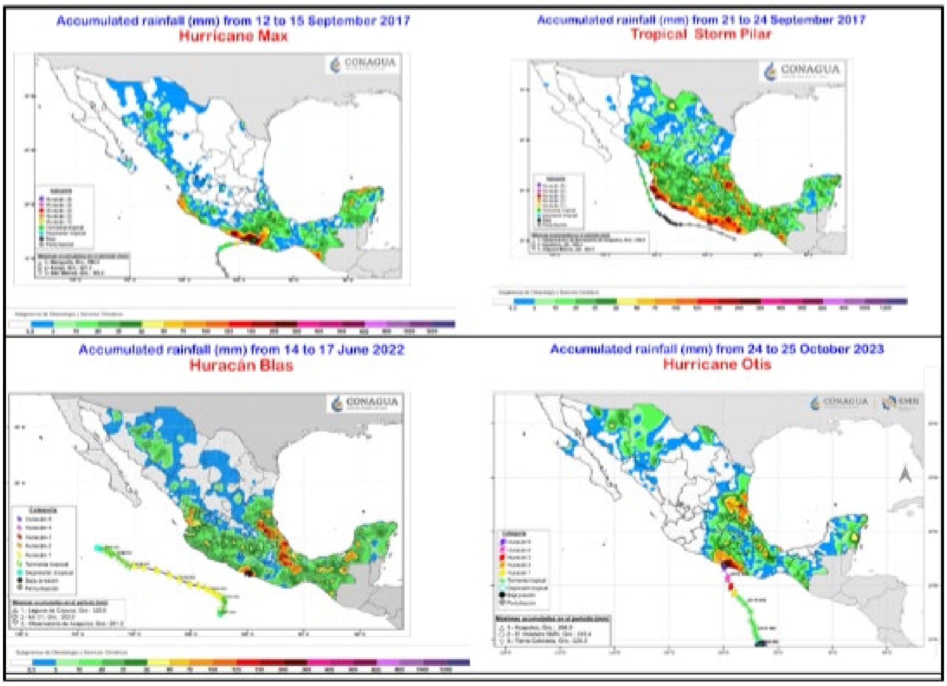
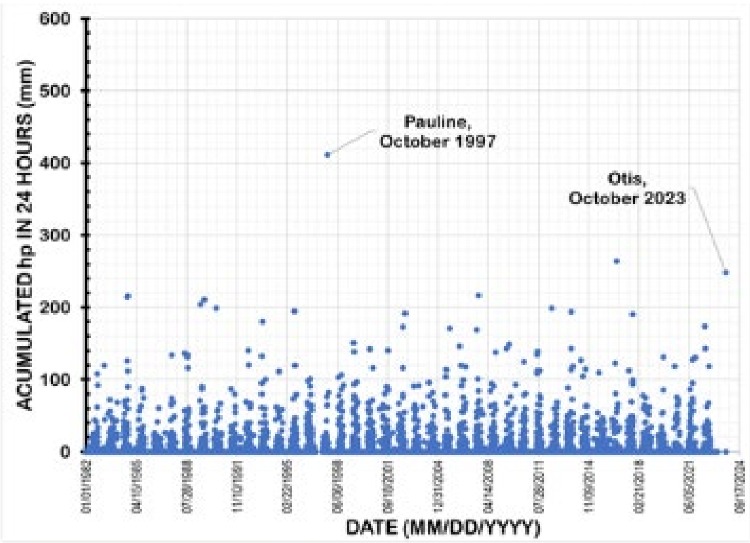


Fig. 5. Trajectory and total precipitation recorded by meteors at Pacific Ocean that have impacted Guerrero State. Max, TT Pilar, Blas, Otis. Source: Adapted from [13] CONAGUA, 2023

From Figures 3 to 5 it is observed that hurricanes Pauline (1997) and Carlota (2012) are similar at short phenomenon evolution and have certain parallelism, but Hurricane Carlota impacted Oaxaca state and more. Regarding the highest precipitation values of these three hurricanes, it is observed that Pauline recorded a total of 423 mm at Acapulco station, while with Otis total rainfall recorded in Acapulco was 266 mm, that is, it was 62% less rain with Hurricane Otis than with Hurricane Pauline in Acapulco, but this hurricane caused effects in Acapulco with category 4 and had not yet made landfall [13] (Conagua, 2023) and with a not so frontal inclination, close to 15 degrees with respect to one direction horizontal, while Otis was category 5 and its trajectory was almost 75° from the horizontal. Figure 6 shows the accumulated precipitation in 24 hours from the Acapulco observatory station; this figure illustrates that, with respect to the occurrence of Pauline and Otis, precipitation that occurred during Hurricane Otis event was close to 60% of the total precipitation associated with Pauline, despite difference in category (Otis was category 5 in relatively few hours) so it was decided to delve into wind speed magnitude to look for the cause of catastrophic damages.

Date	Rainfall (mm)	Evento
09/10/1997	411.2	Pauline
04/09/2016	264.0	Newton
25/10/2023	248.4	Otis
01/09/2007	216.8	Henriette
21/09/1984	216.0	Odile
13/09/1984	214.0	
19/09/1989	210.6	Kiko
21/06/1989	204.0	Cosme
05/07/1990	199.0	
17/06/2012	198.9	Carlota
08/08/1995	194.7	DT 6
15/09/2013	194.4	Manuel
04/11/2002	191.8	
21/09/2017	190.2	Pilar
06/07/1993	180.0	Calvin
16/06/2022	173.6	Blas
26/09/2002	173.2	Julio
06/10/2005	171.0	Stan



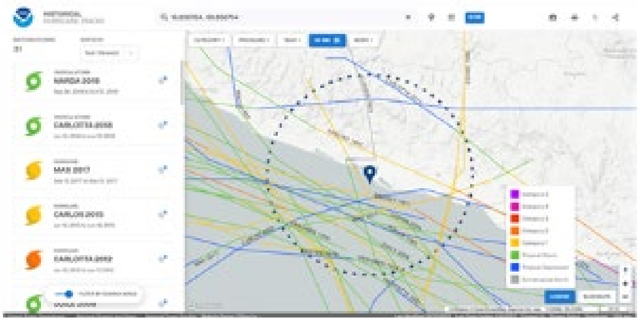


Fig. 6. Total meteor precipitation data that occurred at Mexican Pacific Ocean and reports from Acapulco observatory station in comparison with Pauline (1997) and Otis (2023) events. Source: [6,7,14,15] NOAA, 2023

Comparing isohyets prepared by former Ministry of Communications and Transportation [16] (SCT, 2022) with precipitation reports caused by Hurricane Otis, it is estimated that total rainfall from storm associated with Hurricane Otis has an approximate return period of 100 years (Figure 7).

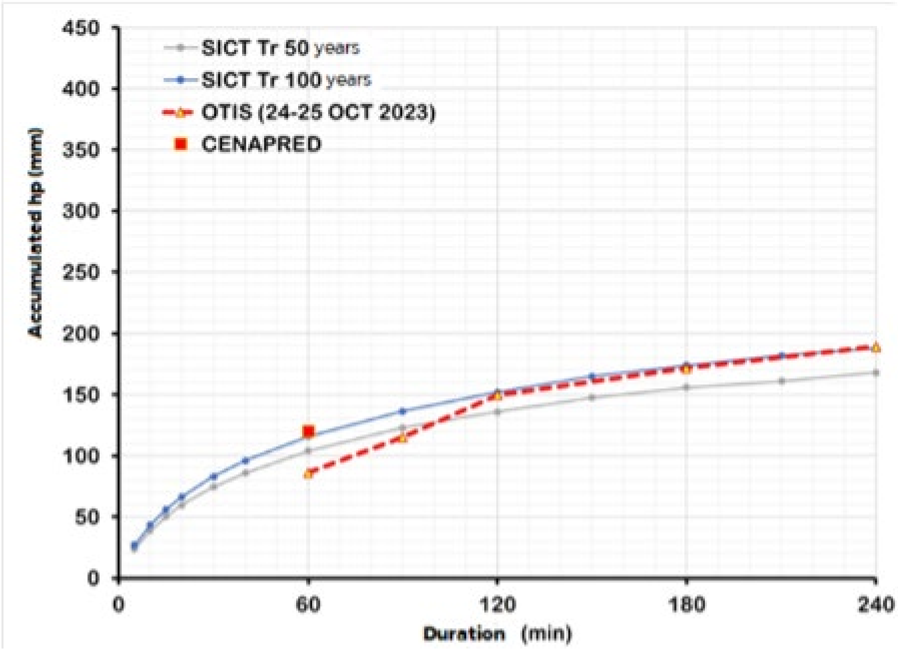


Fig. 7. Precipitation comparison with a 50 and 100 years return period from SCT vs. precipitation produced by Hurricane Otis. Source: Own design

4. Tide information analysis

Figure 8 highlights 27 stations that belong to monitoring network from National Tide Service (Servicio Mareográfico Nacional, 2023) [17], of which stations 7 Acapulco and 8 Acapulco Api report the tide behavior at Acapulco Bay, Gro. (Figure 9).

Fig. 8. National Tide Service Monitoring network. Source: Adapted from [17] Servicio Mareográfico Nacional, 2023

Fig. 9. Two tide gauge stations spatial location at Acapulco, Gro. The Yates station is located in Club de Yates and the API station at National Port System Administration (ASIPONA-Acapulco). Source: Adapted from: [17] Servicio Mareográfico Nacional, 2023

Figure 10 shows the behavior of the tide reported between October 23 and 25, 2023 in Acapulco, corresponding to the astronomical tidal forecast calculated based on the data recorded in Puerto Ángel, Oax. and in Zihuatanejo, Gro. Although the behavior of the tide does not always indicate the arrival of a hurricane, in this case in Acapulco the meteorological conditions and the predictions of the National Meteorological Service were indicators along with the tide of the event that was on its way.

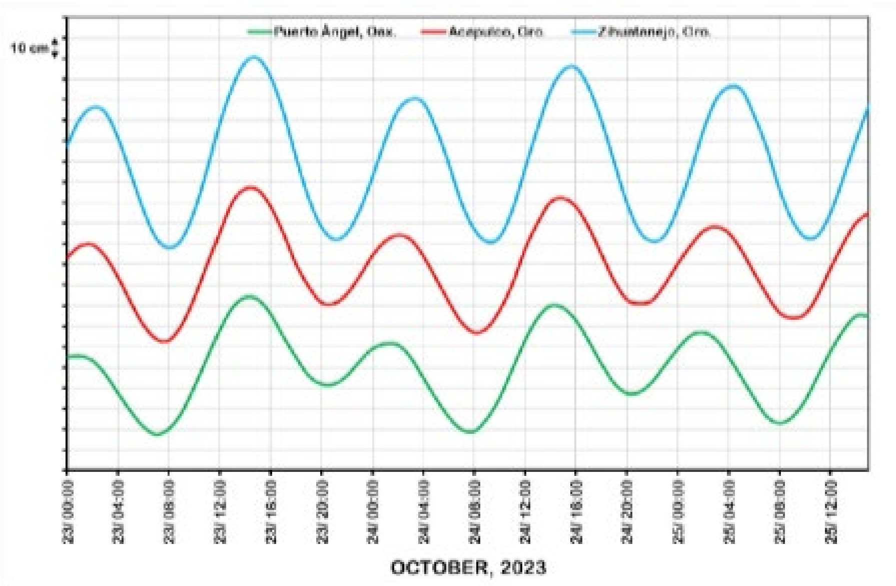


Fig. 10. Tide gauge Record stations affected by Hurricane "Otis" from October 23 to 25, 2023. On vertical axis is the height, where each box represents 10 cm, and on the horizontal axis is time in UTC. The curves correspond to astronomical tide forecast. Source: Image adapted from [17] the Servicio Mareográfico Nacional, 2023©

Figure 11 shows Wind Speed (km/h), burst Speed (peak) (km/h) and also tide forecast is included to analyze the storm surge. This figure clearly describes how tide records between October 24 and 25 were approximately reproduced by the forecast between 3 pm on October 24 until approximately 12 am (zero hours) on October 25, but subsequently the actual tide behavior reversed its concavity and magnitude, appearing contrary to forecast for almost 6 hours; in addition, the magnitude rose to values close to 2.4 m, while the forecast indicated close to 1.4 m; on the other hand, between 12 am (zero hours) and almost 1:30 am, a clear correspondence is observed between tide, wind speed and its bursts. In this case, the maximum wind speed reported by this station was 120 km/h.

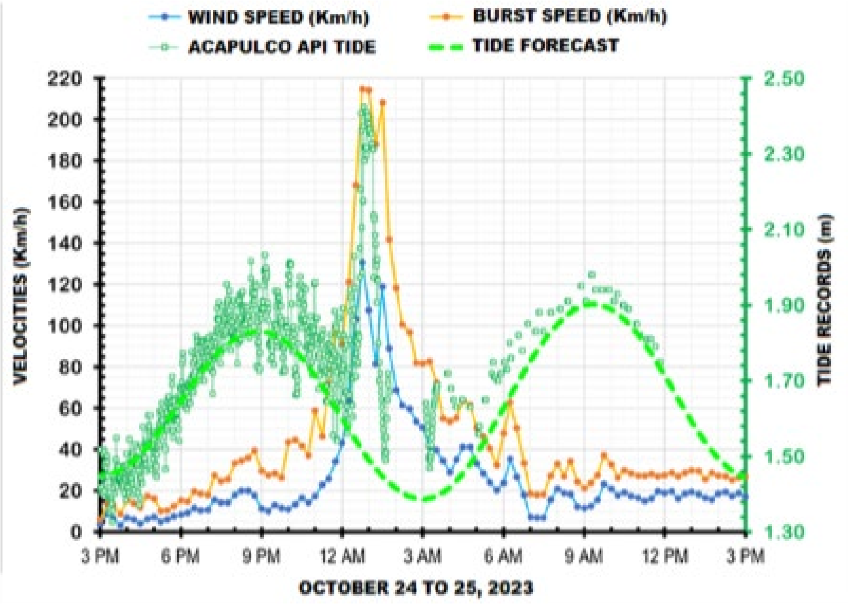


Fig. 11. Contrast between behavior Acapulco API station tide; tide forecast, wind speed and Burst in km/h. Source: Adapted from [17,18] Servicio Mareográfico Nacional, 2023

5. Different hurricane events wind speeds comparisons that have impacted at Guerrero State, Mexico

Figure 12 shows a comparison of maximum wind speeds reached by different hurricanes that have caused effects in Acapulco Bay, highlighting Otis with the highest value. From an automated meteorological station (EMA) of the National Meteorological Service [19], the maximum winds per event were calculated, and from there, the maximum recorded values were obtained.

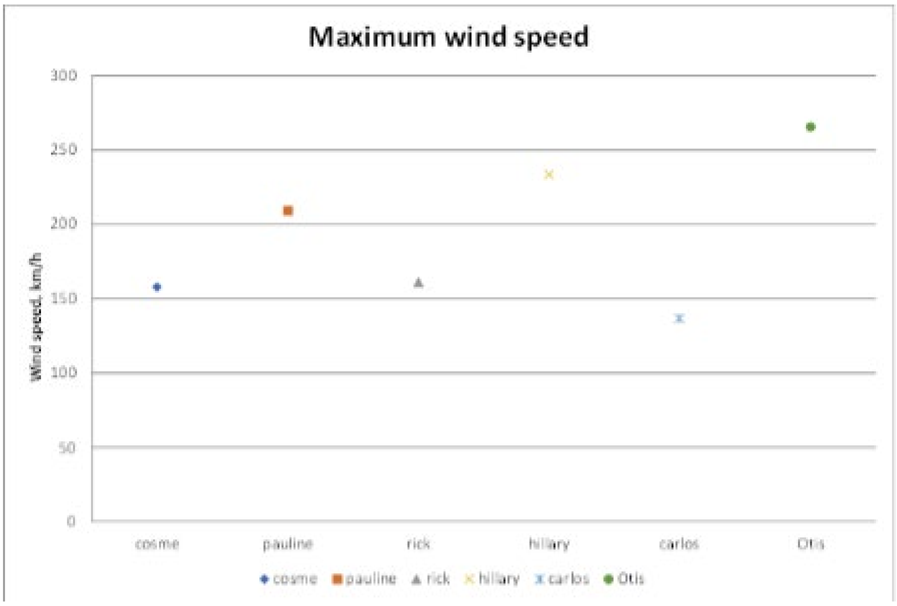


Fig. 12. Maximum wind speed reached by different historical hurricanes at Mexican Pacific Ocean. Source:

Own design from [19] SMN, 2023.

On the other hand, a comparison is made using accumulated rains [20,14,15] from zero to 96 hours due to different hurricanes and it is observed that in 24 hours Otis had magnitudes similar to Hurricane Manuel (Figure 13), that is, in a few hours a high accumulation of rain is observed but it no longer continued to increase after 48, 72 or 96 hours; in this case Hurricane Pauline was more adverse in accumulated precipitation.

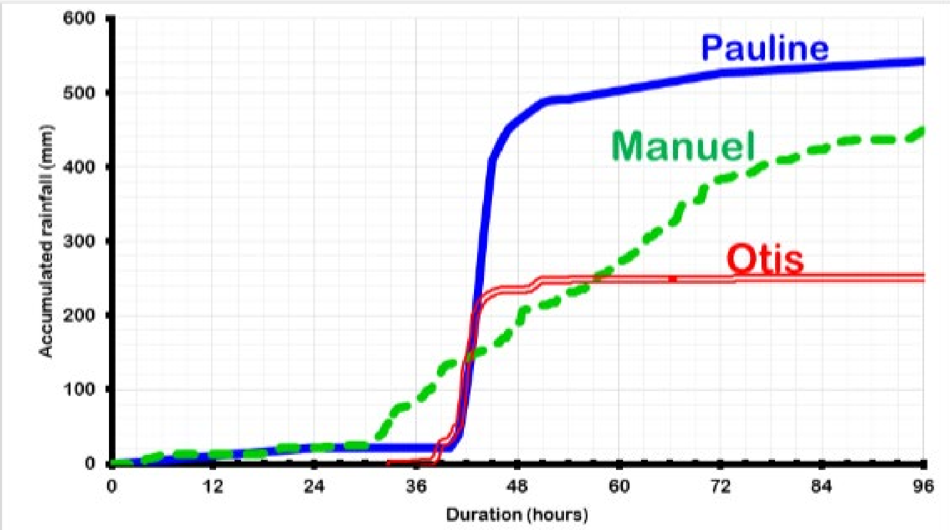


Fig. 13. Accumulated precipitation duration 96 hours for different historical hurricanes that have impacted Guerrero, Mexico vs. Hurricane Otis. Source: Own design.

Losses and material damage: The forensic hydrological relationship between loss and property damage is based on the study of how extreme hydrological events, such as floods or storms, can cause significant economic loss and property damage. By analyzing hydrological and property loss data, forensic hydrology experts can investigate how factors, such as rainfall intensity, terrain topography, and drainage infrastructure, influence the magnitude of property loss and damage caused for a specific event. This relationship is essential to understand and mitigate the impacts of natural disasters in vulnerable areas and to develop more effective risk management strategies. Table 1 summarizes approximate damages quantification and deaths caused by different hurricanes, of different categories, that have impacted the Mexican Pacific Ocean. It can be seen that lower category hurricanes, such as Pauline and Hillary, caused similar or lesser human losses compared to other storms. Pauline standing out for its total and longer duration rainfall, while Hillary apparently did not produce such high rainfall but its strong winds did (Fig. 12). In the case of Hurricane Otis, its category 5, strong winds, and high tides combination and its initial 24-hour rain, coupled with direction of its trajectory when it impacted Acapulco Bay, were factors contributing to its destructive power.

Table 1: Damage, Deaths and categories of hurricanes that have impacted the state of Guerrero, Mexico. Source: [10,15] National Climatic Data Center, 2023, National Centers for Environmental Information, 2023.

Hurricane	Date	Category	Damages (USD)	Deaths
Cosme	06/22/1989	2	-	30
Pauline	10/08/1997	4	$448 million	230-500
Rick	11/07/1997	2	-	-
Hillary	09/23/2011	3	$448 million	2
Carlos	06/14/2015	3	$1.4 million	-
Otis	10/22/2023	5	$ 16 billion	≥ 485

6. Conclusions

This paper explores the profound impact of Hurricane Otis on Acapulco Bay, shedding light on its extreme nature and the devastating toll it exacted on both property and human lives. Comparing the impacts of Hurricane Otis and Hurricane Pauline in Acapulco reveals significant differences in their effects: Hurricane Pauline, which struck Acapulco in 1997, wrought catastrophic devastation, leading to over 400 fatalities and extensive damage to infrastructure, homes, and livelihoods. The economic losses were staggering, estimated in the billions of dollars. In contrast, Hurricane Otis, hitting Acapulco in 2023, left a similarly profound impact. While the exact count of casualties and missing persons is still under assessment, property losses alone were estimated at approximately $16 billion. Otis caused widespread destruction, resulting in substantial structural damage and losses in the affected areas. Both hurricanes had severe consequences, impacting the lives and properties of Acapulco residents. While Hurricane Pauline had a higher casualty count, Hurricane Otis caused immense property damage, highlighting the region’s ongoing vulnerability to powerful storms and emphasizing the continuous need for disaster preparedness and resilience efforts.
Coastal regions, including Acapulco Bay, need to formulate urban planning and water management strategies to anticipate rising sea levels, intensified storms, and altered precipitation patterns. This involves fortifying water infrastructure, advocating for sustainable water usage practices, and increasing public awareness about conserving and appropriately managing this essential resource. In summary, this paper underscores the urgency of addressing the intersection between water dynamics and climate change, particularly in vulnerable coastal regions susceptible to extreme events. Only through a comprehensive understanding of these interactions and the implementation of suitable measures can sustainable water management be assured within the context of climate change.

Acknowledgments

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