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# Coastal vulnerability to typhoon inundation in the Bay of Bangkok, Thailand? Evidence from carbonate boulder deposits on Ko Larn island

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ABSTRACT

At the head of the Gulf of Thailand, the subsiding Chao Phraya delta and adjacent low-lying coastlines surrounding the Bay of Bangkok are at risk of coastal flooding. Although a significant marine inundation event has not been experienced in historical times, this work identifies coastal depositional evidence for high-energy waves in the past. On Ko Larn island in eastern Bay of Bangkok, numerous coastal carbonate boulders (CCBs) were discovered at elevations up to 4+ m above sea level, the largest weighing over 1.3 tonnes. For the majority of CCBs, their karstified appearance bears testimony to long periods of immobility since original deposition, whilst their geomorphic settings on coastal slopes of coarse blocky talus is helpful in recognising lifting (saltation) as the probable mode of wave transport. In the absence of local tsunamigenic potential, these CCBs are considered to be prehistoric typhoon deposits, presumably sourced from fringing coral reefs by high-energy wave action. Application of existing hydrodynamic flow transport equations reveals that 4.7 m/s and 7.1 m/s are the minimum flow velocities required to transport 50% and 100% of the measured CCBs, respectively. Such values are consistent with cyclone-impacted coastlines studied elsewhere in the tropical Asia–Pacific region. Overall, the evidence of elevated carbonate boulder deposits on Ko Larn implies that typhoons before the modern record may have entered the Bay of Bangkok. The recurrence of a similar event in future would have the potential to cause damaging marine inundation on surrounding low-lying coastlines.



## 1. Introduction

Bangkok, a sprawling mega-city of over 10 million inhabitants, and the capital and commercial centre of Thailand, occupies >1500 km$^2$ of the delta of the Chao Phraya River. The Chao Phraya drains into the Bay of Bangkok at the northern margin of the Gulf of Thailand (GoT) (Fig. 1) and the delta it and neighbouring rivers have built is the third largest in Southeast Asia with an area of 10,400 km$^2$. During recent decades, the worst floods affecting Bangkok have been river floods associated with above-average monsoonal rainfalls in the upper Chao Phraya basin in northern Thailand, as was indeed the case in 2011 (Komori et al., 2012; Ziegler et al., 2012). In contrast, Bangkok and the wider Chao Phraya delta are presumed to be at a relatively low risk of high-energy marine inundation (HEMI) because the city "is not subject to direct hits from tropical typhoons or cyclones" (World Bank, 2010: 25).

On a recent historical timescale, this "low risk" assessment appears to be substantiated by data on tropical storm tracks going back to 1951 for the western North Pacific, including the South China Sea (SCS) and the GoT, available from the RSMC[1] Tokyo (JMA, 2014) and the IBTrACS[2] archive maintained by NOAA (2014). These databases reveal that over six decades since 1951, only 7 tropical storms have tracked through the GoT (Fig. 2), generally on east to west trajectories. This path is typical for storms arriving from the SCS, normally in the months of November or December (Terry and Feng, 2010; Phantuwongraj et al., 2013). Because the Bay of Bangkok has a narrow width of approximately 100 km, wave fetch is therefore limited for storms migrating in the usual east–west

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[1] Regional Specialized Meteorological Centre.
[2] International Best Track Archive for Climate Stewardship.

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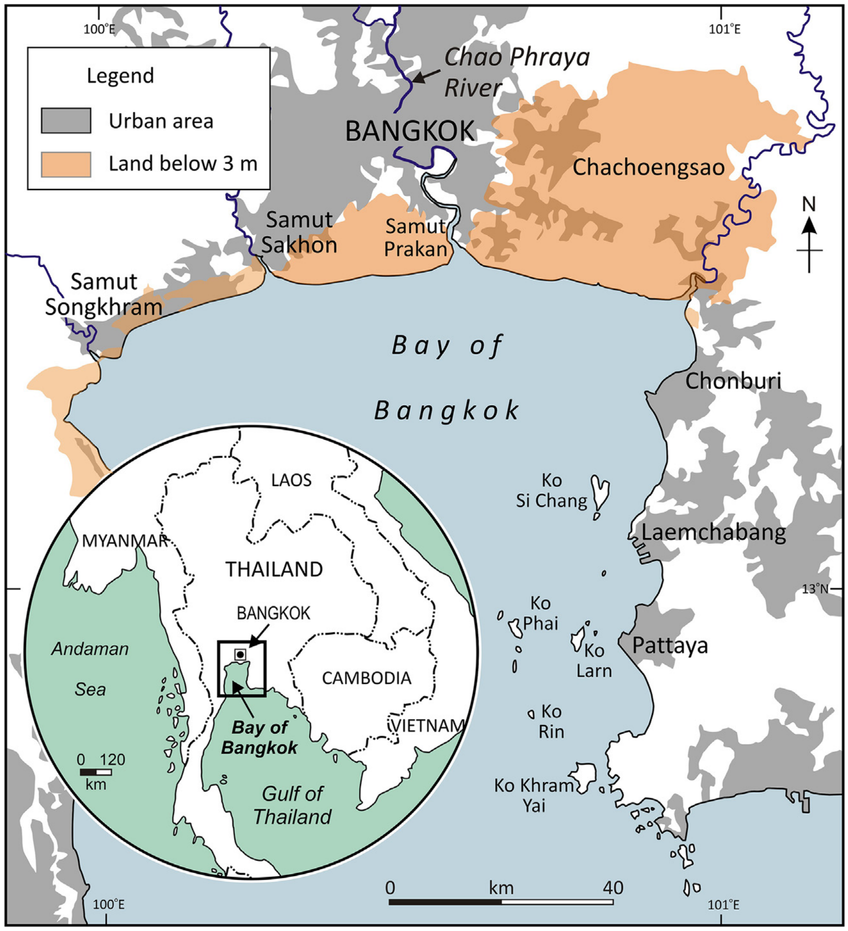


**Fig. 1.** Bangkok and other urban areas, also showing low-lying coastal areas and islands in the Bay of Bangkok.

direction. Consequently, the Chao Phraya delta has suffered no severe coastal flood events driven by storm surge over the historical period. Only Typhoon Linda in 1997, being the most severe storm to traverse the GoT in recent decades, was able to generate wave heights up to 4 m near Huahin on the western side of the upper GoT (Aschariyaphotha et al., 2006). Yet, even for this extreme event, the Bay of Bangkok remained relatively sheltered, experiencing lower wind stress and sea surface elevation than the exposed western GoT coastline (Aschariyaphotha et al., 2011; Wannawong and Ekkawatpanit, 2012). The southern provinces of Thailand have not escaped unscathed, however, with strong winds and storm surges from Typhoon Harriet in 1962 and Typhoon Gay in 1989, each causing casualties and infrastructural damage (Phantuwongraj and Choowong, 2012).

Notwithstanding the absence of a major HEMI event in recent decades in the Bay of Bangkok, the question of whether Bangkok, the wider Chao Phraya delta and other low-lying coastal cities in the Bay of Bangkok, such as Pattaya and Sri Racha (pop. >300,000 and >200,000) remain entirely safe from the possibility of storm-driven coastal flooding should not be ignored. There are several reasons why this question deserves further consideration. First, although the available archive for tropical storm tracks extends back to 1951, this is still a relatively short period upon which to assess spatial distributions, preferred tracks and associated storm surge risk for the Bay of Bangkok. Second, two tropical storms on record have tracked northwards through the GoT, instead of following the normal east–west path, indicating that atypical northwards trajectories are possible. In late October 2003, Tropical Storm 23W was unusual for forming within the GoT itself and subsequently tracked north-north-westward to intersect the Thai–Myanmar Peninsula immediately south of the Bay of Bangkok. In late November 2004, Typhoon Muifa recurved northwards along the western GoT coast before dissipating approximately 250 km south of Bangkok (Fig. 2). Neither of these two storms caused extensive damage, but they underscore the potential for more powerful systems in future to follow similar atypical paths northwards towards the Chao Phraya delta.

Third, examination of tropical storm tracks that make landfall on the Red River delta in northern Vietnam provides a useful comparison. The “Terrific Tongkin Typhoon” of October 1881 was a notable exception. This typhoon followed an uncommon northward-curving trajectory into the Gulf of Tonkin, so devastating the Red River delta and killing over 3000 people (Dechevrens, 1882; Terry et al., 2012). This example illustrates how modern track archives may not capture rare and exceptional storms for the SCS–GoT region and thus cannot serve as definitive guides on the risk of HEMI events in future. Fourth, on other major Asian deltas, past HEMI events have been responsible for some of the highest tolls in human life. In 1970 Cyclone Bhola struck East Pakistan (now Bangladesh) and India's West Bengal. Horrific flooding of the Ganges delta led to an estimated 500,000 deaths. More recently, powerful storm surge driven by Cyclone Nargis in 2008 deeply penetrated the Irrawaddy delta in Myanmar, resulting in more than 138,000 lives lost. These examples serve as tragic