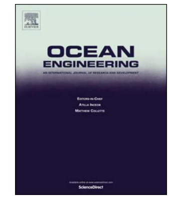
Ocean Engineering 129 (2017) 117–132

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng



# Flood frequency analysis for alterations of extreme maximum water levels in the Pearl River Delta

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A R T I C L E  I N F O

*Keywords:*
Coastal flooding
Return period
Water level
GEV model
Pearl River Delta

A B S T R A C T

Based on the annual maximum water level record spanning about 60 years at 34 gauging stations, we conduct flood frequency analysis in the Pearl River Delta (PRD) with generalized extreme value (GEV) distribution. The GEV model performs sound estimation with the correlation coefficient at most stations larger than 0.99. To better understand the flood risk especially in ungauged regions, the spatial distribution of flood-stage is displayed for three given return periods, 10-year, 20-year and 50-year. Similar pattern can be identified for different return periods except the difference in magnitude, which generally exhibits a decreasing trend from the upper region to offshore area with a scope of about 2–9 m. Additionally, a comparison between pre-1980 and post-1980 is carried out to quantify the flood-stage alteration. The results show that most stations display increasing flood risk except for some stations in the upper estuaries, which experienced slight water level decline. Particularly, the lower part of the PRD is vulnerable to the most severe flood-stage increment. The estimated extreme water level increases by 0.35 m (14.96%), 0.59 m (21.23%) and 1.06 m (29.96%) on average at stations corresponding to 10-year, 20-year and 50-year return period, respectively.

## 1. Introduction

Flooding is an inevitable natural hazard posing a high risk to many places around the world (Shiau, 2003). Especially for low-lying river deltas and coastal regions, high water of a spring tide along with possible changes in large storm surges will increase the likelihood of coastal flooding (Haigh et al., 2010; Warner and Tissot, 2012). Although it has a small probability of occurrence, such extreme events can lead to significant economic loss and casualty in the highly populated coastal regions. Globally, over 200 million people are exposed to flooding induced by extreme sea level events and the threatened population is growing considerably (Nicholls and Cazenave, 2010). Thus, coastal flooding has gained wide public attention. Three options, namely to protect, to accommodate and to retreat, are suggested by the Intergovernmental Panel of Climate Change's (IPCC) to manage the increasing coastal flood threat (Parry, 2007). In terms of protection, flood risk management projects and efficient defenses need to be designed precisely, which require sound estimations of the frequency and magnitude of extreme water level.

Approaches to estimate the extreme water level of different periods include the classic annual maxima method (Gumbel, 1958; Jenkinson, 1955), the r-largest events method (Smith, 1986; Tawn, 1988), the Monte Carlo Method, the Empirical Simulation Technique (Scheffner et al., 1996) and the joint probability method (Pugh and Vassie, 1979, 1980). When the historical observed water level data are available, the Federal Emergency Management Agency (FEMA) of the United States suggests the frequency analysis with GEV distribution (FEMA, 2004), which has been widely applied and has proved to be successful on the analysis of extreme water level (Morrison and Smith, 2002; Phien and Fang, 1989; Sobey, 2005). The Justification for applying the GEV distribution is that the GEV corresponds to the class of all possible limiting distributions for maxima and it is relatively insensitive to violations of the distributional assumption with low variability and bias (Menéndez and Woodworth, 2010). Furthermore, for the analyses of regional heterogeneity on flood frequency estimation, the GEV shows to be quite insensitive to regional variation in the coefficient

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http://dx.doi.org/10.1016/j.oceaneng.2016.11.013
Received 11 July 2016; Received in revised form 23 September 2016; Accepted 12 November 2016
Available online 23 November 2016

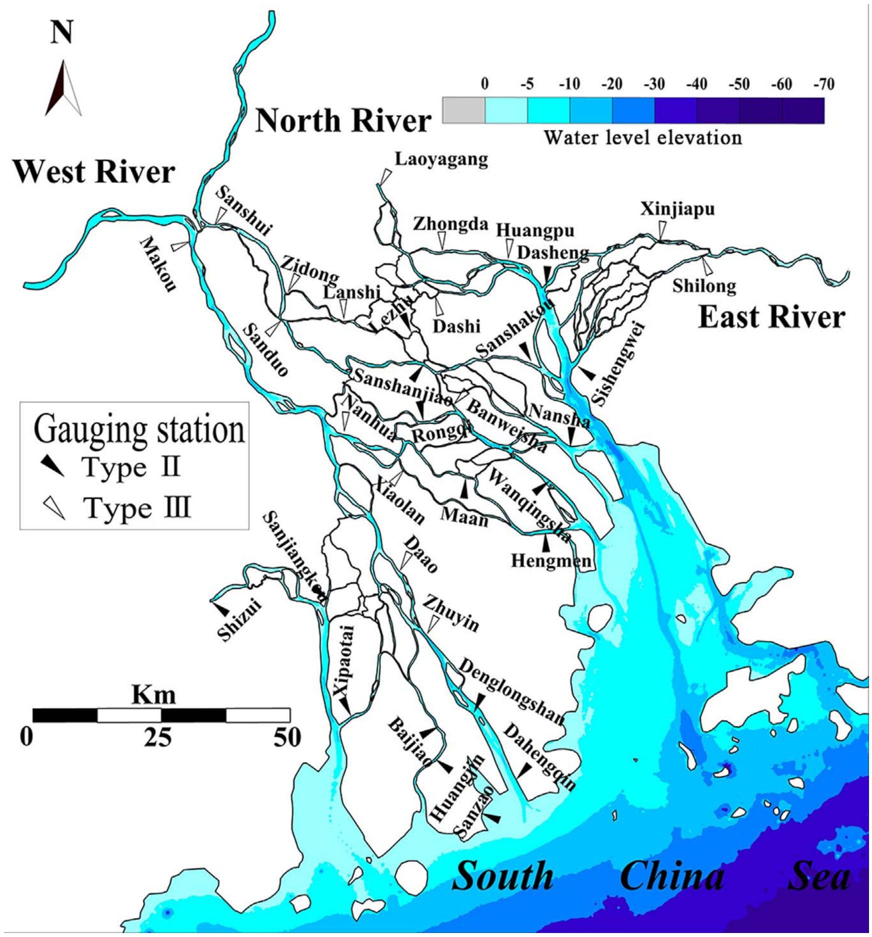


**Fig. 1.** Location of 34 gauging stations with GEV types in the PRD.

(Lettenmaier et al., 1987). Huang et al., (2008) evaluated the extreme water levels based on long-term history data at nine water-level stations. The result confirms that the GEV model can well estimate the extreme water level with return period close to 100 year in the coast of the United Stated. D'Onofrio et al., (1999) estimated the return periods of extreme levels combining with tides and surges in the Rio de la Plata Estuary in Argentina. The Gumbel distribution (GEV typeI) is found to be the best fit for the extreme surge data. For the Yangtze Estuary in China, four common distribution models were applied to estimate the 100-year extreme water level. The GEV model provides the best performances with minimum error compared to observed data (Xu and Huang, 2011).

The Pearl River Delta (PRD), one of the most complicated river networks and deltaic drainage systems in the world, is the most prosperous area in the southern China. Over the past several decades, it has experienced high socio-economy development and rapid population growth. Furthermore, the PRD is characterized by the low-lying topography, which makes the PRD prone to extreme events such as floods, storm surges and typhoons, etc. According to the historical record, the PRD suffered a great deal of flood hazards from 1993 to 1998. The 1994 flood, in particular, caused 2 billion US dollars direct losses (Liu et al., 2003). On the other hand, well-evidenced sea level rising will undoubtedly intensify the probability of extreme events in the coastal region (Cheon and Suh, 2016; Fortunato et al., 2016). The rate of global sea level rise is about 2 mm per year during the last century and has the potential to increase in the future due to the impact of global warming (DeConto and Pollard, 2016; IPCC, 2007) Therefore, it is necessary to conduct the flood frequency estimation and investigate the changing behaviors of flooding disaster in the PRD, which is of great importance for hazard prevention, mitigation and sustainable region development (Al-Futaisi and Stedinger, 1999; Singh and Strupczewski, 2002).

With more public awareness and attention on the issue of flooding disaster, frequency analysis by establishing a probability distribution and estimating parameters is widely applied on the extreme water level study in the PRD. Yang et al. (2010) presented a regional flood frequency analysis using the well-known L-moments approach. The flood-stage with a decreasing tendency from the riverine system to coastal areas was detected. Zhang et al. (2009b) provided a better understanding of extreme water level variations under the changing environment through Wakeby distribution. Many other researchers fitted the extreme water level with Pearson type III model in the PRD (Chen et al., 2001). What's more, trend analyses with change point of the extreme water level dataset were conducted in the PRD (Chen et al., 2009). Zhang et al., (2009c) detected the spatial and temporal variations of the annual maximum water level (AMWL) in the Pearl River Delta region and implied that most abrupt change points occurred in 1980s-1990s. This indicates that the extreme water level presents a changing pattern in the last several decades. However, the magnitude of extreme maximum water level changes is still uncertain. There is a great necessity to make efforts to explore the quantitative changes of flood-stage in the PRD. Therefore, the pattern of extreme maximum water level is studied by GEV distribution model based on the record of AMWL from 34 gauging stations in the PRD. The objectives of this paper are: (1) to fit the observed dataset with GEV distribution and evaluate the goodness of fit by calculating the percentage of errors; (2) to investigate the extreme maximum water level corresponding to return periods of 10 years, 20 years and 50 years