Coastal Engineering 90 (2014) 40–50

Contents lists available at ScienceDirect

Coastal Engineering

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

Human impacts on tides overwhelm the effect of sea level rise on extreme water levels in the Rhine–Meuse delta

N.E. Vellinga [a,b,*], A.J.F. Hoitink [b], M. van der Vegt [a], W. Zhang [c,b], P. Hoekstra [a]

[a] Institute for Marine and Atmospheric Research Utrecht (IMAU), Department of Physical Geography, Utrecht University, PO Box 80.115, 3508 TC Utrecht, The Netherlands
[b] Hydrology and Quantitative Water Management Group, Department of Environmental Sciences, Wageningen University, Droevendaalsesteeg 4, Wageningen, The Netherlands
[c] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing 210098, China

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 8 April 2014
Accepted 10 April 2014
Available online 16 May 2014

Keywords:
Rhine–Meuse tidal river network
Extreme water levels
Human intervention
Non-parameter test
Harmonic analysis
Tidal and subtidal water level

ABSTRACT

With the aim to link tidal and subtidal water level changes to human interventions, 70 years of water level data for the Rhine–Meuse tidal river network is analysed using a variety of statistical methods. Using a novel parameterization of probability density functions, mean high and low water levels are examined, and extreme water levels are investigated by applying the combined Mann–Kendall and Pettitt tests to find trends and trend changes. Tidal water levels are studied based on harmonic analysis. Results show that the mean water levels throughout the system rise with the same pace as the mean sea level. However, high- and low water levels do not show the same increase, and the spatial variability in decadal trends in high- and low water levels is high. High water and low water extremes generally decrease. Both the extreme water level analysis and the harmonic analysis display significant trend breaks in 1970, 1981 and 1997. These breaks can be attributed to the closure of the Haringvliet estuary, the removal of sluices and the removal of a dam, respectively, which radically alter the tidal motion. These results demonstrate that the direct human influence on the tidal motion can overwhelm the effect of mean sea level rise on water level extremes.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Deltas with estuaries are among the most fertile and densely populated areas of the world (Syvitski and Saito, 2007). The combined effects of variable river discharge and tidal forcing, generating non-linear interactions, render channel networks in deltas with highly dynamic and complex environments (Buschman et al., 2009, 2010, 2013; Sassi et al., 2011a, 2012; Valle-Levinson, 2010). Today, many deltas face threats from changing boundary conditions. Among those, sea level rise and land subsidence have received ample attention both in academic research and in the media (Barker, 2007; Syvitski et al., 2009). Flood vulnerability relates to peak surface levels rather than to the mean surface level relative to the delta. Here we show that peak surface levels, in turn, may not be linearly related to mean surface levels, and are strongly dependent on the tidal motion.

Variation of the tidal elevation amplitudes in a delta can be caused by changes in conditions at the landward and the seaward boundaries of the delta, but more often, human activity including dredging, sand extraction, dam construction and confinement or widening of channels play a dominant role. The effect of engineering works on water levels ranges from basin-wide effects from large-scale interventions and dredging (e.g. Chen et al., 2010; Deltacommissie, 1961), to local changes from smaller-scale measures (e.g. Rijkswaterstaat, 1992). Since most engineering works are constructed over the timespan of several years, the effects on water levels and tides can be seen as an abrupt change in the system, whereas the effects of sea level rise or land subsidence are gradual. Partially due to a lack of data, not much is known about the short-term and local influences of engineering works on water levels in tidal river networks. So far, studies have mainly focused on long-term trends and changes caused by human-induced climate change, or long-term dredging (Abghari et al., 2013; Syvitski and Saito, 2007; Zhang et al., 2010b).

The objective of this paper is to quantify and understand the spatio-temporal variability in tidal and subtidal water levels in a delta channel network in response to engineering works, relative to sea level rise. The Rhine–Meuse tidal river network in the Netherlands is chosen as a subject of study, where up to 70 years of historical surface water levels is available at 13 measurement stations. It represents an area subject to both sea level rise, tidal intrusion and a large number of engineering works, including channel deepening, dam construction and the creation of shortcut canals. Existing hydraulic studies in this region mainly focus on the morphological consequences of large-scale engineering works (Dastgheib et al., 2008; Eelkema et al., 2012; Elias et al., 2003; Tinbergen, 1961). Recent estimates of future flood risks consider sea

---

* Corresponding author at: Institute for Marine and Atmospheric Research Utrecht (IMAU), department of Physical Geography, Utrecht University, PO Box 80.115, 3508 TC Utrecht, The Netherlands. Tel.: +31 30 253 3864.
E-mail addresses: n.e.vellinga@uu.nl (N.E. Vellinga), ton.hoitink@wur.nl (A.J.F. Hoitink), m.vandervegt@uu.nl (M. van der Vegt), zhangweihhu@gmail.com (W. Zhang), p.hoekstra@uu.nl (P. Hoekstra).

http://dx.doi.org/10.1016/j.coastaleng.2014.04.005
0378-3839/© 2014 Elsevier B.V. All rights reserved.

level rise to be an important factor increasing high water levels (Deltacommissie, 2008), without demonstrating the direct influence of sea level rise on high and low water levels. Here, we show that the effect of sea level rise over the past 70 years on high and low water levels is overwhelmed by human-induced changes in tidal amplitudes.

2. Regional setting

2.1. Geomorphological setting

In the south-western part of the Netherlands, the rivers Rhine and Meuse combine into an extensive channel network, which is subject to tidal influence. The channel network flows through thick layers of Holocene fluvial and marine deposits and peat (Berendsen and Stouthamer, 2000). It has been subject to a long history of human influences, which started during the Middle ages with the building of dikes and the development of polders. River and floodplain morphology has significantly changed due to these early anthropogenic interventions. To guarantee navigation depths, increasingly large measures were taken changing the planforms, depths and widths of the river channels. This process was accelerated by rapid advances in marine technology from 1850 onwards, yielding steam-engine dredging boats and building equipment (Hesselink et al., 2003; Ploeger, 1992; van de Ven, 1976).

2.2. Historical overview of engineering works

Since 1850, three major works were realized in the area: the construction of the New Waterway in 1872, relocation of the lower Meuse to avoid confluence with the Rhine branch Merwede in 1904, and closure of the Haringvliet estuary in 1970. The New Waterway, today's most important discharge outlet for the Rhine and Meuse, was created between 1865 and 1872 (Fig. 1a). The major aim of digging this new outlet to the sea was to improve the accessibility of the Rotterdam harbours for seafaring ships, since the old channel was silting up (Rijkswaterstaat, 1858). During the 19th century, confluence of the Rhine and Meuse river discharges occurred in the Boven Merwede channel, a branch of the Rhine river. In the early 19th century, plans existed to deflect the Meuse discharge to the south (Blanken, 1819). In 1904, the Meuse was dammed at its northern confluence with the Boven Merwede, and since then the Meuse discharges into the Hollandsch Diep estuary via the newly constructed Bergsche Maas and Amer. The Nieuwe Merwede was created to direct the majority of Rhine discharge towards the Hollandsch Diep. Via the Hollandsch Diep, the combined Rhine and Meuse discharge reached the sea via the Haringvliet estuary (Fig. 1b).

In 1969 and 1970 the seaward boundaries of the southern estuaries Haringvliet and Hollandsch Diep were closed off by dams (Fig. 1c). This closure was part of a nation-wide flood protection program referred to as the Deltaworks (Deltacommissie, 1961). Another goal of closing the Hollandsch Diep and Haringvliet estuaries was to prevent siltation of the New Waterway, to guarantee the accessibility of the Rotterdam harbours. The Rhine and Meuse jointly discharge up to 1500 m^3/s through the New Waterway; excess discharge is ventilated to sea through the Haringvliet sluices. After closure of the Haringvliet a large freshwater basin developed, receiving tidal energy from several small channels (Fig. 1). Apart from the three major interferences mentioned above, many smaller engineering works were conducted in the river channel network. These include extensive dredging for depth maintenance and sand mining, relocation or fixation of river banks, building harbours or straightening river bends (Rijkswaterstaat, 2000). In the Hartel Canal, sluices were removed in 1980 and a dam was breached in 1997 to improve harbour accessibility (De Goederen and Fioole, 2003).

2.3. Response of the physical system

The hydrodynamic and morphologic consequences of the construction of the New Waterway and the closure of the Haringvliet have been monitored closely (Haring, 1978). From 1870 to 1970, the discharge gradually shifted from the Haringvliet to the New Waterway, as a result of the widening and deepening of the New Waterway (Haring, 1970, 1977). In 1970, the closing of the Haringvliet caused a sudden increase in discharge through the New Waterway, because of the diminished discharge through the Haringvliet (Fig. 2). Besides the variations in the discharge regime, large changes in tidal amplitude (schematically obtained as the difference between high and low water levels) were recorded from 1870 through 1970. An increase in tidal amplitudes occurred in both the northern and the inland channels, in response to the deepening of the New Waterway. This was followed by a sudden decrease in tidal amplitudes in 1970 in the southern and inland parts of the system, due to the conversion of the Haringvliet and Hollandsch Diep estuary into freshwater basins (Deltacommissie, 1961; Haring, 1978; Rijkswaterstaat, 1961).

The morphological adaptation to the drastically changed hydrodynamics since 1970 has been documented in four sediment budget overviews (Allersma, 1988; Haring, 1978; Snippen et al., 2005; van Dreumel, 1995). In general, erosion took place in the small connecting channels Spui and Dordtsche Kil, while deposition dominated in the Haringvliet and Hollandsch Diep. In a large part of the study area, morphological change is dominated by dredging activities (Fig. 3). Today, river discharge enters the network via three branches: the two Rhine branches Lek (which has a yearly average discharge of 390 m^3/s) and Boven Merwede (1500 m^3/s) and the Meuse (260 m^3/s), which is illustrated in Fig. 2 (Allersma, 1988; Haring, 1977). The network has two seaward boundaries: the New Waterway in the north, which is open to sea with a mean tidal range of 1.9 m and the Haringvliet basin in the south, which is closed at the seaward boundaries and discharges only excess river water through a parallel series of sluices in the Haringvliet dam.

3. Methods and materials

3.1. Data availability and approach

In the Netherlands, monitoring of water levels on a daily basis started in the 18th century. The oldest measurement stations along the Rhine are located upstream. The first continuous water level measurements in the tidal channel network date back to the 1930s and 1940s. Only in 1944—1946, around the end of the Second World War, three stations show data gaps up to 18 months. Apart from these major data gaps, no values are missing. Before 1970, water levels were measured visually once every 3 h at six different stations. From 1970 to 1987, hourly measurements were taken using pressure sensors at thirteen stations. All these data have recently been digitized. Since 1987, water levels are being measured fully automatically with 10-min intervals. The data is obtained from Rijkswaterstaat, the executive arm of the Dutch Ministry of Infrastructure and the Environment, and summarized in Table 1. The locations of the measurement stations are depicted in Fig. 1. An example of the water level measurements, showing the semidiurnal tidal variation at two different stations in the network, is given in Fig. 4.

The water level data are analysed as follows. First, a general data description is obtained using probability density functions, to gain insight in mean water levels and the most frequently occurring high and low water levels. The method of Zhang et al. (2009) was adopted, using the combined Mann–Kendall and Pettitt tests to detect trends and significant change-points, representing trend breaks in time-series of extreme water levels. Zhang et al. (2009) explain that the advantage of the Mann–Kendall test is that it is distribution-free and does not assume a special form for the distribution function of the data (Yue and Wang, 2002). The Pettitt (1979) test is a generic, widely applied method to

Download English Version:

https://daneshyari.com/en/article/1720718

Download Persian Version:

https://daneshyari.com/article/1720718

Daneshyari.com