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Risk assessment and driving factors for artificial topography on element heterogeneity: Case study at Jiangsu, China ☆

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ABSTRACT

The rapid expansion of construction related to coastal development evokes great concern about environmental risks. Recent attention has been focused mainly on factors related to the effects of waterlogging, but there is urgent need to address the potential hazard caused by artificial topography: derived changes in the elemental composition of the sediments. To reveal possible mechanisms and to assess the environmental risks of artificial topography on transition of elemental composition in the sediment at adjoining zones, a nest-random effects-combined investigation was carried out around a semi-open seawall. The results implied great changes induced by artificial topography. Not only did artificial topography alter the sediment elemental composition at sites under the effect of artificial topography, but also caused a coupling pattern transition of elements S and Cd. The biogeochemical processes associated with S were also important, as suggested by cluster analysis. The geo-accumulation index shows that artificial topography triggered the accumulation of C, N, S, Cu, Fe, Mn, Zn, Ni, Cr, Pb, As and Cd, and increased the pollution risk of C, N, S, Cu, As and Cd. Enrichment factors reveal that artificial topography is a new type of human-activity-derived Cu contamination. The heavy metal Cu was notably promoted on both the geo-accumulation index and the enrichment factor under the influence of artificial topography. Further analysis showed that the Cu content in the sediment could be fitted using equations for Al and organic carbon, which represented clay mineral sedimentation and organic matter accumulation, respectively. Copper could be a reliable indicator of environmental degradation caused by artificial topography.

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1. Introduction

Even though coastal zones are narrow in the area, they are critical for human beings given the large and steadily increasing human populations, as well as the scale of related economic and social benefits. In this context, coastal reclamation means obtaining dry land from the intertidal zones by creating artificially engineered defences for protection from ocean water intrusion. This provides an acceptable choice for people with an urgent need for land. Large population densities and accelerated urban expansion, combined with the inherent stress by tides are increasingly threatening this zone. Reclamation projects have raised many concerns. In most cases, the tide-derived influence on the land is blocked by such defences and results in many environmental consequences such as reduction of marine input (Yang et al., 2017, 2016; Cui et al., 2012), disorder of hydrodynamics (Kuang et al., 2013) and loss of habitat for endangered species (Ma et al., 2014) triggered by the construction of the seawall. Moreover, the sediments in the reclamation zones also suffer impacts from agriculture (Cui et al., 2012; Ding et al., 2017), aquaculture (Hung et al., 2013), industry (Peng et al., 2013) and even harbour utilization.

However, the increasing human-population density and stress of economic growth presents policy-makers with a significant dilemma. Some local governments even ignore the ecological and

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environmental risks to gain more land and the benefits from reclamation (Ma et al., 2014). Behind this facade, the ecological value of wetland might be underestimated and the potential environmental risks of reclamation are ignored (Woo and Takekawa, 2012; Adam, 2002). One among these risks is the artificial topography (AT) created by reclamation. While there are some recent studies on the structures built by reclamation projects, most of them relate to blocking of seawater inundation. Recently however, studies of matter transportation around AT sites show that the existence of AT enhances sedimentation (Wang et al., 2012), calling for further risk assessment of the sediment element composition.

Pollution indices, such as the geo-accumulation index (Salmanighabeshi et al., 2015; Varol, 2011; Christophoridis et al., 2009) and enrichment factor (Bing et al., 2016; Audry et al., 2004; Lu et al., 2009), are widely used in the risk assessment of pollution. On most occasions, the geo-accumulation index and enrichment factor were used to estimate the severity of trace metal contamination, especially the consequences of artificial emissions. In the present study, we found the concentration of plant residue was also remarkable, so analyses of biogenic elements including C, N, S and P were also undertaken for risk assessment. Moreover, it is less rigorous to disregard the disturbance cause by seasonal variation in the assessment of environmental pollution risk, because the elemental composition is affected by complicated factors with prominent seasonal regimes (Weng and Wang, 2014). These include uptake by plants (Bai et al., 2014; Carey and Fulweiler, 2014), relative dominance between allochthonous and autochthonous inputs (Stribling and Cornwell, 2001), extreme weather events (Rodriguez-Iruretagoiena et al., 2016), transition of microflora (Yazdani Foshtomi et al., 2015; Zhu et al., 2013; Islam et al., 2004) and interaction between elements (Lin et al., 2010; Gubelit et al., 2016). Apart from seasonal dynamics, in practice, site choices are also of concern and are ill-chosen in some situations. Linear mixed models have potential for providing more robust estimation of the consequences of certain environmental decisions or artificial discharges by treating the site choice and seasonal dynamics as random effects. However, no practical applications have been published so far.

The objectives of this study were: (i) to reveal the possible mechanisms driving sediment element heterogeneity caused by AT, (ii) to assess the environmental risks of AT via comprehensive consideration of both biogenic and trace elements, and (iii) to identify the most appropriate element for tracking the influence from AT.

2. Materials and methods

2.1. Study area

The investigation was carried out in Rudong, a typical coastal county in the east of Jiangsu Province, China (Fig. 1). The total area of beach in Rudong is 693 km^2, and the annual mean air temperature there is 15 °C. The tide in Rudong is regular and semi-diurnal, with a mean range of 4.61 m (ME, 1986). The coastal zone of Rudong is critical for both ecological and social reasons. As part of the huge tidal flat in the north of Jiangsu, the salt-marsh in Rudong provides important habitat for birds using the East Asian Australasian flyway (Ma et al., 2014). As for the aquatic environment, the coastal zone at Rudong was confirmed as the origin of the great green tides caused by the *Ulva* macro-algal blooms in the North Yellow Sea from 2007 to 2013 (Huo et al., 2013).

Given a coastline length of 106 km in Rudong, reclamation is always a competitive choice for land acquisition. The history of reclamation in Rudong can be dated back to AD 1027, when the Fangong Seawall was built as a cross-county renovation of the Hanhai Seawall. In its infancy, reclamation was mostly for the purpose of managing seawater intrusion, but later was followed by economic developments such as the salt industry or land expansion. In fact, half of the landmass of Rudong is from reclamation. Accompanying the reclamation project, the average elevation of tidal flats reclaimed has decreased at an increasing rate since the 1990s (Zhao et al., 2015). However, there are still fifteen reclamation projects with a total region of 230 km^2 in Rudong today (Li et al., 2015). The seawall was built in 2010; then was shelved soon after construction. A long-period passed before this investigation, and the direct impact of the construction process on the elemental loading in the superficial sediment might be reduced. Unlike a common seawall, this one was semi-open, meaning that the influence of tidal flooding was not completely blocked.

2.2. Site setting and sample collection

Ten sites were set in this study and sorted into four groups (Fig. 1). Three sites in the control (CL) group were located in the middle and high marsh with *S. alterniflora*. Two element accumulation (EA) sites were set around the seawall to estimate the effects of AT, with one site (EA1) seaward and the other site (EA2) landward. Tidal impact is also a critical factor in the spatial pattern of the sediment element composition; so three direct wave exposure (WE) sites were set at the margin of the *S. alterniflora* marsh to compare the effects between the AT and the well-established natural influence of tides. Near the semi-open seawall two sites were set where there was no vegetation (NV) colonization occurring to reveal the roles of vegetation in the element transport.

Samples were collected during low tide in April, July and November of 2013. At each site, replicate samples were collected within three quadrats, which were randomly selected and spaced > 10 m apart because the area of the NV sites was too small for larger spacing. The composite sampling method was used in the investigation (Carter and Gregorich, 2006). Five subsamples, including four at the corners and one at the center of each quadrat, were collected and mixed homogeneously in the field. Then the samples were stored at −4 °C before analysis. The outlines of the physiochemical parameters of the collected sediments, including texture, carbonate content, pH and identification of mineral phases were shown in Table A.1 & A.2.

2.3. Assay for element contents in the sediment

The samples were freeze-dried then ground and passed through a 100-mesh sieve before analysis. All chemicals used in the digestion were of analytical reagent grade and all solutions were prepared using distilled deionized water from a Millipore water purification system (Barnstead, USA). Certified reference material (GSD-12) was used for the assessment of validity between batches.

Total carbon (C), total nitrogen (N) and total sulphur (S) were measured using an Element Analyser Vario EL (Elementar Analysesysteme GmbH, Hanau, Germany) under CHNS mode. Organic carbon (org-C) content was measured using the elemental analyser after removal of carbonate by 1 M HCl (Cheng et al., 2006). The total phosphorus (P) content in the sediment was measured using the molybdate blue colorimetric method after digestion with a H_2SO_4-$HClO_4$ mixture (Gunduz et al., 2011).

For analysis of the total amount of heavy metals in sediments, about 0.1 g samples were carefully weighted into pure Teflon (PTFE) digestion vessels, then closed-vessel high pressure digestion was proceed by adding 5 mL HNO_3, 2 mL $HClO_4$ and 1 mL HF sequentially. The PTFE vessels were well closed and placed into stainless steel digestion bombs during the digestion. The temperature for digestion is at 80 °C for the first 2 h and then at 140 °C for another

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