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Ecological risk assessment of the Assaluyeh and Bassatin estuaries (northern Persian Gulf) using sediment quality indices

Hamid Davoodi [a, b], Mohammadreza Gharibreza [b, *], Hossein Negarestan [a], Mohammad Sedigh Mortazavi [c], Razieh Lak [d]

[a] Iranian Fisheries Science Research Institute, P.O.Box:13445-1136, Tehran, Iran
[b] Soil Conservation and Watershed Management Research Institute, Agricultural Research, Education and Extension Organization (AREEO), P.O.Box:13445-1136, Tehran, Iran
[c] Persian Gulf and Oman Sea Ecological Research Institute, P. O. Box:70145-1597, Bandar Abbas, Iran
[d] Research Institute for Earth Sciences, Geological Survey of Iran, P.O.Box:13185-1494, Tehran, Iran

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The Assaluyeh and Bassatin estuaries are located in Nayband Bay in the northern Persian Gulf, which faces long-term contamination and ecological risks. The research objectives of this study were designed to assess the ecological risks for human health and aquatic life and to evaluate impacts on environmental changes. Accordingly, an index analysis approach (using the contamination factor C_f, contamination degree C_d, potential ecological risk factor for individual metals E_r, and potential ecological risk index for the basin, RI) in conjunction with the enrichment factor (E_f) and sediment quality levels (comprised of the threshold effect level, TEL, the probable effect level, PEL, and the effects range medium, ERM) were employed. In total, 147 sediment samples were tested to determine the content of organic matter and sulfur, as well as the concentrations of terrestrial and rare earth elements (REEs) and toxic metals, namely As, Cd, Cr, Cu, Ni and Hg, using inductively coupled plasma optical emission spectroscopy (ICP-OES). Gulf War oil spills in addition to oil and gas industries of the Pars South Especial Economic Zone (PSEEZ) were identified as the primary source of pollution in the study area. Gulf War contamination in the study area is highlighted by increased levels of C_d and RI at key horizons at 29 cm, 35 cm and 49 cm depth in the sedimentary columns of the Assaluyeh and Bassatin estuaries and Gavbandi River, respectively. Adverse effects of PSEEZ were revealed by increasing concentrations of toxic metals, P and S in the top 25–30 cm of the sedimentary columns. As a result, superficial sediments have been severely polluted by As, Ni, Cd, Cu and Cr, while the entire sedimentary column of the Assaluyeh estuary has been polluted by Hg. Based on the locations of the key horizons, the sedimentation rates of the previous decade at the Assaluyeh and Bassatin estuaries and the Gavbandi River were calculated to be 1.26 cm, 1.52 cm, and 2.13 cm, respectively. The capability of the index analysis approach, as well as of certain lanthanides, for highlighting environmental evolutionary trends in catchments in which extensive land use changes have occurred was demonstrated by the present investigation. The present research concluded that aquatic life and human health in the study area have been subjected to different ranges of hazards by toxic metals due to regional and local anthropogenic activities.

1. Introduction

Estuaries are well-known as important coastal sedimentary environments, many of which are located along the northern Persian Gulf. Nayband Bay, which encompasses the Assaluyeh and Bassatin estuaries, is one of the most important biological heritage sites in the northern Persian Gulf area. However, estuaries have been substantially influenced by the rapid growth of industrial plants and land development projects over the previous two decades (Danehkar and Mashinchian, 2004; Gharibreza et al., 2014; Gharibreza, 2012; Agah et al., 2012).

A review of the existing literature (Agah et al., 2012; Bayati et al.,

* Corresponding author.
E-mail addresses: gharibreza4@yahoo.com, gharibreza@scwmri.ac.ir (M. Gharibreza).

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2014; Chapman and Wang, 2001; Ettler et al., 2016; Pashaei et al., 2015) shows that most ecological risk assessments based on water and sediment quality had primarily focused upon the present-day circumstances of estuaries. An assessment of risks corresponding to the sediment column of sedimentary environments, meanwhile, constitutes a noticeable gap in the majority of previous studies. The effects on the environment from the contamination of oil and metal pollutants could be detectable in specific layers of the sedimentary column. Generally, the physico-chemical conditions of coastal aquatic media provide the appropriate situation with which to observe contaminants within sedimentary layers (UNEP, 1999; Ashraf et al., 2015; Tavakoly-Sany et al., 2014). These layers could thus be introduced as key horizons for the interpretation of sedimentary regimes during past decades (Gharibreza et al., 2013). Estuaries are suitable environments for benthic organisms and burrowers which live throughout the sedimentary column. Therefore, the identification of the polluted thickness of the sedimentary column is a critical step for recommending appropriate management practices in order to decrease hazards for aquatic life.

Consequently, this research assumed that the tracing of key horizons, which are represented by remarkable changes in chemical composition within the sedimentary columns, of estuaries, would reveal and highlight the contributions of regional and local events. Furthermore, key horizons could serve as historical markers, and could be used to estimate the relative sedimentation rate in sedimentary basins.

Geochemical techniques have been widely employed to evaluate natural and artificial issues within sedimentary environments (Lee et al., 2013; Ettler et al., 2016; Zhang et al., 2016). Previous studies introduced frameworks with which to estimate the ecological risks for aquatic life as well as human health (Birch and Hogg, 2011; Buruaem et al., 2012; Ashraf et al., 2015). Sediment quality guidelines (SQGs) have been recognized as suitable professional tools with which to demonstrate the adverse effects of toxic metals for both aquatic and human life (Persaud et al., 1993; CCME, 1995; CBSQG, 2003; Caeiro et al., 2005; Tavakoly-Sany et al., 2014). For example, Lyman et al. (1987), Macdonald et al. (1996), Chapman and Wang (2001) and Ferreira-Andersen et al. (2011) introduced numerous marine benchmarks (interim sediment quality values, ISQVs; threshold effect level, TEL; probable effect level, PEL; sediment quality criterion, SQC) in order to quantify and analyze the pollution status of coastal and marine sediments. Toxic metal concentrations that exceed the severe effect level (SEL) thereby require additional toxicity analysis. The probable effect level (PEL) represents the lowest limit range of chemical concentrations that are typically or always associated with adverse biological effects.

Elaborate ecological risk assessments were initially presented by a series of in-depth investigations (Müller, 1979; Hakanson, 1980, 1994; Tomlinson et al., 1980; Persaud et al., 1993; Burton, 1998; Pataki and Cahi, 1999; GIPME, 1999; Sutherland and Tolosa, 2000). For example, Hakanson (1980, 1994) introduced a methodology that is widely utilized by many researchers worldwide. This method introduced a number of significant factors, namely the contamination factor (Cf), degree of contamination (Cd), ecological risk for individual toxic metals (Er), and ecological risk index for basin (RI), in order to assess ecological risks that impact human health and aquatic life.

Rare earth elements (REEs) comprise the elements belonging to the lanthanide family on the periodic table with atomic numbers ranging from 57 to 71. Rare earth elements are separated into two categories: light rare earth elements (LREEs) and heavy rare earth elements (HREEs). The LREEs consist of lanthanum, cerium, praseodymium, neodymium, and samarium (atomic numbers 57–62), while the heavy rare earth elements constitute atomic numbers 64–71 as well as yttrium, which has an atomic number of 39. REEs have been employed by several previous studies (Soltani et al., 2014; Pagano et al., 2015; Ong et al., 2016) as tracing metals to find the origin of pollution in water, soil and sediments. The geochemistry of REEs was considered in this research to provide additional evidence for the origin of pollutants, as well as to reveal relationships between major toxic metals and REEs.

Accordingly, the authors of this research were encouraged to investigate the circumstances of hazards that impact aquatic life and human health using sediment quality indices, and consequently, the research objectives of this study were designed to evaluate the consequences of environmental changes, as well as to assess the magnitude of ecological risks for both human and aquatic life.

1.1. Study area

The Assaluyeh and Bassatin estuaries are located in Nayband Bay in the northern Persian Gulf, and are situated between 52°37′ and 52°42′ E longitude and 27°22′ and 27°29′ N latitude (Fig. 1). This area is a structural component of the Zagros mountain range, in which oútcrops of geological formations ranging from Jurassic to Quaternary enclose Nayband Bay. Accordingly, Nayband Bay developed within a synclinal depression. Nayband Bay is well known for its environmental setting, for which it was designated a natural protected area by the World Commission of Protected Areas (WCPA), which is a branch of the International Union of Conservation of Nature (IUCN), in 2004. Coastal environments in the bay constitute a territory of dense mangrove forests (0.73 km^2) (Danehkar and Mashinchian, 2004). The Assaluyeh and Bassatin estuaries have been identified as mesotidal and bar-built estuaries. The overall morphology of the coastline of Nayband Bay represents a wave-dominated shoreline wherein sandbars have been developed parallel to the shoreline. A series of fossil beaches, which are units of the retrogressive sedimentary sequence, have been developed between the two estuaries. Fossil beaches are superficial outcrops within the series known as the Falling Stage System Tract (FSST), and were initially introduced in Coe et al. (2003). The FSST series delineates a trend of sea level fall and concordant deposition of coastal facies atop marine facies. According to the glacio-hydro-isostatic model of Lambeck (1996), sea level eustasy achieved a rise of 2–4 m, which peaked during mid-Holocene time and decreased gradually after 4000 BP. The HST of the mid-Holocene transgression (≈6000 BP) was discovered at a distance of 1930 m from the present shoreline of Nayband Bay. Thus, the mean rate of shoreline regression was calculated to be 0.48 m y^{-1} since 4000 BP. The annual precipitation and humidity of this area are 195 mm and 63%, respectively. The Gavbandi River, characterized by an 1166 km^2 catchment area and an annual water discharge of 49 MCM, is responsible for an annual sediment transport of 685 tonnes into Nayband Bay (Lar, 2007). The Gavbandi River is directly connected to the Bassatin estuary, and its seasonal overflow is discharged into the Assaluyeh estuary.

The PSEEZ gas field has been developed in various phases over an area of 30,000 ha with the ambition of supplying an increasing demand for natural gas. Land development could increase to encompass 28 additional phases, as well as 15 immense petrochemical complexes and a wide range of downstream petrochemical industries and other different but related (e.g., semi-heavy and marine) industries (PSEEZ, 2016). Land development projects, including PSEEZ industries and supportive establishments, have surrounded Nayband Bay and its coastal sedimentary environments.