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Residence and transport time scales associated with Shatt Al-Arab discharges under various hydrological conditions estimated using a numerical model

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ABSTRACT

Over the last several decades, concerns in the Northwest Arabian Gulf have risen regarding water quality and ecological conditions, particularly near Kuwait. This interest is mainly attributed to the reduction of freshwater discharge and its associated constituents from the Shatt Al Arab as a result of human activities at diverse scales. From the hydrological perspective, the reduction has also resulted in alteration to the dynamic regime and related residence time and transport conditions. Using a previously well-validated three-dimensional numerical model of the Northern Arabian Gulf (NAG) (Alosairi and Pokavanich, 2017), the residence and transport conditions of numerical tracers have been assessed through a series of numerical tests. The results indicate that density-driven circulations have played a key role in reducing the residence time in the Northwest Gulf by approximately 15% to 20% compared to tidal forces only. The transport conditions correlated well with the Shatt Al Arab discharges, but they were only significant along the Kuwait coast due to counter-clockwise circulations and alongshore currents. Arrival times and mixing processes varied reasonably with the Shatt Al Arab discharges; the results exhibited the enhancement in mixing and transport with increases in discharge. Residence times in the NAG associated with Shatt Al Arab discharge displayed spatial variations, particularly in Kuwait Bay, where the residence time increased by 60 days during low discharge compared to high discharge.

1. Introduction

Concerns over the rise of nutrients, trace metals and other pollutants discharged into coastal waters and estuaries have increased over the last several years. Numerous estuaries and coastal waters have entered a eutrophic state, proportional to the rising trends of anthropogenic activities and nutrient inputs (Nixon, 1995; Smith et al., 1999; Anderson et al., 2002). Specifically, recent studies of the outfalls along the Kuwait coastline have shown that nutrient input is often in phase with phytoplankton biomass near discharge areas (Alosairi et al., 2015). Several studies have indicated that riverine discharges and the associated nutrients and biological growth are well-correlated, as in Patuxent River estuary (Jordan et al., 2003) and the estuary at the Northern Arabian Gulf (NAG) (Al-Yamani et al., 1997; Saburova et al., 2009). For typical estuarine systems, some time is needed for a pollutant, discharged from a river, to be transported to an offshore location. However, the concentration of the pollutant is directly related to the extent of the discharge and the prevailing coastal processes. These processes include mixing associated with near field turbulence, as well as turbulent and shear dispersion from the near to far field (Alosairi et al., 2011). The temporal scale of near field mixing may take several minutes, while the dispersion into the far field may vary from hours to days (Fischer et al., 2013). Traditionally, river discharges are highly associated with sediments and follow a seasonal pattern: large during spring and reducing significantly during early winter (Devlin et al., 2015; Al-Ghadban and El-Sammak, 2005; Khalaf et al., 1982). Therefore, under such hydrographic conditions, mixing and transport processes may vary considerably. In addition, anthropogenic activities, such as the construction of dams or offshore structures, add extra complexity to the historical discharge regime of a typical river and its associated dynamic processes.

It is vital to identify the temporal and spatial scales of pollutant transport and distribution associated with river discharges from a coastal management and ecological sustainability perspectives. Residence time is a predictable parameter that is often used to represent the time scale of physical transport processes and is characteristically compared with the time scales of biogeochemical processes (Liu et al., 2011). This parameter is defined as the average time that a dissolved or suspended material resides in a typical water body before being transported to offshore water. Several studies have used this time scale to understand nutrient transport (Dettmann, 2001); approximate chlorophyll concentration (Monbet, 1992); and estimate travel times of radio-active material (Dabrowski and Hartnett, 2008), bacterial growth in estuarine systems (Crump et al., 2004), and phytoplankton biomass (Lucas et al., 2009) For example, under ideal conditions if algal growth is faster than loss (e.g., decomposition, grazing, sedimentation), then phytoplankton biomass would increase with increasing transport time. Alternatively, if the loss is faster than growth, phytoplankton

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biomass decreases with increasing transport time. If growth and loss are nearly balanced, phytoplankton biomass is rather insensitive to transport time (Lucas et al., 2009). In the previous study of the NAG, specifically in Kuwait, the long-term patterns of various nutrients were reported (Devlin et al., 2015). The authors remarked that the long-term patterns in the nutrient data reflected the variability associated with the Shatt Al Arab River and the reduction in flow (Fig. 1). Yet, the residence times and transport time scales were never been assessed nor quantified in the region. The main objectives of this study are estimating the residence times and the far field transport time scales of dissolved matter associated with Shatt Al Arab discharges in the NAG region. This investigation considers the historic and the hydrologic conditions of river discharge and the flushing of dissolved matter using a series of numerical model simulations and experiments with artificial conservative tracers. The current research also aims to provide an insight of the impact of Shatt Al Arab flow reduction from the hydrodynamic point of view. Perhaps this supports the explanations of the historical patterns of various water quality parameters in the region that was studied recently in Al-Sarawi et al. (2015) and Devlin et al. (2015).

2. Description of the study site

The Northwest Arabian Gulf, Shatt Al-Arab (formed by the confluence of the Euphrates and the Tigris Rivers) is considered the main supply of freshwater to this region (Fig. 1). This area, including Kuwait Bay and around Boubyan Island, is characterized by shallow waters that rarely exceed 8 m in depth. Boubyan has minimal human activity and is one of the largest islands in the Gulf covering an area of 775 km^2. The northern portion of the island is composed of narrow and irregular shallow channels and tidal lagoons of complex geometry, which occasionally experience flooding and drying. Tides in this region are generally semi-diurnal and have tidal ranges among the highest in the whole basin; typically 3–4 m. Tidal currents reach 0.9 m/s in Khor Abdullah and Khor Al Sabiya, and slightly less in neighbouring regions. Because of the proximity to Shatt Al Arab discharges and the prevailing morphological conditions, the Northwest region is characterized by elevated levels of nutrients, biological components, trace metals, and suspended sediments in comparison to the southern coast of Kuwait (Al-Ghadban and El-Sammak, 2005, Al-Yamani et al., 1997). However, extensive anthropogenic activities along the river channels of the Euphrates and Tigris during the last 60 years have resulted in an unsystematic discharge of Shatt Al Arab, which also shows a decreasing trend (Isaev and Mikhailova, 2009, Al-Yamani, 2008).

2.1. Shatt Al-Arab discharges

Shatt Al-Arab is a self-governing hydrographic feature that links the river systems of the Euphrates and Tigris rivers with the NAG. At the upper reaches, the rivers flow far from one another (typically 400 km) gradually moving closer at the middle reaches. At the lower reaches, both rivers pour into the Mesopotamian, southward sloping lowlands that are formed from the sediments of the rivers (Isaev and Mikhailova, 2009). Past the Mesopotamian marshlands, the Euphrates and Tigris Rivers meet at Shatt Al-Arab and empty into the Gulf. Importantly, human interventions have played significant roles in the reduction and alteration of the flow regimes at Shatt Al-Arab. Those activities include upstream dam construction (Altinbilek, 2004), diversion of the Karun and Karkha river paths (Iran) that both feed into Shatt Al-Arab (Al-Tawash et al., 2013), desiccation of the Mesopotamian marshlands (Sama et al., 2012), extensive catchments and side channels used for irrigation (Jones et al., 2008), and on the global scale variation of precipitation levels due to climate change (Yürekli, 2015). In a previous study of Shatt Al-Arab discharge, Hartmann et al. (1971) estimated an annual discharge of 0.022 m/yr, while Saad (1978) reported a larger figure of 0.15 m/yr. Other recent studies reported a discharge rate of 0.19 m/yr (Reynolds, 1993), 0.37 m/yr (Isaev and Mikhailova, 2009), and 0.34 m/yr (Dai and Trenberth, 2002); various techniques were

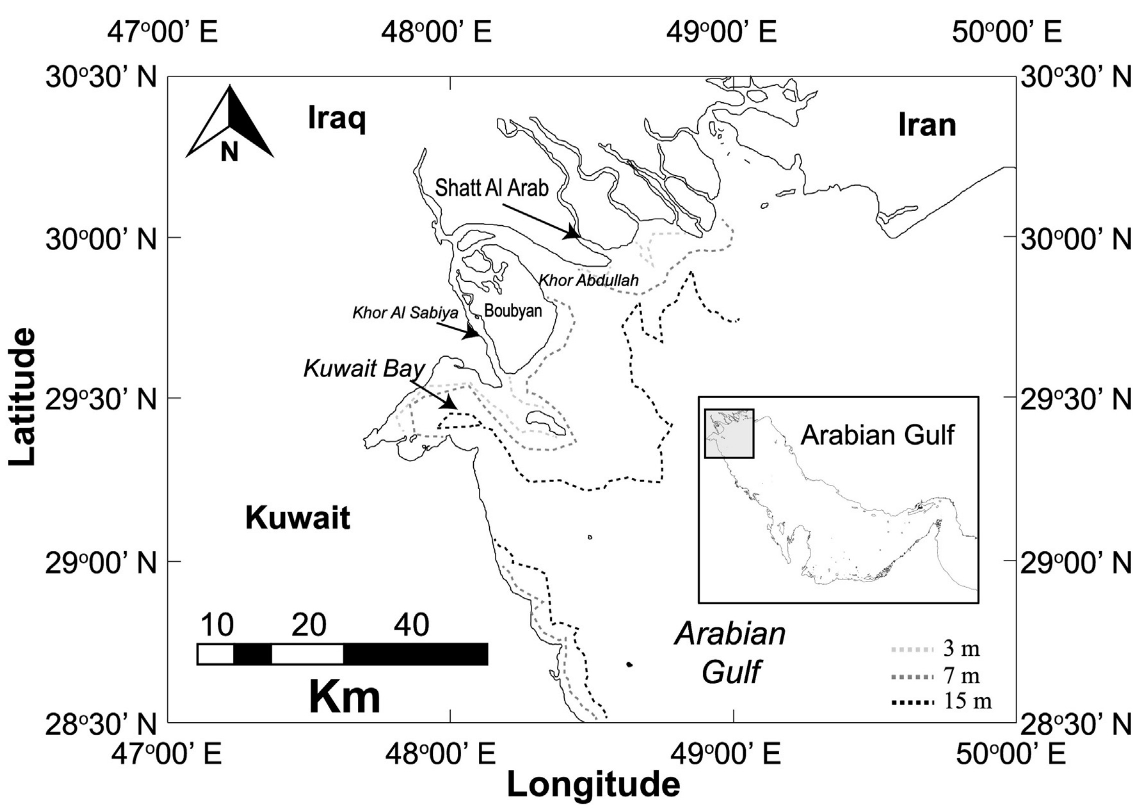

Fig. 1. Map of the Northwest Arabian Gulf and the adjacent coastal regions.

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