Marine Pollution Bulletin 116 (2017) 270–290

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Seasonal circulation assessments of the Northern Arabian/Persian Gulf

Y. Alosairi *, T. Pokavanich

Coastal Management Program, Environmental and Life Sciences Research Center, Kuwait Institute for Scientific Research, P.O Box 24885, Safat 13109, Kuwait

ARTICLE INFO

Article history:
Received 6 October 2016
Received in revised form 5 December 2016
Accepted 21 December 2016
Available online 12 January 2017

Keywords:
Hydrodynamics
Numerical modelling
Residual currents
Inverse-estuary
Kuwait Coastal Jet
Upwelling

ABSTRACT

Due to the continuous human activities linked to economic expansion in the Arabian Gulf area (also known as Persian Gulf), various activities have had an adverse impact on the coastal environment. Furthermore, reduction of precipitation and river flows has resulted in alterations to the hydro-environment regime at various levels. The current study uses a detailed numerical model that was validated with recent field measurements to determine the comprehensive seasonal circulations of the Northern Arabian/Persian Gulf (NAG). The seasons were studied individually using a three-dimensional setup and by considering the baroclinic effects and meteorological forcing. It was found that the NAG exhibits distinctive circulation characteristics each season. In winter, a dense water mass that forms near Kuwait flows toward the southeast near-bed, whereas relatively weak Indian Ocean Surface Waters (IOSW) flow along the Iranian coast and, to a lesser extent, oppose these currents. In spring, the southeast near bed circulations are weaker, while the IOSW is in highest conditions reaching the northern latitudes of the Gulf without being significantly diluted. In summer, a thermocline develops, particularly at the main axis of the NAG, and increases the chances of upwelling. The surface water during this season is significantly controlled by wind. Most distinctive, a non-uniform flow is evident at the offshore regions along the Arabian coast due to strong density gradients. In the fall, the circulations are relatively weaker compared to other seasons; however, cyclonic features are evident at the southeast of the estuary. Well-known counter clockwise circulations NAG are evident throughout the season, but at various strengths; summer is the most active season, while fall is the least active season. In a similar manner, the along shore current varied spatially and temporally throughout the seasons.

1. Introduction

The Arabian Gulf (also known as Persian Gulf), hereafter referred to as the Gulf, is a relatively large, diagonally oriented basin from northwest to southeast with a length of 980 km along its main axis (Fig. 1). At the northern end of the basin, the Gulf has a width of 218 km between Kuwait and Iran that gradually increases moving toward the south until it reaches a maximum width of 350 km between the United Arab Emirates and Iran. Then, it exhibits a trapezoid shape where the narrow part ends at the Strait of Hormuz and is reduced to 56 km in width (Fig. 1). The surface area of the estuary is approximately 239,000 km^2, and the volume is 8780 km^3. The geographical characteristics surrounding the estuary are distinctive; at the northern end, it is bounded by flat land and the Delta of Shatt Al-Arab, where most of the fresh water discharges (Reynolds, 1993 and Elhakeem et al., 2015). In the west, large dry land is associated with extremely arid conditions and limited precipitation that result in frequent dust storms (Al-Sharhan et al., 2001). The eastern side of the estuary is characterized by arid-semiarid climates with relatively higher precipitation rates but extensive potential evapotranspiration (Amiri and Eslamian, 2010). The bathymetric characteristics of the Gulf can be generally described as shallow water with a mean depth of 36 m. The western side of the estuary is characterized by shallow water, in particular, the northern regions near Kuwait have waters with a typical depth of 3 m. Comparatively, the eastern portion of the Gulf is deeper, where it reaches 100 m close to the strait and gradually deepens toward the Gulf of Oman.

One of the main forms of energy that directly input to the sea surface are wind stress and atmospheric pressure gradients. Additionally, tides are a form of mechanical energy that input forces in a consistent manner to the shelf seas. Both forces inject enormous amounts of kinetic energy to an estuarine system that results in various circulation features. In addition, significant seasonal exchange of heat energy and freshwater fluxes are important elements when studying the density driven circulations. Both factors establish horizontal gradients in the form of potential energy that induces circulations proportional to the buoyancy extent.

However, with accelerated human activities and associated pollutants on the one hand and climate change matters on the other hand, energy fluxes have been altered (Moss et al., 2010), which impacts the natural patterns of circulation at various levels. Though

* Corresponding author.
E-mail address: yosairi@kisr.edu.kw (Y. Alosairi).

http://dx.doi.org/10.1016/j.marpolbul.2016.12.065

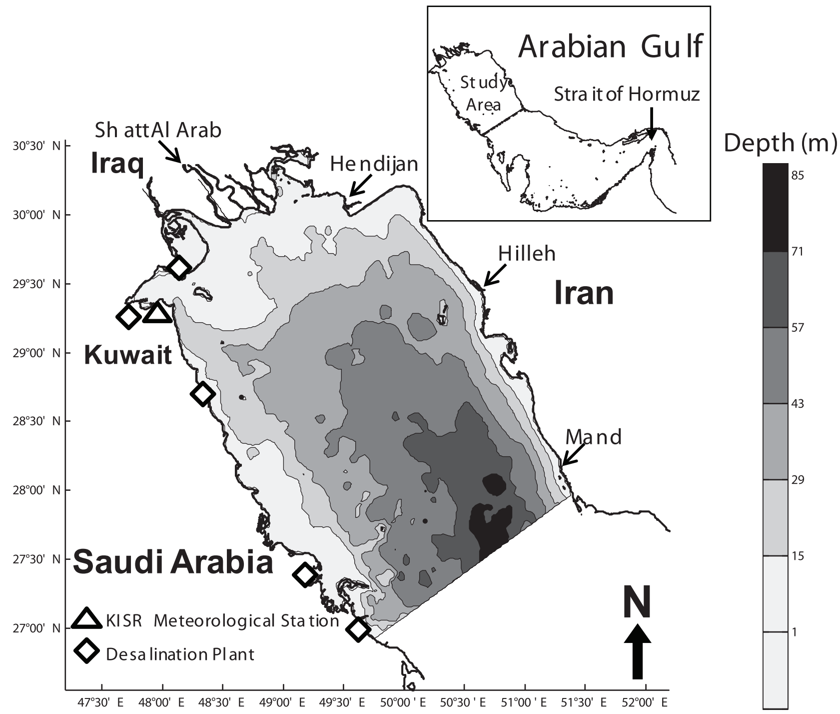

Fig. 1. Geographical features of the Arabian/Persian Gulf and the study area.

inter-annual variability is of interest for the study area, it will not be explicitly described here. For further explanations and understanding of this topic, details are given in Pous et al. (2015). Having said that, Al-Rashidi et al. (2009) studied the factors governing the sea surface temperatures of the northern regions of the Gulf and concluded that between 1985 and 2002, the sea surface temperature has progressively increased at a rate of 0.6 ($\pm$0.3) °C/decade due to local, regional, and global effects. In a similar perspective, the hydrological regime of Shatt Al Arab discharges has been distorted dramatically due to a number of anthropogenic activities upstream of the river, such as the construction of dams along the Tigris and Euphrates Rivers and Mesopotamian marshland desiccation (Al-Yamani et al., 2007). Both activities lasted from the mid-1970s to the early 1990s when the marshlands lost 90% of their total area by 2000 along with minimal discharge at Shatt Al Arab, which is currently its under restoration (Al Maarofi et al., 2012). Regionally, desalination plants have been considered to be the main freshwater source to the Gulf state countries. However, such technologies result in adding approximately 2 ppt locally to the ambient water salinity due to brine waste discharge, which creates manmade, horizontal gradients at various levels depending on the plant capacity (Hashim and Hajjaj, 2005). In addition, coastal region, such as the Gulf, have relied on hydrodynamics to disperse and reduce the effects of pollutants so that once diluted, biological breakdown renders them harmless to the receiving hydro-environment (Alosairi et al., 2011).

Traditionally, the physical study of a typical estuarine system has been accomplished via field observations or mathematical models to describe detailed or generic characteristics of water dynamics. In recent numerical model studies of the Gulf, Pous et al. (2013, 2015) studied wind induced circulations and showed that north-westerly winds create an anticyclonic gyre (anticlockwise) at the northern regions of the Gulf. They added that the same wind conditions are responsible for enhancing the mixing of the plume discharged from Shatt Al-Arab, which generates surface flow along the Arabian coast toward the south. However, in that particular study, an idealized model configuration was assumed, i.e., thermohaline effects

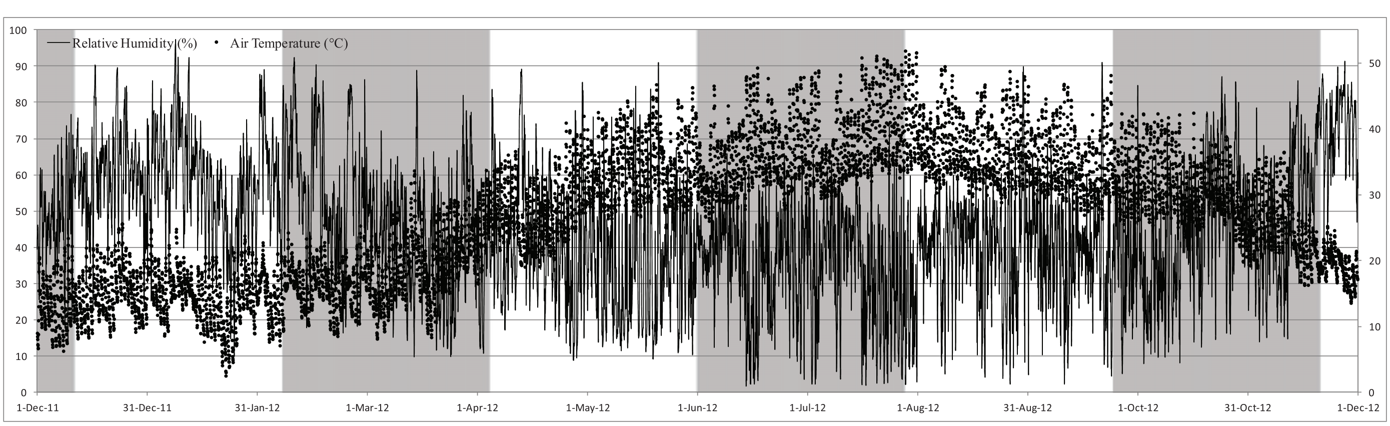

Fig. 2. The relative humidity and air temperature at the KISR meteorological station during the study period.