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Baseline

Three-dimensional hydrodynamic modelling study of reverse estuarine circulation: Kuwait Bay

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ABSTRACT

Hydrodynamics and associated environmental processes have always been of major concern to coastal-dependent countries, such as Kuwait. This is due to the environmental impact that accompanies the economic and commercial activities along the coastal areas. In the current study, a three-dimensional numerical model is utilized to unveil the main dynamic and physical properties of Kuwait Bay during the critical season. The model performance over the summer months (June, July and August 2012) is assessed against comprehensive field measurements of water levels, velocity, temperature and salinity data before using the model to describe the circulation as driven by tides, gravitational convection and winds. The results showed that the baroclinic conditions in the Bay are mainly determined by the horizontal salinity gradient and to much less extent temperature gradient. The gradients stretched over the southern coast of the Bay where dense water is found at the inner and enclosed areas, while relatively lighter waters are found near the mouth of the Bay. This gradient imposed a reversed estuarine circulation at the main axis of the Bay, particularly during neap tides when landward flow near the surface and seaward flow near the bed are most evident. The results also revealed that the shallow areas, including Sulaibikhat and Jahra Bays, are well mixed and generally flow in the counter-clockwise direction. Clockwise circulations dominated the northern portion of the Bay, forming a sort of large eddy, while turbulent fields associated with tidal currents were localized near the headlands.

1. Introduction

Coastal dynamics have been utilized by man to disperse effluents so that, upon entering a marine system, they spread via various physical processes, such as turbulence and mixing, while biological activities play a role in rendering them harmless in the surrounding water (Alosairi et al., 2011). The temporal scale of the mixing and transport of effluents determines the effects of pollutants, for example, nutrients, on the biological activities in a marine system. On a spatial scale, the distributions of effluents are adjusted and gradually homogenized as one moves further away from the source in the receiving water. This is mainly attributed to the scale of the motion that a water body may experience, which is governed by the prevailing conditions. For example, estuaries that experience strong seasonal riverine discharges are subject to intense density-driven circulations compared to lower ones or during low seasons. Subsequently, this leads to enhanced hydrodynamics that may improve transport compared with well-mixed conditions, particularly in shallow waters. In addition, wind forces add an extra dimension to the complexity of water circulations, principally at the surface, which again contributes from a different perspective to transport and mixing. Henceforth, hydrodynamics of a water body should be well understood prior to any attempt to resolve the distributions of given water parameters.

Kuwait Bay, hereafter called ‘the Bay,’ is an elliptically shaped embayment that extends in the westward direction from the farthest north of the Arabian/Persian Gulf, hereafter called ‘the Gulf,’ as shown in Fig. 1. The Bay is characterized by comparatively shallow water throughout, and the depth ranges from 2 m near the coastal region to 18 m at the boundary with the Gulf estuary (Fig. 1). It covers an area of approximately 720 km^2 and has a boundary length of 20 km with the Gulf estuary. Due to the geographical location of the Bay, tides are mixed with predominantly semidurinal characteristics and experience some of the highest tidal range of the entire Gulf (occasionally > 4 m) (Alosairi et al., 2016). The coastal region of Kuwait is crucial as it serves most of the Kuwaiti population, particularly at the southern region of the Bay where > 50% of the population exists (Al-Rashidi et al., 2007). The coastal region is an important resource for the country, but it is a recipient of various suspended and dissolved materials, including nutrients, pollutants from oil transportation and sewage discharges (Alosairi et al., 2015). Furthermore, the Bay receives vast amounts of

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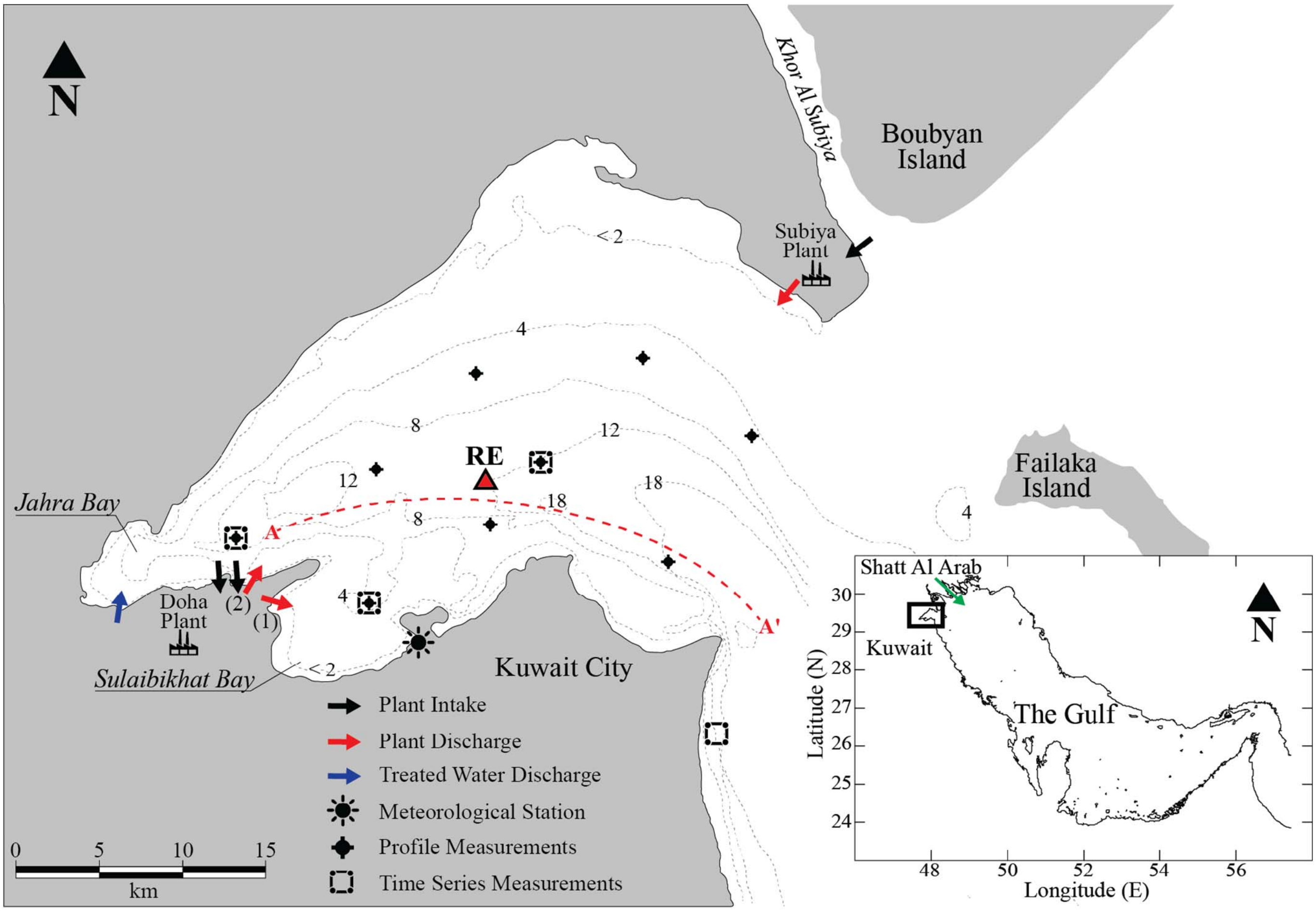

Fig. 1. Kuwait Bay physical characteristics and field measurement locations, RE is short of Reverse Estuarine and remarks the location where such assessment was conducted.

fine sediments originating from Shatt Al Arab and nearby areas, which is considered the main natural provider of fresh water to the northern Gulf region near the Bay (Alosairi and Pokavanich, 2017a, 2017b) (see Fig. 1). From a biological viewpoint, the Bay has intermittently experienced various algal blooms, particularly during warm seasons (Glibert et al., 2002), and has been categorized as a stressed water body within the Gulf. Thus, knowledge of hydrodynamics, including the circulations and flow fields, is fundamental for understanding the fate, transport and accumulation of solutes in the Bay. This would also enable the building of comprehensive management strategies and long-term monitoring plans for better water quality. Previously, limited studies were conducted to understand the hydrodynamics of the Bay. Pokavanich and Alosairi (2014) focused on the flushing characteristics but lacked detailed circulation assessments, while Rakha et al. (2010) studied the same topic but used a two-dimensional model. In the latter study, the model achieved reasonable fidelity with sea level observations and, to a lesser degree, with the tidal currents. However, the model is incapable of addressing material fluxes over time scales longer than the tidal cycle, e.g., spring-neap cycle, since the model omits the mean estuarine circulation by gravitational convection, and its renditions of the wind-driven flows are inherently improper.

The main aim of the present study is to investigate the spatial and temporal hydrodynamic characteristics of the Bay in a three-dimensional manner. The study is focused on the dynamics of the summer season when various environmental issues occur, specifically fishkill. This will be achieved by utilizing a numerical model in which the vital physical forcing parameters, including meteorological effects, will be considered in detail. Using the data of extensive field measurements conducted during the summer of 2012, the numerical model is validated. Following that, the model is used to study the Bay's prevailing hydrodynamics to reveal the residual circulations and the mean distributions of physical parameters. The work presented here is considered an important step towards understanding of the governing flow conditions in the Bay and other embayments within regions of similar arid hydro-environmental conditions.

The Gulf including the Bay is situated near the low northern latitudes and is close to the Tropic of Cancer (frequently referred to as the Northern Tropic), between longitudes of 48 and 59°E (Reynolds, 1993; Al-Sharhan et al., 2001). This area is recognized as one of the largest deserts in the World and is considered the boundary between tropical circulations and the synoptic weather systems of the mid to low latitudes (Reynolds, 1993; Al-Sharhan et al., 2001). Dry air between these latitudes generates clear skies and extremely arid conditions with limited precipitation and clouds (Al-Sharhan et al., 2001). In general, during the warm season, typically between May and October, the main path of the jet stream managing the passage of depressions passes north of the Pontic Mountains (Turkey) (Al-Sharhan et al., 2001). During the relatively cooler periods, typically November to February, the path of the jet stream shifts southwards and covers the northern region of the Gulf (Al-Sharhan et al., 2001). The Gulf climate, including the Bay, is characterized by high temperature, high relative humidity, limited precipitation and northwesterly winds (regionally known as 'Shamal' winds) that occur perennially (Al Senafi and Anis, 2015; Alosairi et al., 2011; Reynolds, 1993).

Similar to the previous hydrodynamic studies in the area (Alosairi and Pokavanich, 2017a, 2017b), the months June, July and August for the year 2012 are considered the main period representing the summer season for the current study. To further understand the prevailing