Reclaimed islands and new offshore townships in the Arabian Gulf: potential natural hazards

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Some of the Arabian Gulf states are busy developing several large, reclaimed islands and offshore townships. These structures are undoubtedly futuristic and the ideas are quite novel. However, there are serious issues of long-term sustainability of these townships. This article reviews and discusses natural hazards that have struck this region in the past and have the potential to strike again any time in the future. Potential dangers and consequences are identified.

Keywords: Natural hazards, offshore townships, reclaimed islands.

SEVERAL new townships are being developed in the Arabian Gulf on reclaimed land along the coastal regions (Figure 1). The United Arab Emirates (UAE), Qatar and Bahrain are spending huge sums of money on such mega urban development projects. Saudi Arabia used reclamation to expand the size of Tarut Island for urban development. The city of Dubai is at the forefront of such projects, where five new giant offshore island communities are being developed (http://en.wikipedia.org/wiki/Palm_Islands and http://www.nakheel.com). They are 'The Palm Jebel Ali', 'The Palm Jumeirah', 'The Palm Deira', 'The World' and 'The Universe'. 'The Pearl Qatar' is a similar type of a mega project being developed by Qatar on reclaimed land (http://www.thepearlqatar.com/main.aspx). The Kingdom of Bahrain too is developing a similar urban development project (http://www.durratbahrain.com) on reclaimed land. These islands have been designed and are under construction for maximum possible length of coastlines, so that a large number of beachside luxury homes could be built. Townships are being constructed on these islands for thousands of luxury homes with sea-side views. These will include tens of thousands of homes, apartments, hotels, marinas, golf courses, and other types of commercial and recreational complexes. Such projects in Qatar and Bahrain include high-rise apartment complexes also.

This article investigates long-term sustainability of these projects in view of possible geological and atmospheric hazards that have struck this region in the past and might strike in the future. Geological hazards discussed include seismic, tsunami and/or tidal waves, and erosion due to surface and sub-marine currents. Tropical cyclones and the resulting oceanic surges are the main possible atmospheric hazards that might strike this region any time in future. The likelihood and possible impact of each of these hazardous events and issue of long-term supply of potable water, keeping in view global warming, to such communities is also discussed.

The Arabian Gulf

The Gulf is an epicontinental sea that covers an area of approximately 226,000 km^2. It is about 1000 km long and 200–300 km wide, with maximum width of 370 km. It opens into the Gulf of Oman and the Arabian Sea through the Strait of Hormuz, which is only 60 km wide, separating the Musandam Peninsula of Arabia and the Qeshm Island of Iran. Average depth of the Gulf is around 35 m, but the deepest regions are in the eastern part along the Iranian coast where the depth reaches around 100 m (Figure 2)[1]. The northern end of the Gulf is a delta region of the rivers Euphrates and Tigris which join to form the Shatt al-Arab river. There are a few other smaller streams that flow from the Zagros Mountains of Iran into the Arabian Gulf forming estuaries. At present there are no streams flowing from the Arabian Peninsula into the Arabian

Figure 1. Location of reclaimed islands offshore Dubai, UAE.

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Gulf, but during the Quaternary several smaller streams and large rivers were flowing into the Gulf[2].

The Gulf lies upon the continental shelf and its bottom is gently inclined sloping towards the east. It lacks a 'shelf edge'[1]. High aridity, high summer temperature (~50°C) and partial isolation of the Gulf from the Arabian Sea lead to high salinities throughout the basin, and to the formation of supra tidal flats or sabkhas and precipitation of salt in the coastal lagoons. The presence of the Qatar Peninsula on the western margin of the Gulf influences the marine currents and patterns of sedimentation along the SE side of the Gulf along the coast of UAE. The prevailing regional winds are called 'shamal', which blow from NW to SE direction impacting coastal environments by waves and surface currents[1].

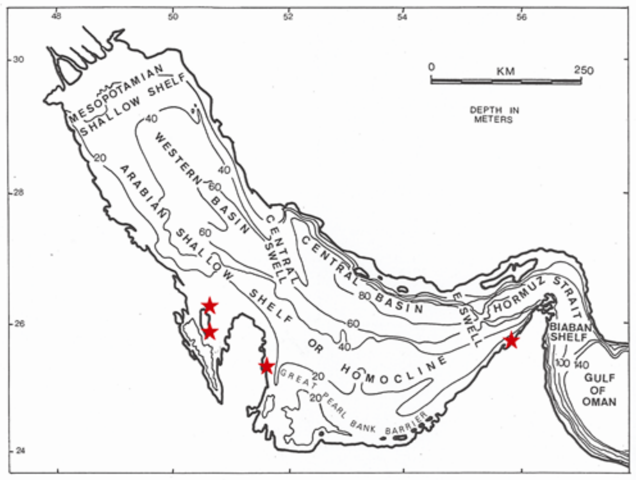

Figure 2. Bathymetry of the Arabian Gulf showing areas of offshore urban development. Stars show location of man-made islands and townships under construction (modified after Purser and Seibold[1]).

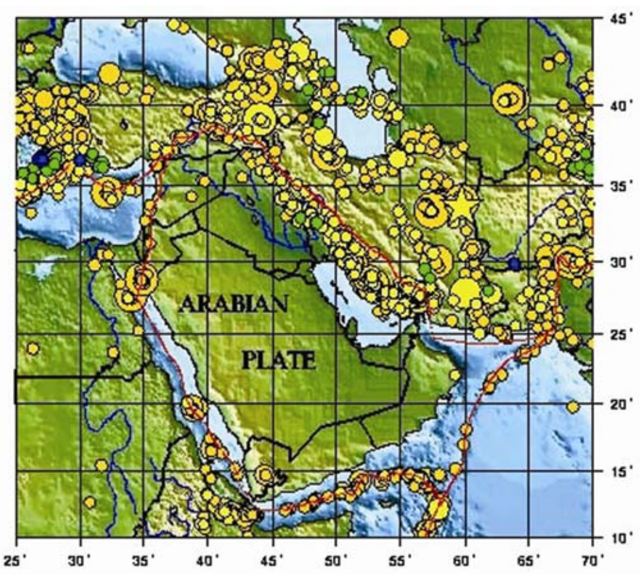

Figure 3. The boundary and seismicity of the Arabian Plate (after Pararas-Carayan[16]).

Potential natural hazards of the Arabian Gulf

There are several different types of natural hazards that have struck this region in the past and have the potential to strike in the future too. Broadly, they may be classified as geological and atmospheric hazards. Geological hazards include earthquakes, tsunamis and/or tidal waves, erosion from currents in the Arabian Gulf. Atmospheric hazards include tropical cyclones. In addition to these hazards, serious problems of groundwater depletion, coastal erosion and loss of biodiversity and mangrove forests have already created serious environmental problems for the region. Effects of global warming have the potential to intensify both atmospheric and geological hazards leading to severe problems of erosion and flooding that would threaten the new offshore island communities.

Geological hazards

Earthquakes: Major urban centres in the Arabian Gulf coastal regions like Dubai and other cities are prone to dangers of seismic activity despite the fact that Arabian Peninsula is considered to be a relatively stable region (Figure 3). According to Al-Amri[3,4], there are 25 seismogenic source zones in the Arabian Peninsula and adjacent countries. They are the rift systems, strike slip and

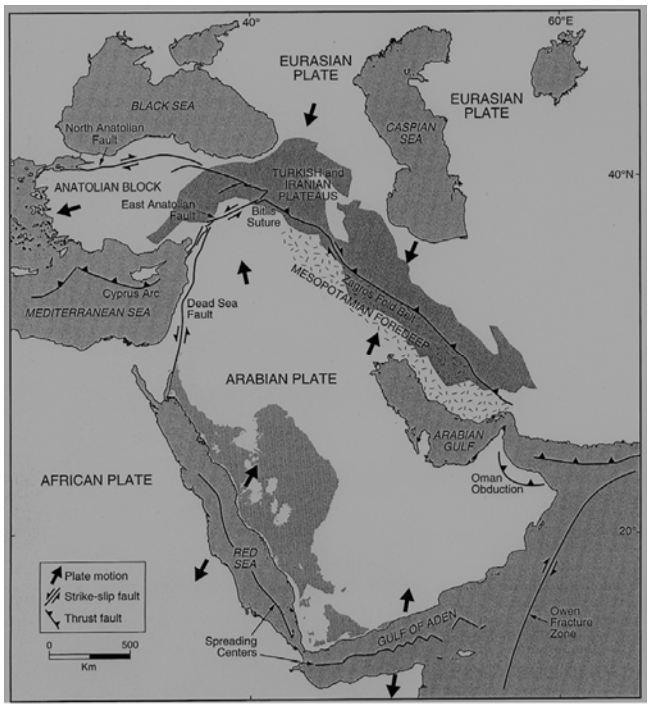

Figure 4. Tectonic features of the Arabian Peninsula and the adjoining regions (modified after Seber *et al.*[27]).

normal faults, joints, lineaments, and subduction and collision zones (Figure 4). The Zagros Thrust Fault demarcates the plate boundary between the Arabian and the Eurasian tectonic plates and is a seismically active zone[5]. Large ($M \leq 5$) earthquakes occur frequently along this thrust. Even low-frequency ground-motion amplification could be significant because it can excite vibrations in tall buildings[6]. Earthquakes originating from the Iranian Coastal Source Zone (100–400 km away) could cause catastrophic damage to high-rise buildings of the UAE (Figure 5). Seismic hazard of tall, non-earthquake-resistant buildings poses a high level of risk from distant earthquakes[7].

The danger of earthquakes would be higher in the reclaimed islands and their tall buildings because reclaimed land is potentially more susceptible to liquefaction and slope failure. Reclamation material here is mainly dredged carbonate sand and little is known about the underlying or nearby fracture zones and seismicity[8]. All these factors make tall buildings constructed on reclaimed islands quite dangerous and prone to seismic destruction.

Tsunami and tidal waves: Since the Arabian Gulf is an inland sea with an opening to the Arabian Sea through the narrow Strait of Hormuz, it is to an extent protected from tidal waves, storm surges and tsunamis generated in the Arabian Sea or the Indian Ocean. Thus the Arabian Gulf and surrounding regions are often protected from various types of natural hazards arising from a variety of geological events. However, some tsunami energy could always leak into the Arabian Gulf region[9]. Bhaskaran *et al.*[10] calculated tsunami travel time for 250 locations in 35 countries around the Indian Ocean for the 26 December 2004 Sumatra Earthquake. The authors included Manama (Bahrain), Bandar Abbas, Bander-e-Bushehr and Jask (Iran), Kuwait City (Kuwait), Doha and Dukhan (Qatar), Abu Dhabi, Dubai and Sharjah (UAE) from the Arabian Gulf region. The Kachchh and the Makran coasts have in the past experienced tsunamigenic earthquakes[11].

Figure 5. Structure and tectonic elements of the Makran coast of Iran and Pakistan showing the epicentre of 28 November 1945 tsunamigenic earthquake (after Pararas-Carayan[16]).

Rastogi *et al.*[11], and Rastogi and Jaiswal[12] have compiled a comprehensive list of tsunamis of the Indian Ocean region and tsunamigenic earthquakes in the Arabian Sea that potentially had impacted the coastal regions of the Arabian Gulf also (Table 1). Similarly, Jordan[13] compiled a list of earthquakes and possible tsunami events in the Arabian Gulf (Table 2).

The Makran earthquake of 28 November 1945 and the resulting tsunami were the deadliest for the South Asian region, which generated wave heights[14] up to 11.5 m and run-ups up to 17 m on the Makran coast[15,16]. More than 4000 people were killed along the Makran coast and few in Kachchh and Mumbai. This tsunami also affected the Iranian coast in the Arabian Gulf region[16,17]. The Makran tsunami waves also swept into the Arabian Gulf and washed out a large sandbar at Ras al-Khaimah, UAE[13].

Although there are no records of the Makran coast tsunami in the Arabian Gulf, some people remember the sudden upsurge in wave height affecting coastal communities in Saudi Arabia. According to Pararas-Carayan[16], 'seismotectonics of the Makran subduction zone, historical earthquakes in the region, the recent earthquake of 8 October 2005 in Northern Pakistan, and the great tsunamigenic earthquakes of 26 December 2004 and 28 March 2005, are indicative of the active tectonic collision process that is taking place along the entire southern and southeastern boundary of the Eurasian plate as it collides with the Indian plate and adjacent microplates. Tectonic stress transference to other, stress loaded tectonic regions could trigger tsunamigenic earthquakes in the Northern Arabian Sea in the future'. He concludes by mentioning that, 'the Makran subduction zone has a relatively high potential for large tsunamigenic earthquakes'.

Erosion from currents and waves in the Arabian Gulf: Surface and submarine currents in the Arabian Gulf are generated by the combined effects of wind direction and velocity in the region, and drastic seasonal temperature variations and varying density of the water masses within the Arabian Gulf and the Arabian Sea. The circulation patterns of the Arabian Sea are controlled by different sets of oceanographic and atmospheric factors.

Direct observations of the circulation within the Persian Gulf are scarce, but analysis of ship drift records indicates northwest flow with speeds greater than 10 cm/s along the Iranian coast from the Strait to the change in trend of the coast near 51.5°E and southwest flow in the regions of the southern Gulf away from Iran[18]. Ship drifts, current meters and changes in the salinity field suggest northward flow at 4–5 cm/s for the Iranian half of the Gulf south of 27.5°N, whereas current meters and Lagrangian drifters at nearby locations suggest weaker flow to the west or south. The relatively high evaporation rate combined with restricted exchange with the open ocean lead to the formation of a saline, dense water mass known as the Persian (Arabian) Gulf Water (PGW), leading

Table 1. Tsunamis of the Indian Ocean region and tsunamigenic earthquakes in the Arabian Sea[11,12]

Date	Location	Cause
326 BC	Kachchh region/Indus Delta (western India and southern Pakistan)	Earthquake
1 April–9 May 1008	Iranian coast in the Arabian Gulf	Earthquake
AD 1524	Off Dabhol coast, Maharashtra, India	Earthquake
16 June 1819	Kachchh region, Gujarat, western India	Earthquake
19 June 1845	Kachchh region, Gujarat, western India	Earthquake
28 November 1945	Makran coast, southern Pakistan	Earthquake

Table 2. Earthquakes and possible tsunami events in the Arabian Gulf[13]

Date	Location	Tsunami	Comments
Spring 1008	Siraf, Iran	Large waves sank ships	Not clear if it was a tsunami or a storm surge
November 1426	Near Bahrain	None recorded	
~1832	Hufuf, Saudi Arabia	None recorded	
13 June 1858	Bushire, Iran	None recorded	
19 May 1884	Qeshm Island, Iran	None recorded	Felt at Ra's al-Khaima
27 November 2005	Qeshm Island, Iran	None recorded	Felt in Dubai, Sharjah, UAE

to a reverse circulation through the Strait of Hormuz[18]. The Indian Ocean Surface Water (IOSW) normally flows into the Gulf from the open ocean along the northern side of the Strait and continues northward along the Iranian coast[19].

Atmospheric hazards

Since the Arabian Gulf is surrounded by land, it has essentially a continental climate. Thus, due to a lack of oceanic buffering it has marked seasonal fluctuations providing instability and variability to the sedimentary environments within the basin[1]. During winter months, the strong shamal wind blows mainly from the NW in the northern part of the Gulf, while the summer months are usually calm. The shamal winds create waves and surface currents and transport terrigenous sediments, including pre-Holocene dolomitic dust to the marine environments. Average annual rainfall in coastal Arabia[20] is <5 cm; thus fluvial influx is low and is limited to occasional flooding of desert wadis due to rains. Most fluvial terrigenous sediments are brought into the Gulf by the Tigris, Euphrates and Karun rivers joining to form the Shatt Al-Arab. Smaller rivers and streams from the Zagros Mountains also bring terrigenous sediments to the basin.

During summer due to heavy evaporation and limited fluvial inflow into the Gulf, surface waters of the Arabian Sea flow in an anticlockwise pattern along the Iranian coast[21]. This movement of water determines the distribution of salinity, temperature and nutrients within the Gulf. During summer average surface temperature in the Gulf is around 36°C, but during winter months surface waters cool significantly to 20°C. Highly saline cool waters sink to the bottom, raising the salinity and lowering the temperature of deeper waters[21]. This water flows out of the Gulf through the deeper parts near the Masandam Peninsula.

Tropical cyclones: These occasionally form in the Arabian Sea and they seldom exceed the tropical storm intensity. In 2006, the tropical storm 'Mukda' was the only tropical system to form in the region and it remained well out to sea before dissipating. However, the tropical cyclone 'Gonu' (Figure 6) proved that such events do occur in the Arabian Sea and can also be devastating. On 5 June 2007, the intensity of Gonu had reached Category 5, with sustained winds measuring 160 miles/h (http://www.nasa.gov/vision/earth/lookingatearth/gonu.html). According to the Joint Typhoon Warning Center (http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id=14328), it was the most powerful cyclone ever to threaten the Arabian Peninsula since record keeping began in 1945. This cyclone had weakened by the time it hit Muscat, Oman. It still caused enormous damage to the city infrastructure and loss of life and property. Tropical cyclone '03B' followed Gonu. It originated in the Bay of Bengal on 25 June 2007. It crossed India and was reforming in the Arabian Sea, south of Pakistan. At the time, winds measured 40 miles/h. It also caused flooding and wind damage in Karachi, where the death toll was around 200. Storm surge from 03B was predicted to be moderately high, even though the storm was not strong, because the offshore waters are shallow.

Impact of climate change and global warming and other environmental issues: A wide range of issues related to global warming have been discussed by the Inter Governmental Panel on Climate Change (IPCC) (http://www.ipcc.ch) and various other scientific and environmental organizations all over the world. This issue is important because it could lead to far-reaching socio-economic and political changes in the world and potentially has disastrous consequences for all life forms on earth. Environmental impact of global warming on new offshore island communities should be understood in terms of possible changes on the coastal environments. In the Arabian Peninsula, over 90% of the area is suffering from some form of desertification and 44% of the area is severely degraded. Its plant biodiversity is low (~3500 species), which is also getting reduced due mainly to overgrazing[22]. Goudie[23], while discussing the impact of global warming on the geomorphology and hydrology of arid lands warns that 'changes in vegetation cover, associated with decline of soil moisture availability, will increase the risk of soil erosion by wind, and may accelerate dust storm activity and cause sand dune activity to be reactivated'. He further states that, 'arid coastlines will be subjected to sea-level change that will lead to transformations in the nature of such environments as deltas, estuaries and sabkhas'. As a result of global warming sea-levels are expected to rise at around 5 mm/yr. This could seriously impact low-lying coastlines such as the Sabkhas of the UAE and due to the high degree of infrastructure development in such coastal environments, this is a serious issue for cities such as Abu Dhabi[23]. Thus it can be argued that such offshore townships built on reclaimed islands could potentially be affected by inundation and erosion due to sea-level rise and increase in storm surge events.

Any rise in average global air temperature due to global warming will require more water for crops in the Arabian region due to higher evapotranspiration. This will lead to higher soil salinity and consequently desertification will be accelerated[24]. This logic also applies to increased growth in human population in these new communities and thus higher consumption of water will have similar consequences. Kendell *et al.*[25] predict that all the coastal lagoons of the UAE will fill naturally or by human-driven reclamation and a concurrent microclimatic change would destroy the current halophytic cover of the coastal dunes. Khan and Al-Homaid[26] used Landsat images to demonstrate the destruction of mangrove forests and disturbance of coastal environments within a span of 30 years, caused by rampant and unplanned urban growth along the coast of Tarut Bay and Tarut Island on the east coast of Saudi Arabia.

Figure 6. Cyclone Gonu of 7 June 2007; http://en.wikipedia.org/wiki/Gonu.

Discussion

The Arabian Gulf region is susceptible to both geological and atmospheric hazards. The geological hazards include earthquakes, tsunamis and tidal waves, and coastal erosion. Due to constant subduction pressure of the Arabian Plate under the Eurasian Plate, Iran and the surrounding regions are prone to high-level seismic activity. In the past this region has been hit by several tsunamigenic earthquakes. Movement of surface and submarine currents in the Arabian Gulf poses severe threat of erosion to these man-made islands. Constant stabilization effort will be required to sustain them.

Although tropical cyclones affecting the Arabian Peninsula and the Gulf are not common, they are becoming more frequent due to the effect of global warming. These can be severe and hazardous, as demonstrated by the cyclone Gonu in June 2007.

The problems of environmental pollution and algal blooms due to eutrophication within the closed water bodies due to lack of circulation, absence of currents and surface waves, and heavy input of organic waste are expected to be serious issues. Damage to coral reefs, sparse halophytic biotic communities and other coastal environments will only compound the problem. It can be safely hypothesized that these problems will throw major challenges to long-term sustenance of such communities.

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