

Artificial Island Developments

Subjects: Environmental Sciences

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Artificial island development (AID) to tackle rampant urbanization on scarce land puts all marine biodiversity at huge risk and is recognized as a global conservation issue worldwide.

Keywords: artificial island development ; environmental implications ; land reclamation ; Sustainable Development

1. Introduction

1.1. Gulf Artificial Island Developments (AID)

Rapid economic development and social prosperity has played a noteworthy role in transforming the Gulf from an insignificant desert to ultra-modern nations with continuously growing coastal cities ^[1]. However, due to rapid population expansion and urbanization, as well as increased energy and water needs, this places a great strain on land resources, which are constantly at the point of depletion ^{[2][3][4][5][6]}. Authorities find it challenging to develop infrastructure on scarce land to accommodate the growing population. To alleviate the problem, marine resources have attracted considerable attention. Hence, Gulf countries are developing artificial islands, as shown in **Table 1**, in the surrounding Gulf waters to tackle the swift urbanization and population challenges followed by other industrial, commercial, economic, and strategic benefits ^{[7][8]}. The Kingdom of Bahrain is a prominent example of an archipelago, an extensive network of islands ^[9], having a commercial zone offshore or within the sea to cope with land-scarcity issues ^[10].

Table 1. Some major artificial island developments across the Gulf region ^[11].

Gulf Country	Artificial Island	Development Status	Purpose
United Arab Emirates	Palm Jumeirah Island	Completed in 2008	Commercial, residential, tourism
	Bluewater Island	Completed in 2018	Hospitality, residential
	Pearl Jumeirah Island	Completed in 2012	Residential area
	Burj Al Arab Island	Completed in 1999	Commercial, hospitality, tourism
	Jumeirah Bay Island	Completed in 2016	Residential
	Amwaj Island	Completed in 2016	Residential
Bahrain	Durrat Al Bahrain	Completed in 2009	Residential, commercial, tourism
Qatar	Reef Island	Completed in 2010	Residential, commercial
	Pearl Island	Completed in 2006	Residential, commercial
	Ras Laffan	Established in 1996	Industrial harbor
Kuwait	Green Island	Completed in 1988	Recreational, tourism
	Sabah Al Ahmad Sea City	The first phase was completed in 2004	Residential
Saudi Arabia	Jazan Economic City	The first phase was completed in 2010	Residential, industrial

Unlike natural islands, an artificial island is basically a manmade formation that has been constructed by humans over water bodies rather than formed through natural processes. They are constructed by different methods such as land reclamation, extending existing islets, rocks, or coral reefs, or linking small groups of islets into one bigger island using different construction materials ^[12]. The phenomena behind the construction of artificial islands are to support people,

economy, energy needs, defense infrastructure, and mainly to promote tourism, which is common in Asia and Gulf countries. The United Arab Emirates (UAE) is the pioneer in developing artificial islands ^[13]. In 2001, UAE started to build an archipelago, Palm Islands and World Islands, followed by Jebel Ali and Deira, each bigger than the last. This tremendous achievement of the UAE encouraged other Gulf countries such as Qatar, Oman, Bahrain, and Kuwait to utilize their existing coastlines as artificial islands, which can later serve as tourist spots, economic hubs, petroleum reserves, and residents for the growing population ^[14].

Although the Gulf region is home to the world's largest and most modern artificial islands, these islands come at a greater cost to nature, facing incessant environmental degradation ^[15]; in 2016, the construction of oceanic islands was identified as a "global conservation issue" due to unsustainable development ^[16].

1.2. Potential Environmental Impacts of AID

The construction of Gulf artificial islands using different dredging methods and land reclamation ^[17] might affect the productivity of numerous marine ecosystems. Like many other island countries, the Gulf faces uninterrupted environmental degradation of coastal and marine habitats due to human-induced interventions ^[18]. Similarly, sediments and heavy metals contaminate the water quality and constantly enhance its turbidity, which poses serious threats to seagrasses and coral reefs, burying oyster beds and causing disturbance to natural water currents that ultimately erode shorelines ^{[19][20]}. However, sustainable practices, including ecoengineering, adaptation management, and hybrid approaches, can reduce some of these impacts. Moreover, another offset is the rising sea level due to climate change ^[1], which is likely to inundate the artificial islands of Dubai in the future, which are just 4 m above sea level. Therefore, the construction of artificial islands must be according to the relevant legislation (The Convention on the Law of the Sea, 1982) and sustainable enough to foresee current and future environmental challenges ^[21].

2. Detailed Analysis of the Literature

Urbanization followed by economic advancement place a considerable burden on the available land resources to meet the innumerable needs of urban centers. However, in recent years, the concept of artificial islands has been widely being used for housing, commercial, industrial purposes, trade, tourism, and strategic motives to manage the inevitable increase of urban space volumes ^[22]. These mega coastal projects will threaten the existing marine ecosystems if appropriate measures are not considered intently ^[23].

2.1. Environmental Impacts of Artificial Islands Development (AID) among Gulf Countries

In recent years, UAE has started reducing its dependence on oil for economic growth and emphasizing tourism for revenue. By 2006, Dubai's GDP had reached 22% because of the high number of hotels in the coastal areas ^[17]; hence, Dubai needed to create more hotels on the coasts to promote the tourism industry. In line with this policy, artificial island development has caused severe degradation of numerous natural ecosystems. Dredging high volumes of sand in island construction has resulted in increased turbidity, whereas land-reclamation activities have shown a conspicuous loss of many fish species ^{[24][25][26]}. Due to these anthropogenic interventions, coral reefs, shells, and oyster beds are buried under the sediment. High levels of sediment, nutrients, and heavy metals in the marine water have played a significant role in increasing the toxicity, turbidity, temperature, and salinity, which have accelerated the degradation of the economically high-valued coral reefs ^{[27][28]}. Although the "Convention on the Law of the Sea" gives Dubai the right to construct these islands, the loss and environmental degradation led by these islands require dire attention of policymakers to design the artificial islands meticulously by considering all the environmental effects, promoting sustainable development, and securing the rights of other neighboring countries ^[17].

Unsustainable development, weak regulatory compliance, and lack of environmental impact-assessment (EIA) studies are seriously threatening the ecosystem along the Gulf's coast. The rapid development of artificial islands in the Gulf between the Arabian Peninsula and Iran has transformed the entire coastline. In the project of Palm Jumeirah, around 94 million cubic meters of sediments were dredged up to make the islands, badly affecting the marine life, as the species of fish were not the same as before the project. The water remained stagnant for weeks, increasing the risk of algal blooms ^[29]. Since 2001, the region has diminished around 70% of its coral reefs and put severe threats on the rest. Due to the poor compliance with legislative and regulatory frameworks in the said projects, environmental assessments could take years to seek approval from Western Union, which might be conducted in ten weeks in the Gulf. Similarly, the lack of environmental monitoring and scientific data in the projects is another area that requires attention ^[30].

United Nations University launched a policy report on human-induced interventions in the coastal marine ecosystems in 2011, in which uncontrolled coastal development and its impacts on marine ecosystems were highlighted ^[29]. These

ecological interventions led to the permanent loss of many fish species. Similarly, pollution due to coastal development can disrupt shore and offshore habitats [31]. Dredged material for coastal development construction can lead to decreased water transparency and accelerate the process of sedimentation. It can also be a source of numerous contaminants that may bioaccumulate in a species and become a part of the food web. Dredged sand has been found to disrupt water-current patterns near the shoreline (**Figure 1**). Several studies revealed that natural patterns of water movement could be disturbed due to construction activities along the coast, such as dredging, that alters sediment distribution. This variation increases the probability of erosion by changing the shape of a shoreline [29].



Figure 1. Interruption in natural sediment drift: the red arrow on the left indicates the increased sedimentation that might modify the natural shape of the shoreline (Source: Umm Suqeim 2 Harbor 25°09'08.01" N and 55°11'50.46" E) [32].

Nearshore habitats play a prominent role in lowering species diversity by affecting their early stages of development. This might increase the probability of lowering the diversity of commercial fisheries; similarly, sedimentation due to developmental activities contributes to high levels of turbidity and is known to alter species composition, leading to stress and badly affecting their growth [33]. High turbidity followed by suspended particles at the top surface of the water badly disrupts the amount of light required for the photosynthesis process to support benthic communities such as seagrasses, algae [19], and sensitive corals. However, the magnitude of these known damages and ecological implications is still unknown because of limited knowledge of artificial islands in the Gulf [34]. **Figure 2** illustrates the environmental implications of an artificial island in the Gulf.

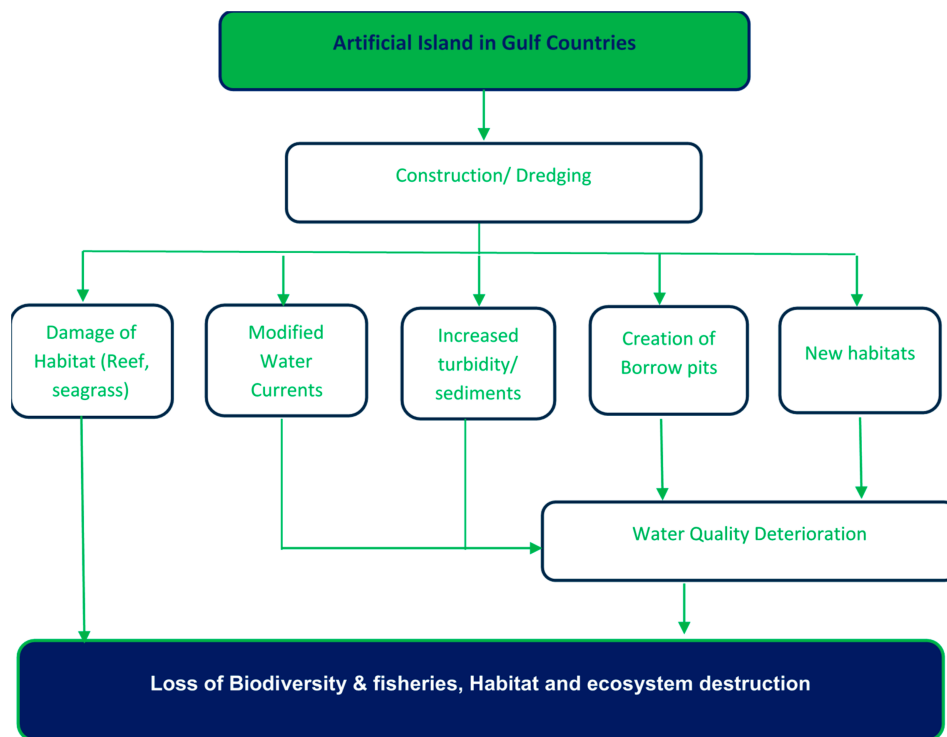


Figure 2. Summary of artificial island developments' impacts on the marine environment.

Over the past five decades, the population of coral reefs has been diminishing at an enormous rate worldwide. Unlike other countries, the Gulf, having 1.5% of the global reef species, is one of the major regions affected by anthropogenic activities; 70% of reef cover is expected to be lost. In contrast, the remaining 27% is on the verge of extinction (see **Figure 3**) [35].

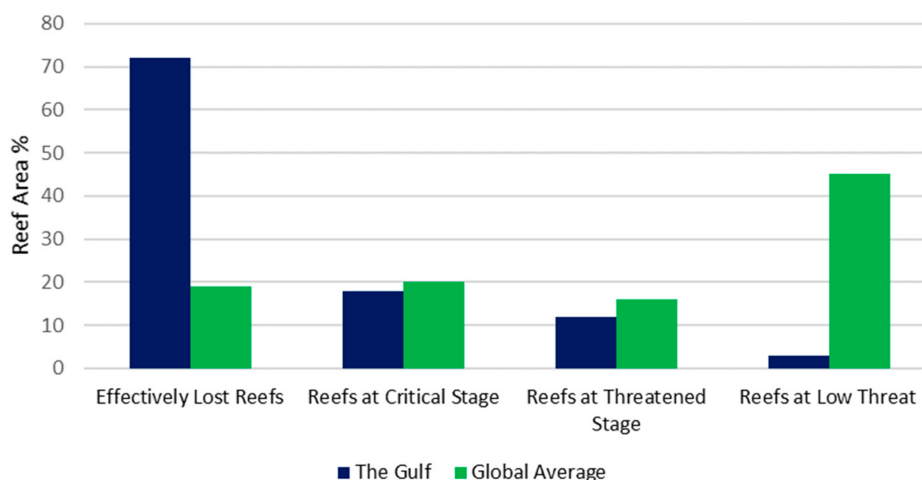


Figure 3. Comparison of reefs affected by anthropogenic activities in the Gulf and at the global level.

Artificial islands and coastal developments are the major contributors to the sedimentation that affects the coral reefs' population. Hence, to overcome this irreversible loss, authorities should heed this very issue before the construction phase of any coastal development projects. Palm Jumeirah is a few miles away from the beachfront; hence, it sought regular monitoring and replenishment activities to tackle intrusions in sediment drift [29].

A similar study was conducted in Bahrain, in which impacts of land reclamation and dredging activities for artificial island developments, waterfront cities, ports, and harbors on the environment of Bahrain were carefully analyzed [36]. The Kingdom of Bahrain consists of a group of almost 40 islands, an archipelago, and various islets and coral reef patches in the Arabian Gulf. Like other island countries, Bahrain is experiencing severe environmental repercussions such as degradation of the coastal and marine environment owing to human-induced interventions [19]. Among many other environmental challenges, the increasing demand for urban infrastructure for several residential, tourist, and other commercial-activity projects is a major threat to Bahrain's coastal and marine ecosystems [9]. Hence, coastal-reclamation activities and artificial island development at regular intervals to reduce the burden of land have significantly deteriorated the marine habitats that include reefs, seagrass, and mangroves, followed by several species of fish. These unsustainable or rapid developments without an adequate framework have affected Bahrain's fish industry. Through remote-sensing

imaging technology, the loss of over 10.2 km² of seagrass beds was registered between 1985 and 1992, whereas a loss of 218,700 m² of corals in the largest reef (Fasht Al-adam) was recorded by [37]. The main reason behind these significant losses is dredging and reclamation activities that, in turn, increase the level of sedimentation and pollution to disrupt the marine environment [38][39].

Another study was conducted in Bahrain to examine the disastrous impact on the species and their habitats due to massive reclamation activities. For this purpose, a microcosm was tested to investigate the response of three common microbenthic invertebrates to mud burial using marine sediment extracted from a nearby burrow. These invertebrates were collected from the proposed reclaimed coastal location. A noteworthy difference in terms of survival was observed during the experiment. Of all the selected species, 41.8% survived. Studying and quantifying species' responses to sediment burial that occurred due to dredging and reclamation activities will help anticipate the ecological impacts of coastal developments. Through this approach, effects associated with coastal intervention are likely to be minimized. This, in turn, will lead to sustainable utilization of coastal and marine ecosystems of the Arabian Gulf [9].

Another state of the Gulf, Qatar, is well known for its complex network of islands and artificial island projects owing to the great interest of investors across the globe. One of the important and valuable artificial islands among others in the heart of the Doha Sea, Qatar, is Pearl Island, a state-of-the-art integrated city. In recent decades, continuous development activities over coastal ecosystems have experienced unprecedented environmental degradation due to massive land reclamation and dredging activities. These unsustainable actions have considerably changed the habitat of coral reefs, oysters, and mangroves and disrupted the seagrass meadows [34]. Due to these activities, the photosynthesis process can be disturbed with increased turbidity, which plays a significant role in clogging fish gills. In addition, coral health affects badly due to less available light for coral communities [40]. Development in coastal areas without considering the habitat, environmental conditions, impact assessments, and restoration plans provides the greatest threats to coral communities, mangrove ecosystems, and many other species such as xerophytes and halophytes [41]. Similarly, during the night, construction activities such as noise due to machinery might distract migratory birds and have the potential to cause collisions. One of the migratory birds in Qatar, the Socotra cormorant, a diving bird of the Al Aliyah Island, was disturbed due to the removal of seagrass during the construction phase [42].

A comprehensive study was conducted using a stakeholder participatory approach to evaluate the detrimental effects of major land-reclamation projects in Doha, Qatar. Pearl Island, Lusail City, and Hamad International Airport are major areas where massive land-reclamation projects have been planned in the recent decade. Stakeholders were divided into six major categories. Most of them had over 20 years of experience in the marine environment. These stakeholders involve officers from the navy, active fishermen, nonactive fishermen, coast guards, government officials, and recreational staff. After deliberate discussions with stakeholders, it was determined that unplanned land-reclamation projects have harmful and damaging impacts on the coastal environment, such as high levels of sedimentation, odor, and turbidity that might disturb the food chain and oxygen level required for the marine life. One of the stakeholders believed that three fish species such as parrotfish, stingrays, greasy groupers, as well as the turtle community, showed a significant decline since construction activities. To effectively manage these emerging impacts, a balanced approach, planned strategy, and a comprehensive study are essential to save nature from the menace of unplanned development in Qatar [43].

2.2. Environmental Impacts of Artificial Island Developments among Other World Countries

Rampant population growth is the omen of land shortage for future generations. Many countries on the map addressed their land-availability issues through land-reclamation activities or by creating new islands to accommodate the inevitable growth. While anticipating the needs of future generations, many other countries have developed artificial islands in coastal areas to ensure the provision of adequate basic necessities. Still, it puts a significant burden on marine ecology [44]. Even highly developed countries face environmental implications due to the development of artificial islands.

A comprehensive study was conducted to identify the environmental ramifications of large-scale dredging activities during the construction of artificial islands in the Netherlands. The adequate methods to maintain water quality, less disruption of bottom sediments and dredging effects on plankton, fisheries, and other bottom fauna, and recovery time of the affected marine ecosystem were discussed. The impact on marine species can be reduced by a comprehensive study of the specific area [45]. China created numerous artificial islands over 3 years, from 2013 to 2015, with a total area of about 3000 acres in the Spratly Islands, South China Sea. Through land-reclamation activities, dredging and construction of artificial islands are not new to China, but the rapid development undermined the biodiversity and ecology of the region. Damaging effects on coral reef communities and the health of fisheries in the South China Sea made China's action one of great concern [46].

A detailed study in China was conducted to assess the dispersal and contamination of heavy metals such as cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), arsenic (As), and mercury (Hg) in the sediments of the Longkou Bay and the artificial island of adjacent areas. Heavy-metal accumulation in the sediments resulted from coastal engineering and reclamation activities. As a consequence of the construction of artificial islands offshore, the natural coastline of Lonkou experienced significant changes in hydrodynamic conditions. It is anticipated that this might affect the tidal fields and lead to erosion around the bay [20].

In Malaysia, rapid coastal land-reclamation activities commenced in the early 1990s due to rapid urbanization and the higher cost of available land in the urban cities. Many artificial islands have been constructed in different parts of the Malaysian state, such as Johar, Malacca, Labuan, and Panang [47]. These artificial island development projects led to severe environmental degradation of the marine ecosystem, in which the most prominent species reported, are coral reefs, seagrass meadows, and mudflats. It is anticipated that this might disrupt faunal biomass in the bottom and change the species composition if appropriate measures are not taken for their recovery. Benthic animal communities are usually more prevalent in the shallower water of coastal zones. Alterations in the ocean floors through reclamation activities are a real threat to the survival of benthic organisms. Similarly, disturbance to bottom sediment while dredging activities or marine sediment extraction might remove epifauna [48]. Degraded ecosystems with varied compositions cannot provide a sufficient environment to sustain aquatic life due to the suspension of heavy metals, organics, and other contaminants [49].

A study was conducted in Barcelona, located along the coast of Spain, to explore the influence of artificial island structures on the waves, currents, and mean water level in the surrounding marine habitat using different numerical simulation models [50]. It was revealed through the findings that when an artificial island is developed, it increases the probability of altering the hydrodynamic conditions of the particular area. These changes and modifications may affect the biotic communities [51]. One modification is the change in sediments that might affect the functionality of the coastal area, such as a significant alteration in wave-energy dissipation. However, wave height is one of the major parameters to determine the effects of artificial islands. An adequate decision-making process can address different situations or minimize the long-term effects through the wave-height model. Another study was conducted in Belgium to highlight the environmental implications of waste processing on artificial island development. The study revealed that the construction of said island resulted in noise, bad odor, and aesthetic issues coupled with water pollution. Therefore, it is recommended to reconsider installing a waste-processing plant on the island so the island can be used for other recreational and commercial purposes [52].

From a detailed overview of the Gulf and other world countries' AID literature, these developments must have severe consequences on the environment. There is a need to manage and strategize the environmental implications of said development at national and global levels. **Figure 4** and **Table 2** represent the geographical distribution of included studies and a comparison of AID environment implications in the Gulf and other world countries.

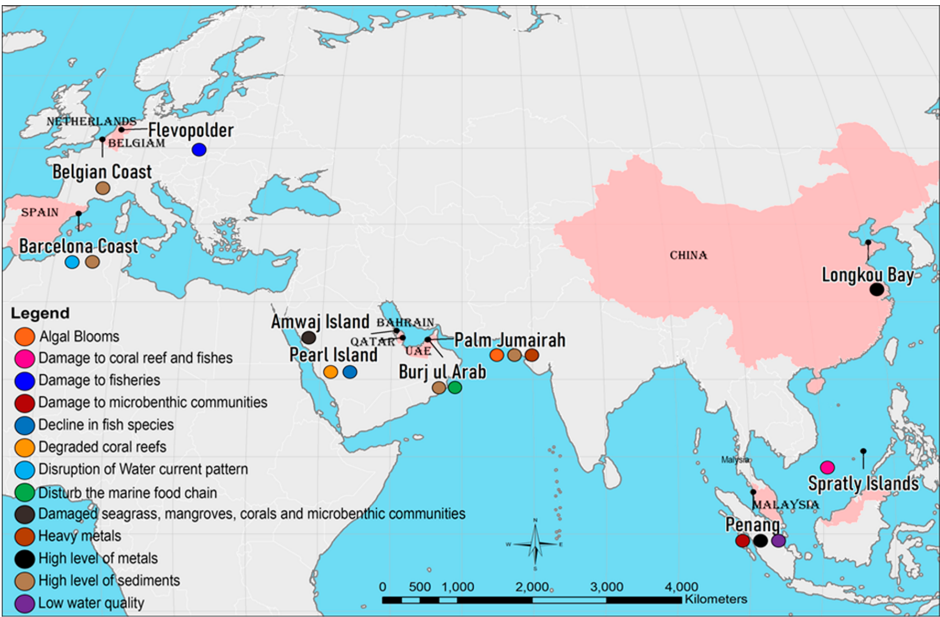


Figure 4. Geographical distribution of included studies and comparison of AID environment implications in the Gulf and other world countries.

Table 2. Geographical distribution comparison with AID environment implications in the Gulf and other world countries.

Country	Artificial Island	Environmental Impact	Reference
Gulf Countries			
Dubai, UAE	Palm Jumeirah	Algal blooms, high level of sediments, heavy metals	[18]
	Burj ul Arab	High level of sediments, disturbed marine food chain	[29]
Bahrain	Amwaj Island	Damaged seagrass, mangroves, corals, and microbenthic communities	[34]
Qatar	Pearl Island	Degraded coral reefs, decline in fish species	[43]
Other World Countries			
Netherland	Flevopolder	Damage to fisheries	[20]
China	Spratly Island	Damage to coral reefs and fishes	[47]
	Longkou Bay	High level of metals	[47]
Malaysia	Penang	Damage to marine life, high level of metals, poor water quality	[50]
Spain	Barcelona	Disruption of water-current pattern, high level of sediments	[52]
Belgium	Belgian Coast	High level of sediments	[53]

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