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Environmental Security of the Gulf During Armed Conflict: Marine Pollution Risks, GCC Preparedness, and a Regional Emergency-Response Framework

ALI ALNUAIMI*

ABSTRACT

The Gulf is a strategically crucial and environmentally vulnerable semi-enclosed marine system supporting petroleum industries, international shipping, desalination facilities, coastal ecosystems, and urban centers. Alongside chronic industrial and maritime pressures, armed conflict introduces severe risks via direct military operations, targeting of energy infrastructure, drone and missile strikes, hazardous material releases, and disruption of monitoring networks. This review evaluates the potential marine pollution consequences of armed conflict in the region, examining historical precedents, pollution pathways, and institutional governance across the member states of the Regional Organization for the Protection of the Marine Environment (ROPME), with specific attention to GCC national preparedness. It proposes treating conflict-driven pollution as a core regional security priority rather than an isolated environmental management concern. To mitigate these risks, the paper introduces the Gulf Environmental Conflict and Emergency Monitoring System (GECEMS), a five-layer response framework integrating real-time satellite surveillance, autonomous marine sensing, oil-spill modeling, standardized data exchange, and post-incident environmental forensics.

Keywords: *Gulf, environmental security, marine pollution, armed conflict, oil spill, GCC, ROPME, desalination*

I. INTRODUCTION

The Gulf is a shallow, semi-enclosed marine environment bordered by eight sovereign states: Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. These eight states are the members of the Regional Organization for the Protection of the Marine Environment (ROPME), and the ROPME Sea Area they define extends beyond the Gulf itself, running through the Strait of Hormuz into the Gulf of Oman. The Gulf exchanges water with the open ocean only through that strait, a restriction that shapes its distinctive ecological character even as the basin supports massive industrial and petroleum operations.

* Author is a Lecturer at Police College, Abu Dhabi, United Arab Emirates.

Despite its modest size, the Gulf sustains a distinctive assemblage of coral reefs, seagrass meadows, mangrove stands, and intertidal mudflats that have adapted to some of the most extreme thermal and saline conditions tolerated by marine life anywhere (Riegl & Purkis, 2012; Samimi-Namin & Hoeksema, 2023). At the same time, the basin has been characterized as “a young sea in decline,” reflecting cumulative pressures from coastal development, dredging and reclamation, industrial discharges, and intensive resource extraction (Sheppard et al., 2010). By the early 1990s more than 40% of the coast of most Gulf states had already been modified by development (Sheppard et al., 2010), and the basin’s slow flushing, with modelled water residence times exceeding three years along the Arabian coast, and shorter along the Iranian coast, magnifies the residence time of any contaminant introduced into its waters (Alosairi et al., 2011). These converging pressures have prompted repeated calls for stronger, ecosystem-based regional management (Sale et al., 2011).

The Gulf’s baseline environmental vulnerability is amplified by physical characteristics including elevated water temperatures, high salinity, shallow average depth, and slow water turnover. These traits cause pollutants to persist longer in the water column and in coastal habitats than they would in open-ocean systems (Samimi-Namin et al., 2026). Concurrently, the region hosts extensive offshore production platforms, pipelines, refineries, export terminals, and dense commercial shipping corridors. An accidental or deliberate event involving oil tankers, energy facilities, desalination plants, or naval assets therefore poses severe risks of large-scale hazardous releases.

While chronic sources of marine contamination, such as industrial discharges, ballast water releases, and coastal reclamation, are well documented (Freije, 2015), military conflict introduces transboundary hazards that bypass standard regulatory controls. Unlike routine discharges, conflict-driven releases are unplanned, potentially simultaneous at multiple sites, and occur under security conditions that delay or prevent response. Geopolitical escalations therefore threaten not only shipping safety and energy infrastructure but the entire architecture of regional environmental governance on which coordinated response depends.

This study addresses a key question: how can Gulf states strengthen environmental protection and cross-border cooperation to prevent, monitor, and mitigate marine contamination arising from armed conflict, infrastructure targeting, and regional instability?

The remainder of this paper is organized as follows. Section 2 describes the methodology; Section 3 reviews the Gulf’s physical vulnerability and baseline pollution; Section 4 examines conflict-driven pollution pathways, beginning with historical precedents; Section 5 assesses

regional governance and national preparedness; Section 6 introduces the proposed GECEMS framework; and Sections 7 and 8 present recommendations and conclusions.

II. METHODOLOGY

This paper uses a qualitative desk-research methodology, synthesizing peer-reviewed scientific literature, international treaty mechanisms, United Nations and UNEP documentation, ROPME institutional reports (ROPME, 2013), and oceanographic oil-spill modeling studies (e.g., Aghajanloo et al., 2025; Garouniatis et al., 2026).

The regional oil-spill modeling literature provides the quantitative backbone for this framework. Early hydrodynamic and weathering packages such as Gulfspill were developed specifically for the Gulf's shallow, wind-driven circulation (Al-Rabeh et al., 2000), and subsequent numerical simulations refined predictions of slick trajectories and oil weathering processes in the basin (Aghajanloo et al., 2013). More recent basin-scale hazard assessments resolve seasonal variability in transport patterns and provide probabilistic maps of coastal exposure that can inform contingency planning (Aghajanloo et al., 2025; Garouniatis et al., 2026). As a structured narrative review, however, this study does not generate primary field data, and its conclusions are bounded by the scope and quality of the published record.

Rather than attempting to calculate the statistical probability of specific military actions, the study applies an environmental risk framework based on the following continuum (Figure 1):

Hazard	→	Exposure	→	Vulnerability	→	Consequence	→	Response Capacity
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Figure 1. The environmental risk continuum applied in this study.

Sources were selected for direct relevance to the ROPME Sea Area, with priority given to peer-reviewed studies and official institutional documents; findings from adjacent basins were used only where regional evidence was unavailable. Throughout, the analysis maintains a clear distinction between:

1. Documented baseline marine pollution.
2. Historically documented military or maritime incidents.
3. Credible physical pathways through which pollutants disperse.
4. Theoretical risk scenarios requiring emergency preparedness.

III. PHYSICAL VULNERABILITY AND BASELINE POLLUTION

A. Environmental sensitivity

The Gulf's ecological assets, including coral reefs, mangrove forests, seagrass beds, and intertidal flats, provide vital ecological services and support commercial fisheries. Restricted hydrodynamics and environmental stressors such as high sea surface temperatures and emerging hypoxia lower the threshold at which ecosystems suffer irreversible degradation from chemical contaminants (Samimi-Namin et al., 2026).

Coral communities in the Gulf persist near the physiological limits of reef-building organisms and are widely regarded as natural laboratories for thermal adaptation (Riegl & Purkis, 2012). Seagrass meadows covering roughly 7,000 km² support penaeid shrimp fisheries, pearl oyster beds, and the world's second-largest dugong population (Erftemeijer & Shuail, 2012). Climate change compounds these baseline stresses: niche modeling under a business-as-usual scenario projects local extinction of up to 35% of initial species richness in parts of the Gulf by 2090, with fish catch potential in Qatar and the United Arab Emirates declining by more than a quarter (Wabnitz et al., 2018). Expanding seasonal hypoxia in the deeper basin and the Strait of Hormuz further reduces ecological resilience to chemical insults (Saleh et al., 2021).

B. Chronic contamination pathways

Existing pollution originates from offshore crude extraction, coastal petrochemical production, municipal wastewater discharges, and high-density maritime traffic. Elevated levels of petroleum hydrocarbons, trace heavy metals, and persistent organic contaminants are documented across multiple Gulf marine protected areas and coastal sediments (Freije, 2015; Ghaemi et al., 2024).

Localized hotspots of chronic metal contamination are consistently reported near industrial facilities, desalination plants, and refineries, even where basin-wide averages remain moderate (Naser, 2013). Sediment profiles from marine protected areas in the northern Gulf likewise record measurable burdens of heavy metals and persistent organic pollutants (Ghaemi et al., 2023). Desalination itself adds a distinctive chronic pressure through thermal and brine discharges containing biocides, anti-scalants, and corrosion products (Lattemann & Höpner, 2008). This contaminated baseline matters for conflict scenarios: any wartime release would be superimposed on ecosystems already carrying a measurable pollutant burden, complicating both ecological recovery and forensic attribution.

IV. CONFLICT-DRIVEN POLLUTION PATHWAYS

A. Historical precedents: the 1991 Gulf War

The 1991 Gulf War remains the largest marine oil release on record and the region's defining precedent. An estimated 6–8 million barrels of crude oil entered Gulf waters, while more than one billion additional barrels were consumed in the Kuwaiti oil-well fires (Vogt, 1995; Westing, 2013). Rapid assessment surveys conducted from Kuwait to Oman in mid-1991 found that severe oiling was largely confined to approximately 400 km of the Saudi Arabian coastline and that the spilled oil weathered considerably faster than initially feared (Readman et al., 1992). Comparative pre- and post-war measurements of hydrocarbons and trace metals in nearshore sediments and biota documented both the contamination pulse and its subsequent decline (Fowler et al., 1993; Al-Abdali et al., 1996). Ecological outcomes were heterogeneous: coral reefs on the Saudi Arabian coast survived largely unscathed (Vogt, 1995), whereas polycyclic aromatic hydrocarbon signatures remained measurable in shoreline sediments more than a decade after the event (Bejarano & Michel, 2010). The crisis also produced institutional innovation, including the establishment of a marine wildlife sanctuary along the affected Saudi coast (Krupp & Jones, 1993), and it remains the most comprehensively documented case study of conflict-driven marine pollution (Sadiq & McCain, 1993). The 2003 Iraq war subsequently reinforced the need for systematic post-conflict environmental assessment in the region (UNEP, 2003).

B. Vulnerability of energy and maritime infrastructure

Military operations and strikes using precision weapons, first-person-view (FPV) drone attacks, or naval mines create environmental hazards distinct from routine industrial releases (Figure 2). Critical pathways include:

- Damage to offshore drilling rigs, seabed pipelines, and coastal refineries.
- Direct targeting, grounding, or sinking of crude oil tankers and chemical vessels.
- Destruction of port facilities, causing concurrent releases of bunker fuel, hazardous chemicals, and fire-suppression runoff.
- Unexploded ordnance and underwater mine deployments along commercial shipping routes.

Each of these pathways differs from routine industrial discharge in tempo and scale. Strikes can rupture multiple containment barriers simultaneously, disable the very facilities that would normally lead the response, and create security conditions under which spill-response vessels

cannot safely operate. Unexploded ordnance and mines additionally impede access to affected waters, delaying containment during the critical early hours when a slick is still concentrated and recoverable.

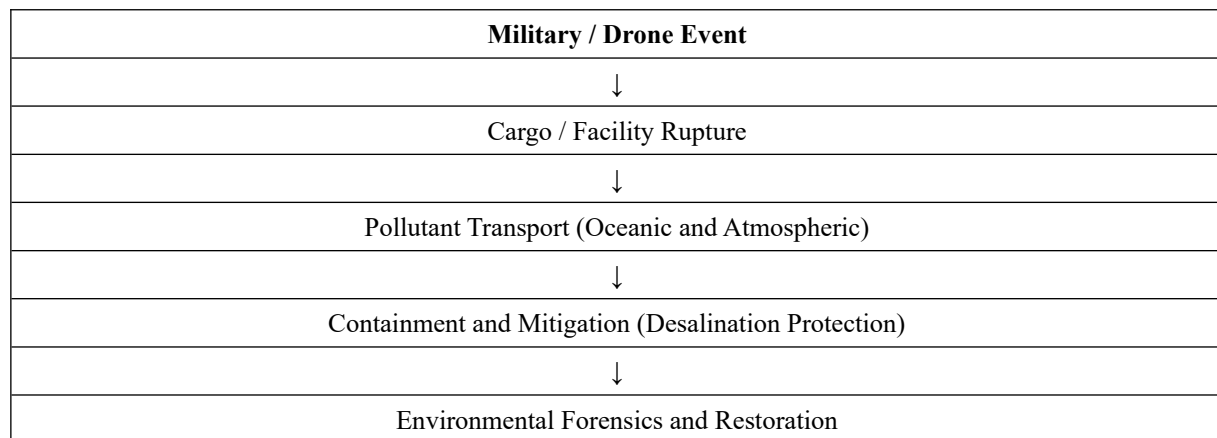


Figure 2. Conflict-driven marine pollution event chain and response sequence.

C. Threat to desalination and water security

The Gulf has long been the most intensive center of seawater desalination worldwide (Lattemann & Höpner, 2008), and desalination plants supply a large share of potable water across the GCC states. Hydrocarbon slicks or dissolved chemical contaminants near seawater intake zones threaten national water supplies. Contamination of intake water, or damage to the intakes themselves, can disrupt drinking-water production and force desalination plants offline (Samimi-Namin et al., 2026). Unlike ecological damage, which unfolds over months or years, an intake shutdown is felt within days in municipal supply networks, giving water security the shortest response horizon of any consequence examined in this review. During periods of regional tension, even unverified reports of slicks near intakes can trigger precautionary shutdowns, so the water-security cost of conflict includes false alarms as well as actual contamination, a dynamic that places a premium on fast, credible verification capability.

V. REGIONAL GOVERNANCE AND PREPAREDNESS GAPS

A. The existing ROPME framework

The legal basis for regional environmental protection rests on the 1978 Kuwait Regional Convention for Co-operation on the Protection of the Marine Environment from Pollution and its companion Protocol concerning Regional Co-operation in Combating Pollution by Oil and Other Harmful Substances in Cases of Emergency, both adopted at Kuwait in April 1978 and in force since 1 July 1979 (UNEP, 1978a, 1978b). ROPME coordinates technical initiatives among member states (ROPME, 2013). These regional instruments operate alongside the global International Convention on Oil Pollution Preparedness, Response and Co-operation, adopted

in 1990 and in force since 1995 (IMO, 1990). However, traditional environmental agreements were designed for commercial shipping accidents, not rapid military escalations or targeted infrastructure attacks. Post-conflict environmental assessments conducted after the 1991 and 2003 wars illustrate both the value and the limitations of ad hoc international responses mobilized only after damage has occurred (Sadiq & McCain, 1993; UNEP, 2003).

B. Breakdown of environmental governance during conflict

Effective marine emergency response depends on continuous data streams: baseline water quality, vessel movements, current and wind fields, and habitat condition. Armed conflict interrupts these flows precisely when they are most needed. Geopolitical friction often degrades environmental monitoring capabilities through:

- Interruption of transboundary scientific data exchange and joint research.
- Security-related restrictions on research vessel deployments and field sampling.
- Disruption of laboratory supply chains and environmental agency operations.

These consequences are not hypothetical. Documentation gaps that followed past regional conflicts complicated damage assessment and compensation claims for years afterwards, underscoring the operational cost of interrupted monitoring (Westing, 2013). Because environmental data collection in the Gulf depends heavily on cross-border scientific cooperation, geopolitical rupture degrades precisely the information systems on which effective emergency response depends (Sale et al., 2011).

C. GCC state preparedness strategies

National preparedness postures across the GCC share common building blocks, namely satellite surveillance, contingency planning, and protection of desalination intakes, but differ in emphasis according to each state's coastal geography, industrial profile, and exposure to shipping lanes:

- United Arab Emirates: prioritizing continuous coastal water monitoring, satellite oil-slick detection, and integration of environmental authorities with maritime security centers.
- Saudi Arabia: strengthening containment capabilities near primary export terminals, expanding offshore surveillance, and protecting desalination intakes along the Eastern Province.
- Kuwait: enhancing hydrodynamic spill modeling, monitoring sediment contamination, and updating contingency response plans.

- Qatar: expanding environmental monitoring around major natural gas and petrochemical offshore infrastructure.
- Bahrain: focusing on rapid water-quality testing, early-warning slick detection, and protection of local fisheries.
- Oman: maintaining surveillance over major deep-water shipping corridors and international vessel transit routes.

These national efforts, while increasingly sophisticated, remain largely uncoordinated at basin scale. Because pollutant transport in the Gulf is inherently transboundary (Al-Rabeh et al., 2000; Garouniatis et al., 2026), unilateral preparedness cannot substitute for interoperable regional response capacity, which is the gap the framework proposed in the next section is designed to close.

VI. PROPOSED GULF ENVIRONMENTAL EMERGENCY FRAMEWORK

To modernize regional emergency capabilities, this paper proposes the Gulf Environmental Conflict and Emergency Monitoring System (GECEMS). The framework builds directly on capabilities demonstrated in the regional literature: operational spill models calibrated for Gulf conditions (Al-Rabeh et al., 2000; Garouniatis et al., 2026), in-situ observation of temperature, salinity, and dissolved oxygen already motivated by the basin's expanding hypoxia (Saleh et al., 2021), and biodiversity baselines that remain incomplete for large parts of the basin (Samimi-Namin & Hoeksema, 2023). Its five layers are summarized in Table 1.

The layers are designed to operate as an integrated pipeline rather than as parallel programs. Satellite surveillance (Layer 1) and maritime tracking (Layer 2) provide wide-area detection and anomaly cueing; autonomous in-situ sensors (Layer 3) confirm and quantify contamination at specific locations, including desalination intake zones; predictive modeling (Layer 4) converts confirmed detections into trajectory and impact forecasts; and the regional emergency hub (Layer 5) translates forecasts into standardized notifications to military, coast guard, environmental, and water-utility authorities. Critically, the system is dual-use: the same infrastructure that monitors conflict-driven releases serves routine needs such as harmful algal bloom warning, hypoxia tracking, and shipping-accident response, which strengthens the case for sustained peacetime funding.

Layer	Component	Core Operational Function
Layer 1	Satellite Surveillance	Optical and Synthetic Aperture Radar (SAR) detection of surface slicks, fires, and infrastructure damage.

Layer	Component	Core Operational Function
Layer 2	AIS and Maritime Tracking	Monitoring abnormal vessel maneuvers, sudden signal loss, and proximity to sensitive ecosystems.
Layer 3	Autonomous In-Situ Sensors	Buoy networks monitoring sea temperature, salinity, dissolved oxygen, turbidity, and hydrocarbons.
Layer 4	Predictive Modeling	Coupled hydrodynamic and atmospheric forecasting to model spill trajectory and impact timing.
Layer 5	Regional Emergency Hub	Standardized notification protocols connecting military, coast guard, and environmental authorities.

Table 1. The five layers of the proposed Gulf Environmental Conflict and Emergency Monitoring System (GECEMS).

A. Environmental forensics and eDNA baselines

To assign responsibility and evaluate post-conflict ecological damage, states must implement standardized environmental forensic protocols. Hydrocarbon fingerprinting and chain-of-custody sampling enable authorities to distinguish newly introduced military pollution from pre-existing background levels. Concurrently, baseline environmental DNA (eDNA) profiling should be established across critical marine habitats to measure biological recovery over time. Legacy studies from the 1991 spill demonstrate the feasibility of long-term forensic attribution: hydrocarbon signatures in shoreline sediments remained diagnostically distinct twelve years after the event (Bejarano & Michel, 2010). Establishing such baselines before a crisis, rather than reconstructing them afterwards, is the single most cost-effective investment states can make in post-incident accountability.

VII. RECOMMENDATIONS

1. Establish a ROPME conflict emergency center: form a specialized sub-unit focused specifically on conflict-related environmental risks and real-time response coordination. A standing unit with pre-negotiated mandates would compress the mobilization time that ad hoc arrangements consumed in past regional crises.
2. Implement early-warning desalination buffers: install automated sensor arrays around critical water intakes to provide immediate shutdown alerts during contamination events. Because intake protection decisions are currently made plant by plant, regional alerting would convert scattered observations into actionable lead time.

3. Formalize environmental forensic protocols: adopt shared regional procedures for post-incident water, sediment, and biological sampling. Common chain-of-custody standards would ensure that evidence collected by any member state supports regional and international claims processes.
4. Institutionalize joint drills: conduct annual multinational emergency simulations modeling complex scenarios, such as combined drone attacks and commercial tanker ruptures. Exercises should rotate among member states and include desalination operators, port authorities, and naval commands alongside environmental agencies.
5. Separate environmental data sharing from political disputes: draft protocols that guarantee open exchange of unclassified marine health and pollution tracking data during periods of diplomatic tension. Ring-fencing environmental data exchange from political disputes would preserve the scientific baseline on which post-incident attribution and recovery assessment depend.

Taken together, these five measures would give the Gulf states a standing capability to detect, model, and respond to conflict-driven marine pollution within hours rather than weeks, and to document environmental harm to the evidentiary standard that compensation and accountability mechanisms require.

VIII. CONCLUSION

Environmental security in the Gulf is inextricably linked to energy stability, maritime security, and national water supplies. The evidence reviewed here shows that the region combines exceptional ecological vulnerability with exceptional exposure: a shallow, slowly flushed sea already burdened by chronic contamination, hosting the world's densest concentration of desalination infrastructure, in one of its most conflict-prone maritime corridors. The 1991 precedent demonstrates both the scale of damage armed conflict can inflict and the decisive value of rapid, credible scientific assessment. While the region possesses an established legal infrastructure through the Kuwait Convention and ROPME, modern conflict dynamics require upgraded technological and organizational tools. Deploying integrated monitoring systems such as GECEMS, establishing robust forensic baselines, and maintaining cross-border scientific data exchange are essential steps to safeguard the Gulf's marine ecosystem and regional water security. Future work should extend this framework in two directions: quantitative scenario modeling that couples specific strike locations with seasonal circulation patterns, and institutional analysis of how a conflict-focused emergency mandate can be embedded within ROPME's existing legal architecture.

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