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Cracow University of Technology

Congress on Ecology and Energy · Kraków

PKE 80

Fifty Years of Coastal Urbanization and Environmental Change in the Persian Gulf

Ecological Lessons for International Research and Cooperation

Figures and data throughout: Dahy, Al-Memari, Al-Gergawi & Burt (2024), Front. Remote Sens. 5:1422910 — CC BY 4.0

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FRAMING

Why this case belongs in a congress on ecology and energy

A sea that runs on energy

About 21 million barrels of oil a day pass through the Gulf. The same coastline hosts the desalination plants, ports and power stations that make the cities there possible.

A sea that is already extreme

12 °C to 36 °C annually, hyper-saline, shallow (mean 30 m), semi-enclosed. Its organisms live at the edge of their tolerance before any human pressure is added.

A sea we can only see from orbit

Eight states, no shared monitoring system, restricted field access. Satellite remote sensing is the only instrument that crosses those borders consistently.

This is why an ecology congress and an energy congress are, on this coastline, the same congress.

AGENDA

Route of the talk

01 **The setting**
Fifty years of growth on an energy coastline

02 **The method**
A PRISMA systematic review of 186 studies

03 **Where the evidence is**
Temporal, spatial and thematic distribution

04 **What the cities did**
Urban growth, reclamation, coast by coast

05 **What the ecosystems did**
Habitats, pressures and state changes

06 **What follows**
Fifteen recommendations, and a Kraków connection

THE FINDING IN ONE SENTENCE

We have spent fifty years measuring what was lost. We have barely begun to use the same data to decide what gets built.

186

peer-reviewed remote-sensing studies, 1971–2022, across eight Gulf states

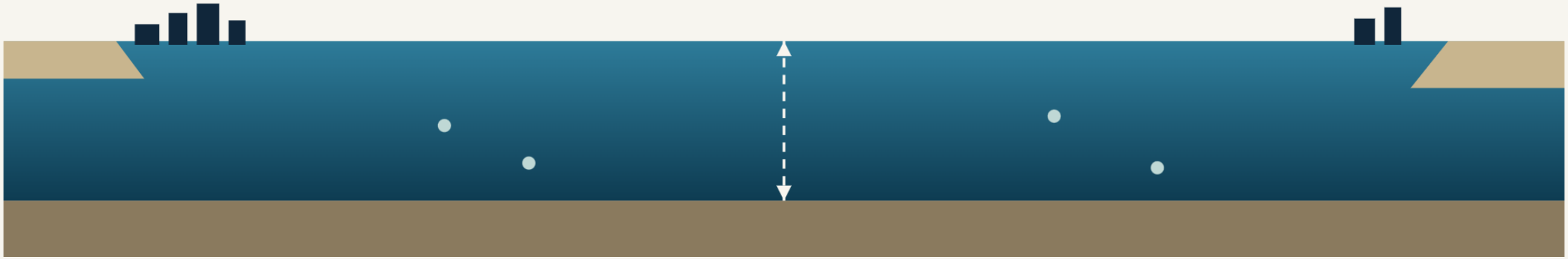
2

of those studies used remote sensing for a site-suitability assessment to guide planning

PART ONE
THE BASIN

The setting

One of the most extreme seas on Earth — before we arrive



Dahy, Al-Memari, Al-Gergawi & Burt (2024), Front. Remote Sens. 5:1422910 — CC BY 4.0

30 m

mean depth — a shallow, semi-enclosed basin with slow exchange through the Strait of Hormuz

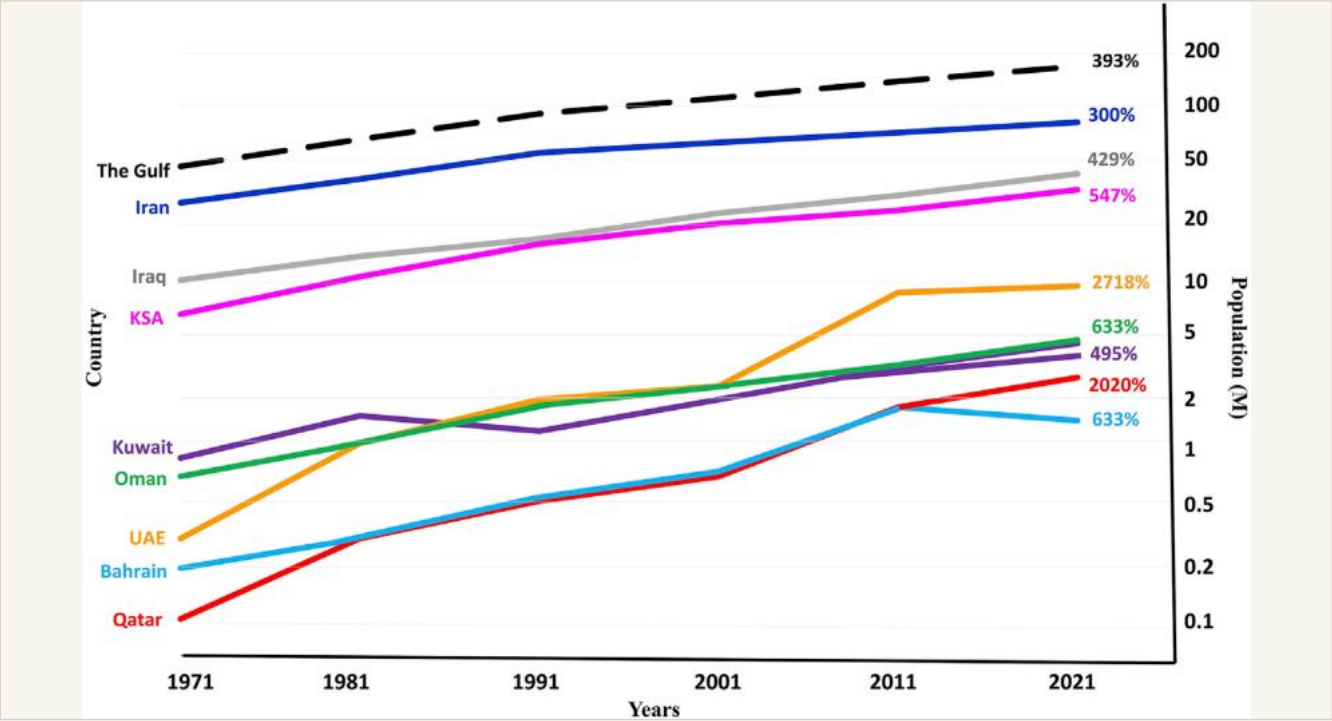
12–36 °C

annual sea-surface temperature range; among the most variable and severe on Earth

4×

population of the eight Gulf states, 1971–2021: from 48 million to 189 million

Forty-eight million to one hundred eighty-nine million, in fifty years



Growth is not evenly shared. Iran and Iraq dominate in absolute numbers; the smaller Gulf states grew fastest in *rate*, driven by labour migration after the oil boom.

Urbanization here is not new — Dilmun in Bahrain dates to 3000 BC, Umm Al-Nar in Abu Dhabi to 2800 BC. What changed after oil is the **rate** and the **form**.

The planning consequence: almost all of this growth landed within a few kilometres of the shoreline.

Dahy et al. (2024), Frontiers in Remote Sensing, 5, 1422910. CC BY 4.0.

The Manufactured Coastline: A New Urban Type

Mega-project	Country	Form	Documented coastal effect
Palm Islands · World Islands	UAE	Offshore reclaimed archipelago	**Dubai** reclaimed >**68 km²** since the early 2000s
The Pearl	Qatar	Reclaimed island district	Part of Doha's 10 km² of dredge-and-fill, 1972–2002
Durrat Al Bahrain	Bahrain	Reclaimed resort islands	National land area 695 km² (1989) → 814 km² (2018)
Sabah Al Ahmad City	Kuwait	Canal city on the coast	Coastline length 339 km → 479 km, 1972–2011
Lulu, Saadiyat, Yas, Al Reem	UAE	Island urban extensions	New land = c. 16% of Abu Dhabi's land area, 1972–2000

These are not buildings placed on a coast. They are new coasts, built to be built on.

SPATIAL LOGIC

Urbanization is a gradient, and it is steepest at the water

‘At-coastal’ — c. 2.5 km

Highest built-up intensity and the earliest onset of urbanization. Directly overlaps the intertidal habitat belt.

‘Near-coastal’ — c. 20 km

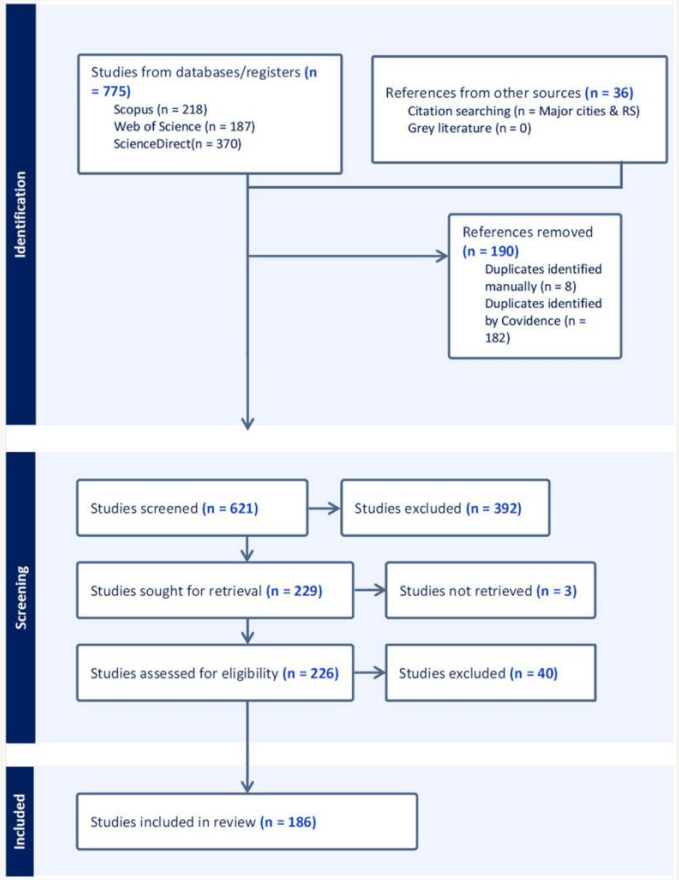
Second wave. Industrial estates, desalination and power plants, logistics.

‘Far-coastal’ — c. 46 km

Latest and thinnest. Desert hinterland, still functionally tied to the coastal city.

Zone definitions after Al-Ruzouq et al. (2022), as synthesised in Dahy, Al-Memari, Al-Gergawi & Burt (2024), Front. Remote Sens. 5:1422910 — CC BY 4.0

Method — From 651 Records to 186 Studies



Three databases
190 duplicates removed
186 studies included

Criterion	Included	Excluded
Marine province	Arabian / Persian Gulf	Anything outside the Gulf
Country	All eight bordering states and their urban centres	Countries and cities that do not border the Gulf
Topic	Remote-sensing methods applied to coastal zones	No remote sensing, or no coastal focus
Type	Peer-reviewed journal articles	Reviews, book chapters, policy reports, editorials, conference papers
Language	English or Arabic	All other languages
Time frame	All papers published up to 2022	Papers published after 2022
Structure	Accessible full text	Abstract only

Inclusion and exclusion criteria

Dahy et al. (2024), Frontiers in Remote Sensing, 5, 1422910. CC BY 4.0.

A shared sea, studied one country at a time

MOST STUDIED

Iran	22.6%
United Arab Emirates	22.6%
Entire Gulf (regional)	15.6%
Saudi Arabia	11.8%
Kuwait	11.3%

LEAST STUDIED

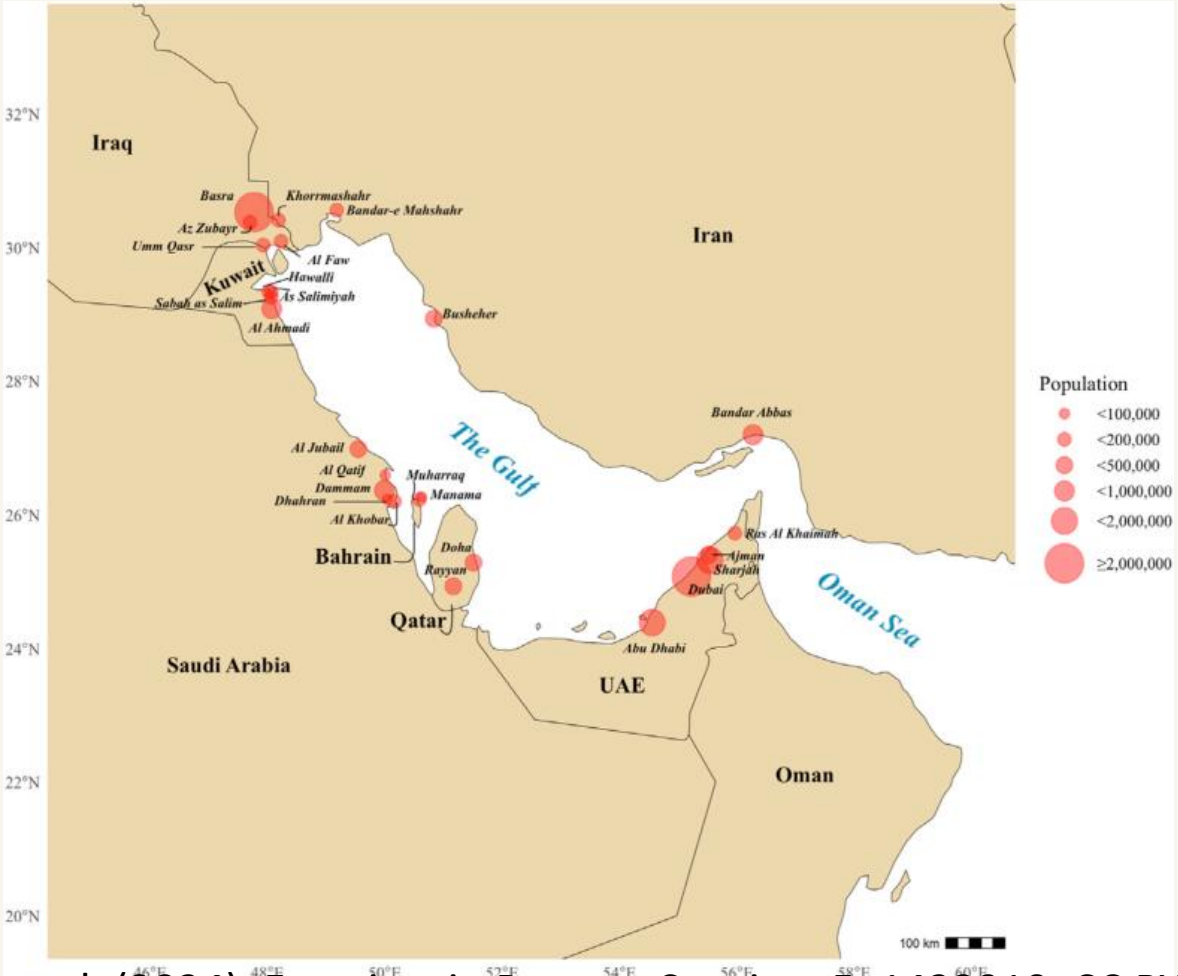
Qatar	low
Bahrain	low
Oman (Musandam)	low
Iraq	lowest
—	—

The structural problem

Research is **siloed inside national borders**. Only 15.6% treats the Gulf as one system — and most of that is chlorophyll and sea-surface temperature, because those products come ready-made from MODIS.

The water does not respect the borders. Iraqi and Iranian river sediment, and desalination brine from every state, cross them daily.

Twenty-six major urban centres on one shared shoreline



~15 M

people in the coastal urban centres — about 8% of everyone living within 50 km of the coast

The Arabian side — Kuwait, Bahrain, Qatar, the UAE — is heavily urbanized and holds most of its national population on the coast.

The Iranian side is different: lower densities, slower growth. Only Bandar Abbas exceeds half a million; Bushehr, Bandar-e Mahshahr and Khorramshahr exceed 100,000.

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Southern coast — UAE and Qatar: the fastest urban transformation on record

City · coast	Period	Finding	Character of growth
Bahrain main islands · W	1986–2020	+7.5% / yr; built-up now c. 40% of the islands	Reclamation-led
Dammam, KSA · W	1985–2019	+7.8% / yr; +42.5 km², over 25 km² of it in 2015–2019	Inland — blocked from the coast
Al-Khobar, KSA · W	1990–2013	+117% (1990–2001), then +43.5% (2001–2013)	Decelerating
Eastern KSA coast · W	1992–2013	+31%, +19%, +37% in successive 7-year steps	Pulsed, not smooth
Kuwait · N	1972–2011	+205 km²; urban 32.5% → 53% of national area by 2021	**Bare soil** → urban; coast-polarizing
Basra, Iraq · N	1990–2020	+218 km²; only 1.2% / yr in 1990–2003	**Vegetation** → urban

City	Period	Built-up change	Rate
Ajman, UAE	1975–2015	c. 12-fold increase	over 40 years
Abu Dhabi, UAE	1972–2003	c. 7.5-fold; 20 km² → 257 km² by 2000	over 31 years
Dubai, UAE	2000–2015	96 km² → 624 km²	10% / yr since 1972; +31 km² / yr after 2000
Doha, Qatar	1987–2013	106 km² → 421 km² (+315 km²)	5.5% / yr; peak >13% / yr in 1998–2003
Doha, Qatar	1972–2002	only +35 km² before the millennium	then ×3 in 13 years, 1997–2010

The southern coast is only **20% of the Gulf shoreline** but produced **39.5%** of all coastal-urbanization studies. Attention follows capital.

Two different machines: in the GCC cities, desert is converted to city. In Basra, farmland and vegetation are converted to city — a different ecological ledger entirely.

The Iranian coast — the longest shoreline, the thinnest urban record

Bandar Abbas · 1956–2012
Built-up area c. 4 km² → c. 50 km² — more than a tenfold increase over 56 years. Peak growth 123% in 1975–1987; minimum 29% in 2001–2012. Multi-source study using historical aerial photography.

Qeshm Island · 1996–2014
Time-series Landsat with on-screen digitizing. Significant built-up growth; mangrove disturbance mapped at five levels, from 202 km² of very low to 35 km² of very high disturbance.

The whole Iranian Gulf coast: two cities studied

Iran holds the longest Gulf coastline. Iranian researchers produced the joint-largest share of *all* Gulf remote-sensing studies — 22.6%.

But on **coastal urbanization specifically**, only two urban centres have ever been studied: Bandar Abbas and Qeshm.

Drivers named in the literature: construction demand, population growth, rural–urban migration. Bushehr, Bandar-e Mahshahr, Khorramshahr, Bandar Lengeh: essentially unstudied.

Manufacturing land: the reclamation ledger

119 km²

cumulative land reclaimed along the entire UAE coast — Dubai alone 68 km² (over 70%), Abu Dhabi 35 km², Ras Al Khaimah c. 7 km²

91 km²

reclaimed in Bahrain, 1963–2008 — peaking at 21 km² per year between 1997 and 2007

10 km²

added to Doha's coastal area by reclamation and dredging, 1972–2002

Muharraq, Bahrain

Coastline area expanded from 35 km² to 166 km² between 1951 and 2007 — a 4.7-fold enlargement of a single island.

Abu Dhabi

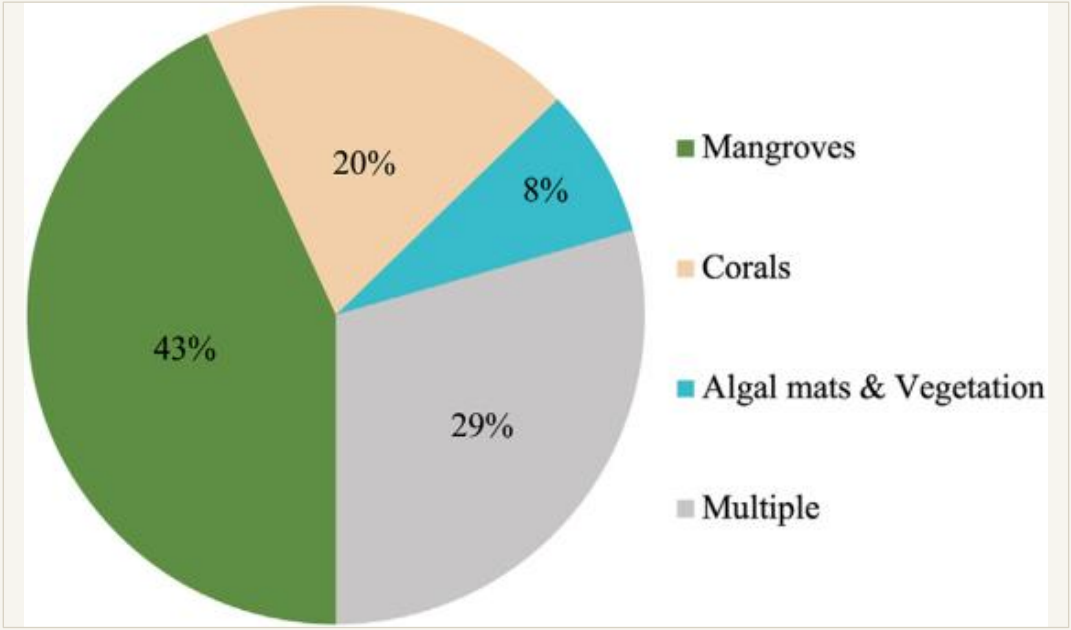
New land in Abu Dhabi waters amounted to about 16% of the total land area between 1972 and 2000.

The ecological accounting

Reclamation removes shallow seabed — seagrass, algal mat, nursery ground — and the dredging plume degrades water quality far beyond the footprint.

What the ecosystems did

What Is Easy to Observe Can Shape What We Study



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Mangroves 43% — tall, dense, spectrally distinctive. Easy for a satellite.

Multiple habitats 29% — combined mapping exercises.

Coral reefs 20% — high biodiversity value drives attention despite the difficulty.

Algal mats and tidal vegetation 8%. **Seagrass: never studied on its own** — always as part of a mixed class.

Yet seagrass covers roughly **27% of the Qatar shelf** alone and is flagged as high-risk.

Mangroves: the measured ledger of loss — and one recovery

Site	Period	Change	Attributed cause
Ras Tubli, Ras Sanad, Sitra · Bahrain	1967–2020	3.3 km² → 0.5 km² (−95%)	Reclamation, urban expansion
Tarut Bay, Qatif · KSA	1986–2021	c. 13 km² → c. 4.5 km²	Landfill; continuous tree cutting
Abu Dhabi · UAE	1990–2006	Successive declines of c. 2.9 and 2.2 km²	Reclamation and dredging
Al-Khafji to Dammam · KSA	—	Significant loss, esp. Jazirat Al Kazzami	1991 Gulf War oil spill; oil transport
Khor Al Bazam · UAE	—	Increase	Planting, shipyard closure, public awareness

Iran holds 48% of the Gulf's mangrove extent; the UAE 40%.

Corals and seagrass: the difficult habitats

Coral reefs — 11 studies in fifty years

Six from Iran, three UAE, one Qatar, one Kuwait. Drone imagery outperformed satellites: it distinguished coral types and visually detected bleaching, cost-effectively. QuickBird mapping of Kish Island reached 89.2% accuracy.

Reef communities are just **2% of the Qatari sea bottom**. In Kish, 28% of corals were identified as bleached over 2005–2008.

Counter-intuitive result: UAE corals showed **resilience to extreme SST** — already adapted to a sea at the thermal limit.

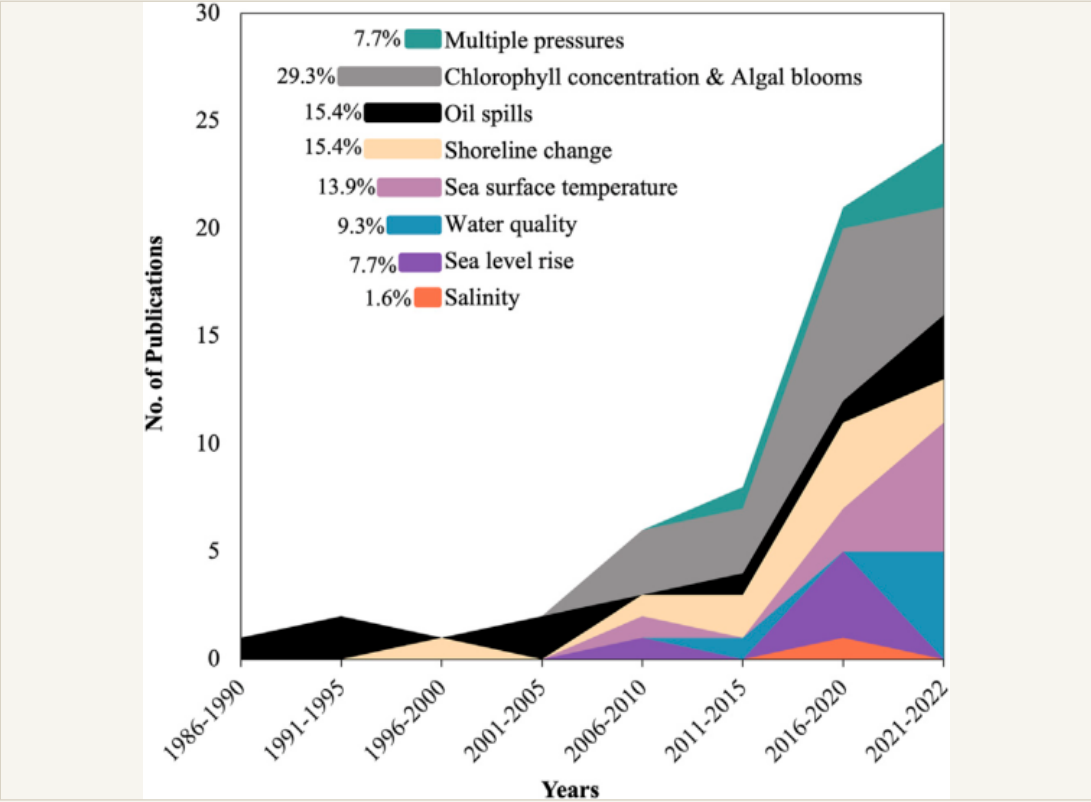
Seagrass — no dedicated study at all

Only ten studies touch it, all on the southern and western coasts. None on the northern or Iranian coasts.

Bahrain, 1963–2008: reclamation and dredging cut seagrass by **23.5%**, and the mixed sand–seagrass–algae class by **34%**.

Northern UAE: c. 21.6 km² mapped across Ras Al Khaimah and Umm Al Quwain — the only regional figure we have.

The largest category — and the one that began with a war



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29.3% chlorophyll and harmful algal blooms — mostly Gulf-wide, using MODIS

15.4% shoreline change — mostly Iran, then Kuwait

15.4% oil spills — mostly Saudi Arabia and Iran

13.9% sea-surface temperature

9.3% water quality · **7.7%** multiple · **1.6%** salinity

> The field was founded by the January 1991 Gulf War oil spill. Environmental remote sensing here begins as **disaster response** — and has never entirely stopped being that.

Four pressures that planning and design can help address

Desalination · the energy–water–heat loop

Thermal desalination discharge alters both water quality **and** sea-surface temperature. Brine is hotter and saltier; the effect is measurable in the surrounding water.

Reclamation · the turbidity plume

After Palm Jumeirah, water reflectance in the 0.5–0.8 µm range rose — the spectral signature of suspended sediment, far beyond the project footprint.

Rivers · the transboundary flux

In the Zohreh delta, Iran, 80% of sediment is carried into the Gulf's subtidal zone; 20% is deposited at the river mouth. Land-use change upstream moves sediment downstream, across borders.

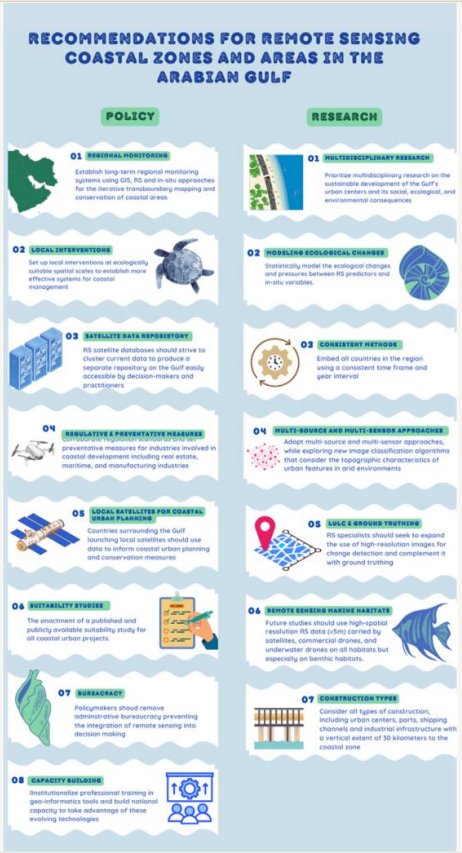
Shoreline · erosion and accretion

In Hormozgan, c. 25% of 2,240 km of shoreline is highly vulnerable to erosion. In the UAE, maximum erosion at Umm Al Quwain and Ras Al Khaimah; maximum accretion at Abu Dhabi.

Sea level rose 120–150 mm over 40–50 years in Kuwait — but erosion there was worsened by beach houses built near the high-water line and by slipways blocking littoral sand transport. Design decisions, at the scale of a plot.

THE AGENDA **What follows**

From Monitoring Change to Guiding Change



Key recommendations for policy, planning and research

1. One monitoring system for one sea. Long-term, transboundary RS + GIS + in-situ, mapping hotspot zones across all eight states.

2. An open Gulf data repository, GIS-compatible, usable by decision-makers — not only by researchers.

3. Published suitability studies required for every coastal urban project, before approval.

4. Operational thresholds — e.g. stop-work turbidity limits near dredging, verified from orbit.

5. National capacity — institutionalised geo-informatics training, and regional satellites turned toward planning.

THE SHIFT THE FIELD NEEDS

From describing the past to deciding the future

TODAY

Descriptive

Measure, map, monitor. Post-classification comparison of two dates. Publish the loss.

NEXT

Statistical

Model the relationship between RS predictors and in-situ variables. Explain, do not only record.

GOAL

Predictive & prescriptive

Future scenarios of coastal vulnerability. Site selection for restoration — and for sustainable urban expansion.

One study area, one time frame, one interval for all eight coasts — so growth rates can finally be compared.

Beyond pixels: machine learning and object-based classification using shape, adjacency and topography — not spectra alone.

<5 m resolution and drones, with ground truth, over a 30 km coastal band — ports and marine infrastructure included.

Where this meets my own work — and this Faculty

My doctoral research reads the spatial logic of historic urban fabric — the bazaar of Hamadan — using **Space Syntax**, **Conzenian morphology** and **GIS**, with Kraków's Rynek Główny as the comparative case.

That work and this review meet at one question: **how does the geometry of a settlement determine what it does to its environment — and what its environment does to it?**

Remote sensing gives us the *extent* of change. Morphology gives us the *reason*. Neither is sufficient alone.

Three potential contributions from Kraków

Morphological method. The Faculty's tradition of reading historic urban form is exactly the missing layer in a literature that counts pixels but never asks about fabric.

Climate-adaptive precedent. Compact, shaded, low-energy historic fabric — bazaar and Old Town alike — as a tested model for extreme-climate cities.

A neutral academic platform. Eight states will not easily build a shared monitoring system alone. A European university can convene what the region cannot.

CONCLUSION

Three things to take away

01 **One Gulf, one interconnected ecological system**

Only 15.6% of fifty years of research treats the Gulf as a single basin. Sediment, brine and oil cross the borders daily; our methods do not.

02 **We measured the loss; we did not guide the building**

186 studies, 2 suitability assessments. The instrument is pointed backwards. Turning it forwards is a decision, not a technical problem.

03 **Environmental decline is not always irreversible**

Khor Al Bazam’s mangroves recovered when policy changed. Two open-data decisions produced more science than thirty years of funding. Decline here is a choice, not a law.

SOURCES

References and credits

Primary source of this presentation

Dahy, B., Al-Memari, M., Al-Gergawi, A., & Burt, J. A. (2024). Remote sensing of 50 years of coastal urbanization and environmental change in the Arabian Gulf: a systematic review. *Frontiers in Remote Sensing*, 5, 1422910. doi:10.3389/frsen.2024.1422910

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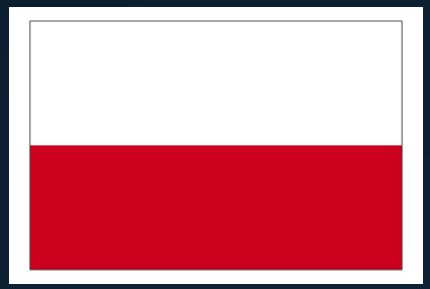

Dziękuję bardzo

Thank you

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