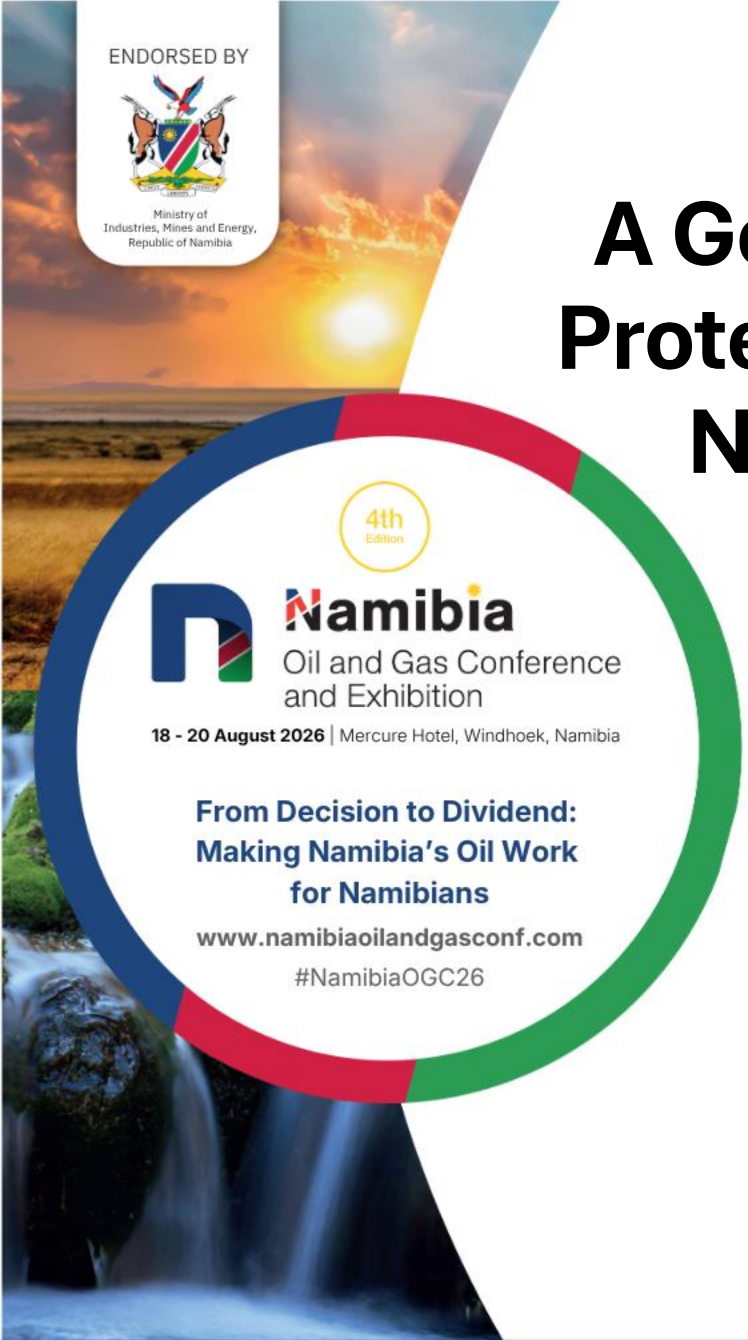


A Geospatial Framework for Environmental Protection and Oil Spill Response Planning in Namibia's Offshore Oil and Gas Sector

Ryan Theodore Benade [1, 2] & Prof. Oluibukun Gbenga Ajayi [1,3]

(1) Department of Land and Spatial Sciences, Namibia University of Science and Technology

(2) Faculty of Environmental Management and Sustainability Sciences, IUM, Windhoek

(3) Department of Geography, Geoinformatics and Meteorology, University of Pretoria

Why Namibia needs this now

Offshore development is accelerating

Major Orange Basin discoveries are moving Namibia towards appraisal and potential development.

250-300 km offshore

Deep-water operations are located far from coastal response bases and environmentally sensitive receptors.

No national sensitivity baseline

Namibia currently has no published national oil spill sensitivity atlas to guide preparedness and response prioritisation.

Research objective

To develop a geospatial framework that integrates Earth Observation, GIS and spatial risk modelling to support oil spill preparedness along Namibia’s offshore and coastal environment.

1. Detect

- Identify potential oil slicks from Sentinel 1 SAR imagery.

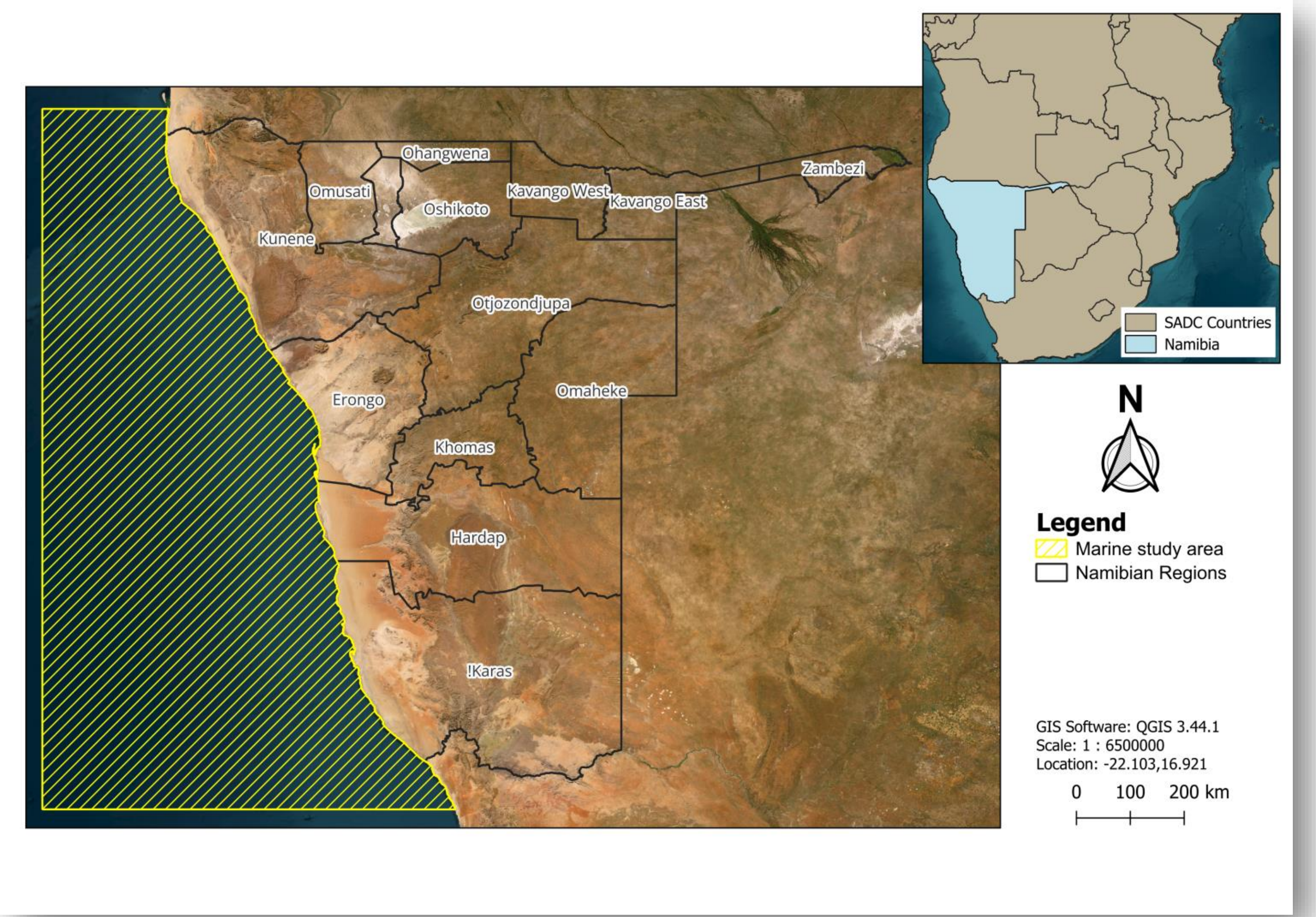
2. Map

- Characterise coastal and marine environmental sensitivity.

3. Prioritise

- Identify areas requiring greater oil spill preparedness and response attention.

Study area



Extent

9.5 to 17.2 °E, 16.8 to 29.5 °S Namibia's offshore and coastal environment.

Marine area

664,991 km^2 of marine waters after removal of land.

Environmental setting

The northern Benguela upwelling system, among the most biologically productive marine systems globally.

Methodological framework

SAR data and methods

Component	Description
Primary imagery	Sentinel 1 GRD, IW mode, VV polarisation
Study period	February–August 2024; **40 scenes processed**
Study area	Namibia’s offshore and coastal environment
Wind data	ERA5 hourly reanalysis, 10 m u/v wind components
Ocean currents	HYCOM sea-water velocity
Land / coastline	LSIB boundaries with distance-transform coastline derivation
Detection logic	Dual test: **absolute dark threshold + local backscatter anomaly**
Processing platform	**Google Earth Engine**

SAR coverage over Namibian waters

143

Sentinel 1 IW scenes intersecting the study area

0

scenes covering offshore test points

58%

of scenes contained no marine area

- Sentinel 1 IW acquisition over Namibia is concentrated inland.
- Coverage of the offshore licence areas was effectively absent during the study period, so free routine SAR monitoring of Namibia's petroleum development area was not available.
- **Sentinel 1B failed in December 2021 and Sentinel 1C was not operational during the study period, reducing acquisition capacity over lower-priority regions.**

Corroboration: The 2015 Swakopmund slick

A documented Namibian case demonstrates the same monitoring limitation identified by this study.

- **Incident-**Oil-covered penguins were reported along the coast near Swakopmund.
- **Satellite response-**Researchers narrowed the likely source area using penguin foraging ranges and requested emergency satellite imagery.
- **Detection-**Radar imagery subsequently revealed two linear slick features consistent with vessel-related discharge.
- **Key implication-**The imagery was specially tasked, it was not available through routine satellite coverage.

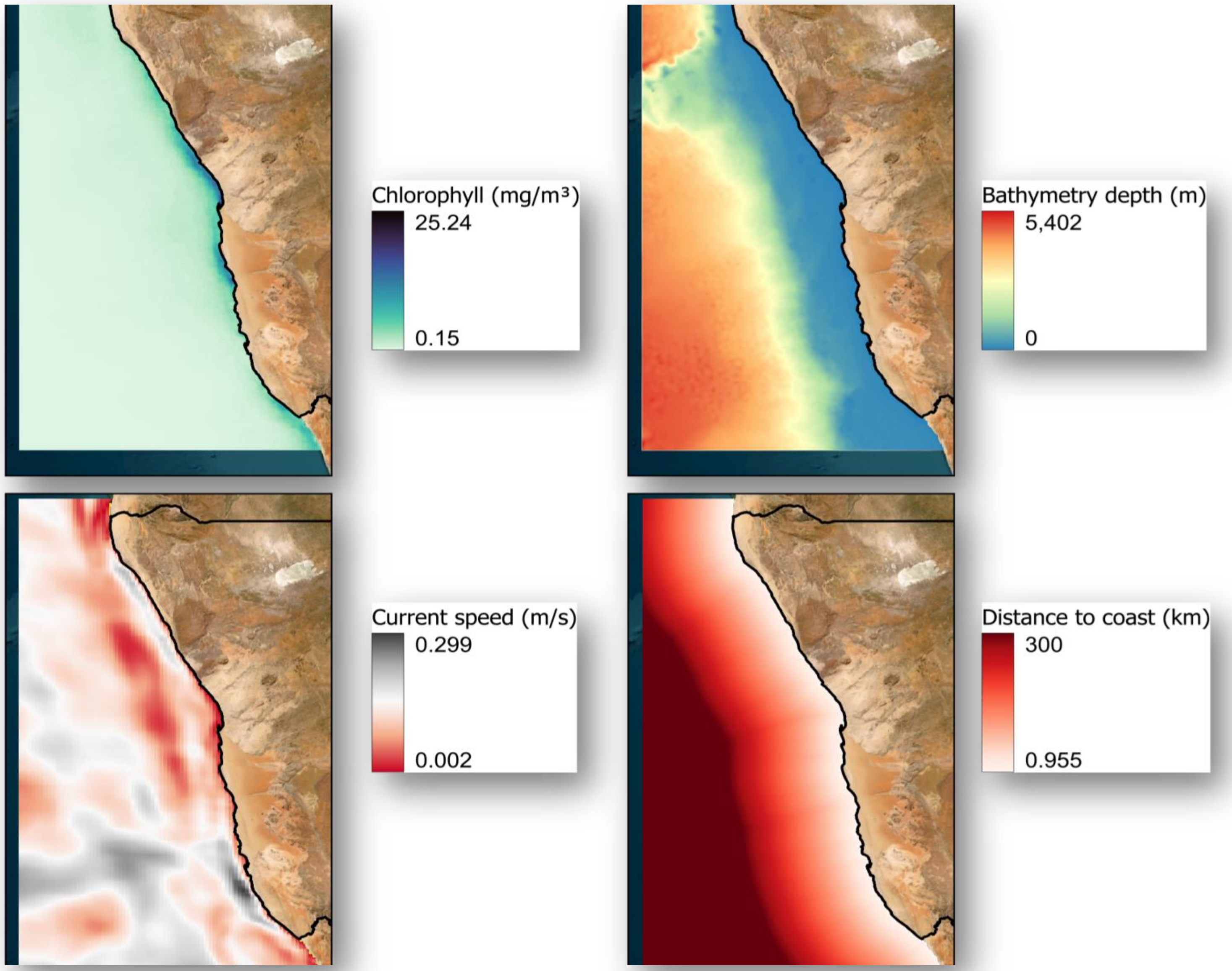
Emergency-tasked radar detection of the 2015 Swakopmund oil slick
Source: The Namibian (2015).

Environmental sensitivity model

Indicator	Dataset / Representation
Biological productivity	MODIS-Aqua chlorophyll-a
Protected areas	World Database on Protected Areas
Coastal population	JRC Global Human Settlement population grid
Shoreline proximity	Distance from coastline
Bathymetric shallowness	ETOPO1 bathymetry
Current transport	HYCOM surface current velocity

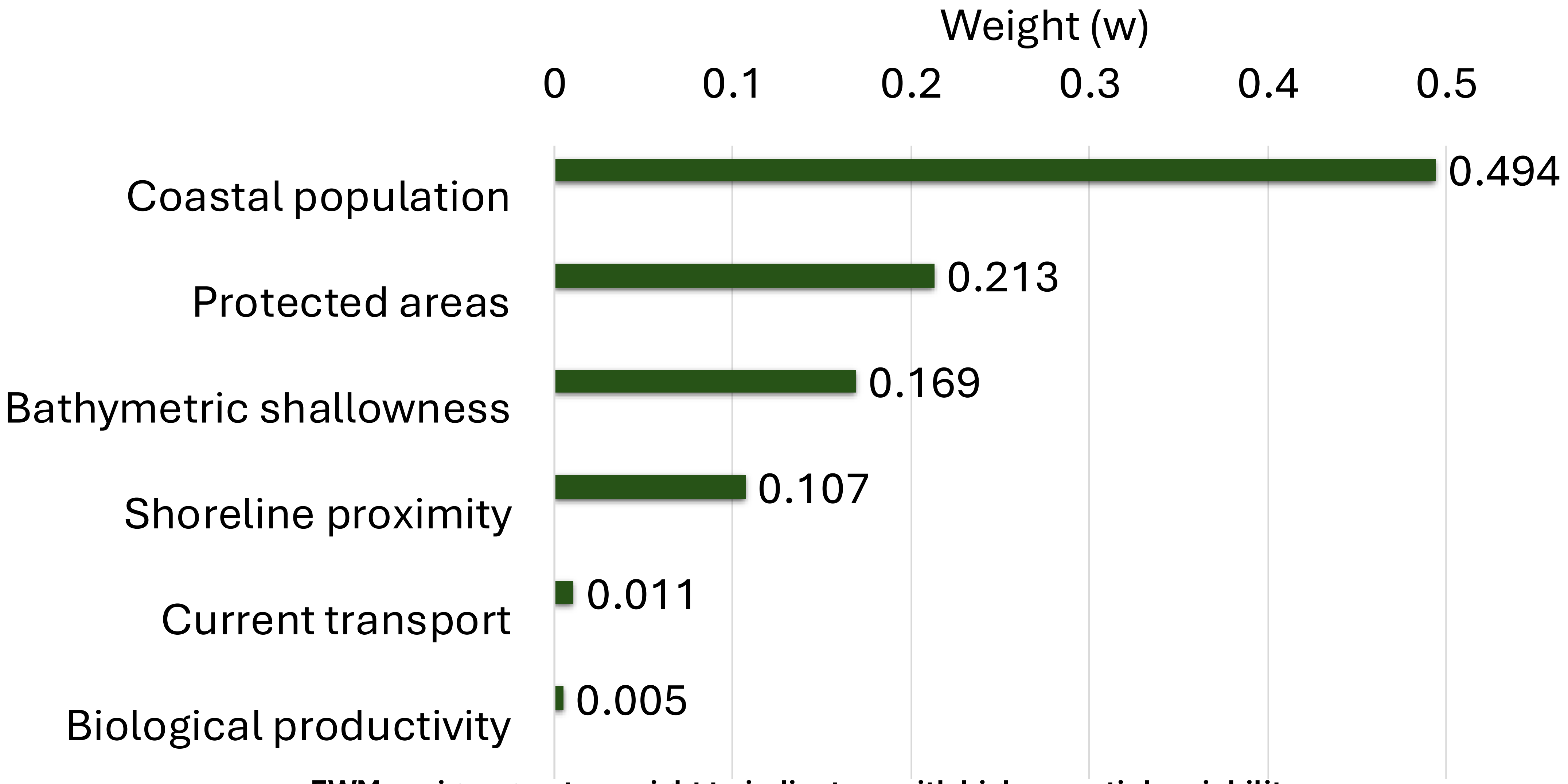
Spatial scale: 5 km strategic planning scale
Weighting method: Entropy Weight Method (EWM)
Weights were derived from the information content of the data rather than assigned subjectively.

Overview of sensitivity data



Derived weights

Entropy Weight Method (EWM) · 29,186 analysis cells



EWM assigns greater weight to indicators with higher spatial variability.

Composite sensitivity index

Index range

0.005 to 0.963 across 664,991 km^2 of Namibian marine waters.

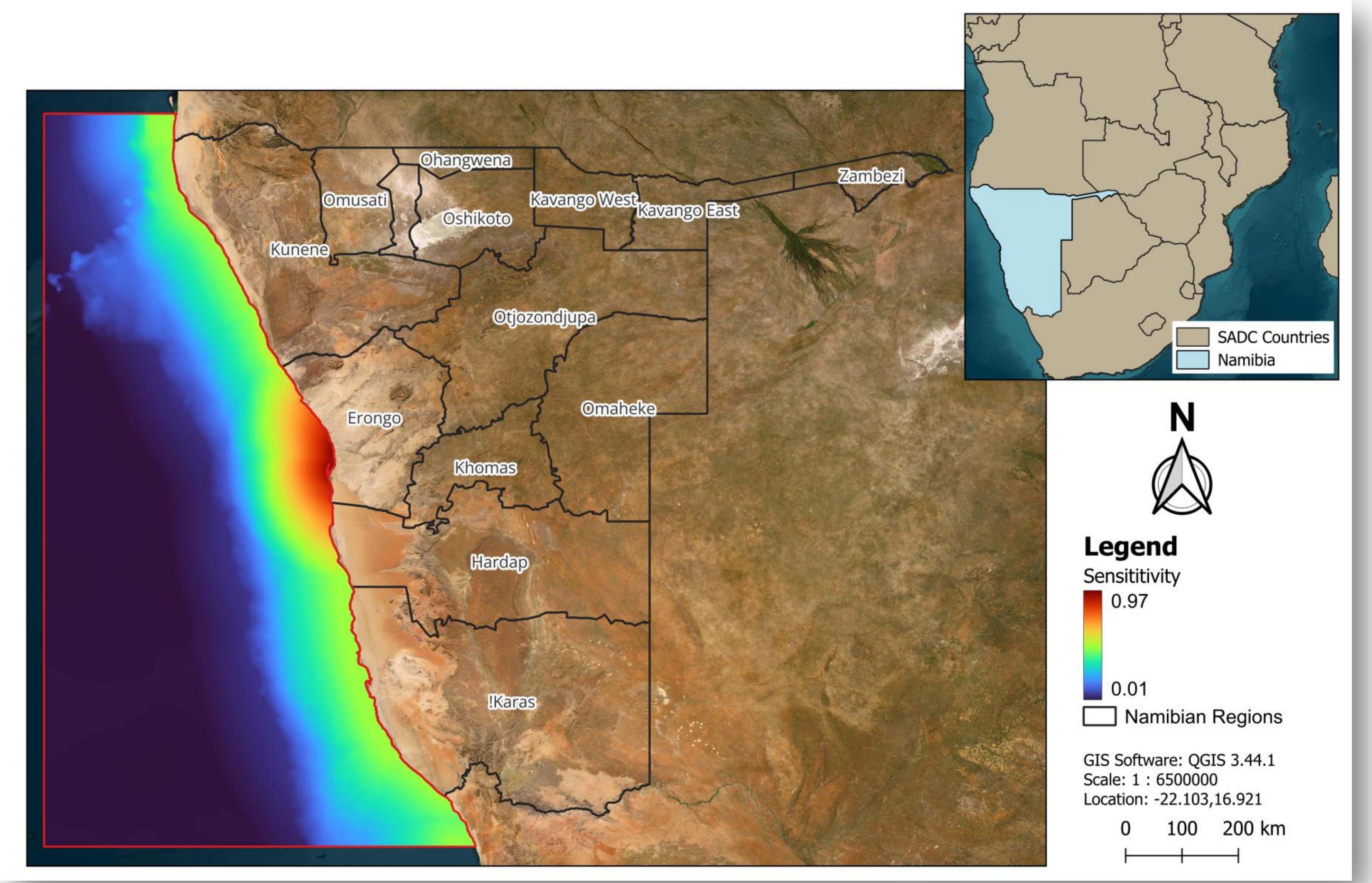
Spatial pattern

Sensitivity is concentrated in a narrow coastal band and falls away sharply offshore.

Highest values

Walvis Bay, Sandwich Harbour, Lüderitz and the Namibian Islands MPA.

Working scale 5 km - strategic screening tier per IPIECA-IMO-IOGP.



Hazard and receptor are spatially decoupled

Offshore hazard

- Petroleum activity located offshore
- Sensitivity index: 0.006

250–300 km

Coastal receptor

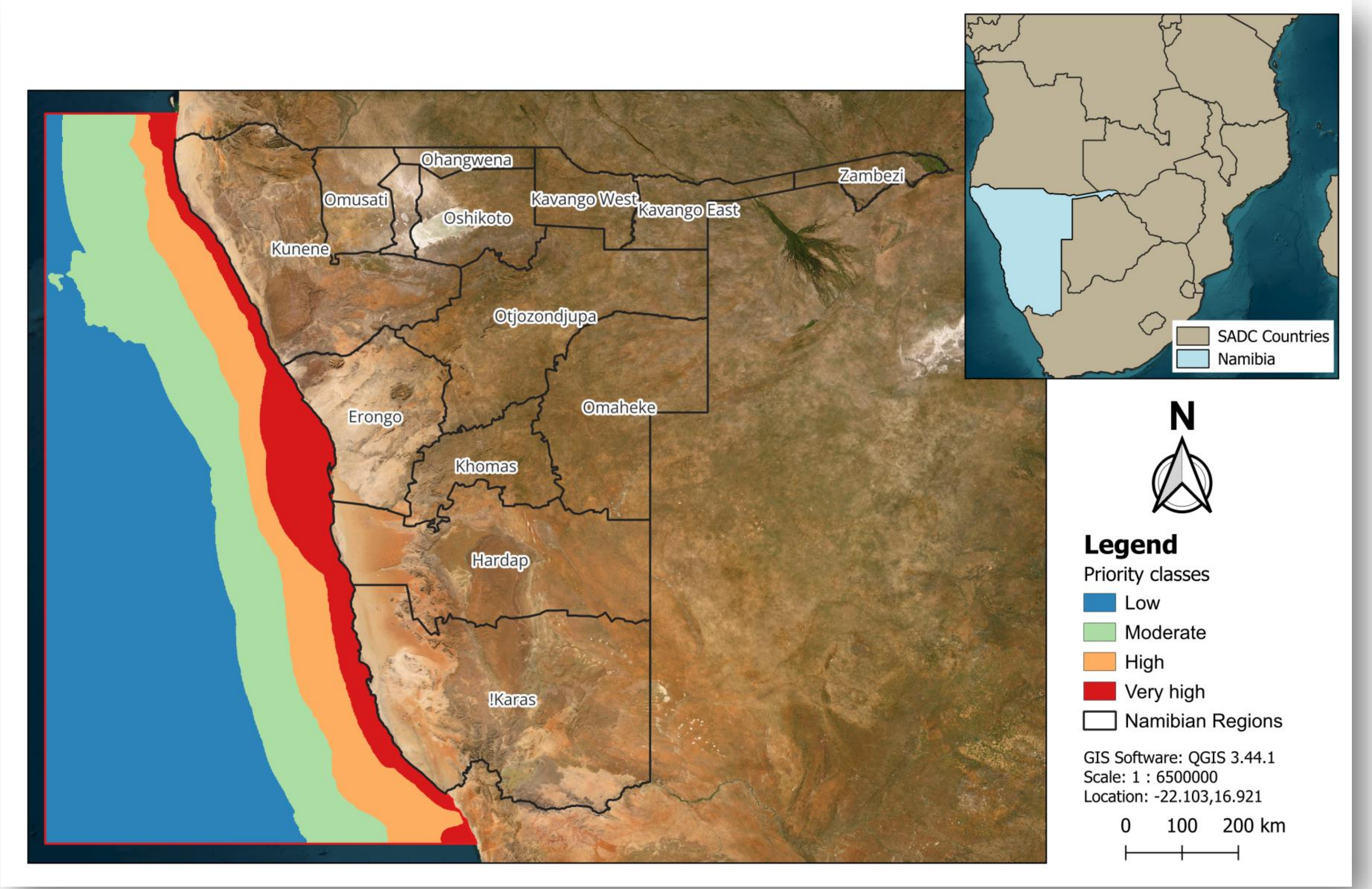
- Sensitive receptors concentrated along the shoreline
- Walvis Bay Lagoon
- Sensitivity index: 0.951

Risk is governed by transport, not proximity.

Response priority classes

Very high 67,839 km²

- High 99,200 km²
- Moderate 164,384 km²
- Low 330,938 km²



Recommendations

1

Quantile classification
Represents relative preparedness priority rather than absolute environmental sensitivity.

2

Entropy weighting
Weights reflect spatial variability rather than ecological importance, resulting in a low weight for relatively uniform indicators such as chlorophyll-a.

3

No trajectory modelling
Spill transport and exposure pathways were not simulated and therefore require further modelling before operational application.

4

Strategic spatial scale
The 5 km resolution is appropriate for national screening but not detailed site-level response planning.

DATA

WEIGHTING

TRAJECTORY MODELLING

MONITORING GAP

Conclusion

- A data-driven marine environmental sensitivity map was developed for Namibian waters using six independently sourced indicators and Entropy Weight Method-derived weights.
- The model successfully distinguished known sensitive coastal sites from low-sensitivity open-ocean controls.
- Environmental sensitivity is concentrated along the coast, while offshore petroleum activity is located approximately 250–300 km away.
- This spatial separation shows that spill risk is driven by transport pathways rather than simple proximity.
- Routine free Sentinel 1 SAR coverage over Namibia’s offshore petroleum areas was effectively absent during the study period, highlighting an important monitoring and preparedness gap.

References

Gundlach, E.R. & Hayes, M.O. (1978). Vulnerability of coastal environments to oil spill impacts. Marine Technology Society Journal.

Ivanov, A.Yu. & Zatyagalova, V.V. (2007). A GIS approach to mapping oil spills in the marine environment. ESA Symposium Proceedings.

IPIECA–IMO–IOGP (2012, rev. 2016). Sensitivity mapping for oil spill response. IOGP Report 477.

Michel, J., Christopherson, S. & Whipple, F. (1994). Mechanical protection guidelines. NOAA / Research Planning Inc.

Wang, Y., Du, P., Liu, B. & Wu, X. (2023). GIS-based comprehensive oil spill risk assessment in China's Bohai Sea. Frontiers in Marine Science 10:1141962.

Wegeberg, S. et al. (2024). EOS – Environment & Oil Spill Response: an analytic tool for environmental assessments to support oil spill response planning. Marine Pollution Bulletin 199:115948.

Brekke, C. & Solberg, A.H.S. (2005). Oil spill detection by satellite remote sensing. Remote Sensing of Environment 95:1–13.

Data sources: NASA MODIS-Aqua · UNEP-WCMC WDPA · JRC GHSL · NOAA ETOPO1 · HYCOM · US DoS LSIB · Copernicus Sentinel-1