Coastal Early Warning and Alerting System
“SAGAR SAATHI”

Hackathon Project Report

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- **Importance of coastal areas :**
  - Store blue carbon (carbon captured by ocean ecosystems)
  - Support rich biodiversity
  - Drive local economies
- **Key threats faced by coasts :**
  - Storm surges
  - Cyclones
  - Marine heatwaves
  - Sea-level rise
  - Pollution
  - Illegal activities
- **Proposed solution: Early warning & alerting platform :**
  - Data sources:
    - Physical sensors → tide gauges, weather stations, buoys
    - Satellite feeds
    - Historical records
  - AI/ML processing:
    - Detects anomalies and patterns
    - Predicts looming threats
    - Computes near-term risk levels (e.g., two-hour outlook)
  - Alert dissemination:
    - SMS messages
    - Mobile app notifications
    - Web dashboards for authorities & communities

1 Introduction

Coastal ecosystems provide substantial climate mitigation through blue carbon sequestration and support fisheries, tourism, and maritime trade. However, climate change and anthropogenic pressures increase hazard frequency and intensity, including:

- Hydrometeorological events: storm surges, cyclones, extreme storms.
- Oceanographic changes: marine heatwaves, sea-level rise.
- Environmental hazards: pollution episodes, illegal dumping, algal blooms.

Traditional monitoring systems are often siloed, reactive, and lack integrated intelligence. This project fills that gap with a fused data pipeline and AI-driven risk analysis for fast, trusted, and targeted early warnings.

2 Problem Statement

Key challenges:

- **Fragmented data:** Sensor, satellite, and archival datasets exist but are under-integrated.
- **Limited predictive insight:** Many systems focus on current conditions over near-term forecasts.
- **Alert fatigue:** Alerts may be late, non-actionable, or poorly targeted.
- **Equity and access:** Coastal communities need low-bandwidth, multilingual delivery options.

Goal: Build an *integrated* early warning system that fuses multi-source data, predicts two-hour risks for multiple hazards (marine heatwave, tsunami, cyclone, storm, pollution, sea-level rise), selects the most critical risk, and disseminates calibrated alerts with recommended actions.

3 DataSources

Our pipeline integrates:

- **Physical sensors:** Tide gauges, weather stations, ocean buoys (sea level, wind, pressure, precipitation).
- **Satellite feeds:** Sea surface temperature (SST), ocean color (chlorophyll, turbidity), SAR/wave products, shoreline change indicators.
- **Historical records:** Event catalogs, reanalyses, tide tables, climatologies, blue-carbon site maps.
- **Hackathon datasets:** Two-hour risk percentages per hazard (label/target) and observational covariates (e.g., recent tides, SST anomalies, wave height).

Table 1: Illustrative input features (fused across sources).

Domain	Example Features
Meteorological	Wind speed/gusts, pressure tendency, rainfall rates (5–30 min).
Oceanographic	Sea level residual, significant wave height/period, swell direction.
Thermal	SST anomaly, marine heatwave category, subsurface temp (if available).
Water quality	Chlorophyll-a, turbidity, colored dissolved organic matter.
Geomorphology	Shoreline change rate, beach slope, intertidal extent (from SAR/optical).
Human activity	AIS density (ships), outfall locations, known dumping hotsp ots.
Temporal context	Hour-of-day, tide phase, seasonality, holiday/weekend flags.

4 System Architecture

Figure 1 depicts the end-to-end architecture: ingestion, processing, ML scoring, risk fusion, and alerting.

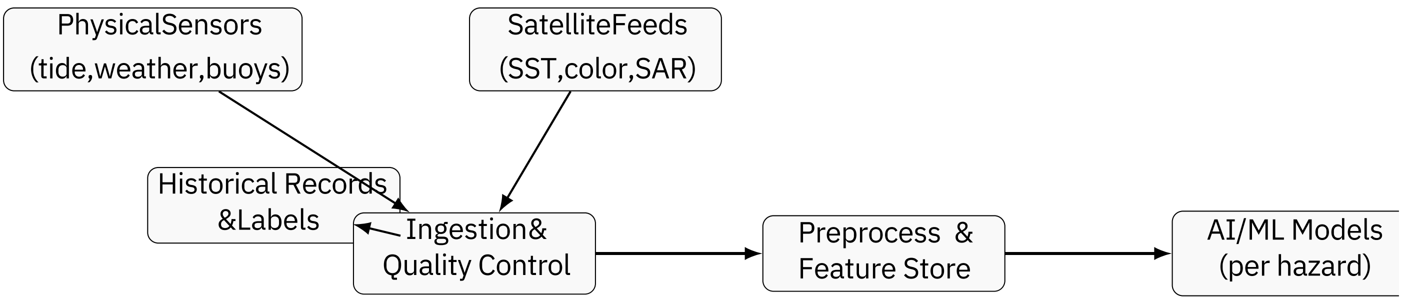

Figure 1: High-level architecture of the Coastal Early Warning and Alerting System.

5 Methodology

5.1 Preprocessing and Feature Engineering

- Temporal alignment to a common cadence (e.g., 5min); gap-filling with flags.
- Outlier detection (e.g., Hampel filter) and quality flags from source providers.
- Derived features: rolling means/volatility, tide-phase encodings, SST anomalies vs. baselines.

5.2 ModelingStrategy

Each hazard gets a dedicated model for two-hour risk:

- **Marine heatwave:** Gradient-boosted trees or temporal CNN on SST/SSTa sequences.

- **Tsunami:** Rule-based proxy (distant/near-field triggers) + anomaly detection on sea-level residuals; hybrid with supervised labels if available.
- **Cyclone/Storm:** Sequence models (LSTM/Temporal CNN) using pressure, wind, wave, and radar/satellite nowcasts.
- **Pollution:** Supervised classifier on ocean color time series (chlorophyll/turbidity) and proximity to outfalls/traffic.
- **Sea-level rise (acute risk):** Short-term extreme water-level predictor from tides + surge residual nowcasts.

5.3 Risk Fusion and Decision Logic

- **Hysteresis:** Promote/demote only if thresholds crossed for k consecutive intervals.
- **Spatial coherence:** Smooth risks across neighboring coastal cells.
- **Source confidence:** Weight scores by data quality (sensor uptime, cloud cover).

Table 2: Illustrative alert thresholds (tune per hazard/site).

Level	Riskrange(%)	Color	Action cue
Advisory	40–59	Yellow	Increased vigilance; check resources.
Watch	60–79	Orange	Prepare response assets; pre-notify stakeholders.
Warning	80–100	Red	Execute SOPs; evacuate if directed.

6 Alerting,Delivery,andUsability

Channels: SMS (GSM), mobile push, and a responsive web dashboard. Messages are compact, multilingual, and include location, hazard, lead time, confidence, and top actions.

Web Dashboard (MVP).

- Live risk meters for each hazard and Rmax.
- Map layer with cells colored by primary risk.
- Time-series panels (last 24h + 2h outlook).
- Alert log with acknowledgements and *readiness* checklists.

7 Evaluation Plan

- **Backtesting:** Train/test splits by event; leave-one-event-out to avoid leakage.
- **Metrics:** AUC/PR for event detection; MAE for risk regression; lead-time accuracy.
- **Operational KPIs:** Alert timeliness, delivery success, acknowledgment rate, false-alarm rate.

Table 3: Illustrative MVP success criteria

Category	Target
Model AUROC (storm/-cyclone)	≥ 0.90 on holdout events
Risk MAE (2h horizon)	≤ 8 percentage points
Alert timeliness	95% delivered within 60s of generation
Uptime (ingest → alert)	≥ 99% during pilot

8 Security, Ethics, and Reliability

- **Data governance:** Source licenses respected; PII minimized; audit trails for alerts.
- **Robustness:** Redundant message gateways; caching when satellites are occluded.
- **Human-in-the-loop:** Authority override and *explainability cards* for each alert.

9 Implementation Roadmap

1. **Week 1–2:** Data connectors (sensors, satellite), feature store scaffold, basic dashboard.
2. **Week 3–4:** Per-hazard baselines, initial fusion, QA flags, alert API, SMS integration.
3. **Week 5–6:** Backtests, threshold tuning, multilingual messages, onboarding SOPs.
4. **Week 7+:** Model hardening, MLOps, telemetry, public pilot with authorities.

10 Conclusion

We demonstrate a practical, extensible early warning platform that fuses sensor, satellite, and historical data with AI/ML to deliver two-hour risk forecasts for multiple coastal hazards. With calibrated thresholds, human oversight, and inclusive delivery channels, the system aims to reduce losses and strengthen climate resilience for coastal communities.

References & Reputable Data Sources

(All links verified at time of writing.)

1. **NOAA Tides & Currents** (tide gauges, sea level, flooding): https://tidesandcurrents.noaa.gov/
2. **NOAA Marine Heatwave Portal** (SST anomalies, MHW categories): https://psl.noaa.gov/marine-heatwaves/
3. **NASA Earthdata** (SST, ocean color, SAR catalogs): https://earthdata.nasa.gov/
4. **Copernicus Marine Service** (ocean forecasts, waves, biogeochemistry): https://marine.copernicus.eu/
5. **IPCC SROCC** (Sea Level Rise and Coasts): https://www.ipcc.ch/srocc/
6. **Indian Meteorological Department (IMD)** (cyclone tracks, warnings): https://mausam.imd.gov.in/
7. **NOAA High Tide Flooding Outlook** (impact-based flooding): https://tidesandcurrents.noaa.gov/high-tide-flo o ding/
8. **ESA Sentinel Missions** (Sentinel-1 SAR, Sentinel-2/3): https://sentinels.copernicus.eu/
9. **Global Fishing Watch / AIS (where applicable)**: https://globalfishingwatch.org/