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Jellyfish Aggregation Information Interactive Portal (Jelly-AIIP)

by

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Abstract (100 words):

The Jellyfish Interactive Information Portal is a web-based decision-support system developed to compile, organize, and visualize historical jellyfish aggregation events information along the Indian coastline. Jellyfish records derived from published literature were structured into a relational MySQL database and integrated with interactive geospatial mapping and analytical tools. The portal enables visualization of occurrence patterns by type, species, year, duration, and frequency, including overall and monthly frequency analyses. Additional modules provide multilingual jellyfish sting first-aid guidance, emergency contact information, and a dashboard for the data summary and statistics. The system supports scientific analysis, public awareness, and coastal management applications.

1. Introduction

1.1. Background and Rationale

Jellyfish aggregation, swarming, and beach stranding events have been increasingly reported worldwide, with notable ecological, socio-economic, and public health implications (Purcell et al., 2007; Richardson et al., 2009). Along the Indian coastline, recurrent jellyfish occurrences have affected fisheries, coastal tourism, power plant operations, and public safety through stinging incidents (Baliarsingh et al., 2020; Siddique et al., 2022;). Despite their growing importance, information on jellyfish distribution, temporal patterns, and associated risks in Indian waters remains fragmented across scientific publications, reports, and local observations.

Digital platforms and web-based portals have proven effective for integrating biodiversity data, improving accessibility, and supporting decision-making for coastal management (Costello et al., 2017). Furthermore, citizen science initiatives have emerged as valuable tools for collecting large-scale, real-time biological observations, particularly for gelatinous zooplankton such as jellyfish (Gershwin et al., 2015).

There is a need to develop a web-based portal which includes historical jellyfish swarming, beach strand locations, species involved, frequency at different locations, seasonality of jellyfish occurrences etc.

1.2. Purpose and Objectives of the Jelly-AIIP

The Jellyfish Aggregation Information Interactive Portal (Jelly-AIIP) (Figure-1) was developed with the primary objective of providing a centralized, interactive, and geospatially enabled platform for accessing historical jellyfish occurrence information along the Indian coast. The portal serves as a unified digital repository and visualization system designed to consolidate, store, and disseminate jellyfish-related observations for researchers, coastal managers, policymakers, and the general public.

Jelly-AIIP integrates occurrence data extracted from published literature with modern web-based geospatial and graphical visualization tools. This enables users to explore spatial and temporal patterns, supports scientific analysis, enhances public awareness, and strengthens coastal decision-making frameworks. Beyond data visualization, the platform functions as a long-term ecological repository capable of accommodating real-time observations in the future, thereby linking historical baselines with emerging monitoring systems.

Specifically, the portal aims to:

- **Document historical jellyfish swarming and beach-stranding events** across coastal regions of India.
- **Provide overall, annual, and monthly occurrence frequency analyses** to help identify temporal trends and seasonal patterns.

- **Offer an interactive dashboard** with graphical visualizations such as bar charts and pie charts, enabling intuitive data exploration.
- **Disseminate multilingual jellyfish sting first-aid information** to strengthen public safety, particularly for coastal communities, fishers, and tourists.
- **Display emergency contact information and institutional support resources** for immediate assistance during jellyfish sting incidents.
- By integrating scientific datasets, visual analytics, and public outreach tools, Jelly-AIIP bridges the gap between research outputs and societal needs. The portal also establishes the groundwork for future enhancements including real-time reporting, mobile-based observations, and operational jellyfish forecasting services aligned with emerging digital ocean and marine early-warning system frameworks (Glenn et al., 2016).

The portal interface is available at: https://incois.gov.in/site/services/jelly.jsp

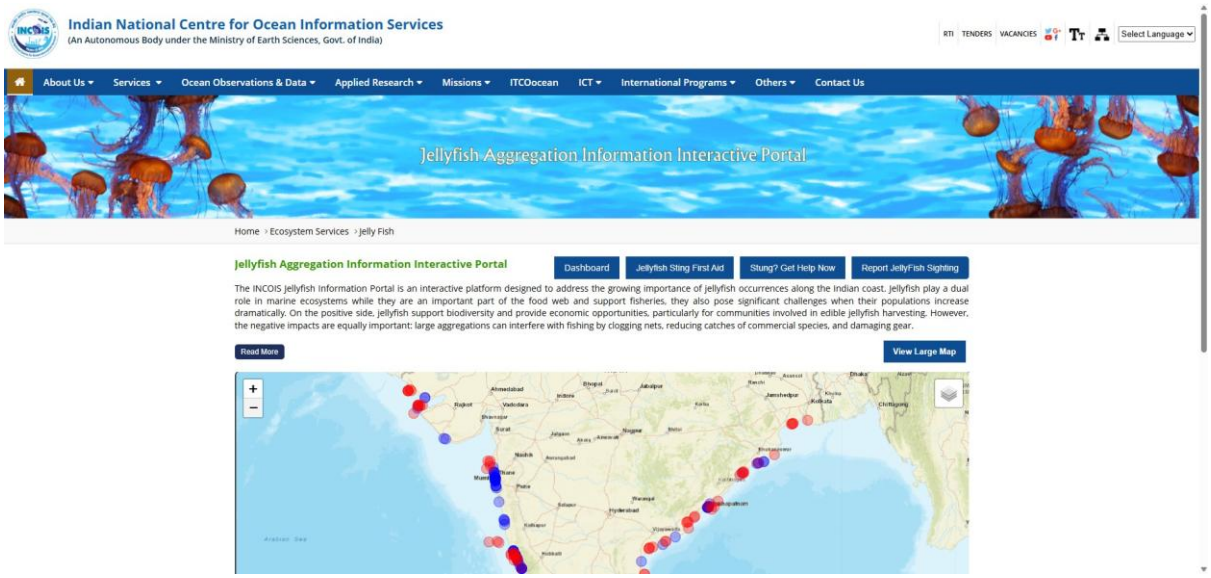

Figure-1: Web Page of the Jellyfish Aggregation Information Interactive Portal displaying key modules and primary navigation components.

1.3. Major Functional Components:

I. Interactive Geospatial Mapping

The portal features an interactive geospatial mapping system that allows users to explore jellyfish occurrences along the Indian coastline through multiple analytical perspectives (Figure-2). The occurrence-based visualization tools enable users to examine spatial patterns by event type such as swarming events or beach strandings as well as by species and year of observation.

To support event characterization, the system includes duration-based visualization, where variable-sized markers represent short-term events (approximately one week) and long-term events (extending up to a year). This provides insights into the persistence of jellyfish aggregations at specific locations.

Additionally, frequency analysis is implemented using a hexagonal grid framework to illustrate the overall intensity of jellyfish occurrences across the coastline. Month-wise filters further allow users to explore seasonal trends, highlighting temporal variability and recurring patterns.

Collectively, these geospatial and analytical tools enable the identification of jellyfish hotspots while enhancing the understanding of both spatial and temporal dynamics of jellyfish occurrences along the Indian coast.

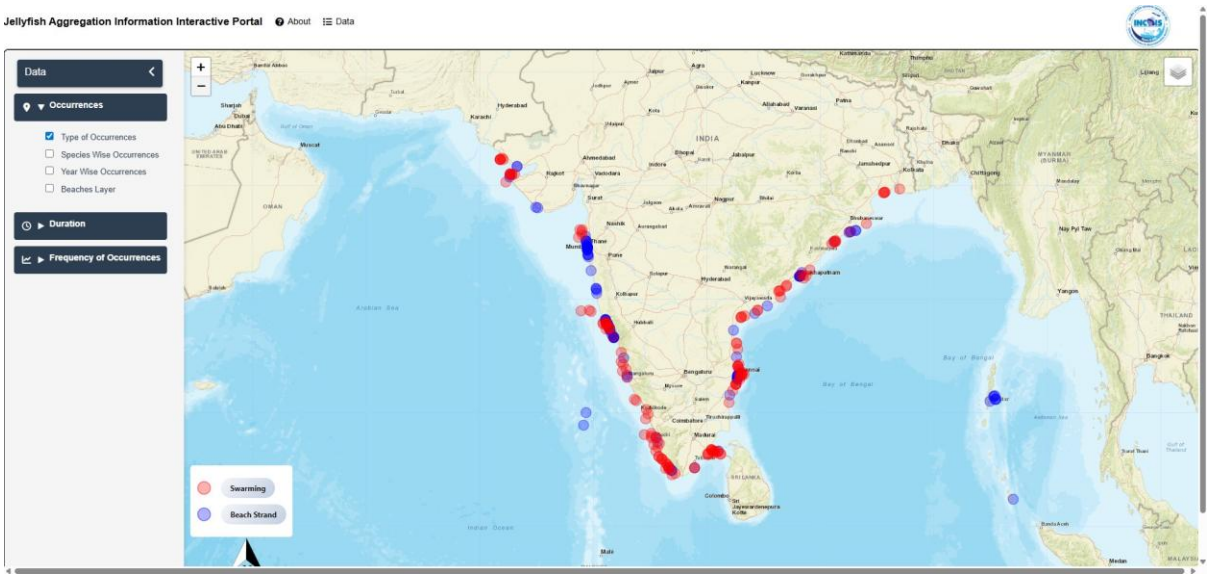

Figure-2: Interactive WebGIS Application of Jelly-AIIP

II. Dashboard for Data Visualization

A dedicated dashboard module provides graphical summaries of the jellyfish dataset using bar charts, pie charts, etc. The dashboard facilitates quick interpretation of: Species composition, occurrence types, temporal distribution, regional patterns, latitudinal and longitudinal distribution patterns etc. (Figure-3).

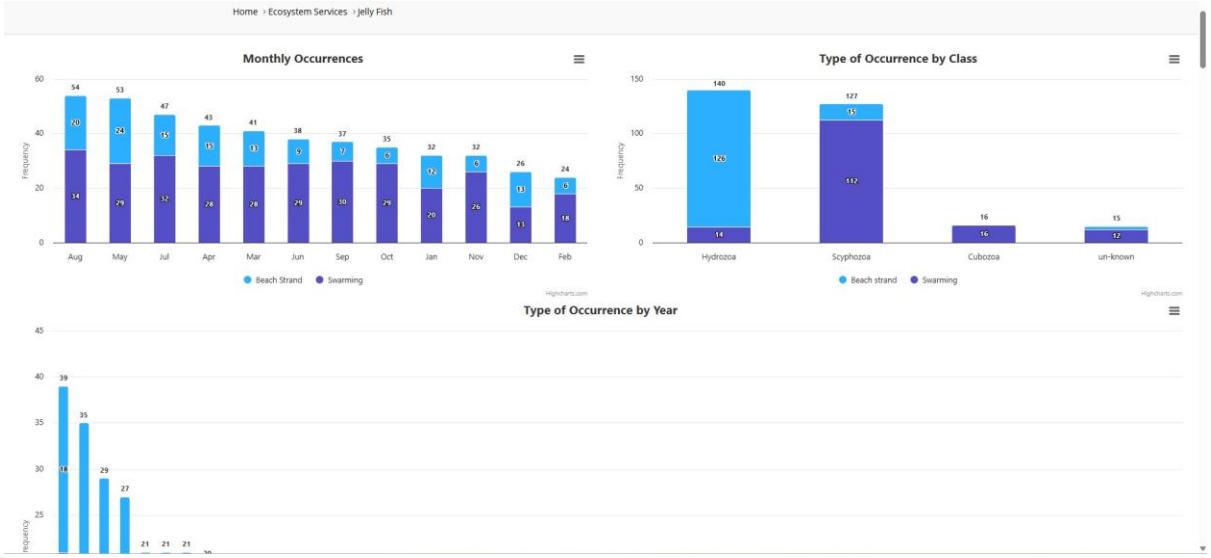

Figure-3: Dashboard interface of the Jelly-AIIP platform displaying various analytical and visualization components.

III. Jellyfish Sting First Aid Information

The portal includes a dedicated “Jellyfish Sting First Aid” module aimed at enhancing public safety and awareness (Figure-4). It offers clear, step-by-step first aid guidance in a simple, user-friendly format suitable for the general public. To ensure widespread accessibility, the module supports multiple languages through a dropdown menu, covering major coastal languages of India—Hindi, Gujarati, Marathi, Kannada, Malayalam, Tamil, Telugu, Odia, Bangla, and English. This feature is especially valuable for coastal communities, tourists, and beach visitors, enabling them to respond promptly and appropriately to jellyfish sting incidents.

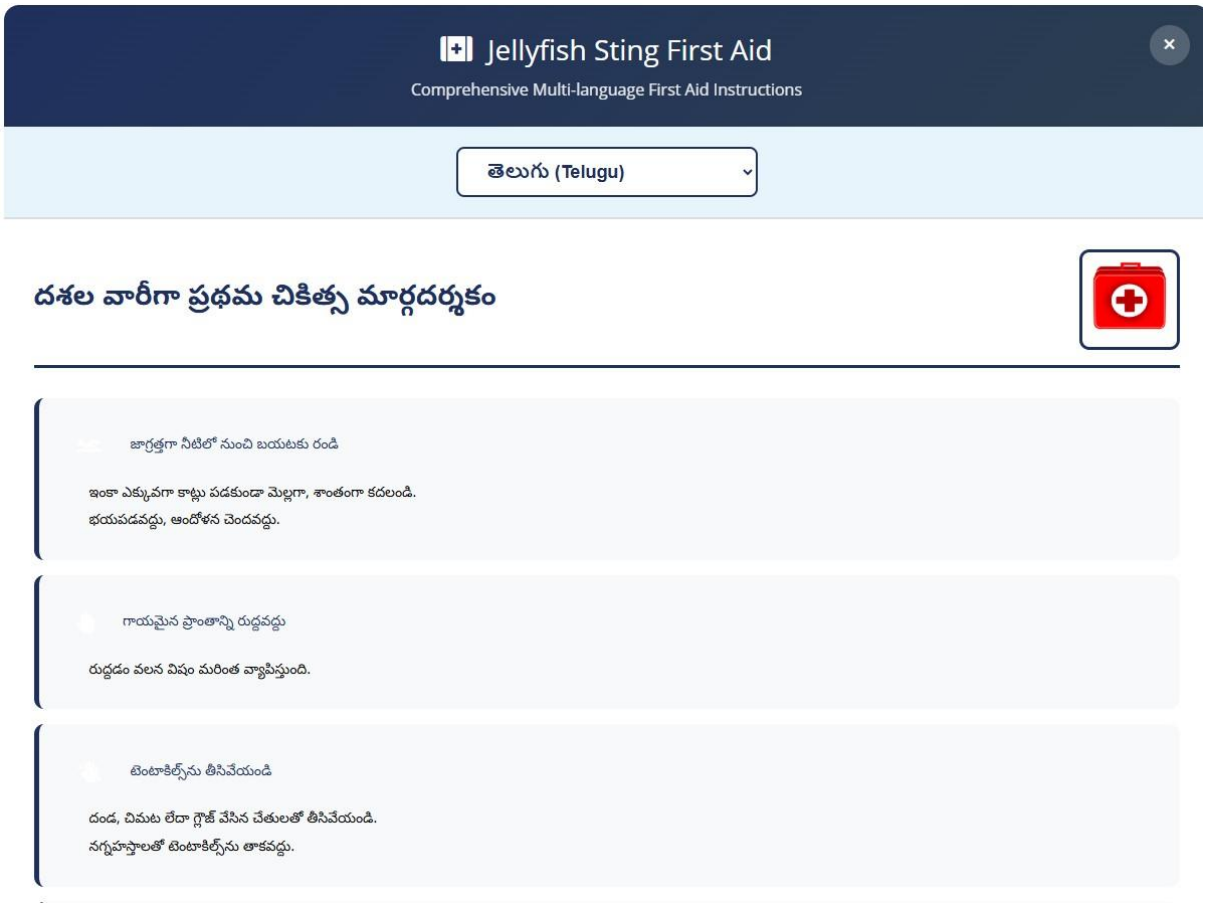

Figure-4: Jellyfish sting first-aid module displaying step-by-step emergency response guidelines.

IV. “Stung? Get Help Now” Emergency Support

To enable prompt and effective response to jellyfish sting incidents, the portal features a dedicated “Stung? Get Help Now” emergency support section (Figure-5). This section provides

information on beach assistance services such as Drishti Marine Services, along with emergency contact details of nearby government hospitals for major coastal locations across India. By offering quick access to local medical facilities and on-ground support services, the portal enhances public safety and helps users take timely action during jellyfish sting emergencies.

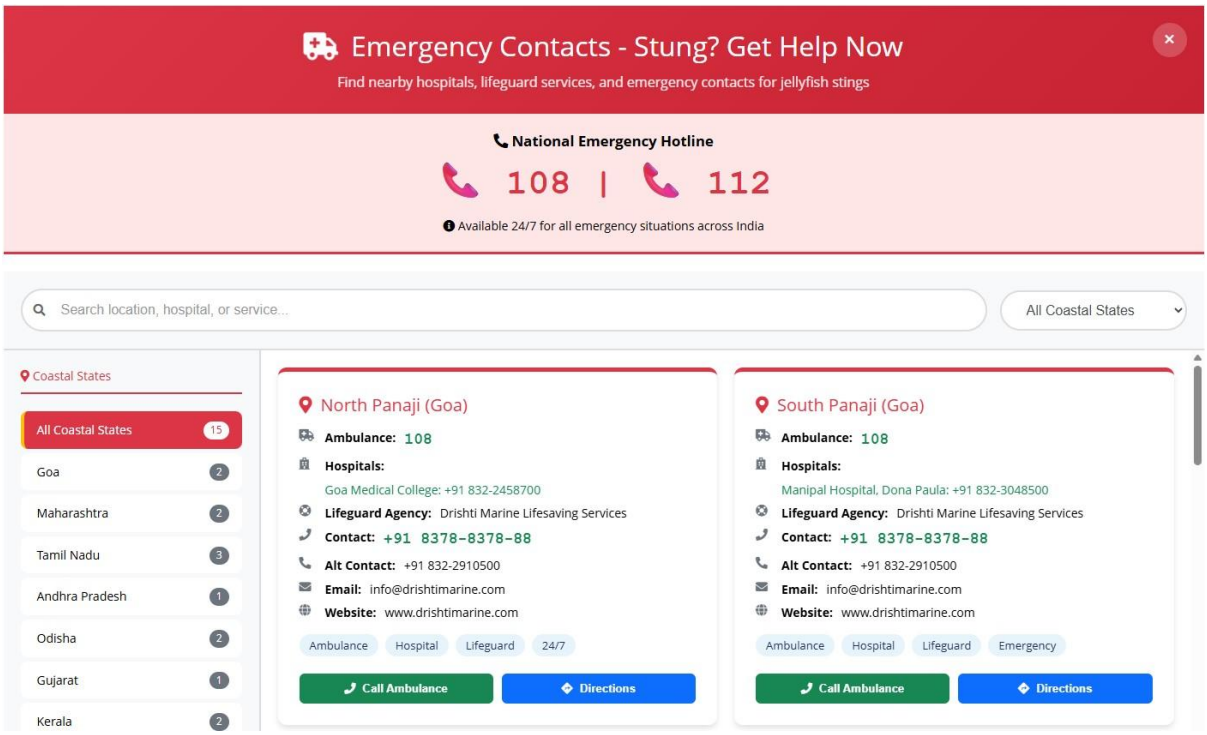

Figure-5: “Stung? Get Help Now” emergency assistance module of the JellyAIIP system

1.4. Intended Users

The Jelly-AIIP portal serves multiple user groups along the Indian coast:

- **Marine scientists and researchers**, who analyze spatial and temporal patterns of jellyfish occurrences, including seasonal frequency trends.
- **Coastal and disaster management authorities**, who utilize occurrence data to support preparedness and response planning in bloom-prone regions.
- **Fisheries, tourism stakeholders, and coastal power plant operators**, who rely on occurrence information to minimize operational disruptions and enhance safety.
- **General public and coastal visitors**, who access jellyfish occurrence updates, sting first-aid guidance, and emergency contact information for safer recreational activities.

2. System Architecture

2.1. High-Level System Design

The Jellyfish Interactive Information Portal is designed using a three-tier architecture, consisting of the Presentation Layer, Application Layer, and Data Layer.

This architecture ensures clear separation of responsibilities, supports modular development, and enables scalability and maintainability. Each tier independently handles its designated functions while interacting seamlessly with the others.

2.2 Presentation Layer (User Interaction Layer) - Frontend

The Presentation Layer enables users to access the portal through a standard web browser. This layer is responsible for rendering all visual and interactive components of the system.

Key functionalities include:

- Interactive geospatial maps for visualizing occurrence locations
- Analytical dashboards displaying charts and temporal patterns
- Filtering tools for species, year, occurrence type, duration, and frequency
- Public information modules, including:
  - ✓ Jellyfish sting first-aid guidelines
  - ✓ Emergency contact information

User inputs- such as filter selections-dynamically update the displayed maps and dashboards. The frontend utilizes asynchronous communication to ensure smooth updates without requiring page reloads.

2.3. Application Layer (Server & API Services)

The Application Layer forms the core processing unit of the system. It is implemented using Jakarta Server Pages (formerly Java Server Pages (JSP)) deployed on an Apache Tomcat Server and accessed via Reverse Proxy in Apache httpd Web server.

This layer performs the following activities:

- Receives and validates requests sent from the frontend
- Processes user-defined filter parameters
- Executes database queries using dedicated backend API modules
- Returns structured results to the frontend in JSON format

The major API endpoints include:

- Duration Analysis API
- Frequency Analysis API
- Monthly Distribution API
- Species-wise Analysis API
- Year-wise Analysis API
- Occurrence-type API

These APIs are optimized for delivering fast, filter-based results required for interactive data visualization.

2.4. Data Layer (Database)

The Data Layer consists of a **MySQL relational database** that stores detailed jellyfish occurrence information. The database schema is designed to support efficient **spatio-temporal querying** and **species-wise analytics**.

Key data elements include:

- Geographic coordinates (latitude, longitude)
- Species identification
- Event duration (from-date and to-date)
- State/location
- Event implications
- Source reference link

The database is structured to allow straightforward addition of new jellyfish events. Any newly added information is automatically propagated to the application layer and subsequently reflected on the frontend visualizations via API responses.

2.5. Interaction Workflow (Bird's-Eye View)

The interaction between system components follows the sequence below:

1. The user interacts with the portal through a web browser.
2. JavaScript functions on the client side initiate requests to backend JSP-based API endpoints hosted on the Apache Tomcat server.
3. The server processes the incoming parameters and performs relevant database queries.
4. The MySQL database returns the query results to the API layer.
5. The API responds with **JSON-formatted data**, enabling dynamic updates to maps and dashboards on the frontend **without requiring page refresh**.

This workflow ensures a smooth, real-time, and interactive user experience.

System Architecture

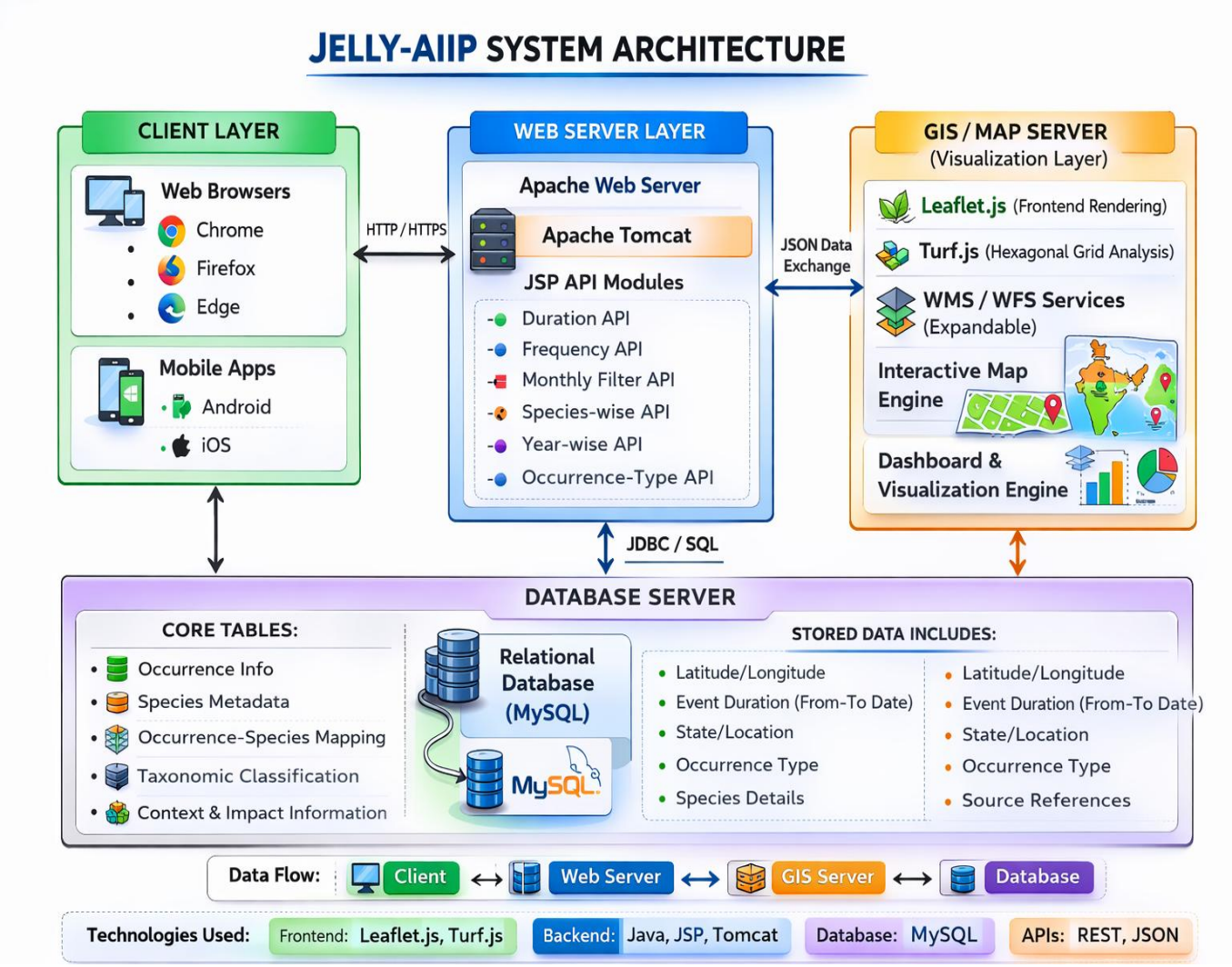

Figure-6: Overall system architecture diagram of the Jelly AIIP framework.

2.6. Technology Stack

Software Stack Overview

The **Jellyfish Aggregation Information Interactive Portal (Jelly-AIIP)** is developed using a layered technology framework designed to ensure **modularity**, **scalability**, and **efficient data exchange** across system components. The technology stack integrates widely adopted open-source platforms and tools across the **presentation**, **application**, and **data** layers. This multi-tier architecture enables seamless interaction between the user interface, server-side logic, and backend data storage systems, supporting both real-time visualization and analytical processing.

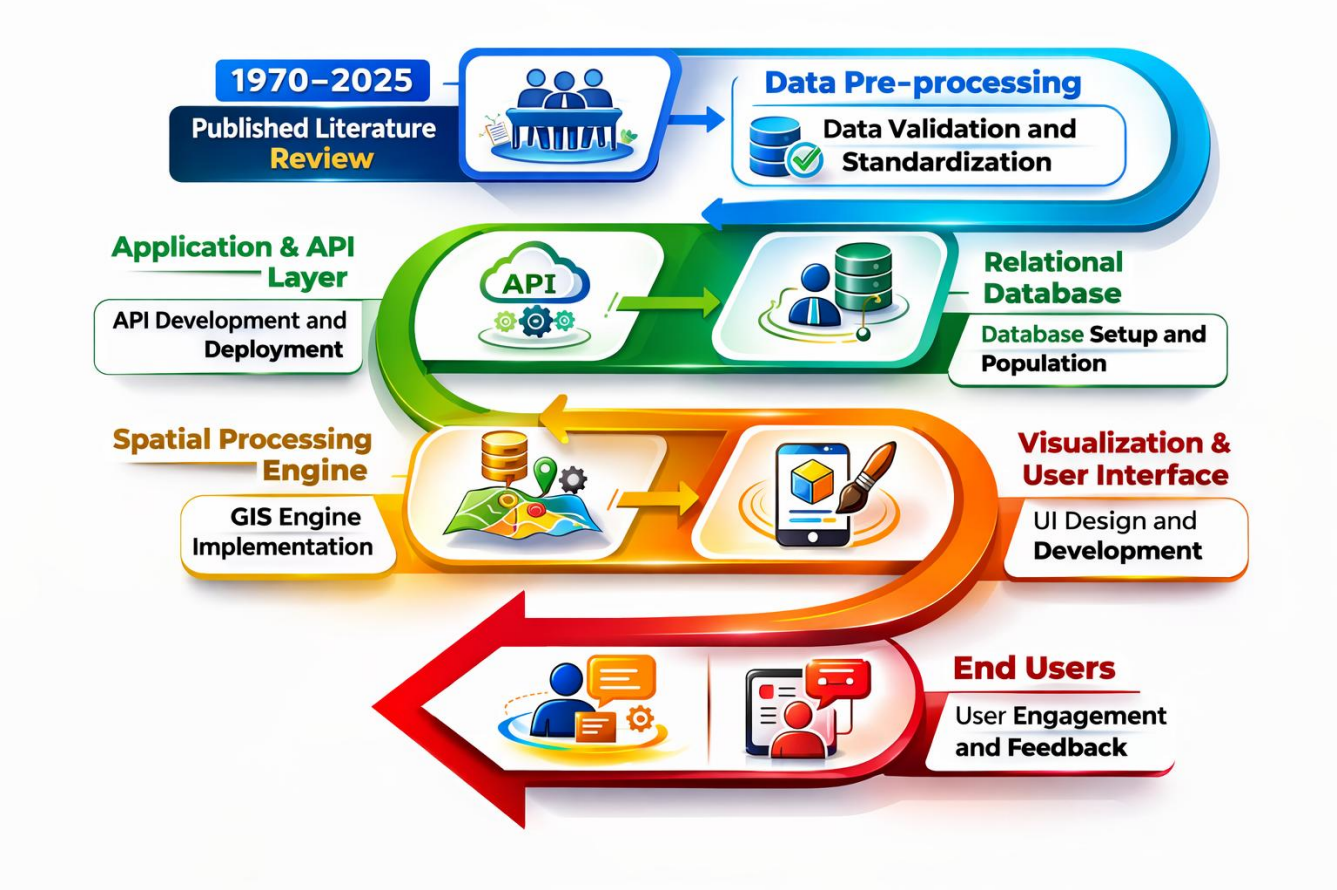

Figure-7: Geospatial data system architecture illustrating the workflow for data integration, processing, and visualization.

2.7. Design Advantages

The adopted system architecture establishes a strong and scalable foundation for the long-term operation of the Jelly-AIIP portal. Its modular, layered structure promotes efficient development workflows, supports clear separation of concerns, and simplifies ongoing maintenance activities. This design also enables the seamless integration of new features and analytical components as system requirements evolve.

API-driven data exchange ensures high-speed retrieval of datasets from multiple sources, providing reliable communication between system layers and enabling timely updates across all modules. This approach enhances interoperability while reducing dependency on tightly coupled components.

The architecture is optimized to deliver responsive, interactive user experiences across diverse device types, including desktop systems, tablets, and mobile platforms. Its scalable configuration allows for significant growth in data volume, analytical complexity, and visualization capabilities without necessitating major architectural changes.

Furthermore, the system is fully compatible with institutional server environments, ensuring dependable deployment, operational stability, and straightforward integration within existing IT and data management infrastructures.

3. Frontend Design and UI

Frontend Design and User Interface

The Jellyfish Interactive Aggregation Information Portal (Jelly-AIIP) is deployed with a structured, user-centric frontend design that serves as the primary interaction layer for all system functionalities. The interface integrates multiple core modules, including:

- Interactive geospatial visualization
- Analytical dashboard access
- Jellyfish sting first-aid and safety guidance
- Emergency contact and response information
- Dynamic, map-driven exploration and filtering tools

These components are seamlessly unified within a central interface that acts as the integration layer between frontend visualization elements and backend data services. This architecture ensures smooth navigation, responsive interactions, and real-time updates across all portal modules.

Analytical and Visualization Engine

The portal incorporates a dynamic analytical module that serves as the central engine for spatial and temporal exploration of jellyfish occurrence data. This module integrates database-driven records with interactive GIS-based visualization tools, enabling users to examine:

- Spatial distribution patterns
- Year-wise and multi-year temporal trends
- Species-specific occurrence distributions
- Duration and progression of aggregation events
- Frequency patterns and hotspot identification

Through real-time communication between frontend GIS interactions and backend database services, the module ensures precise data retrieval, rapid processing, and responsive visualization. This tightly coupled interaction facilitates seamless analytical workflows, allowing users to dynamically filter, compare, and interpret information without delays or redundant data loading.

Data Handling and Structure

The system is built on a centralized relational database architecture, where the primary database stores jellyfish occurrence records in a structured and query-efficient format. Each record incorporates essential attributes such as geographic coordinates (latitude and longitude), year of occurrence, species name, state or locality, occurrence type (classified as *swarming* or *beach stranding*), data source, and event duration expressed in days.

To enhance performance and analytical flexibility, the portal employs a dynamic grouping and filtering mechanism. Under this strategy, records are organized into logical subsets—such as year-wise, species-wise, occurrence-type, and seasonal datasets—allowing users to explore specific patterns without requiring repeated full-dataset queries.

This optimized data structuring significantly improves the responsiveness of the interactive map and analytical tools. Users can dynamically visualize selected trends and distributions in real time, ensuring smooth system performance and an efficient, uninterrupted exploration experience.

Technologies and Libraries Used

The frontend of Jelly-AIIP is developed using modern, lightweight, and open-source technologies selected for their efficiency, cross-platform compatibility, and suitability for both field and desktop environments. These technologies collectively support the portal's core operational requirements, including:

- **Responsive UI layouts**, ensuring consistent usability across desktops, tablets, and mobile devices
- **Interactive GIS rendering** for map-based visualization and spatial exploration
- **Dynamic charting and dashboard visualization** to support analytical insights and trend evaluation
- **Asynchronous communication with backend APIs** for real-time data fetching and seamless interactions
- **Browser-independent usability**, enabling reliable operation across all major web browsers
- These technologies together provide a flexible and high-performance frontend environment, capable of supporting real-time geospatial analysis, data visualization, and user interaction without compromising efficiency or accessibility.

Main Interface Components

1. Portal Header and Navigation

The portal header presents the system title, **"Jellyfish Aggregation Interactive Information Portal (Jelly-AIIP)"**, serving as the primary identification element of the user interface. The header also incorporates a structured navigation menu that provides direct access to key functional modules of the portal.

The main navigation buttons include:

- **Dashboard**
- **Jellyfish Sting First Aid**

- **Stung? Get Help Now**

Each navigation option opens a dedicated modal window, enabling users to view information overlays without navigating away from the central map interface. This design approach ensures uninterrupted spatial exploration while providing quick access to critical information and support tools. The modal-based navigation enhances usability by reducing page transitions and maintaining a seamless, integrated user experience.

2. Interactive Geospatial Map Integration

The portal integrates an interactive geospatial map developed using Leaflet JavaScript, which serves as the primary visualization component of Jelly-AIIP. This map provides a dynamic exploration environment for jellyfish occurrence data across the Indian coastline. Key functionalities include:

- Display of georeferenced jellyfish occurrence points
- Visualization based on occurrence type (swarming or beach stranding)
- Species-wise occurrence distribution
- Year-wise and multi-year event visualization
- Duration-based event highlighting
- Frequency-of-occurrence mapping and hotspot identification
- Clickable map features that open information pop-ups containing contextual details

The interactive map is embedded into the main interface using an iframe, ensuring modular separation between the homepage layout and the internal map logic. This design enhances flexibility, improves maintainability, and isolates map-related scripts from the rest of the user interface components.

The map module incorporates several specialized visualization layers and interaction tools, described below.

I) Jellyfish Occurrence Visualization

The **Jellyfish Occurrence Visualization** component provides an interactive, map-based representation of jellyfish aggregation and stranding events along the Indian coastline. This module includes several visualization features, the primary one being:

Type-wise Occurrence:

This mode displays all jellyfish occurrence records collectively, with clear color-coded differentiation based on the **type of occurrence**, specifically:

- **Swarming events**

- **Beach stranding events**

This categorization enables users to obtain a synoptic, national-scale overview of event patterns (Figure-8). Both swarming and beach stranding events can be visualized simultaneously, allowing for comparative assessment of their spatial distribution.

When a user selects an occurrence point on the map, an information pop-up is generated that provides:

- Jellyfish species
- Location details
- Associated implications or consequences
- Source information, including a clickable hyperlink to the original reference

This ensures transparency, supports data verification, and facilitates reliable traceability of all displayed records.

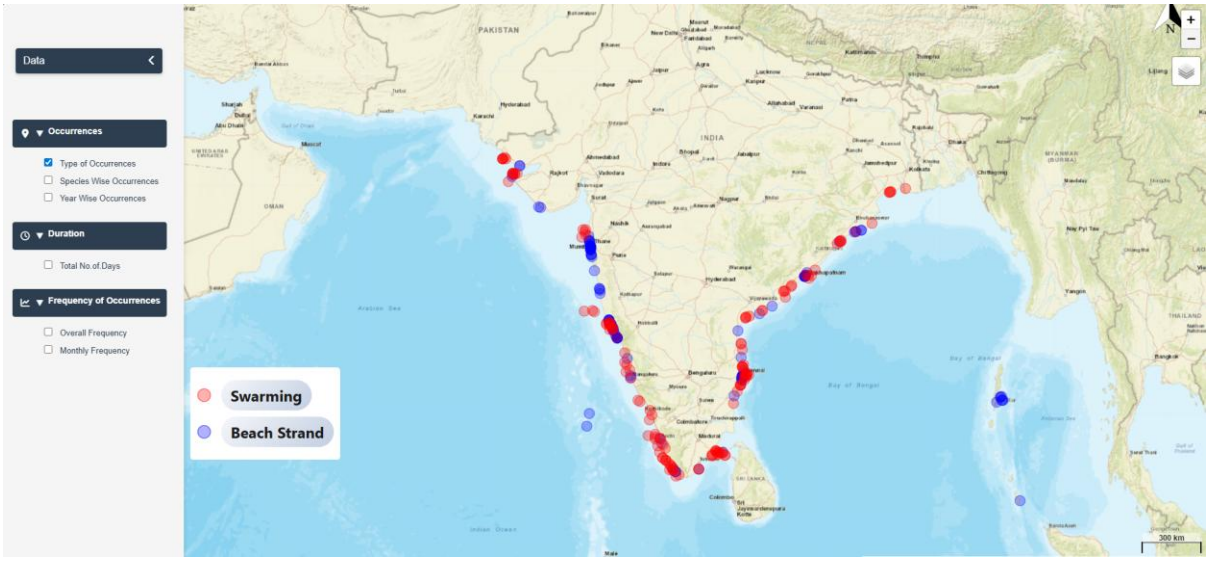

Figure-8: Type-wise occurrence module within the interactive geospatial mapping interface.

Species-wise Occurrence:

The **Species-wise Occurrence** module allows users to explore jellyfish events based on individual species or aggregated groups. Users can select a single species or choose **"Select All"** to visualize multiple species simultaneously. Additional filtering options allow refinement by **beach stranding** or **swarming** events.

For each selected species, the module displays detailed species-specific information, including:

- Scientific name
- Common name
- Venomous status
- Known uses (where applicable)

- Species image
- Image source with a **hyperlinked reference** for traceability

Each species is assigned a **unique color code**, enabling clear visual distinction on the map.

Interactive checkboxes support:

- **Multi-species comparison**, allowing simultaneous visualization of multiple taxa
- **Identification of species-specific hotspots**, aiding spatial, ecological, and distributional assessments

This module provides valuable support for ecological interpretation and taxonomic analysis (Figure-9).

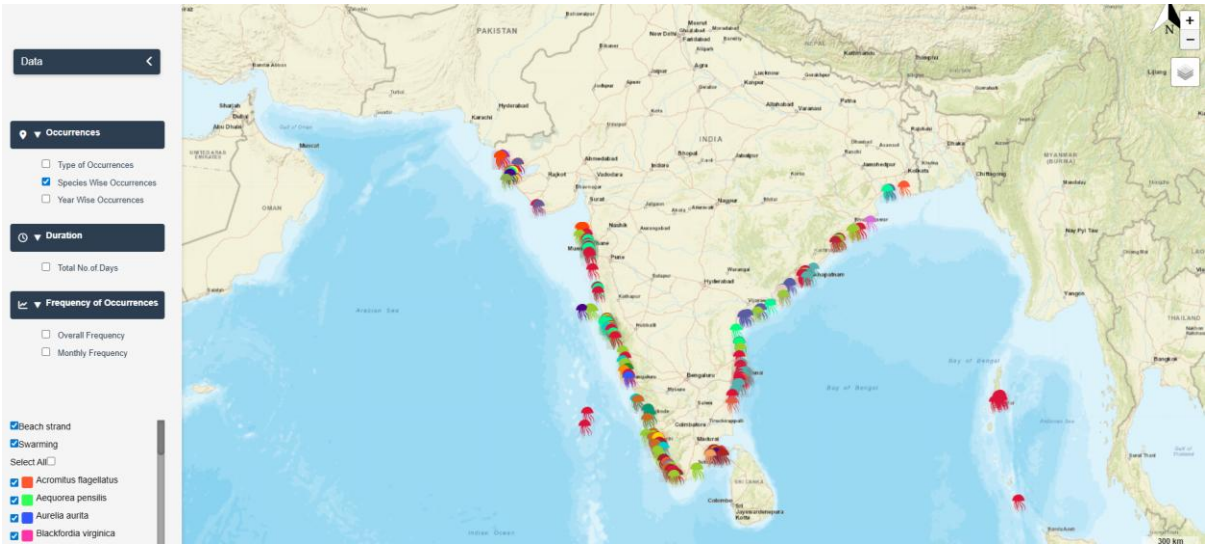

Figure-9: Species-wise occurrence module of the interactive geospatial mapping system.

Year-wise Occurrence:

The **Year-wise Occurrence** module visualizes jellyfish events using color-coded jellyfish icons, enabling users to explore the temporal distribution of occurrences across multiple years. Each event marker is assigned a unique color corresponding to its respective year, allowing clear visual differentiation and facilitating temporal comparison.

Dynamic year-selection checkboxes are automatically generated based on the available years in the database. Users can:

- Select individual years
- Use the **Select All** option
- Filter events by **swarming** or **beach stranding**

This flexible filtering capability supports detailed year-specific and multi-year temporal analysis.

Clicking on an event icon opens an interactive popup displaying:

- Year of occurrence
- Scientific name of the species involved
- Type of occurrence
- Species image for quick visual reference

The year-coded icons and interactive popups together enable users to compare temporal patterns, identify shifts in occurrence frequency, and examine year-to-year variability in jellyfish aggregations and strandings (Figure-10).

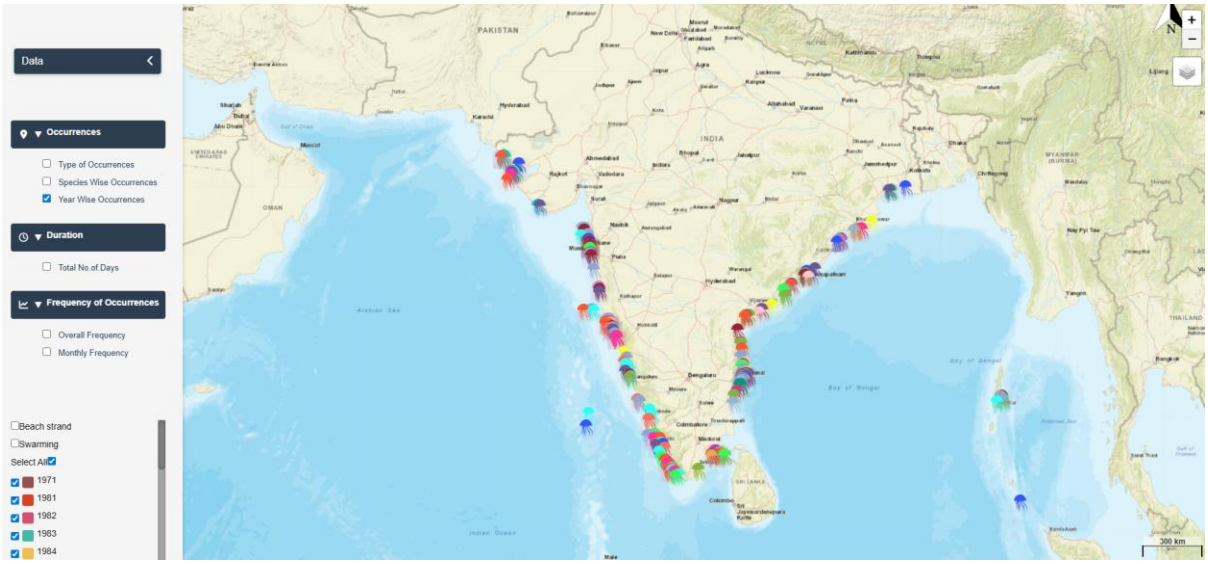

Figure-10: Year-wise occurrence visualization module in the geospatial mapping platform

II) Duration Visualization Module

The **Duration Visualization Module** illustrates the total number of days associated with individual jellyfish events (Figure-11). Events are represented as circular markers whose visual properties correspond to event duration, enabling users to quickly interpret the persistence and severity of occurrences along the coastline.

Key visualization features include:

- **Variable marker size**, where larger dots represent events of longer duration
- **Increasing color intensity** with longer persistence, enhancing at-a-glance interpretation
- **Interactive duration legend**, allowing users to toggle specific duration categories on or off

Duration classes are grouped into intuitive, ecologically meaningful time categories:

- 1 week
- 2 weeks
- 1 month
- 2 months
- 3 months
- 6 months
- 8 months
- 1 year

This structured classification supports rapid identification of prolonged or persistent jellyfish aggregation events. By enabling duration-based filtering and visual comparison, the module helps users assess the **severity, persistence, and temporal impact** of jellyfish events across different regions.

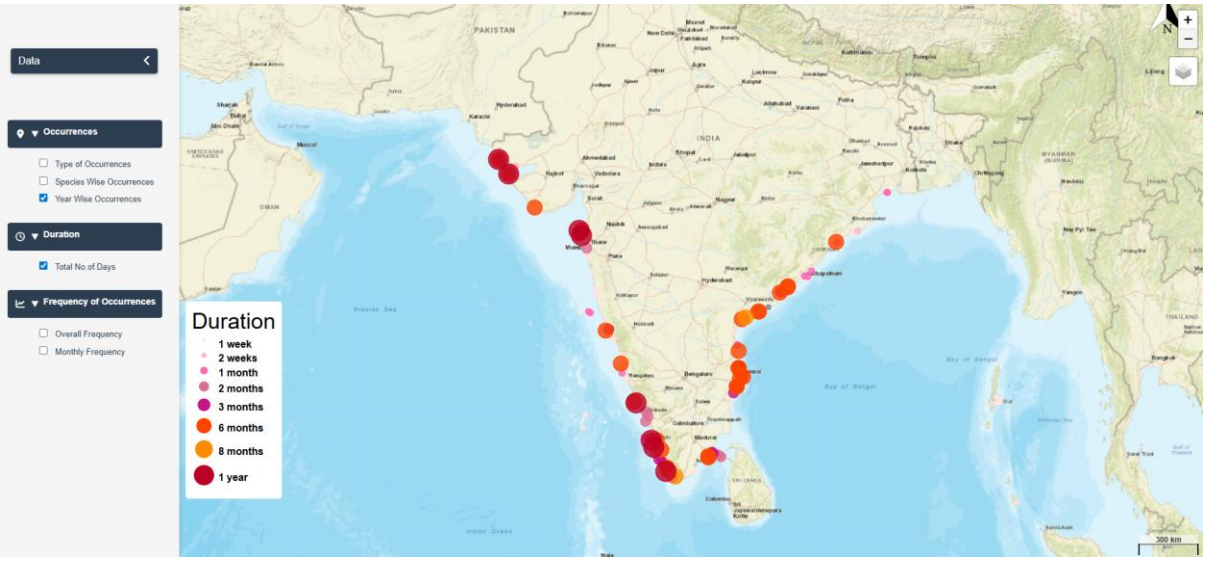

Figure-11: Duration-of-occurrence analysis module in the interactive geospatial system.

III) Frequency of Occurrence Module

The **Frequency of Occurrence Module** analyzes how often jellyfish events recur within a given coastal region. This is achieved by spatially aggregating jellyfish occurrence records into a uniform hexagonal grid system. The module highlights persistent hotspot zones along the Indian coastline where jellyfish aggregations or strandings occur repeatedly.

Overall Frequency

The **Overall Frequency** visualization represents the total number of jellyfish events recorded within each hexagonal grid cell across the entire study period (Figure-12). To compute this metric, all point-based jellyfish occurrence data were spatially aggregated along the coastline using the following methodology:

- The study region was divided into uniform **50-km hexagonal grids** to reduce directional bias and edge effects commonly observed in square grids.
- Hexagons were generated using **Turf.js**, ensuring consistent grid geometry across the entire coastal area.
- The number of jellyfish occurrence points falling within each hexagon was counted.
- Hexagons were then symbolized based on event density, where **darker colors represent higher frequency** of occurrences.

This approach effectively identifies **recurring hotspot zones**, enabling recognition of regions with persistent jellyfish aggregations or repeated stranding events. Clicking on any hexagon displays key details, including:

- **Number of occurrences** recorded within that grid
- **Years in which events were reported**

This module provides essential insight into long-term spatial clustering patterns and supports targeted management and monitoring interventions along the Indian coastline.

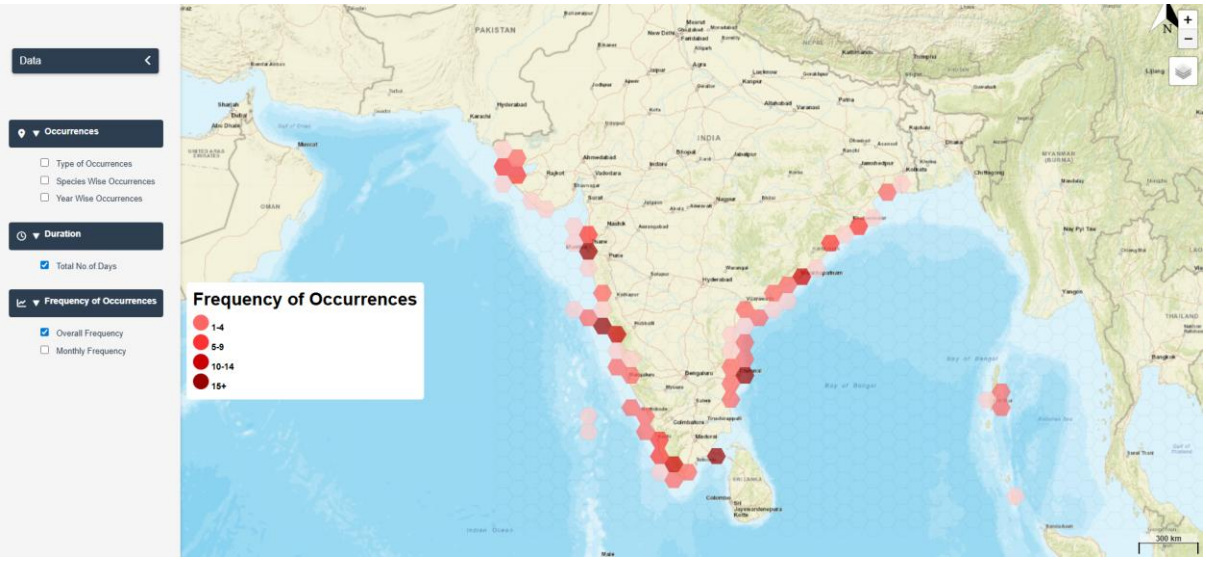

Figure-12. Overall frequency analysis module displaying aggregated jellyfish occurrence patterns.

Monthly Frequency:

The **Monthly Frequency** module enables identification of month-wise and seasonal patterns in jellyfish occurrences. Each event record in the database includes a date of occurrence, from which the corresponding month is extracted for temporal classification.

Users can select any month (January–December) from a dropdown menu. Once a month is selected, only the records belonging to that month are filtered and displayed on the interactive map (Figure-13). The frequency of occurrences is recalculated spatially for the selected month, allowing users to compare seasonal variability across different coastal regions.

This approach aids in:

- Detecting seasonal peaks in jellyfish occurrences
- Understanding month-specific spatial clustering
- Supporting early-warning awareness
- Strengthening seasonal preparedness for fisheries, tourism, and coastal management stakeholders

When a user clicks on a hexagonal grid, the system displays:

- **Monthly frequency of occurrences**
- **Corresponding years** in which events were reported during that month

This module provides valuable insights into spatial–temporal dynamics of jellyfish events and supports informed decision-making based on seasonal patterns.

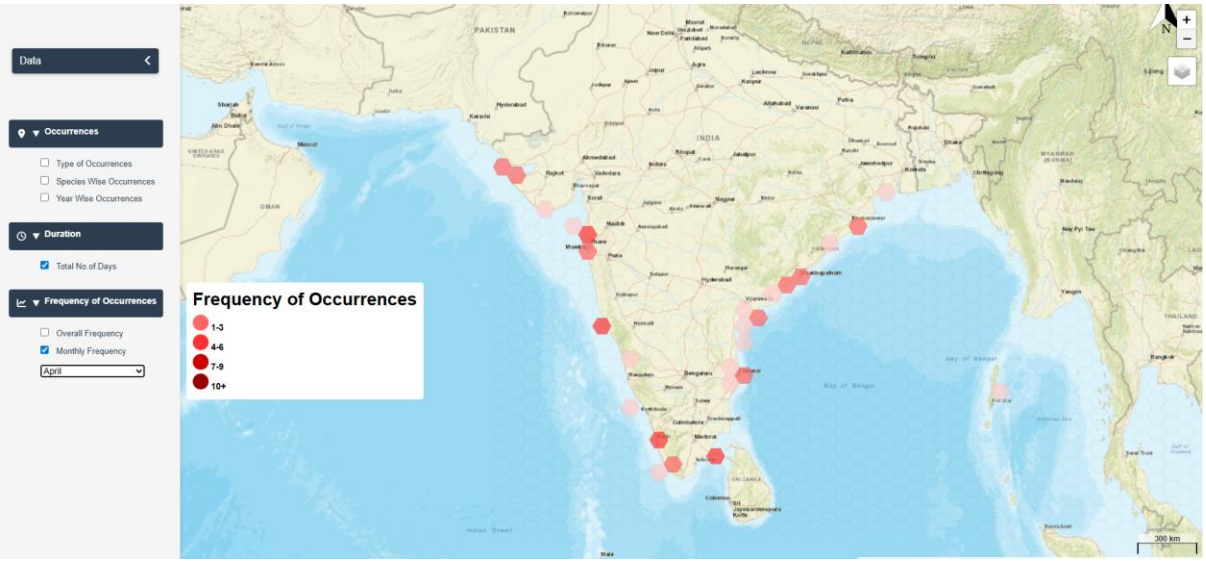

Figure-13: Monthly frequency analysis module illustrating temporal trends in jellyfish occurrence.

IV) Beach Layer Visualization Module:

The **Beach Layer Visualization Module** is a key component of the Jelly-AIIP web portal's frontend, designed to deliver interactive geospatial visualizations of jellyfish occurrences along India's coastal regions. This module integrates seamlessly with the portal's primary mapping interface and enables users to overlay beach-specific data layers through a simple, checkbox-based activation mechanism.

Upon enabling the module, users can visualize jellyfish occurrence data in a species-wise manner, along with additional information related to the **duration** and **frequency** of events at individual beach locations. This allows users to examine jellyfish activity at finer spatial scales, supporting detailed coastal zone assessments and localized decision-making.

The module provides multiple layered visualization options that collectively enhance analytical depth and user understanding of beach-level jellyfish patterns (Figure-14). These layered features allow users to:

- Inspect species-specific occurrence distributions at designated beach locations
- View duration details to understand persistence or prolonged events at particular beaches
- Identify beach-level occurrence frequency through repeated event indicators
- Compare multiple datasets simultaneously via overlay layers

Together, these functionalities make the Beach Layer Visualization Module an essential tool for **coastal monitoring**, **risk assessment**, and **site-specific marine ecosystem analysis**.

Beach Layer Visualization Components

The Beach Layer Visualization Module incorporates multiple overlay components that allow users to examine jellyfish occurrences at the level of individual beach locations. These components support detailed spatial, temporal, and species-specific assessments. The key visualization layers include:

1. Beach Layer and Species Visualization

This layer overlays jellyfish species distribution data onto mapped beach locations. By visualizing species occurrences at specific beaches, users can:

- Identify **species-specific hotspots**
- Compare species presence across multiple coastal zones
- Assess potential ecological or tourism-related implications at each site

This layer provides valuable support for species-level marine biodiversity assessments and coastal ecosystem monitoring.

2. Beach Layer and Occurrence Visualization

This visualization highlights the **spatial distribution of jellyfish sightings or incidents** relative to major beach geographies. It allows users to:

- Examine how occurrence patterns align with coastal features
- Identify beaches experiencing more frequent or concentrated events
- Understand spatial exposure risks for tourism and coastal livelihoods

The layer helps stakeholders align local beach management strategies with observed jellyfish activity.

3. Beach Layer and Duration Visualization

This layer represents the **temporal extent** of jellyfish occurrences at specific beaches. Users can explore:

- Seasonal persistence of events
- Differences in duration across beaches
- Identification of locations experiencing prolonged jellyfish aggregations

This supports temporal impact assessment and improves preparedness planning for extended events.

4. Beach Layer and Frequency Visualization

This component illustrates the **recurrence rate** of jellyfish events at each beach. It helps users:

- Identify high-risk or persistent hotspots
- Compare recurrence patterns among beaches
- Support long-term risk mitigation, monitoring, and coastal advisory planning

The frequency layer contributes to understanding repetitive stress on coastal ecosystems and community activities.

Blue Flag Beach Layer

In addition to the analytical layers, the module includes a dedicated layer highlighting **Blue Flag certified beaches** in India. This layer enables users to:

- Visualize ecologically significant and sustainably managed beaches
- Examine jellyfish occurrences in relation to internationally recognized clean-beach standards

- Support coastal awareness by linking environmental quality indicators with marine biodiversity observations

This integration promotes informed, sustainable coastal management by contextualizing jellyfish events alongside environmentally significant beach zones.

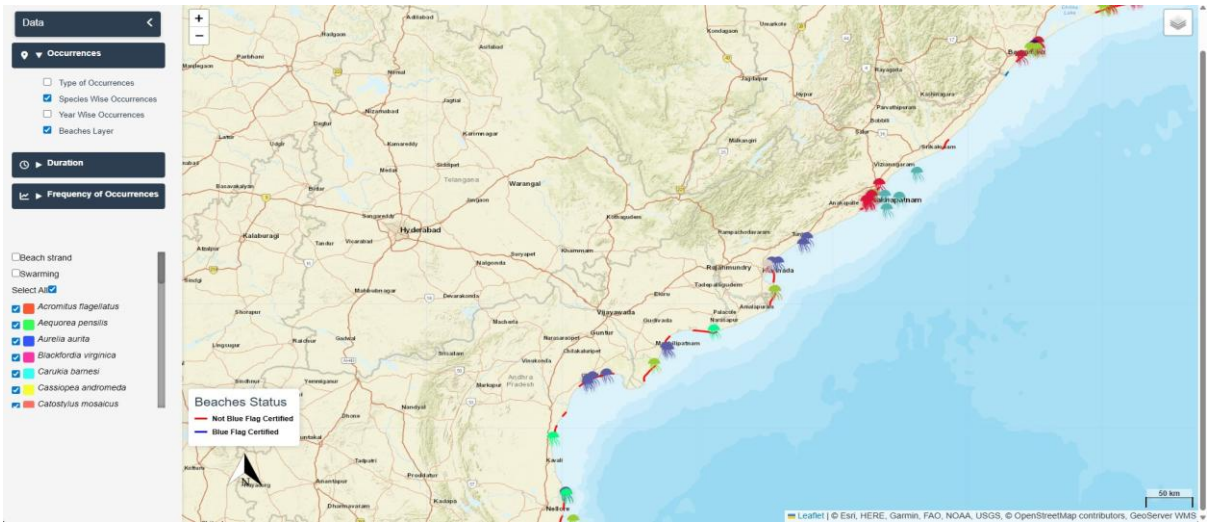

Figure-14: Beach layer visualization used for analyzing jellyfish species occurrence and spatial patterns along coastal regions.

V. Dashboard Integration

The **Dashboard** module is accessed through a dedicated button on the portal interface, which opens a modal window containing multiple analytical visualizations and summary metrics. The dashboard presents:

- **Bar charts**
- **Pie charts**
- **Summary statistics**

These visual components provide insights into:

- Species composition and diversity
- Year-wise trends in jellyfish occurrences
- State-wise distribution patterns
- Latitude- and longitude-based occurrence distributions

The dashboard is loaded via an embedded iframe, ensuring a clear separation between the analytical components and the main geospatial mapping interface. This modular design

enhances maintainability and allows independent updates to analytical functionalities without affecting map-related logic.

VI. Jellyfish Sting First Aid Module

The portal includes a dedicated **multilingual Jellyfish Sting First Aid Module**, implemented using modal dialogs to ensure rapid accessibility during emergencies. This module provides:

- **Step-by-step first aid instructions**
- **Guidance on immediate response actions**
- **Pain relief measures**
- **Warning signs requiring urgent medical attention**
- **Actions to avoid following a sting**

The module supports multiple Indian languages, including:

English, Hindi, Telugu, Tamil, Malayalam, Kannada, Marathi, Gujarati, Odia, and Bengali.

Users can select their preferred language via a dropdown menu. This multilingual functionality improves public accessibility, promotes safety awareness, and supports diverse coastal communities across India.

VII. "Stung? Get Help Now" – Emergency Support

The **"Stung? Get Help Now"** module provides quick access to emergency response information for users experiencing or witnessing a jellyfish sting incident. Features include:

- Contact details of nearby **government hospitals** in major coastal regions of India
- Rapid-access emergency information designed for:
    - Tourists
    - Beachgoers
    - Fisherfolk
    - Coastal community members

By offering immediate guidance and location-specific support, this module strengthens the portal's role as a public safety tool.

VIII. Role in Overall System Architecture

Within the overall system architecture, the portal's main interface functions as the **frontend controller and user interaction hub**. It integrates multiple components, including:

- Backend API services
- Database query handlers
- Geospatial visualization modules
- Public safety and awareness tools

This integration ensures a **modular, scalable, and user-centric** architecture.

The geospatial processing module transforms raw jellyfish occurrence records into a comprehensive decision-support system by integrating:

- Database-driven analytics
- Spatial statistics
- Temporal filtering mechanisms
- Intuitive, user-friendly visualizations

Together, these components support broader applications such as:

- Coastal hazard assessment
- Marine ecosystem monitoring
- Fisheries and tourism advisory planning
- Regional environmental management

4. Backend (Server-Side)

4.1 Overview of the API Module

The backend of the **Jellyfish Aggregation Information Interactive Portal (Jelly-AIIP)** is implemented using **JSP-based server-side scripting** integrated with a **MySQL relational database**. The system exposes a well-structured **Application Programming Interface (API)** layer that returns responses in **JavaScript Object Notation (JSON)** format, enabling seamless communication between backend services and the portal's interactive geospatial mapping and analytical dashboard components.

The API layer acts as an intermediary data service between the relational database and the frontend visualization modules. This architectural approach:

- Enforces a clear separation between data logic and presentation
- Supports modular development
- Improves system scalability and maintainability
- Enables efficient execution of spatial and temporal filtering
- Facilitates real-time analytical processing

All API endpoints are accessed asynchronously through **AJAX or Fetch** calls, allowing dynamic data retrieval without page reloads and ensuring a highly responsive and interactive user experience.

The backend services are responsible for retrieving jellyfish occurrence records, processing spatial and temporal attributes, performing aggregation and grouping operations, and returning structured JSON outputs that support real-time, filter-driven map visualization and dashboard analytics.

4.2 API Architecture and Database Integration

The API layer comprises multiple dedicated endpoints, each specialized for handling specific analytical or visualization functions. All endpoints interact with a centralized **MySQL database** that stores structured jellyfish occurrence records and metadata.

The core database schema includes:

- **Occurrence Metadata Structure**: Primary event records (location, date, type, duration)
- **Species Master Structure**: Biological characteristics and taxonomic details
- **Species Mapping Structure**: Relational mapping between species and event records
- **Location & Consequence Structure**: Geographic context and event impact information

Depending on the complexity of the request, different MySQL query structures are used for optimized performance. Each API endpoint:

1. Executes predefined SQL queries
2. Processes the retrieved results
3. Structures the response in JSON format
4. Sends data to the frontend mapping and dashboard modules for interactive rendering

This architecture ensures efficient data processing, high performance, and reliability across diverse analytical requirements.

4.3 API Functional Modules and Capabilities

Event Duration Analysis Module

This module calculates the **persistence of jellyfish events** by computing the duration from start to end dates using inclusive day-count logic. Key capabilities include:

- Date-based duration computation
- Grouped species aggregation for multi-species events
- Sorted outputs based on event duration
- Output of spatial coordinates, dates, occurrence type, state, and associated species

The processed results are consumed by the frontend to visualize event persistence using variable marker sizes or intensity-based symbology, supporting comparative duration analysis across regions.

Spatial Frequency and Grid Aggregation Module

This component provides essential **latitude, longitude, and year attributes** for generating frequency-based maps. Spatial aggregation—such as **hexagonal grid clustering**—is performed on the frontend using grid-based algorithms.

The module supports:

- Identification of recurring hotspot regions
- Detection of coastline-level spatial patterns
- Computation of overall frequency distributions

It serves as the foundation for hotspot mapping and recurrence-based analysis.

Monthly Overlap Analysis Module

This module enables **seasonal and month-wise frequency analysis** by retrieving all events that intersect a user-selected month. It identifies:

- Events starting within the selected month
- Events ending within the selected month
- Events spanning across the selected month

The response includes spatial and temporal attributes required for seasonal comparison and supports visualization of month-wise variability in jellyfish occurrences.

Species-Specific Analysis Module

This module provides **species-level contextual information** by joining occurrence records with species reference structures. The output includes:

- Latitude and longitude
- Scientific and common names
- Venomous or non-venomous status
- Edible or commercial significance (where available)
- Species imagery with source references
- Occurrence type and year

This module enhances scientific interpretation and public awareness by delivering detailed biological metadata alongside occurrence records.

Occurrence Type Categorization Module

This component categorizes events based on their **type of occurrence**, such as:

- Swarming
- Beach stranding

The output contains:

- Spatial coordinates
- Occurrence dates
- Aggregated species involved
- Location descriptions
- Documented ecological or socio-economic consequences

- Source references

This enables type-wise mapping and supports interactive pop-ups enriched with contextual event information.

Year-Based Temporal Analysis Module

This module supports temporal trend exploration by grouping events by year and returning:

- Geographic coordinates
- Year of occurrence
- Occurrence type
- Associated species

These outputs enable year-wise filtering, multi-year comparative assessment, and animated temporal visualization of jellyfish occurrence patterns through the frontend.

4.4. Data Exchange Format

All API endpoints return data in **JavaScript Object Notation (JSON)** format, ensuring lightweight data transfer, efficient parsing by JavaScript-based frontend components, and rapid updates to interactive maps and dashboards without requiring page reloads. JSON is used throughout the Jelly-AIIP system to maintain consistency, minimize payload size, and support asynchronous communication between the server and client interfaces.

To ensure backend security and protect system integrity, **database credentials are stored exclusively on the server side** and are never exposed to the client or included in API responses. All APIs operate in a **read-only mode**, preventing unintended or unauthorized modification of the underlying datasets while allowing unrestricted data retrieval for visualization and analysis.

This allows flexible integration with frontend components and external visualization modules while preserving backend data security and enforcing strict control over data-write operations. The combination of JSON-based exchange, read-only APIs, and server-side credential management ensures a secure, efficient, and scalable data communication framework for the Jelly-AIIP platform.

5. Database Design, Structure & Data Management

5.1 Overview of the Database

The **Jellyfish Interactive Information Portal** is supported by a structured **relational MySQL database** designed to efficiently store, organize, and retrieve jellyfish occurrence records compiled from peer-reviewed scientific literature (Sathish et al., 2026; preprint available).

The original dataset—initially maintained in **Microsoft Excel**—was systematically transformed into a **normalized relational database architecture** to ensure efficient data management, improved query performance, and seamless integration with the system's geospatial visualization components.

The system operates within an **Apache–JSP–MySQL server environment** hosted on Tomcat. The backend data layer interacts with the portal through server-side API services, enabling real-time data queries, structured JSON responses, and dynamic synchronization between the database and the frontend visualization modules.

5.2 Data Normalization Strategy

To reduce redundancy and enhance query performance, the original flat dataset was decomposed into multiple logically connected entities using standard **relational database normalization principles**.

- The normalization approach incorporates:
- **Unique identifiers** for unambiguous record referencing
- **Relational keys** to establish connections between entities
- Clear separation of **spatial**, **temporal**, **biological**, and **contextual** information
- Improved **consistency** and **data integrity** through structured relational design
- This strategy supports efficient relational joins, flexible cross-dimensional querying (e.g., species-wise, year-wise, taxonomic level), and scalability for future data expansion as new jellyfish datasets become available.

5.3 Core Data Components and Their Roles

Occurrence Information

- This component stores individual jellyfish aggregation or stranding events. Each record contains:
- Geographic coordinates (latitude, longitude)
- Administrative region (state)
- Year of occurrence
- Event type (swarming or beach stranding)
- Event duration (start and end dates)

- Source references
- These records form the primary dataset for spatial and temporal analysis.

Species Metadata

- This table stores detailed biological information, including:
- Scientific and common names
- Venomous or non-venomous status
- Edible or commercial relevance (where applicable)
- Image references and source citations
- This component supports species-specific queries and biological interpretation.

Occurrence–Species Relationships

- A many-to-many relational mapping ensures accurate representation of events involving multiple species. This structure enables:
- Species-wise filtering
- Multi-species event aggregation
- Efficient relational joins during analytical queries

Contextual and Impact Information

- This structure stores descriptive details about:
- Location context
- Observed ecological effects
- Documented socio-economic impacts
- It enriches the dataset for contextual interpretation and supports more comprehensive analysis.

Taxonomic Classification

- Hierarchical classification (e.g., class, order) is linked to species metadata. This supports:
- Taxonomic-level filtering
- Structured biological analysis
- Integration of ecological and classification-based insights

5.4 Relational Architecture

The database follows a **parent–child relational model**, where occurrence records serve as the central entity. Supporting structures—including species metadata, taxonomic classification, and contextual attributes—are linked through relational keys.

- This architecture allows for:
- Complex analytical queries
- Species-wise distribution mapping
- Event-type categorization
- Duration-based persistence studies
- Seasonal and year-wise trend evaluation
- Taxonomic-level comparisons
- The relational structure ensures efficient joins, minimizes redundancy, and maintains consistency across all analytical modules used by the Jelly-AIIP system.

5.5 Integration with the Web Portal

- The database is accessed exclusively through server-side API services that:
- Execute filtered SQL queries
- Process relational joins
- Format results into structured JSON responses
- These JSON outputs are consumed by the **interactive dashboard** and the **geospatial mapping interface**, enabling dynamic visualization of patterns across spatial and temporal dimensions.
- The optimized database design ensures:
- **Fast retrieval** of spatial–temporal datasets
- **Smooth real-time filtering and visualization**
- **Scalability** for future dataset expansion
- **Accurate representation** of historical and recent jellyfish occurrence patterns along the Indian coastline

6. Deployment & Maintenance

6.1 Hosting Environment

The **Jellyfish Interactive Information Portal** is deployed within the institutional server infrastructure of the **Indian National Centre for Ocean Information Services (INCOIS)**. The platform operates in a controlled environment utilizing:

- **Apache HTTP Server** for web hosting
- **JSP-based server-side processing**
- **MySQL relational database** for backend data storage
- **Apache Tomcat** as the application server for deployment, request handling, and backend execution

The architecture is **platform-independent and modular**, enabling future migration to centralized institutional servers or cloud-based environments without altering the core application logic. This ensures long-term sustainability, adaptability, and operational continuity.

6.2 Software and Hardware Requirements

The portal is compatible with both **Windows** and **Linux** operating systems.

Software Requirements

- Apache Tomcat application server
- MySQL Database Management System
- JSP support within the server environment
- Modern web browsers (Google Chrome, Mozilla Firefox, Microsoft Edge)
- Internet connectivity for map tile retrieval and external visualization libraries

Hardware Requirements

- Standard workstation or institutional server
- Minimum recommended memory: **8 GB RAM**
- Adequate storage capacity for the database and associated multimedia resources

The system is optimized to perform efficiently under moderate computational resources while supporting interactive geospatial visualization and real-time analytical processing.

6.3 Data and System Maintenance Strategy

The system supports controlled administrative updates to maintain database quality and platform reliability. New jellyfish occurrence records can be added through structured updates that preserve consistency with the normalized relational schema.

Key maintenance practices include:

- **Periodic data validation** to ensure accuracy, completeness, and consistency
- **Regular database backups** to prevent data loss
- **Monitoring of web server and database performance**
- **Updating frontend libraries and dependencies** to ensure compatibility and security
- **Routine performance checks** for query optimization and system responsiveness

These practices collectively ensure data integrity, reliability, and long-term operational stability of the Jelly-AIIP portal.

6.4 Scalability

The modular architecture of the portal supports **seamless scalability** across multiple operational dimensions. The system can accommodate:

- Integration of additional datasets
- Expansion of spatial and temporal coverage
- Inclusion of advanced analytical and visualization modules
- Migration to centralized institutional servers or cloud-based platforms

This scalability ensures that the Jelly-AIIP platform can evolve to meet future data volume growth, emerging analytical needs, and broader institutional deployment scenarios.

7. Future Scope

The current version of the **Jellyfish Interactive Information Portal (Jelly-AIIP)** primarily focuses on the compilation, visualization, and analysis of historical jellyfish occurrence data sourced from published scientific literature. While this forms a valuable foundation for understanding long-term spatial and temporal patterns, several enhancements are planned to expand the system into a more operational, interactive, and community-driven platform.

A major future enhancement is the development of a **"Report Jellyfish Sightings"** module, which will enable coastal communities, fishers, lifeguards, tourists, and citizen scientists to submit jellyfish observations through a user-friendly interface. Integrating citizen science data will significantly improve the spatial and temporal resolution of occurrence records, support near–real-time monitoring, and complement the existing historical datasets.

Further development phases will focus on integrating hydrographic and meteorological parameters, such as:

- Sea surface temperature
- Ocean currents
- Wind patterns
- Chlorophyll concentration
- Tidal conditions

Incorporating these environmental datasets will facilitate the analysis of potential environmental drivers influencing jellyfish distribution and aggregation patterns. This integration will serve as the foundation for developing **early-warning tools** and **predictive modelling capabilities**, allowing the system to evolve from a historical visualization platform into a **fully operational monitoring and forecasting system**.

The long-term vision for Jelly-AIIP is to support:

- Near–real-time jellyfish surveillance
- Predictive advisories for coastal stakeholders
- Enhanced public safety tools
- Decision support systems for fisheries, tourism, and coastal management
- Broader marine ecosystem monitoring initiatives

These advancements will strengthen the portal's role as a comprehensive and scalable platform supporting scientific research, operational monitoring, and community engagement.

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