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WebGIS for water level monitoring and flood forecasting using Open Source Technology

Shweta Mishra*, Shard Chander, Rohit Pradhan, Amit Kumar Dubey, Markand P. Oza and Shashikant A. Sharma
Space Applications Centre, ISRO, Ahmedabad, Gujarat - 380015
*Email: jaiswals@sac.isro.gov.in

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Abstract: Geographic Information System (GIS) has been widely used as a tool for spatial data manipulation, analysis and dissemination of spatial / non-spatial results in standardised format. This paper describes the design and implementation of a spatial database for satellite altimetry derived water level of large number of water bodies in India on a regular basis. Fully Automatic processing chain is developed which include downloading satellite data, water level extraction using developed models, database insertion and publishing of layers and graphs. The Web-GIS provides user-friendly GIS operations for visualizing thematic maps, as well as reporting services for selecting, displaying and downloading report of water level data for selected waterbody. The presented application developed using Free and Open Source Software (FOSS), facilitate user to visualise and plot the water level of various waterbodies at selected location and time period. It also provides next three days' water level forecast (Experimental), plots and downloading of a report for the Brahmaputra River in form of OGC Web services. Entire Application is developed using FOSS i.e. GDAL, Python, Flask (REST API), GeoServer, PostgreSQL and JavaScript APIs. Developed Application is deployed in Web Portal "VEDAS", developed by Space Applications Centre, ISRO, Ahmedabad and can be accessed through https://vedas.sac.gov.in/vstatic_1/hydro/index.html.

Keywords: WebGIS, Spatial Database, Hydrology, India, FOSS, OGC

1. Introduction

Hydrological data and related information on water resources such as river, reservoirs etc. in terms of water quantity and quality are key prerequisites for water resource management. Due to several human activities such as deforestation, urban development, unmanaged sewage discharge and water pollution, there is additional uncertainty on water resource status and conditions. Several hydrological models have been developed to simulate the hydrological cycle to help in decision-making and to find solutions for better water resource protection and management. Hydrological models mostly developed for research purpose, requires data from different resources (i.e. precipitation, DEM), involves complex interfaces, therefore, these models have not yet been applied to their full potential in terms of water resource management and policy-making (Zhang et al., 2019). To make outputs of these models available for public use for water resource management require tremendous efforts. As a tool, Geographic Information System (GIS) has a capability to acquire, store, and process spatial data for hydrological models. Applications and regular use of hydrological models became possible after integration with GIS. However, for operational deployment of model, user has to manually download required data at their end for further processing of data in GIS and regularly feed it to the model, which is itself a resource intensive task. Further, installation of software, integration of GIS and model all depend on the operating system. Additionally, due to huge cost of software and its maintenance, lack of domain expertise of GIS and hydrological modelling for their integration prevents the usage of models in mainstream use.

Combining GIS with web technologies provides facility to process spatial data, perform spatial analysis and display generated results using interactive maps or graphs in the web browser. Web-based GIS is an open source, distributed technology standardized by OGC (Open Geospatial Consortium) that brings GIS technology to the users in the form of interactive maps at little or no cost. In other words, Web-GIS provides a user-friendly interface to access spatial data, perform on-the-web spatial analysis and visualisation of Web-GIS services using web browser (Chhugani et al., 2018). In order to utilize these advantages, several researchers and application scientists have attempted to integrate scientific models with WebGIS. Mishra et al. (2017) have attempted to estimate crop intensity at pixel level and integrated the intensity estimation model with WebGIS. Vaitis et al. (2019) have developed a spatial database and WebGIS based Information System for Greece which provides a facility of cartographic operations for thematic maps visualisation and manipulation along with reporting services for selected areas. They have used spatial database to produce cartographic layers for climatic and other parameters through database views dynamically. Swain et al. (2015) have reviewed the several Free and Open Source Software (FOSS4G) solutions for web application development for water resources management. Choi et al. (2005) have developed a prototype of a spatial decision support system based on Web-based GIS for watershed management. It provides watershed delineation, map interfaces and data preparation, a hydrologic model for hydrologic/water quality impact analysis and web interface programs for operation through the Internet. Therefore, one of the greatest benefits of using WebGIS technology in decision making is to utilise its potential to overcome limitations in terms of cost, distance and geospatial data transfer. It is not required to install any expensive software and models at user end. User can simply access the developed WebGIS based system for visualising results using their web browsers and use it for further analysis and decision making. The results of the scientific models can be presented to multiple users simultaneously.

The dissemination and management of water related data i.e. water-level using web based information system is a promising technological approach for sharing information both with administrators and the general public. Using WebGIS technology, one can facilitate users with spatial data and descriptive information over the internet /cloud accessible through common web browsers. The data organisation and dissemination are based on standard data formats and transmission protocols (Costantino et al., 2019).

OGC is an international consortium responsible for making standards for geospatial information and services FAIR (Findable, Accessible, Interoperable and Reusable). Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS) are the three important OGC standards. WMS is used to serve raster and vector data as GIS enabled images in PNG, JPEG or GIF format. OGC compliant WFS provides an access to vector data with authentication for insertion, manipulation and updation, whereas WCS is used to serve or share raster or image layers on the web. Web Processing Service (WPS) is another OGC standard that is used for Geoprocessing of data on the web (Sharma and Mishra, 2017).

This paper presents a WebGIS based information system developed using FOSS integrated with hydrological model. In this work, GIS is responsible for data capturing, preparation and providing required data to the model. Water level information generated by model is transferred to the database using developed scripts on daily basis. REST (Representational State Transfer) API (Application Programming Interface) is developed to publish the generated output images automatically and disseminate water level in graphical format. The main aim of this application is to provide water level data of user selected waterbody in user interface along with the overlay layers and related non-spatial data efficiently in web environment. Paper also describes the design and implementation of a spatial database used for satellite altimetry derived water level of water bodies in India on regular basis.

2. Methodology and Development Process

The main aim of this WebGIS information system is to provide appropriate tools under a web-based platform for analysing water level data at different locations which facilitates quick decision making for water management for present and future needs. The framework of the system has interactive Graphical User Interface, Hydrological model for water level estimation from satellite derived data and spatial database for derived water level storage and management. There are two hydrological models viz., i) for water level estimation developed using different satellite derived products at various locations in India, ii) for the inundation probability forecast (Experimental) for Brahmaputra River in North-East Indian region. Brief methodology, specifications of sensors and products used to water level estimation along with relevant references are provided in following sections.

2.1 Water level estimation from Scatterometer and altimeter

Traditional method to measure water level uses in-situ hydrological stations such as water level gauge, radar gauge etc. These instruments are sensitive to long term drift and highly vulnerable during extreme events such as floods. Thus they require time-to-time testing and calibration which is time consuming and expensive. Remote sensing can play a crucial role in estimation of these hydrological variables with acceptable accuracy. Methodology is developed for estimation of river water level and detection of surface inundation using SCATSAT-1 derived backscattering coefficient and Brightness Temperature (BT) datasets respectively (Gupta et al., 2019). SCATSAT-1 is used to estimate river water levels utilizing satellite-measured soil wetness conditions through the process of run-off at the catchment scale. Detailed methodology is described in Gupta et al., (2019). Gauging sites covering some of the major river basins of India such as the Brahmaputra, Godavari, Mahi, Tapi, Narmada, Mahanadi, Subarnarekha, Brahmini and Baitrani were taken for river water level retrieval (Figure 1). Altimeters are non-imaging, nadir looking instruments that covers the same location after fix interval of time, temporal resolution varies between 10 to 35 days depending upon the altitude of the sensor (dense track coverage for later). Altimeters send an electromagnetic pulse towards earth surface and measures the returned power and time information. This time vs power graph is known is "Waveform" in altimetry community. These waveforms can have different shapes such as ocean-like, specular, peaky, rectangular etc. depending on the roughness and dielectric variability within the altimeter foot-print (Desai et al., 2015). These waveforms are than retraced by either physics based models or shape based empirical retrackers (Ganguly et al., 2015).

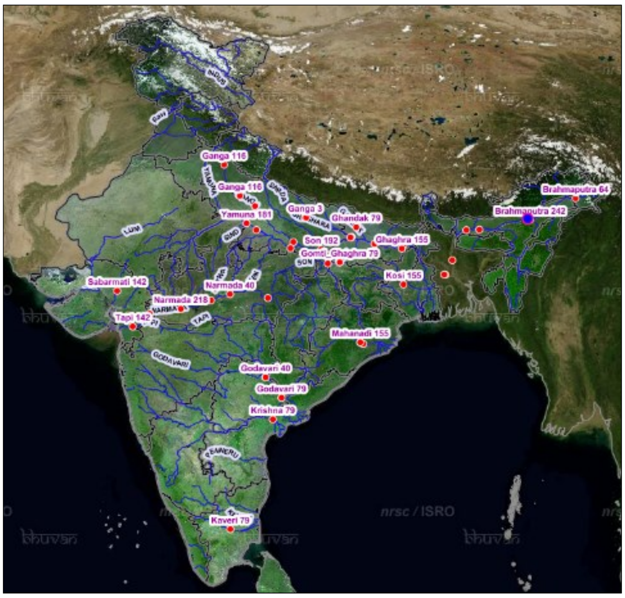

Figure 1: Gauging sites of the major rivers used for river water level retrieval using SCATSAT-1

Dedicated inland water range corrections, that takes care the atmospheric and air-water effects are also required to convert range into water level information (Chander et al., 2017). A complete algorithm chain starting from raw altimetry measurements to water stage estimation is provided in Chander et al., 2017. Figure 2 shows sites of the major rivers used for river water level retrieval using JASON (Joint Altimetry Satellite Oceanography Network) series of altimeter (https://podaac.jpl.nasa.gov/JASON3).

Figure 2: Gauging sites of the major rivers used for river water level retrieval using JASON-3 Altimeter

2.2 Short range water level and inundation forecast for the Brahmaputra River

The Brahmaputra River experiences number of long-duration flood waves during the monsoon season annually. Therefore, near real time flood prediction at basin scale with available weather forecast dataset is necessity for effective flood management. In the present study, WRF-Hydro model was setup over the Brahmaputra river basin for hourly discharge estimation at Guwahati gauge station. WRF (Weather Research Forecasting)-Hydro model is used to predict next 3-day water level and inundation probability in the Brahmaputra river at Guwahati gauge station. VEDAS Hydrology Forecast (2020) provides more insight into water level and inundation forecast for the Brahmaputra River.

2.3 Integration of hydrological models with WebGIS

To feed required datasets to the hydrological models, scripts are coded in python. Script is invoked immediately when data is available at data distribution site and download the data in specified directory. Hydrological models mentioned above are deployed on server and run through a developed python script and generate output on daily basis. For example, in case of model which is used for water level estimation from scatterometer, invoked through a python script, SCATSAT-1 derived backscattering coefficient and BT datasets are used by the model to generate output (text files) containing location IDs of basins along with water level at fixed output directory.

Immediately after the output generation, data from text files get transferred to a spatial database created to insert the water level data along with dates. Here PostgreSQL along with PostGIS is used to store and manage spatial data. PostgreSQL is an open source, spatial and relational database management system with an emphasis on extensibility and standards compliance. PostGIS is a spatial database extension for PostgreSQL which adds support for geographic objects allowing location queries to be run in SQL (https://postgresql.org). Master table containing location Ids and location of basins are stored in database. It is used to extract water level data for selected dates and location using spatial query operations. This table is published in WebGIS Server as Web Map Service (WMS) by making the connection between PostgreSQL and GeoServer. GeoServer (http://geoserver.org) is a WebGIS Server which is used here for sharing geospatial data on the web as WMS. RESTful web service is developed in flask framework in python which can be accessed through Hyper Text Transfer Protocol (HTTP). Python is an interpreted, object-oriented and high-level programming language. It supports modules and packages, which encourages program modularity and code reuse (https://python.org). Some of the packages used in development are GDAL, Psycopg2, Flask and gsconfig. Web service access the required water level datasets from the spatial database on the basis of a selected river basin of user. The same process is applied for water level generation, storage and dissemination from hydrological model using Jason-3 Altimeter products. In case of short range water level and inundation forecast for the Brahmaputra river, a daily 3-day inundation probability forecast (GeoTiff files) are generated. For automatic publishing of images gsconfig library is used. gsconfig is a python library for manipulating a GeoServer instance via GeoServer RESTConfigAPI (https://pypi.org/project/gsconfig/). Next 3-day every hour water-level estimation is also generated and stored in database using psycopg2 library. It is a PostgreSQL database adaptor for python programming language (https://pypi.org/project/psycopg2/).

2.4 WebGIS based Application Framework:

WebGIS provides a way for querying, monitoring, analysis and display of water level data for selected River / Reservoir location in India. The application framework is shown in figure 3. It is consisting of three main components: client, server and database. Client is any terminal that allows the interaction of users with the application and provides spatial and non-spatial information in an interactive way. Server includes Web GIS server, application server and spatial database server. Web server act as middle ware between Client and WebGIS server. When client makes a request, it will reach Web server first and then further Web Server parses the request and forward it to GeoServer for spatial data request and database for non-spatial data request. Thereafter the GeoServer or/and database server completes the query operations according to Web server requests and returns the relevant results to Web server. Subsequently Web server sends the results in the form of images through Web server. RESTful Web Service is created in Python to access the water level data for selected water body in User Interface.

VueJS (www.vuejs.org) JavaScript library and HTML are used for development of web application. Open Source JavaScript library Openlayers5 (https://openlayers.org) is used for creating map and displaying published spatial layers on the web. Geospatial data has no intrinsic visual component. In order to visualise the data with better understanding, style must be provided to the layer which means to specify the color, thickness, and other visible attributes. In GeoServer, OGC standard Styled Layer Descriptor (SLD) is used for styling. SLD is an XML-based markup language used for preparing illustrative visual map depictions.

3. Results

The WebGIS based application described in previous section is shown in figure 4. User Interface is consisting of Map Viewer and two tabs "Reference Layers" and "Data and Analysis" in the bottom. Reference Layer tab contains overlay layers i.e. Administrative boundaries, Rivers and streams, LISS-III Mosaic, Cartosat-1 Mosaic, AWiFS Mosaic etc. which are published as WMS in GeoServer. "Data and Analysis" tab contains three tabs as shown in figure 4.: - (i) Altimeter (ii) Forecast (iii) Scatterometer. By clicking on Altimeter tab, user gets options of selecting waterbody (River / Reservoir), location from combo box and dates. After clicking on submit button user gets water level estimation for selected location in graphical format as shown in figure 5. There is also an option for selecting "year over year profile" which provides facility to compare multiple years' data with each other.

Same functionality is provided in Scatterometer tab for water level visualisation for selected location of river. Daily Inundation Probability Forecast based on WRF-Hydro model is generated and automatically published in GeoServer. Same is shown in figure 6 for August 04, 2019. Graph is showing inundation water level forecast along with three levels (Warning Level, Danger Level and Highest Flood Level) starting from August 04, 2019 6:30 A.M. User can also download the inundation map and graph using "Export to PDF" functionality provided for generating and sharing reports. Developed WebGIS based Information system for Hydrology is deployed in VEDAS (https://vedas.sac.gov.in) Visualisation of Earth observation Data and Archival System (VEDAS) is a portal to showcase end-products from EO applications which feed into decision making system. Application can be access through VEDAS portal.

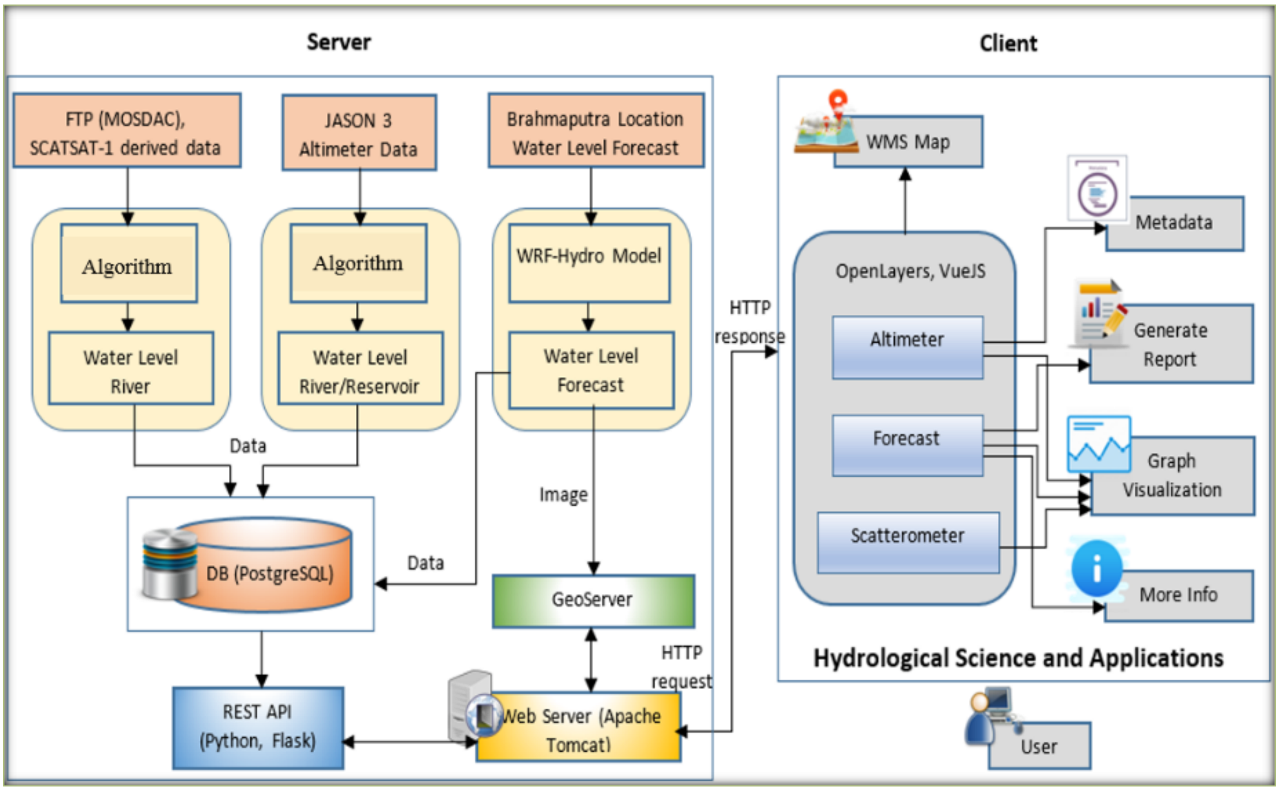

Figure 3: WebGIS based Application framework

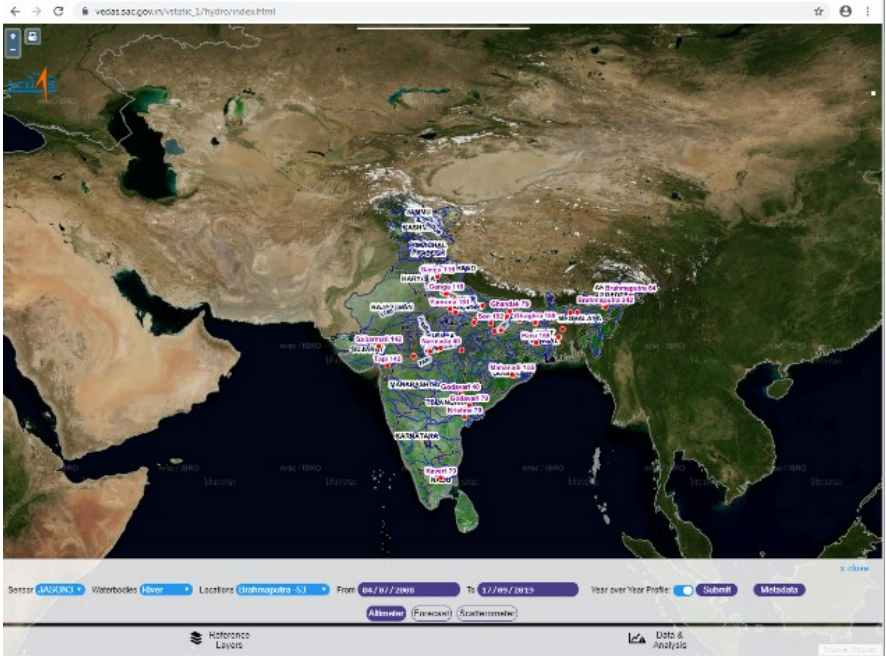

Figure 4: Main User Interface of WebGIS based Application

Figure 5: Water level of location Ganga-192 for selected dates

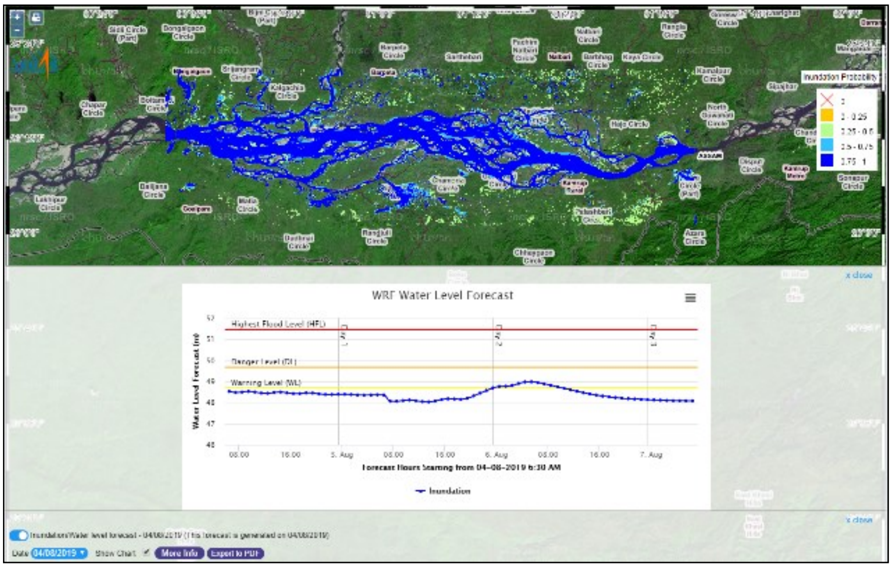

Figure 6: Inundation probability map and water level forecast for 04 August, 2019

4. Conclusion

A Web-based Framework has been developed to dynamically provide observed and predicted EO derived hydrological information for use by decision makers and the general public. It can be a useful system for decision-makers for river basin management and for potential users who require updated and ready access to easy-to-use water fluxes for hydrodynamic modelling. It shares the information and geospatial datasets allowing users with limited GIS knowledge to access the information customized for specific applications that reduces operation costs management.

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