Development of Web-GIS based system for Geo-visualization of AWiFS and Sentinel data

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Abstract: The use of satellite data is very popular and extensive in space applications to develop insights into the phenomenon and broad understanding of its effects in a large area. With the developments in remote sensing and Web-GIS, it is now possible to visualize medium resolution but bulky data covering large geospatial regions on the web. This paper discusses the development of a Web-GIS enabled system as application of open source technologies that not only downloads and processes data but also hosts and visualizes it without human intervention. This data includes daily downloaded AWiFS and Sentinel-2 maximum composite NDVI and Sentinel-1 SAR images. The system also has online data analytics capability to analyse these data using image processing on the web including GIS functionalities viz. pan, scale, temporal pixel drilling and such others. The discussed system is part of VEDAS geoportal and it can be assessed at https://vedas.sac.gov.in/vstatic/vegetation_monitoring/index.html.

Keywords: Web-GIS, AWiFS, Sentinel, Vegetation Monitoring, Open Source Technologies, Geo-visualization

1. Introduction

Geographic Information Science (GIS) is the science underlying geographic concepts, applications, and systems (Patel et al., 2021). When functions of GIS are supported with web technologies then it gives rise to Web-GIS systems. The popularity of a web-based Geo-Information System (GIS) in recent years is attributed to several factors such as the number of satellites and their performance characteristics, increase in the availability of satellite data, development of internet and decrease in the cost of access, the development of web services and standards for the transfer of geospatial data (Yakubailik et al, 2018). These systems are used to give real-time insights into satellite images on the web and provide additional functionality of on-the-web spatial analysis (VEDAS, MOSDAC and BHUVAN).

While systems such as Google Earth Engine (GEE) provide a scripting interface to analyse geospatial information, there is a need for easy to use Web-GIS systems which are application specific and do not require coding efforts to address specific application domain requirements.

Visualization of Earth Observation and Data Archival System (VEDAS) is one such GIS-platform that hosts remote sensing satellite data for various applications of vegetation monitoring (Sharma and Mishra, 2012; Gupta et al., 2019a), new and renewable energy, earth observation, urban sprawl information system, safer ship navigation (Gupta et al., 2019b) etc. using Open Geospatial Consortium (OGC) standards and services.

Murata et al. (2018) developed a web-based data visualization system for Himawari-8 satellite images, which supports tile pyramid representation and parallel processing techniques. Mishra et al. (2020) demonstrated the use of Free and Open Source (FOSS) solutions to visualize water levels of water bodies in India by creating a fully automated procedure.

High temporal and spatial resolution satellites provide enormous data and analytical opportunities to remote sensing researchers in the areas of field level agriculture and vegetation monitoring, Land Use Land Cover (LULC) change map, cryosphere studies to name a few. However, this freedom comes with several issues and challenges viz. efficient data retrieval from huge amounts of storage, fast processing and visualization, complex and difficult management of satellite data and metadata.

This paper addresses these challenges with the development of a Web-GIS based solution that incorporates new technologies for the automation of receiving and processing satellite data as well as storing and visualization of satellite images and metadata.

2. Dataset Details

The developed system is built by integrating Advanced Wide Field Sensor - AWiFS (Resourcesat-2 and Resourcesat-2A), Multi-Spectral Instrument - MSI (Sentinel-2A & 2B) and C-band Synthetic Aperture Radar - C-SAR (Sentinel-1A & 1B) in Interferometric Wide Swath (IW) operation mode data to the system. Sentinel-1 and Sentinel-2 both consist of two polar-orbiting satellites.

While AWiFS sensors are built and launched by the Indian Space Research Organisation (ISRO), Sentinel sensors are built and launched by European Space Agency (ESA). The details are as given in Table-1.

3. Tools and Technologies

The developed system is completely based on Free and Open Source Software (FOSS). Various popular and advanced tools and software are used in the development of this system. These are summarized as given in Table-2. Sources and relevant information about these can be accessed on given URLs in the references.

Table 1. Table summarizing data incorporated for geo-visualization

Parameters	**Resourcesat-2 & 2A (AWiFS)**	**Sentinel-2A & 2B (MSI)**	**Sentinel-1A & 1B (C-SAR in IW mode)**
Number of Bands	4 (Green, Red, NIR, SWIR)	13 (including Green, Red, NIR, SWIR)	Double Polarization (VV and VH) – 2 bands
Spatial Resolution (m)	56	10, 20 and 60 (10 m in VNIR, 20 m in SWIR)	5-by-20 m
Swath (km)	740	290 km in VNIR and SWIR	250
Revisit Period (days)	5	10 days at equator for each satellite	12 days at equator for each satellite
Data Access	BHUVAN	Copernicus Open Access Hub and *Bhoonidhi*	Copernicus Open Access Hub and *Bhoonidhi*

Table 2. Tools and technologies

Tools/Technologies	**Applied in**	**Description**
Python 3.7	development of overall system and integration of other modules.	*Python* is a general-purpose interpreter language that allows Web and Internet Development, Database Access, Desktop GUIs, Scientific & Numeric, Software & Game Development etc.
PostgreSQL with *PostGIS* plugin	development of central RDBMS database to store metadata of downloaded files including geometry.	It is an open source Relational Database Management System (RDBMS). It allows users to access, update and control the database via SQL commands. *PostGIS* plugin enhances its capability to work with GIS data.
Important Python Libraries	performing GIS operations, data download, data processing and database connections.	*GDAL* (Geospatial Data Abstract Library) is a geospatial data manipulation library under open source licence and complies with OGC standards. *sentinelsat* provides a Python API and a command line interface to search, download and retrieve the metadata for Sentinel products. *Numpy* is a fundamental package for array computing with Python which provides linear algebra and other scientific functions seamlessly. *psycopg2* is a popular PostgreSQL database adapter for the Python programming language with thread safety. *Flask* is a web-application development library for python. *Tifffile* is a package to read and store numpy files to and from (.tiff) files.
Client-side JavaScript Libraries	Front end visualization and interactive features.	*Openlayers* is a front-end JavaScript library for developing interactive maps. *VueJS* is a client-side framework for developing user interfaces.

4. System Architecture and Modules

This automated system is made up of multiple subsystems or modules which interact with each other to shape the overall system. The overall architecture of the system is shown in the diagram below in Figure 1. Each subsystem is discussed with AWiFS and Sentinel processing aspects separately to easy understanding of the system.

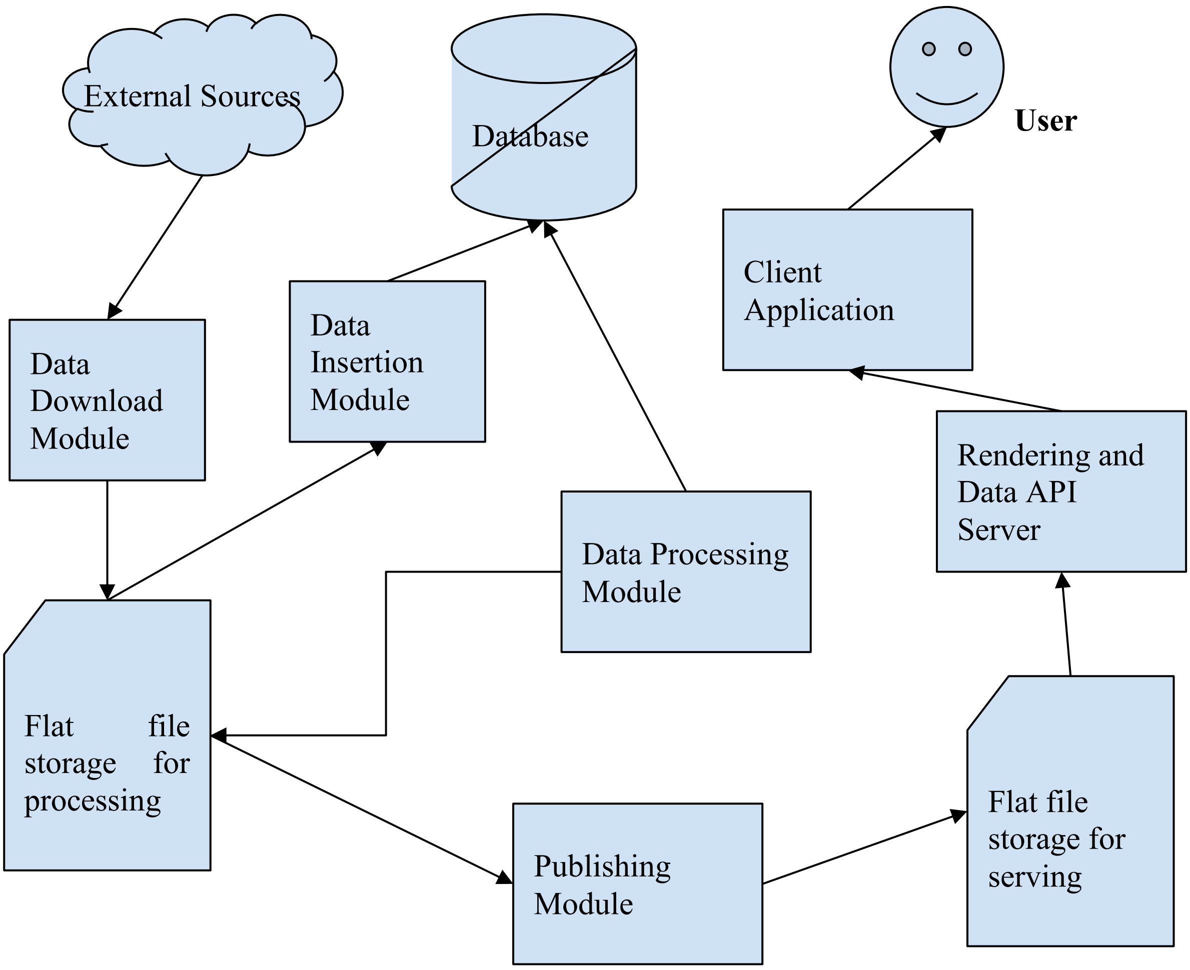

Figure 1. System Architecture

4.1 Download Data Module

This module downloads satellite data from the respective data source server using an automated process. This reduces manual work and facilitates quick and automated data downloading.

4.1.1 Sentinel Data Download

This automated module is developed in python language as an application program interface (API). It comprises two submodules, one downloads data from *Bhoonidhi* server (primary source) available at https://bhoonidhi.nrsc.gov.in/bhoonidhi/index.html and the other submodule downloads data from Copernicus Open Access Hub (secondary source) available at https://scihub.copernicus.eu/dhus/#/home.

Bhoonidhi server, having an added functionality of maximum five concurrent downloads, acts as the primary source of data download for sentinel data. In the case of Sentinel-2, *Bhoonidhi* provides a feature of downloading data based on user defined cloud cover threshold. Both data sources provide data into .zip file format that is extracted to get images in .SAFE directory. Moreover, the data download module is implemented in such a way that it downloads data from both sources without duplicating downloads and resolves any file error that occurred in downloading by re-downloading it.

Each Level-2A Sentinel-2 100-by-100 km^2 ortho-image comes in granule or tile form and is in UTM/WGS84 projection. The bands contain bottom of atmospheric (BOA) reflectances in cartographic geometry and are stored in .jp2 file format inside .SAFE directory. The Sentinel-1 data products are Level-1 Ground Range Detected (GRD) products acquired in IW mode. These products have both VV and VH polarization images in GeoTiff format.

4.1.2 AWiFS Data Download

AWiFS data is downloaded from the *BHUVAN* portal, available at https://bhuvan.nrsc.gov.in/home/index.php that acts as a repository and data distribution platform for Indian remote sensing satellites. The georeferenced and standard (STD) level products are downloaded and checked for any file errors. The band images are in GeoTiff format and in LCC projection. The projection details and sensor parameters are given in band metadata file that comes with each AWiFS subscene .zip file.

4.2 Data Insertion Module

Data insertion module stores metadata of satellite data into its respective tables in the PostgreSQL database. This metadata includes some of the satellite related data and differs in the cases of AWiFS and Sentinel products. The download data module interacts with this module to remove any case of duplicate downloading of files. A set of unprocessed files can be filtered out if the product filename field (MXC in case of AWiFS and Sentinel-2;

VV and VH in case of Sentinel-1) is empty while other fields are filled in the metadata table.

4.2.1 AWiFS Data Insertion

One of the requirements of the developed system is to store NDVI metadata according to the Survey of India (SOI) grid map of 6-by-4 degrees. Therefore, AWiFS table stores grid information of SOI grid map by storing grid names as columns. AWiFS NDVI images are stored in a table such that part of the image which intersects with the grid are stored under that grid column and has NDVI filename as an entry in it. NDVI filename is designed to provide maximum metadata details from its name by separating information by underscore symbols. Each row of the table depicts information of the date of product, download date along with SOI grid name.

4.2.2 Sentinel Data Insertion

Sentinel (Sentinel-1 and Sentinel-2) tables are designed to store metadata of each sentinel file separately in a row. Columns include satellite visit date, download date, unique identification tag of each file (tile id), processing levels, satellite data product type, download source, download file path, product filenames (NDVI, 5-days and 10-days maximum composite NDVI (MXC-NDVI) file paths in case of Sentinel-2; VV and VH file paths in case of Sentinel-1) and extent of satellite data bounding box.

4.3 Data Processing Module

This module acts as the backbone of a developed system that is implemented in python. Its main function is to process those downloaded data that are not processed into product data and update the metadata records in the corresponding table in PostgreSQL. This processing module can be described in two parts:

4.3.1 AWiFS Data Processing Module

AWiFS data is processed to generate Top of Atmospheric (TOA) reflectance based Normalized Difference Vegetation Index (NDVI) images. AWiFS images contain digital number (DN) values that are first converted into radiances as given eqn(1) following Pandya et al. (2015):

$$L_\lambda = \frac{(L_{max} - L_{min})}{Q_{calmax}} Q_{cal} + L_{min} \quad \ldots(1)$$

where L_λ is the spectral radiance at the sensor aperture in $Wm^2sr^{-1}\mu m^{-1}$ unit, L_{max} and L_{min} are maximum and minimum spectral radiance at wavelength λ, Q_{cal} is the calibrated DN, and Q_{calmax} is the maximum possible DN value. L_{max} and L_{min} values of the sensors are extracted from the metadata file that comes with subscene data.

Satellite radiances can be converted into TOA reflectance using below eqn.(2):

$$\rho_\lambda = \frac{\pi L_\lambda d^2}{ESUN_\lambda \cos\theta_z} \quad \ldots(2)$$

where ρ_λ is unitless TOA-reflectance, L_λ is spectral radiance, d is average earth-sun distance in astronomical units, $ESUN_\lambda$ is mean solar exoatmospheric irradiances and θ_z is the solar zenith angle.

NDVI is a two-band remote sensing index ranging between 0 to 1 which signifies vegetation vigour in plants. It is calculated using red band reflectance (ρ_{red}) around 0.66 μm and near-infrared (NIR) band reflectance (ρ_{nir}) around 0.86 μm. Positive values of NDVI show vegetated areas, whereas negative or near-zero values represent water and build-up areas. It is given as shown in eqn.(3):

$$NDVI = \frac{(\rho_{nir} - \rho_{red})}{(\rho_{nir} + \rho_{red})} \quad \ldots(3)$$

Once NDVI images are generated, they are re-projected to Global Coordinate System (GCS) projection from its native reference system i.e. LCC projection, clipped based on Survey of India (SOI) 6-by-4 degrees grid map and corresponding clipped file names followed by extents are stored in AWiFS metadata table.

All NDVI images within a SOI grid are processed to get 5-days and 10-days MXC-NDVI image. For a k-days max composite, each month is divided into equal k-days duration starting from the first day of the month in such a way only the last part will vary in the number of days and will have minimum k-days except in February. The filenames of NDVI and MXC-NDVI images are stored in AWiFS table.

4.3.2 Sentinel-2 Data Processing Module

Sentinel-2 data processing module takes downloaded Level-2A product in .zip format as input and generates 5-days and 10-days maximum composite NDVI (MXC-NDVI) images. It extracts only red and nir bands and creates NDVI images for each file. In the next step, tile wise 5 days and 10 days MXC-NDVI are computed from newly created NDVI files. It communicates to the Sentinel-2 table by fetching a list of unprocessed files, creating k-days MXC-NDVI file by taking a maximum composite of k-days NDVI files and finally updating columns based on newly created file.

4.3.3 Sentinel-1 Data Processing Module

Sentinel-1 data module takes downloaded data in .zip format as input, extracts it to '.SAFE' directory. It uses *sentinalsat* python library to parse '.SAFE' directory and process further. Processing includes calibration, speckle filtering using lee filter of 5-by-5, ellipsoid correction and conversion to sigma naught. This module outputs processed VV and VH Sentinel-2 files in '.tif' format. It communicates to the Sentinel-1 table for fetching a list of unprocessed files and writing VV and VH filenames as metadata.

4.4 Data Publishing Module

The data publishing module takes NDVI files created by the processing module and organizes them for efficient retrieval and visualization. The files are stored in the form of tile pyramids spanning the extents of the tiff file. The pyramid structure is illustrated in the diagram below in Figure-2.

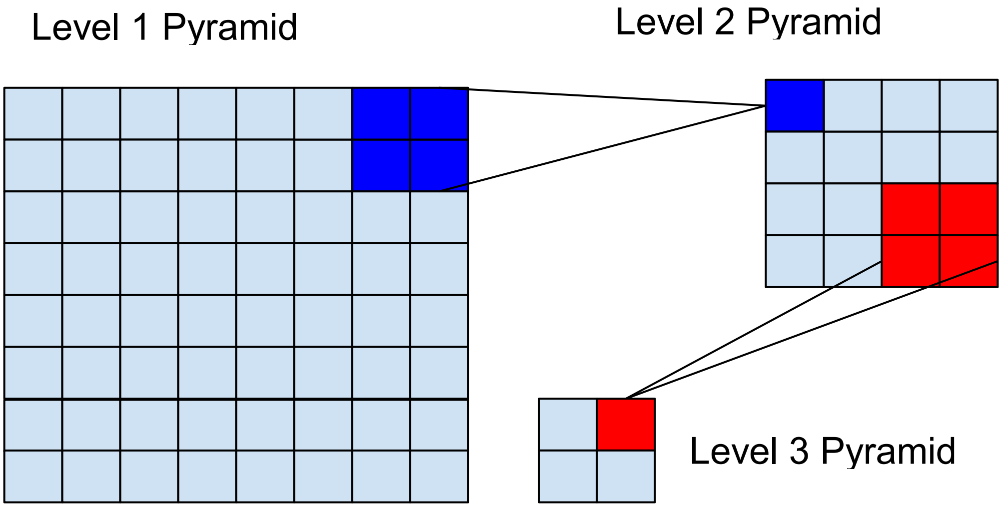

Figure 2. Pyramid structure

This pyramid structure helps by reducing the size of data required to be read while rendering the required Web Map Service (WMS) request in reduced resolution when user is browsing a large area. The appropriate overview level is determined at the time of request processing.

Each subsequent level in the pyramid reduces image dimensions and image size by a factor of 2 and 4 respectively. The pyramid level is calculated using the following formula to ensure that the smallest file has at least one dimension close to 256 pixels.

$$Levels = \frac{log_2 max(w,h)}{7} \quad \ldots(4)$$

where, w and h are width and height of image respectively. This size is arrived upon based on the trade-off between size and performance to visualization of images on web.

4.4.1 Rendering and Data API server

The rendering and data API server is a web application written in *python* that renders images and serves them to the client application as per request. It also provides APIs for accessing temporal data for a location for displaying on the user interface.

4.4.2 Client Application

The client application is a browser-based application written in JavaScript and serves as the user interface for this system. It includes an interactive map developed using the *OpenLayers* library and associated inspection tools which allow the user to access the temporal profile of a specific parameter at a location.

5. Results and Discussions

5.1 Data Volume and Velocity

The system is designed to handle large amounts of satellite data downloaded from respective sources. The volume and velocity of data are given in Table-3. The estimated data presented in the below table is given for a month. It can be seen from the statistics given in Table 3 that overall almost 125 GB of data is downloaded and processed daily. Out of this, Sentinel-2 data is a major proportion i.e. almost 80% of it. Although for NDVI generation only two bands are required, Sentinel-2 data is available as a single file comprising all the thirteen bands to download. Given, its spatial resolution of 10 m and Indian region, it has the highest proportion out of daily downloaded data.

Table 3. Data volume

Sensor/ Satellite	Download Source	Estimated number of Files	Estimated Size (GB)
AWiFS (R2 & R2A)	*Bhoonidhi*	500	150
Sentinel-2	*Bhoonidhi* and Copernicus	4000	3000
Sentinel-1	*Bhoonidhi*	700	650

5.2 Visualization and Data Analysis on VEDAS

A WebGIS based metadata details display system is developed that can be used to monitor daily file downloading and processing status. This subsystem directly fetches data from the download database to visualize it on the web as depicted in Figure-3.

This helps to detect any discrepancy in downloading and processing of AWiFS and Sentinel files. The metadata is shown with different transparency levels of colour to distinguish multiple files in selected duration. Similarly, Sentinel-1 and AWiFS data based query search and metadata visualization is incorporated in it. For Sentinel-2 and AWiFS data, 1-by-1 degree Sentinel and 6-by-4 degrees SOI grids are overlaid respectively over web to enhance the understanding of metadata. A user can search metadata based on the date of pass, download, NDVI generation and MXC-NDVI generation along with tile id as given in Figure-3.

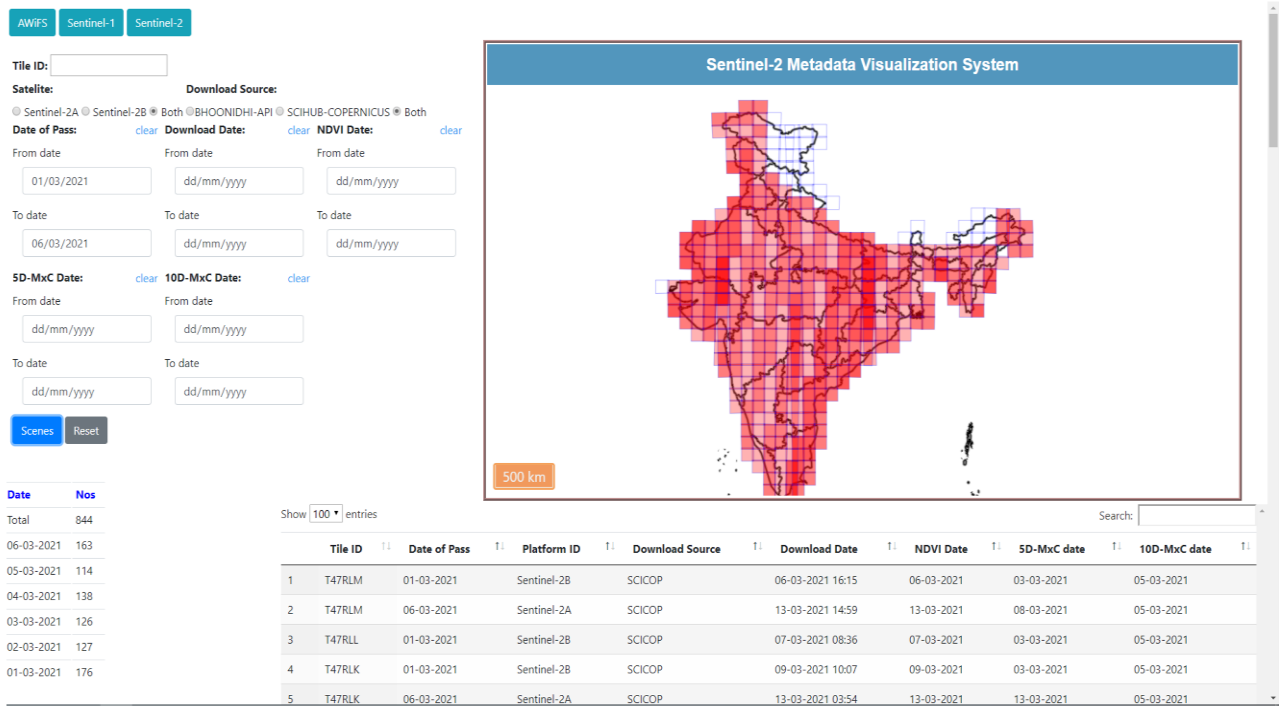

Figure 3. A screenshot of Satellite Metadata Visualization System

The final aim of this work is to visualize NDVI and SAR images from AWiFS sensors and Sentinel satellites respectively that is accomplished successfully as shown in Figure 4.

Here, a user visualizes data on selection of dates from a given list. The developed system comes with many GIS features such as pan, zoom in, zoom out, navigate to a location by giving coordinates etc. It also allows users to generate a 'year-on-year' temporal profile and heat map of NDVI values to compare values of a year with another year on a single click.

Moreover, in the 'Data Analysis' tab, users can analyse data based on in-built platform functionality of image difference, temporal RGB composite, long term analysis for NDVI; SAR composite and backscatter temporal standard deviation for SAR data, respectively. In addition to that, a functionality of swiping images are added to compare two images side by side on a single web page.

The developed system is currently deployed in VEDAS under the 'Vegetation Monitoring' tab. The objective of this work is to give decision makers and stakeholders an idea about spatial distribution and vegetation conditions through visualization of high spatial resolution satellite data. The stakeholders ranges from district or village authorities to national authorities who want overview of vegetation conditions for whole India. Similarly, daily monitoring of SAR backscattering data helps to perform flood assessment, water level monitoring and supports other hydrology applications.

5.3 Performance characteristics

As intended and designed, the system is able to deliver sustained high performance for rendering the datasets at the country level. The performance metrics under different conditions of concurrent access for AWiFS, Sentinel-1 and Sentinel-2 WMS services are summarised below. The performance data is represented in average time-to-first-byte (TTFB) values for 200 requests measured in milliseconds (ms). TTFB is the latency between user requests and the first byte of responses sent by the server and used to measure web-server response time. All requests were for 256x256 pseudo colour rendered tiles. The average tile size was 50 KB.

These tests were performed on a 2 socket Intel Xeon processor with 64 cores and 512 GB of DDR4 RAM. Table 4 shows the performance matrix.

Table-4. Performance Metrics

No. of Requests (Simultaneous)	Sentinel-1 TTFB (ms)	Sentinel-2 TTFB (ms)	AWiFS TTFB (ms)
1	58	52	36
10	62	60	48
100	76	72	54
200	1534	1245	908

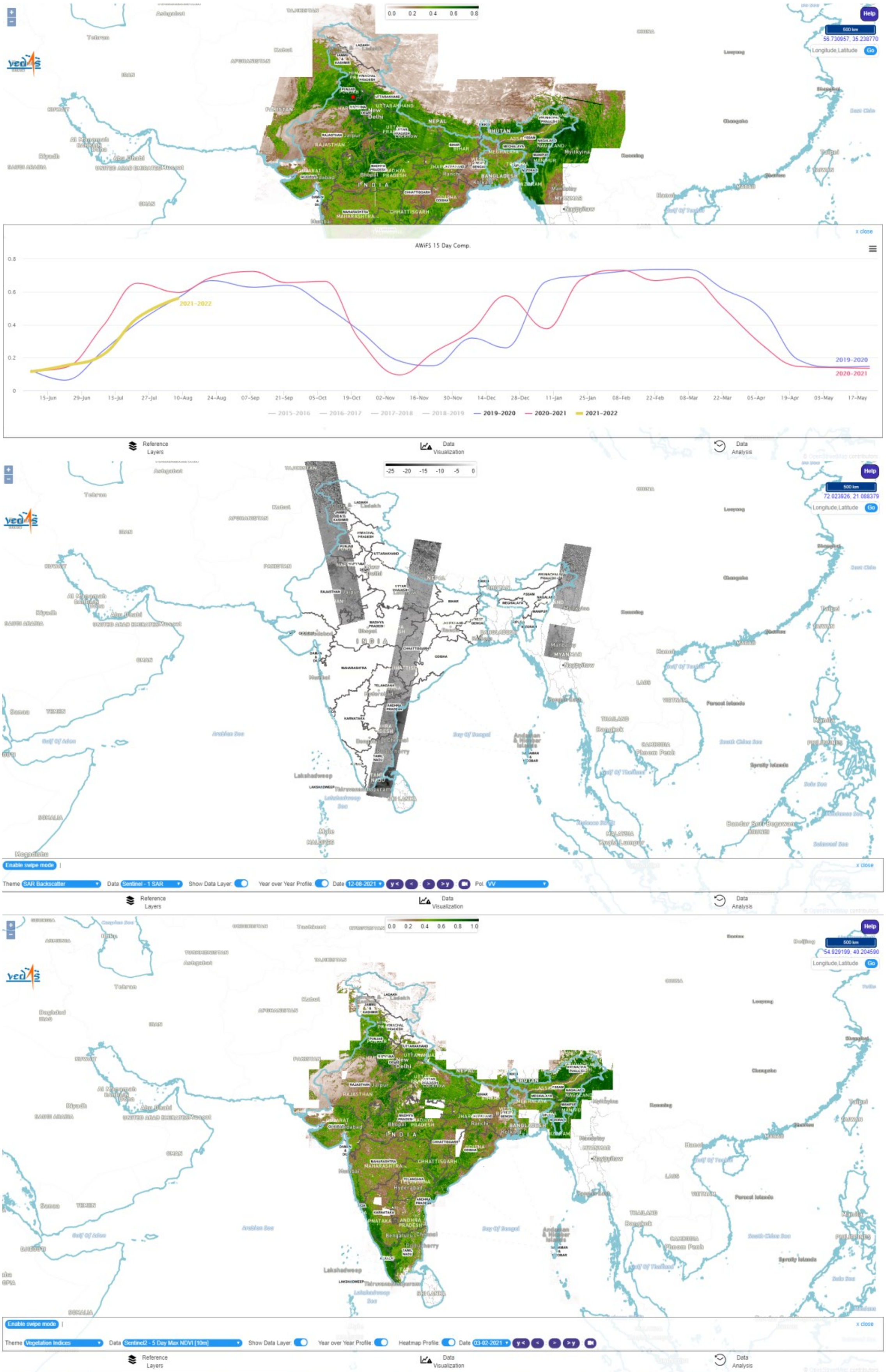

Figure 4. Visualization of (a) AWiFS 15-Days MXC data along with temporal profile (upper), (b) Sentinel-1 SAR backscatter coefficient data (middle), (c) Sentinel-2 5-Days MXC NDVI data (lower)

6. Conclusions

A WebGIS based visualization and monitoring system gives useful information as and when required through the internet. The system downloads, processes and visualizes AWiFS and Sentinel-1&2 data without manual intervention and is developed as an application of existing FOSS technologies. The discussed system improves download to visualization time as it automates whole process. Given the velocity and volume of data, a metadata details system is also developed to monitor downloading and processing status of these data over the web. The response time to visualization of discussed system is very low given the size of tile and simultaneous requests due to use of pyramid structure. This system also enabled with some of the temporal and spatial data analysis techniques. The developed system is currently operationalized under the 'Vegetation Monitoring' section of VEDAS geoportal.

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