Spatial Crop Monitoring System for India using Direct-Broadcast Remote Sensing Data and Open Source Web-GIS technologies

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***Abstract*— The paper describes design, development and application of a web enabled spatial decision support system (SDSS) for near real time crop monitoring at district level and making the information available to different stakeholders for building resilience of agriculture to climate/weather variability. The system uses direct-broadcast remote sensing data available in public domain and free web enabled open source software (FOSS) technologies for building spatial decision support application. The system uses multi-temporal remote sensing images received at IARI satellite ground station from Terra/Aqua MODIS sensor. Regular real-time satellite derived parameters of rainfall, day and night land surface temperature (LST), and crop vigour index of NDVI are generated for crop pixels and aggregated at district level for 579 districts of the country. Using historical values (2000-2014), Weekly anomaly indices of standardized precipitation index (SPI), Temperature Condition Index (TCI) and Crop Condition Index (CCI) are generated for each districts of India for current period. The historical and real-time basic parameters and anomaly indices are archived in a database and are made available on a web portal. Three-tier architecture is implemented on web-portal using open source Web GIS – the data is imported and stored in PostGIS/PostgreSQL in tabular form. The server-tier includes Apache web server, PHP and Geoserver. Open layer is used for visualization of geospatial data for client application. This Geo-portal allows visualization of SPI, VCI and TCI as categorized maps for current period and over the crop season. Besides, for a selected district, it shows the temporal profile of parameters for current year and its comparison with that of previous year and long term average in graphical and tabular format. This prototype SDSS allow researchers, farmers, stakeholders and policy makers to explore and benefit from visualizing and analyzing current weather and agricultural situation. It is expected that such a system will help in managing the agricultural weather uncertainties at the level of decision-makers in federal and provincial government departments and also at farmer's level, thus building resilience of agricultural systems to climate variability at multiple levels.**

Keywords- Crops, Weather, Decision support system, Remote Sensing, Open-Source Web GIS

I. INTRODUCTION

Rapid advancements have been made in newer technologies of remote sensing, weather forecasting and crop modeling, each with its own strength and weaknesses. Remote sensing technology provides real-time synoptic and repetitive coverage of a geographical area with information collection capabilities on a range of spatial scales. Thus, it is ideally suited for crop growth monitoring in relation to abiotic stresses at regional scales and providing early warnings.

Satellite based earth observations that provide direct information on, or indicators of crop parameters are vital for their effective monitoring. A number of international programs such as the USDA Foreign Agricultural Service (FAS) Global Agriculture Monitoring program (GLAM), the UNFAO Food Security Global Information and Early Warning System (GIEWS), the USAID Famine Early Warning System (FEWS) and the EU DG-JRC Monitoring Agriculture with Remote Sensing (MARS) utilize satellite observations in their procedures for regional scale agricultural monitoring. For agricultural monitoring, satellite measurements from optical sensors (visible, NIR, SWIR) provide the primary input data to map and characterize crop area, crop type and crop condition. Such application can be addressed using coarse spatial resolution (250m – 1km), high temporal remote sensing sensors such as the NOAA and MetOP AVHRR's, MODIS, SPOT VGT polar orbiting satellites with a large spatial footprint and daily global coverage. Besides crop condition, the satellite derived bio-geophysical products on daily rainfall, leaf area index, land surface temperature, soil moisture, etc. are being operationally produced, which complements the real time data required for crop environment monitoring.

So, an attempt was made to design, develop and demonstrate a near real-time web-based system of crop health and crop environment monitoring using remote sensing products at district for India. The web-based system, which is economical and effortless way of disseminating GeoSpatial data and processing tools (A. Alesheikh, et al 2002), employed Open Source free web map server technology, database management and graphical APIs. The beta version 1.0 of the system is hosted on public URL http://creams.iari.res.in and has been tested for *kharif* (June-Oct) and *rabi* (Nov – Apr) crop seasons of 2014-15 year.

II. MATERIAL AND METHODOLOGY

A. Data used

The historical Moderate Resolution Imaging Spectroradiometer (MODIS) land surface temperature (LST) product at 8-day temporal resolution (MYD11A2.005) from Aqua satellite and 16-day composite (MOD13A2.005) Normalized Difference Vegetation Index (NDVI) from Terra satellite at 1 km spatial resolution from 2003 to 2013 were retrieved in Hierarchical Data Format (HDF-EOS) from USGS Global Visualization Viewer (http://glovis.usgs.gov). For 2014-15 period, same data was retrieved from IARI ground station in real time. These real time images were composited for period as per the historical datasets.

1) SPI: Long term daily rainfall data at spatial resolution of 0.1×0.1 degree for the time period of 2000 to 2015 collected from ftp.cpc.ncep.noaa.gov and Standard Precipitation Index (SPI) (Mckee et al. 1993) estimated to quantify precipitation deficits at multiple time-scales. Since precipitation is not normally distributed, the long-term precipitation record was first fitted to an incomplete-gamma probability distribution, which was then transformed into a normal distribution to calculate SPI. The frequency of years when SPI was -1 or below was calculated for low rainfall, while the frequency of years when SPI was +1 and more was calculated for high rainfall.

$$SPI = (P_i - P_m)/\boldsymbol{\sigma} \qquad (1)$$

Where, P_i is seasonal precipitation, P_m is long term mean, and $\boldsymbol{\sigma}$ is standard deviation of the long term record.

2) VCI: NDVI (Tucker, 1979) is the most prominent vegetation index derived from remote sensing, used in identification and monitoring of vegetation health and density.

$$NDVI = (\lambda_{NIR} - \lambda_{red}) / (\lambda_{NIR} + \lambda_{red}) \qquad (2)$$

Where, λ_{NIR} and λ_{red} are the reflectance in near Infrared and red bands.

The Vegetation Condition Index (VCI) (Kogan, 1995) derived from NDVI, compares the NDVI of the present month with the maximum and minimum NDVI calculated from long term record.

$$VCI = 100*[(NDVI_j - NDVI_{min})/(NDVI_{max} - NDVI_{min})] \qquad (3)$$

Where, $NDVI_{max}$ and $NDVI_{min}$ are calculated from the long term record for that month (or week) and j is the index of current month. The health/condition of vegetation presented by VCI is measured in percent. The VCI values between 50 and 100% indicate optimal or above normal condition. A VCI value of 100% means that the NDVI value for selected month is equal to $NDVI_{max}$ and value close to 0% reflects an extremely dry month, when NDVI value is close to its long-term minimum. This index normalizes NDVI and it proves to be a better indicator for monitoring water stress condition as compared to NDVI (Kogan and Sullivan, 1993).

3) TCI: The MODIS Land Surface Temperature (LST) derived from two thermal infrared band channels, i.e. 31 (10.78-11.28 µm) and 32 (11.77-12.27 µm) using the split window algorithm (Wan et al. 2002) and calculate Temperature Condition Index (TCI) (Kogan, 1995). It is useful in estimating stress caused by excessive wetness.

$$TCI = 100*[(LST_{max} - LST_j)/(LST_{max} - LST_{min})] \qquad (4)$$

Where, $_{max}$ and $_{min}$ are calculated from the long term record for that month (or week) j.

4) OpenStreetMap(OSM): provides freely available geographical related information (detailed maps having road, terrain information) all over the world and used as base layer for displaying maps. Java script API for OpenStreetMap was imported in OpenLayers(Openlayers.js). This allow user to see the required area with more information from overlaid layers.

B. System Architecture

This application has three-tier architecture consist of:

1) Database: The SPI, TCI and VCI weekly data consisting shapefiles are generated for each district of India from 2000 to 2015. Database management system (DBMS) manages and stores these shapefiles and imports as tables using PostGIS and PostgreSQL. This SPI, TCI and VCI table stores information of each district and fields of weekly date.

2) Server: includes Web and Mapping servers.

- Web server is intermediary for responding to client service requests and transmitting the information to meet the client's request. The browsers (Mozilla, Crome) and Common Gateway Interface (CGI) sends user requests via HTTP servers to establish the connection between internet and GeoServer using Apache Tomcat V7.0 in this interface.
- Geoserver (Java based) allows users to view and edit geospatial data. It is built on Geo-tools, an open source java GIS toolkit as the implementation of OGC standard web map services (WMS). GeoServer receives the user requests and reads the mapfile path and then it finds the information stored in the PostGIS and PostgreSQL in the form of Spatial and nonspatial database. It also supports Web Feature Services (WFS) standard, which allows sharing and editing the data used to generate maps. Geoserver adds new data source type as (ESRI shapefile *.shp) and publishes the layer, set the declared SRS to EPSG: 4326 to display overlay maps to OpenStreet base map. Three SLD are created for SPI, TCI and VCI.
- PHP is a server side programming language which is capable of handling dynamic request of data from database and it can also easily interact with

PostgreSQL. Hence, it is used as the server side language in this interface.

3) Client side: OpenLayer is a javascipt library and html is used to develop web interfaces and to connect WMS and WFS. It can display mapfiles and markers loaded from any source. OpenLayers implement a javaScript API for visualization of a spatial data in a web browser without the need of any server side component. It implements standard WMS and WFS for accessing geospatial data. Client side displays the results of the user requests after GeoServer transfers the relevant information to it via web server (Apache Tomcat).

C. Methodology

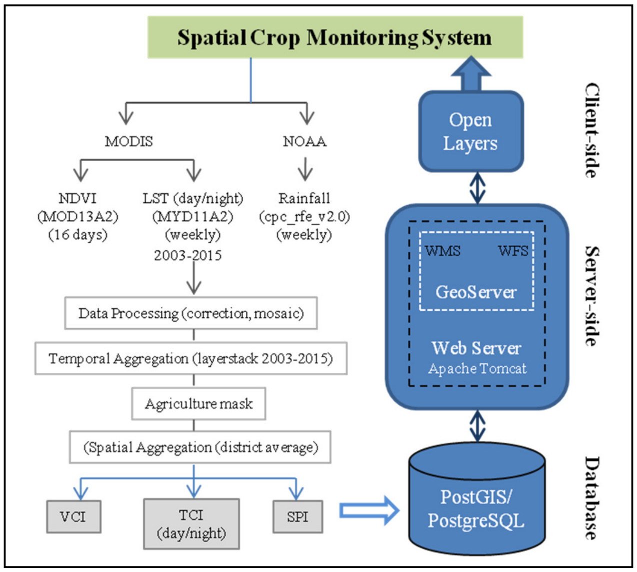

Figure 1. Methodology adopted for Spatial Crop Monitoring System

III. RESULTS

Crop monitoring system manages, visualizes and analysis the spatial SPI, TCI and VCI data in simple and easy way for farmers, stakeholders and policy makers for better understanding of agricultural situations during kharif and rabi season.

The interface contains main map, information and legend panel. The OpenStreetMap loaded as base layer with India state and district boundary. The users have to click on + in the left panel to load other SPI, TCI and VCI layer and has to select the year, month and period from dropdown menu to display the VCI map in main window and the legend of selected layer in the right panel.

It provides some basic function navigation tools of zoom in, zoom out, pan, view history, view next, measure length and measure area and print. By clicking on any district the information of the district will be shown in popup window. The user can select districts with highest and lowest value to VCI by framing customized queries with the help of Query button in the interface shown in Fig. 2.

The CCI, TCI(day/night) and SPI maps fortnightly from 1st Nov 14 to 6th Apr 15 kharif season represented in fig. 3 which shows the very good crop condition in districts of north India with favorable SPI and temperature in day/night. The Rainfall, LST (day/night) and NDVI images are shown below the the VCI, TCI and rainfall image.

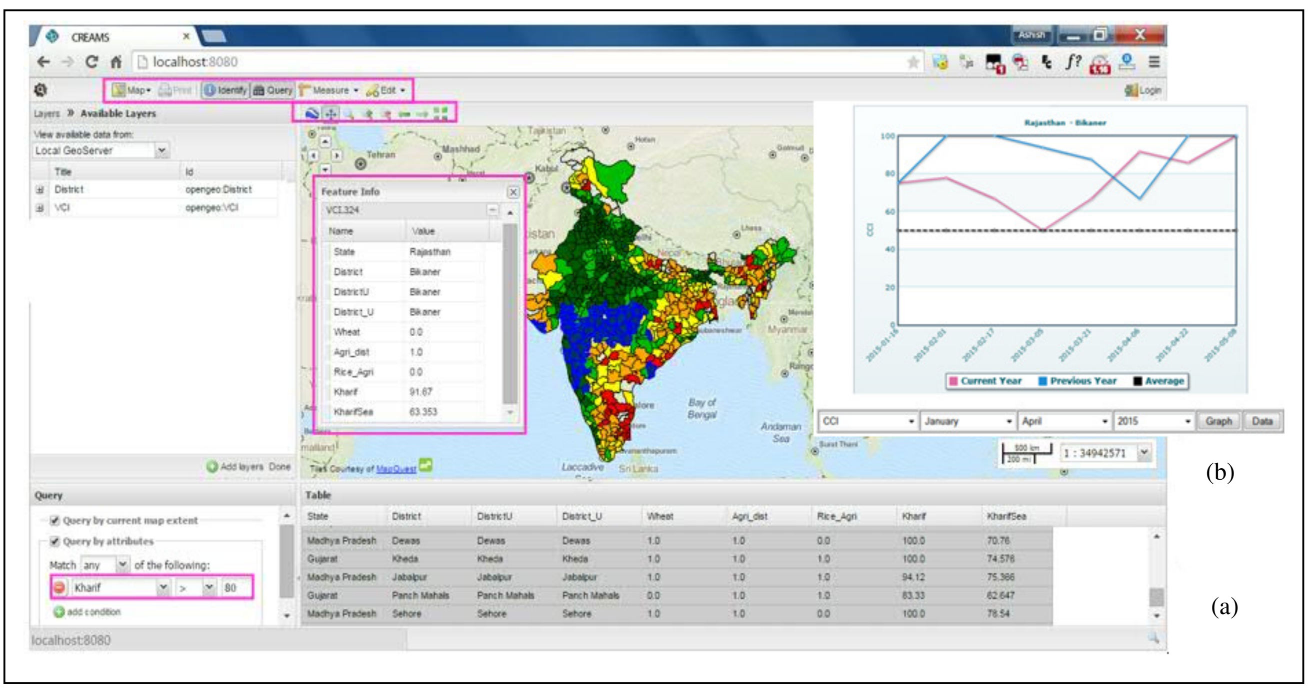

Figure 2. Snapsots of Website (a) Front View, (b) showing graph.

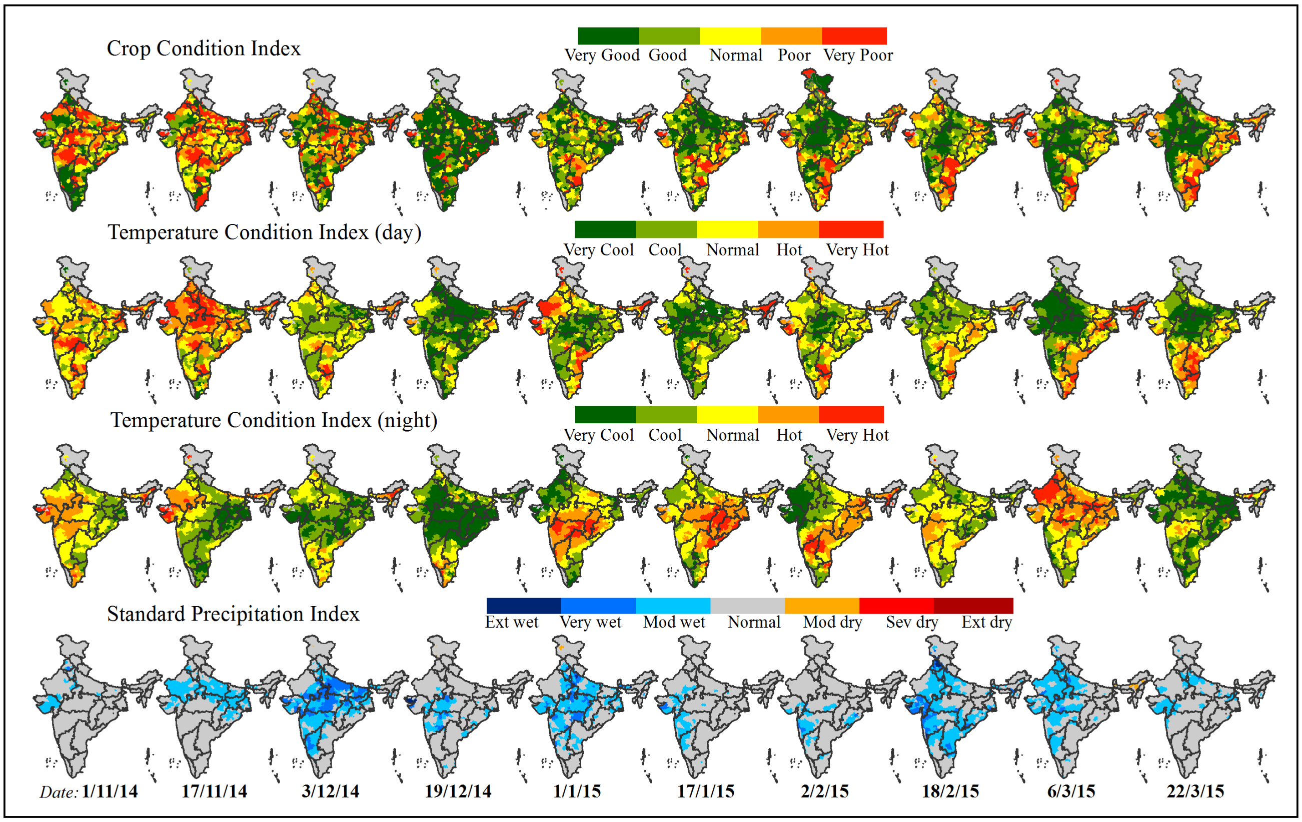

Figure 3. Fortnightly VCI, TCI and SPI maps from 1st Nov 14 to 6th Apr 15 (kharif season).

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REFERENCES

[1] A. Alesheikh, H. Helali and H. A. Behroz, "Web GIS Technologies & its applications symposium on Geospatial Theory," Ottawa Tossi Universite of Technology, 2002, pp. 2-3.

[2] T. Mckee, N. Doesken and J. Kleist, "The Relationship of Drought Frequency and Duration of time Scales," proceedings of the 8th Conference of applied Climatology, Anaheim, CA, 17-22 January, 1993, pp. 17-184.

[3] C. J. Tuker, "Red and photographic infrared linear combinations for monitoring vegetation," in Remote Sensing of environment,8(2), 1979, pp. 127-120.

[4] F. N. Kogan, "Application of vegetation index and brightness tempearture for drought detection," in Advances in Space Research,15, 1995, pp. 91-100.

[5] F. N. Kogan and J. Sullivan, "Development of global drought watch system using NOAA/AVHRR data," in Advances in Space Research, 13, 1993, pp. 219-222.

[6] Z. M. Wan, Y. L. Zhang, Q. C. Zhang and Z. L. Zi, "Validation of land surface tempaerature products retrieved from Terra Moderate Resolution Imaging Spectroradiometer data," in Remote Sensing of Environment, 83(1-2), 2002, pp. 163-180.

[7] R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[8] Geoserver, http://geoserver.org

[9] OpenLayer, http://openlayers.org

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