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Development of Mega-Environment for Maize in India using GIS approach

Debdali Chowdhury[1], Anshu Bharadwaj[1], V.K. Sehgal[2], Mukesh Kumar[1], Sudeep[1], Ankur Biswas[1], Rajender Parsad[1] and Rakeshwar Verma[2]
[1]ICAR-Indian Agricultural Statistics Research Institute, New Delhi
[2]ICAR-Indian Agricultural Research Institute, New Delhi

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SUMMARY

Projections of environmental change are motivating greater emphasis on future constraints to agricultural production.The pace of population, climate and environmental change has compelled the crop community to consider those stresses that are likely to result in significant yield declines. Crop improvement efforts have benefited greatly from advances in available data, computing technology, and methods for targeting genotypes to environments. In this paper, Soil, Climate, Land cover, Land use, Crop Production Statistics maps were prepared for use in spatial analysis and using these maps,Mega-Environment (ME) for Maize using GIS has been developed. An interface for the GIS approach of mapping Mega-Environment (ME) for Maize has also been created by hosting the maps on ICAR Geoportal.

Keywords: Mega environments, Decision Matrix, Geoserver.

1. INTRODUCTION

Spatial variation in biophysical and socioeconomic scenariosare being taken into account agricultural research and development. In this, priorities are already defined andnew technologies are targeted within a settings of a particular crop production. climate whish function of latitude, altitude, etc., soil, users and producer requirements, accessibility, use of input etc., is the source of variability in agricultural production environments. It may be caused by many other things. How effective the agricultural interventions like improved cultivars, agronomic management practices, decision support systems have been proved, entirely depend on these factors. Therefore, it is required by the researchers to delineate the boundaries of the environment where a given technology can be applied and will prove to be effective.

When the CIMMYT started its Maize Program 35 years ago by developing germplasm for maize production environments by efficiently allocating resources to particular needs and problems. This task divided the maize production regions of the world in different major ecologies and by the end of 1980s, these ecologies were subdivided into 30 areas in 70 countries, which were called mega-environments (MEs). A mega-environment can be defined as "a group of locations that consistently share the same best cultivar(s)" (Yan and Rajcan, 2002). It hasthe following essential elements:

i. mega-environments are defined by different winning cultivars, noting that different genotypes can be equally adapted to the same mega-environment and that a mega-environment may need different types of genotypes to stablize the overall production;
ii. mega-environment is a concept of geographical locations; and
iii. the cultivar-location interaction pattern should be repeatable across years.

Corresponding author: Anshu Bharadwaj
E-mail address: anshu.bharadwaj@icar.gov.in

All three aspects are essential for the declaration of different mega-environments.

MEs are also defined as "the largest subunits of a crop's growing or target environment within which a particular variety or related practice was useful" (Pham and Edmeades 1987; CIMMYT 1989b; Delacy *et al.* 1994).

2. MATERIAL AND METHODOLOGY

2.1 Material: Tools and Technology Used

To develop the Mega-Environment, the following have been used:

i. **ArcGIS software 10.5**: This software is mainly used to work with geographic information and maps throughout an organization, country and continent.

ii. **ENVI software 5.2**: This software is mainly used by GIS professionals, image analyst and remote sensing scientists to extract meaningful information from a provided image for better decision making.

iii. **QGIS software 2.1:** It is an open source and free GIS application, used for analyzing, viewing and editing of spatial information along with creation and exportation of maps.

iv. **Geo server**: Geo server is an open source server used for spatial data sharing. It is written in Java and allows the users to share and edit their geospatial data. It is interoperable and using the open standards, it publishes data from any major spatial data source. As the geo server is a community driven project it is developed, tested, and supported by a diverse type of individuals and several organizations throughout the world. Geo server is the reference implementation of the Open Geospatial Consortium (OGC) Web Feature Service (WFS) and Web Coverage Service (WCS) standards, as well as a high performance certified compliant Web Map Service (WMS). Geo server forms the most important component of the Geospatial Web.

5. **ICAR Geo-portal:** ICAR Geo-portal (http://geoportal.icar.gov.in) is a platform which aims to make available the Agricultural geo-spatial data to all the stakeholders. This portal contains the geo-referenced data which has been collected by ICAR institutions. These data are on climate, soil, cropping systems, land-use pattern etc. Under open access,visualization of spatial data is made available, but, there arerestrictions on downloading of layers.

2.2 Methodology

2.2.1 System Architecture for GIS based Mega-Environment

GIS based Mega-Environment for Maize is implemented by using 4 tier architecture which is different from the traditional 3 tier architecture.

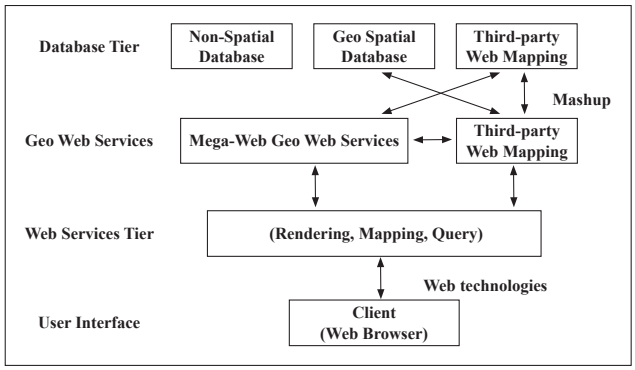


Fig. 1. System architecture

- **User interface tier:** User interface is the first tier which can be tablet, smartphone or any web browser. In this thesis web browser is used as user interface.
- **Web service tier:** In this tier several works such as rendering, mapping or query can be done.
- **Geo web service tier:** This tier provides Mega-Web Geo Web Services and third party web mapping services. We use ArcGIS software tools for Mega-Web Geo Web Services and Google map for third party web map services.
- **Database tier:** This tier includes non-special and geo spatial database and we can use third party web mapping database if necessary.

2.2.2 Mega-Environment development

For creating the Mega-Environment for maize the following steps are followed:

i. Data acquisition

ii. Preparation of maps

iii. Design and Development of Mega-Environment

iv. Hosting the maps to the Geo server

i. Data acquisition

It is the initial and most important step as the input data are gathered in this stage. Based on these data the whole MEs is developed. For generating the season wise suitability map for maize crop several input data are collected from different sources, among these weather data (temperature(max.and min.), precipitation), LULC and soil texture are raster datatype and area-production statistics are of vector data type.

Table 1. Sources of Input Data

Input data	Source
Maximum Temperature	http://worldclim.org/version2
Minimum Temperature	http://worldclim.org/version2
Precipitation	http://worldclim.org/version2
Soil texture for India	http://geoportal.icar.gov.in
Land use land cover (LULC)	https://www.geo-wiki.org/downloads
Area-Production Statistics for Kharif Maize	https://aps.dac.gov.in/APY/Public_Report1.aspx
Area-Production Statistics for Rabi Maize	https://aps.dac.gov.in/APY/Public_Report1.aspx

The weather data are downloaded from the http://worldclim.org/version2 which is of 30 second resolution and the pixel size is approximately 1 km^2. 12 GeoTiff file each for each month have been used. The WorldClim version 2 average monthly maximum temperature, minimum temperature and precipitation data for 1970-2000 has been used. The weather data along with the LULC data (GeoTiff) are on global basis. The soil texture raster dataset is collected from the above mentioned source which is particularly made for Indian soil type. The area production statistics data for maize for both the season is collected from the above mentioned source for 2010-2015 time period. The average area, production and productivity were calculated for both the season to get a better estimation of these statistics.

ii. Preparation of maps

Kharif maize in India is generally cultivated in June-October. But, now a days rabi maize is also becoming popular as well and it is cultivated in many districts in India. The most crucial time for rabi maize is flowering and the flowers come in between January-February. The suitability maps for both the season is prepared using the following decision matrix which is prepared by the breeders, subject specialist along with climatologists.

Rainfall	Sandy soil			Loamy soil			Clay soil		
	Maximum Temperature(°c)			Maximum Temperature(°c)			Maximum Temperature(°c)		
	10-23	>23-33	>33	10-23	>23-33	>33	10-23	>23-33	>33
<400									
400-650									
>650									

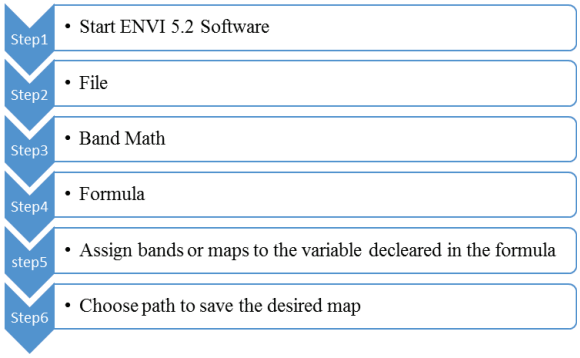
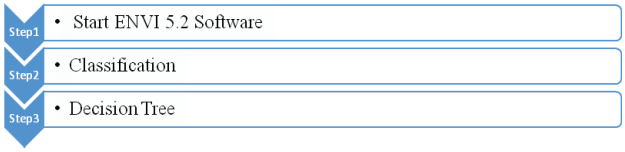
Fig. 2. Decision Matrix for Kharif (rainfed) Maize

For preparing suitability map for kharif maize three factors are taken into consideration and these are maximum temperature (Tmax), precipitation (Rainfall), soil texture.But, for preparing suitability map for rabi crop, maximum temperature (Tmax), minimum temperature (Tmin) and soil texture are taken into consideration.Maps are prepared in ENVI 5.2 software. The steps are given in the following Table 2.

Maximum Temperature (°c)	Sandy soil			Loamy soil			Clay soil		
	Minimum Temperature (°c)			Minimum Temperature (°c)			Minimum Temperature (°c)		
	<10	>10-20	>20	<10	>10-20	>20	<10	>10-20	>20
<15		None	None		None	None		None	None
>15-25			None			None			None
>25									

Fig. 3. Decision Matrix for Rabi Maize

Table 2. Steps for Creating Maps in ENVI 5.2 Software

Sr. No.	Steps
1.	As kharif maize is grown from June-October, the average maximum temperature data set for these 5 months have been calculated using the monthly global maximum temperature maps of GeoTiff format (bands). $Tmax = \{June(tmax) + July(tmax) + Aug(tmax) + Sept(tmax) + October(tmax)\}/5$
2.	Kharif or rain fed maize receives monsoon during its growing period. The total rainfall is calculated during June-September using the monthly global precipitation maps of GeoTiff format (bands). $Total\ rainfall = \{June(prec) + July(prec) + Aug(prec) + Sept(prec)\}$
3.	As flowering stage in rabi occurs in January-February, the average maximum temperature data set for these 2 months have been calculated using the monthly global maximum temperature maps of GeoTiff format (bands). $Tmax = \{January(tmax) + February(tmax)\}/2$
4.	As flowering stage in rabi occurs in January-February, the average minimum temperature data set for these 2 months have been calculated using the monthly global minimum temperature maps of GeoTiff format (bands). $Tmin = \{January(tmin) + February(tmin)\}/2$
5.	Using ENVY software avg. Tmax, avg. Tmin and total rainfall for both the seasons are calculated by repeating few steps- 
6.	India data map has been masked using the soil boundary as defined in the soil texture map otherwise in some places there will be other input data such as temperature, precipitation, LULC can but no soil data as the soil texture map is prepared by NBSS And LUP, Nagpur, Bhopal, India. So resizing of the input data according to the soil texture map has been done.
7.	After extracting the India's data from the global dataset spatial analysis on the maps has been done by forming a decision tree based on the above mentioned decision matrix. In this decision matrix three type of soil texture is used and these are sandy soil, loamy soil and clay soil which are indexed as 1, 6 and 7 respectively in the soil textured map produced by NBSS And LUP, Nagpur. For each season the decision tree is different. At first the maps on which the decision tree is made has been loaded to the ENVI software. 
8.	After applying the decision rules on the input maps, the suitability maps for maize has been generated for both the seasons. Then, the LULC map of India which has been extracted from the global LULC map, has been masked on the suitability maps to remove the non-cropped portion from the suitability maps. Otherwise, some ambiguity will be there.

iii Design and Development of Mega-Environment

The suitability maps for maize Mega-Environment which are based on the decision tree, has been prepared using the ENVI 5.2 software. This software is very useful for creating, viewing, classifying, editing and performing various spatial analysis. From the accrued data source, the final suitability maps for both the season has been generated by going through various intermediate steps. The suitability maps for both the season has been classified as highly suitable (dark green), suitable (light green), moderately suitable (cyan blue), marginally suitable (yellow), not suitable (red) and undefined (magenta).

iv Hosting the suitability maps to the Geo server: Geo server version 2.11.2 is used for carrying out the research work.

1. Two maps were deployed to the http://geoportal.icar.gov.in under the Crop Mega Environment sub folder of Crop Science. The folder Crop Mega Environment has been created under the Crop Science folder using the Linux codes.

2. For the deployment of the maps under the certain folder, at first the maps have been uploaded to the geo server. The suitability maps have been generated and saved as GeoTiff format. But, the maps should be in SLD format to upload in the geo server. So,

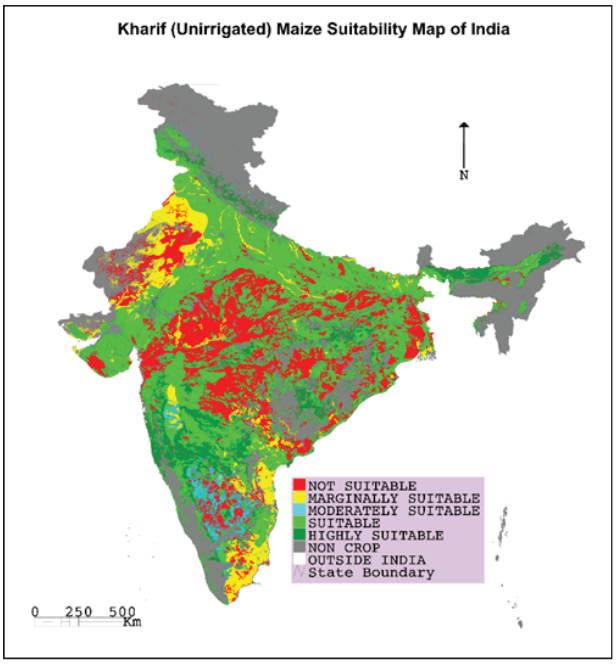


Fig. 4: Suitability Map for Kharif Maize in India

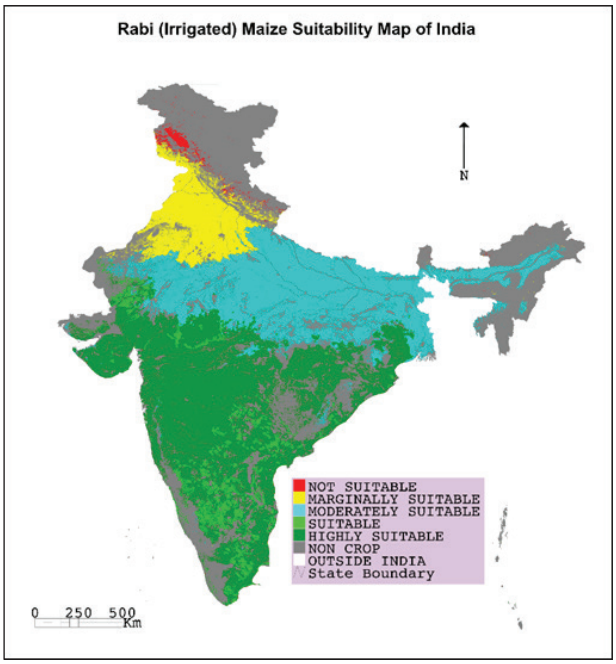


Fig. 5. Suitability Map for Rabi Maize in India

Fig. 6. ICAR Geo Portal

the maps are converted from GeoTiff format to SLD format using QGIS 2.6 software.

***Geo portal*:** ICAR Geoportal consists of several modules and submodules like LAYER, INDIA STATE AND DISTRICT, NATURAL RESOURCE MANAGEMENT, CROPSCIENCE, HORTICULTURAL SCIENCE, AGRICULTURAL ENGINEERING, ANIMAL SCIENCE, FISHERIES SCIENCE, AGRICULTURE EXTENSION, LATEST SATELLITE IMAGES, ICAR INSTITUTE AND BASE MAP.

***Crop Science Module*:** Under the CROPSCIENCE module, there are three sub modules like Crop Statistics, Weed Infestation and the Crop Mega-Environment. Crop Mega-Environment has been created to deploy kharif and rabi season suitability maps using LINUX shell script in the GeoServer Environment.

***Crop Mega Environment*:** Crop Mega environment sub module consists of two suitability maps of maize for both kharif and rabi season. These maps have been deployed to the geo portal through GeoServer.

3. RESULT AND DISCUSSION

The suitability maps created (figure 3 and figure 4) or the mega-Environment for maize were hosted using GeoServer to KRISHI portal and they can be accessed through https://krishi.icar.gov.in.

Visualization of Final Suitability Maps: Suitability maps for both the season can be visualised by everyone.

4. VALIDATION OF RESULTS

The generated final suitability maps for kharif and rabi have been validated with the Area, Production, Productivity data obtained from Crop Production Statistics Information System,Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Govt. Of India. It is available at the following url: https://aps.dac.gov.in/APY/Public_Report1.aspx

5. FEATURES AND FUNCTIONALITY

The necessity for developing the Mega-Environment for maize was taken into consideration because no GIS based methodology could be found in literature, which integrates factors like climate, soil, land cover etc., and can predict the most suitable environment (Area) for growing maize based on its genetic variability for India. Therefore, a methodology is needed which considers the integration of factors like climate, soil, land cover etc., to predict the most suitable Mega- Environment for growing maize based on their genetic variability. This research work is proposed to develop the Mega-Environment rather than to generate the crop growing suitability maps for maize for both the seasons so that the user can visualize where they can grow maize considering the weather factors. The interface used for hosting the maps provides the following features-

- The user can easily visualize and use the maximum temperature, minimum temperature (Rabi season), precipitation maps which is based on growing seasons for maize.
- Visualizing the suitability maps for both the season the user can easily predict the possible areas where the crop can be successfully grown which can reduce the cost and effort for trial method.
- As the maps are tagged with spatial data (gridded data) which are mainly the satellite data, serve as very reliable and accurate source of information.
- The data along with the final maps can be downloaded for further research.

6. CONCLUSION

Maize MEs in India have been developed considering several input factors like max temperature, precipitation, min temperature, soil texture of India, LULC of India. Data has been taken from various different sources such as climate data is taken from http://worldclim.org/version2 site, soil texture data from http://geoportal.icar.gov.in and https://www.geo-wiki.org/downloads respectively. Using these global data sets, data for growing maize in India has been extracted. Using the developed maps and the decision matrix (section 2.2.2) cultivated area of India is classified into homogeneous groups i.e. MEs. Whole India is classified into 5 classes:

- highly suitable,
- suitable,
- moderately suitable,

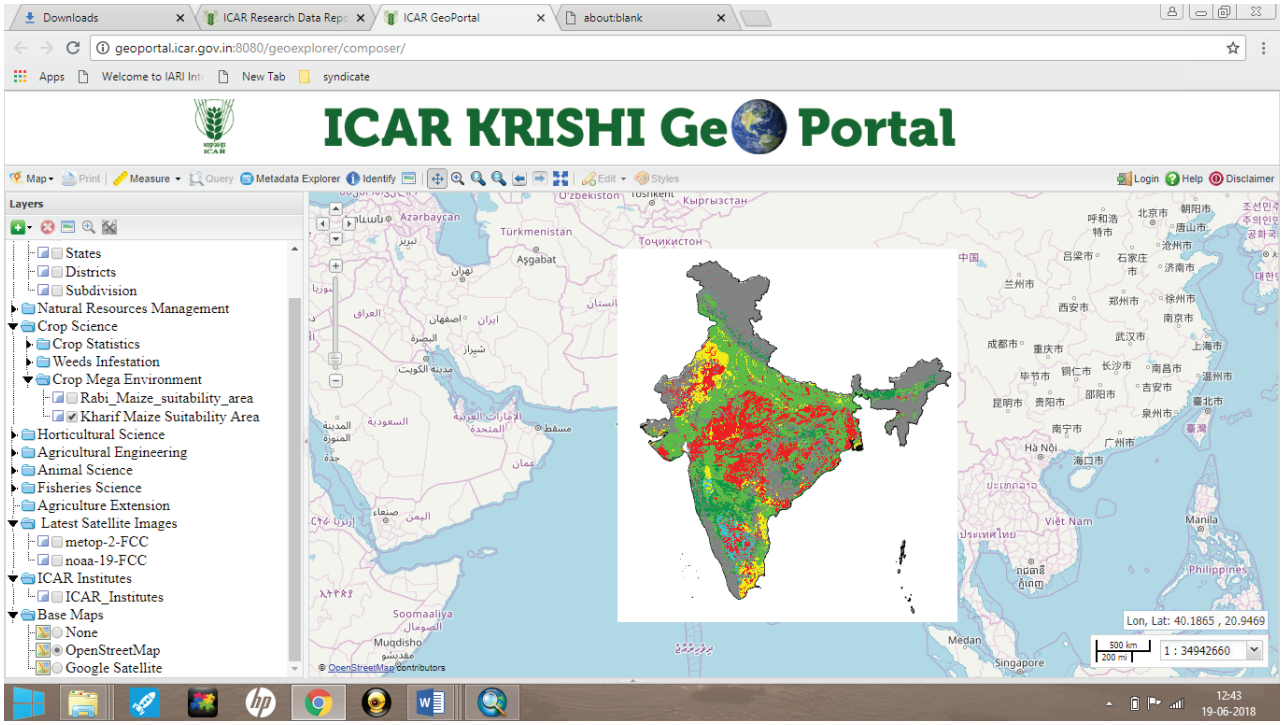


Fig. 7. Deployment of Kharif Maize Suitability Map

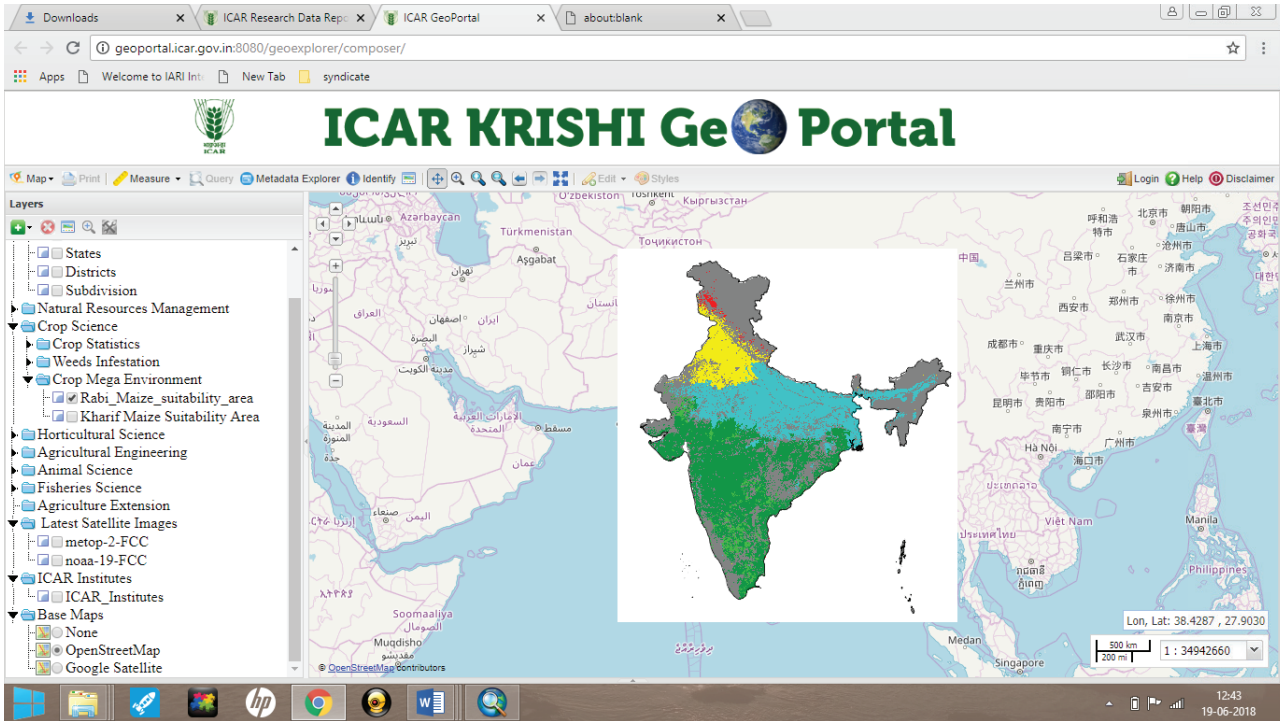


Fig. 8. Deployment of Rabi maize Suitability Map

- marginally suitable and
- not suitable for maize cultivation.

Suitability maps have been developed for both Kharif and Rabi season. By studying this MEs, without going to the field trial method, suitable area for maize can be easily identified which can reduce human error as well as it can be a more economic approach.

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