Agropedology 2014, 24 (02), 222-233

WebGeoSIS as soil information technology: A conceptual framework

T. BHATTACHARYYA, P. CHANDRAN, S.K. RAY, P. TIWARY, AJIT DHARMIK[*], D.K. MANDAL, C. MANDAL, S. CHATTERJI, D. K. PAL, G.P. OBI REDDY, D. SARKAR AND S.K. SINGH

ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur 440 033, India
**6Simplex, Software Solutions Pvt. Ltd., Nagpur*

Abstract: Soil is one of the essential natural resource for plant growth and agricultural production. Besides, there are other soil related concerns in environmental protection, pollution control, carbon sequestration vis-à-vis climate change, organic farming and other aspects of land use. Therefore, there is a need for an easily accessible and standardized soil information database at both temporal and spatial scales which can act as soil information technology (SIT). The SIT would allow a rational transfer of agricultural technologies and management practices and prove to be a sound reference base to facilitate effective transfer of soil information to those involved in planning, decision making and implementation. Web-based technology has facilitated the web publication of geo-referenced soil and other information that will be user-friendly and interactive with wider applicability and can be used by the stakeholders at any time and from any geographical locations. The present paper outlines a conceptual framework of WebGeoSIS, a web-based geo-referenced soil information system, that provides i) access to soil and related data, ii) tools to analyze the soil data, and iii) capabilities to visualize all data in a map- based interface which can pave the way for developing soil information technology.

Key words: *Agricultural technologies, web-based technology, soil information system.*

Introduction

Soil is a crucial natural resource for plant growth and agricultural production. However, there are other soil related concerns in environmental protection, pollution control, carbon sequestration to mitigate climate change, organic farming and other aspects of land use. For the last few decades, soil scientists have remained concerned on the actual and potential problems of soil degradation, including erosion (leading to substantial loss of topsoil) and loss of good agricultural land to urbanization and pollution. They have of late realized the need and importance of developing adequate soil information in combating / preventing soil degradation and facilitating sustainable agricultural production. Therefore, there is a need for an easily accessible and standardized soil information database at both temporal and spatial scales that is stored and/or arranged in an interactive and user-friendly structure.

Well-structured land resource information would allow a rational transfer of agricultural technologies and management practices. Such information would prove to be a sound reference base to facilitate effective transfer of soil information to those involved in planning, decision making and implementation and lead to development of soil information technology.

National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) has been carrying out the task of inventorying and documenting natural resources of the country with special reference to soil. It has generated information on soils and derived maps on various themes of national importance for a wide range of stakeholders. Most of the datasets are in the form of map with specific legend which the stakeholders, users and readers may find difficult to understand. This necessitated adoption of user-friendly approach to publish this information that could be interactive, visible and easy to understand. With the rapid development of Geographic Information System (GIS) in recent years, a large amount of data can be easily stored and retrieved in a well-structured manner. Digitalization of soil maps would facilitate the exchange of information and make these data compatible with those of the rest of the world. The advent of web-based technology would further ease the web-based publication of geo-referenced soil and other information that will be user-friendly and interactive with wider applicability. This will enable the stakeholders/users use the accessed information/datasets for various purposes including land resources inventory and management. Query-based information on soil, land use, etc. along with their spatial distribution can also be accessed for a specific purpose.

Moreover, geo-referenced soil information comprising detailed morphological, physical, chemical and biological properties was also not in place. It is in this respect the project on "Geo-referenced Soil Information System for Land Use Planning and Monitoring Soil and Land Quality for Agriculture" was undertaken with the financial assistance of National Agricultural Innovative Project (NAIP, Component 4) under the overall guidance of ICAR. During the project period, the soil information of 1000 pedons were collected and collated from various sources (either be specific on sources or just mention sources) for two major food growing regions of India, namely, the Indo-Gangetic Plains (IGP) and the Black Soil Region (BSR). Refinement of soil information was carried out for up-to-date geographical coverage, access to secondary soil information through pedo-transfer functions or models from the primary soil data. This was important since monitoring changes in soil characteristics is associated with changes in land use system and process of global climate change.

During the execution of the project, it was contemplated to showcase the entire exercise of the project output in the website of NAIP as WebGeoSIS (http://www.geosis-naip-nbsslup.org/). Through web-based GeoSIS, the datasets/information on soil, land use, crop, climate, physiography and SOTER along with the associated maps can be accessed from any web-enabled equipment.

The present paper outlines a conceptual framework of WebGeoSIS that includes an overview of the WebGeoSIS system architecture, a brief description of its user interface components and a description of the data models that can be created from existing datasets (Bhattacharyya *et al*. 2014a,b; Ray *et al.* 2014; Chandran *et al.* 2014; Mandal *et al*. 2014; Chatterji *et al*. 2014; Tiwary *et al*. 2014) and may be used as a reference for developing soil information technology.

Materials and Methods

Materials

Soils of the Indo Gangetic Plains (IGP)

Geographically the IGP ranks as one of the most extensive fluvial plains of the world extending from 21°45'to 31°00'N latitudes and 74°15' to 91°30'E longitudes and includes the states of Punjab, Haryana, Delhi, Uttar Pradesh, Bihar, West Bengal, Tripura and northern fringes of Rajasthan with total area of 52.01 m ha and represents 8 AER and 17 AESRs (Velayutham *et al*. 1999). IGP covers approximately 13% of the geographical area and produces nearly 50% of India's food grains. Climatically the IGP ranges from arid in the west to humid to per humid in the east. The summer and winter are extreme in terms of both temperature and rainfall in the western part of the IGP and relatively moderate in eastern part. Rainfall ranges from 218 mm in the arid to 2800 mm in the east. It occurs mainly during the summer monsoon (80-90% of the total rainfall). During the winter the western IGP receives cyclonic rainfall from the Mediterranean Sea. The soils of the IGP are formed in one of most extensive fluvial plains in the world. Time differences in precipitation have contributed to formation/development of a variety of soils in the plains. The soils mainly belong to three soil orders of the US Taxonomy (Soil Survey Staff 2006) namely, Entisols, Inceptisols and Alfisols (Bhattacharyya *et al.* 2009), of which Inceptisols alone occupy 37.82 m ha followed by Entisols (14.0 m ha) and Alfisols (2.11 m ha).

Soils of Black Soil Region (BSR)

Traditionally, black soils were believed to be confined to the Peninsular region, but research endeavours at the ICAR-NBSS&LUP, Nagpur identified their presence in other parts of the country as well. The BSR now covers from 8°15 – 26° 50'N and 68° 30' – 84° 45' E and extends to parts of Assam. Understanding the importance of these soils for sustainable crop production, it is essential to assess the spatial distribution of these soils for efficient planning and management. The shrink-swell soils in India cover 76.4 mha of which Vertisols (27 mha) and vertic intergrades Inceptisols (39.7 mha) and Entisols (4.4 mha) are the important soils (Table 1). The BSRs are spread mainly in Maharashtra (27%) followed by earstwhile Madhya Pradesh (21.3%). The states of Gujarat, Tamil Nadu, Karnataka, Andhra Pradesh, Uttar Pradesh and Rajasthan collectively contribute nearly 35.5 per cent area. The georeferencing of 429 pedons indicates that the BSR is extended to West Bengal, Bihar, Chhattisgarh, Punjab, Orissa, Assam, Jammu & Kashmir, Tripura and Kerala in patches.

Table 1. Distribution of different soil orders in black soil region (BSR) of India

Order (Subgroups)	Area (m ha)	
	mha	% *
Vertisols	27.4	35.8
Inceptisols (Vertic)	39.7	51.9
Entisols (Vertic)	4.4	5.8
Others	4.9	6.5

*of total area under BSR

SOTER (Soil and Terrain) database for the IGP and the BSR

The global and national soils and terrain digital databases (SOTER) input software developed at the International Soil Reference and Information Centre (ISRIC), The Netherlands in collaboration with other international organization, *viz.* FAO, UNEP and IUSS is used to create and maintain a digitized map unit and attributes. The SOTER concept is based on the relationship between the physiography, parent material and soils within an area. It provides data for improved mapping and monitoring of changes in soil and terrain resources. The methodology allows mapping and characterization of areas of land with a distinctive often repetitive pattern of landform, lithology, surface form, slope, parent material and soils (van Engelen and Wan 1995). The collated information is stored in the SOTER framework and is linked to a GIS permitting a wide range of applications (Bhattacharyya and Mandal 2009; Batjes and Dijkshoorn 1999; Batjes *et al*. 2007). The database allows periodic updating by removing obsolete or irrelevant data. SOTER is a combination of geographic and attribute data. Terrain information is geographic component indicating the topology of SOTER unit and attribute data gives spatial unit characteristics stored in a set of relational database management system (RDBMS) files. A SOTER unit is made by combining information on terrain attributes and soil attributes (Fig. 1). The database can also store climatic data, data sources, land use and other auxiliary data which are useful for land users. The basic data required for the construction of a SOTER unit are topographic, geomorphological, and geological and soil map ideally at the scale of 1:250,000 to 1:1 m as layers accompanied by sufficient analytical data for soil characterization and mapping.

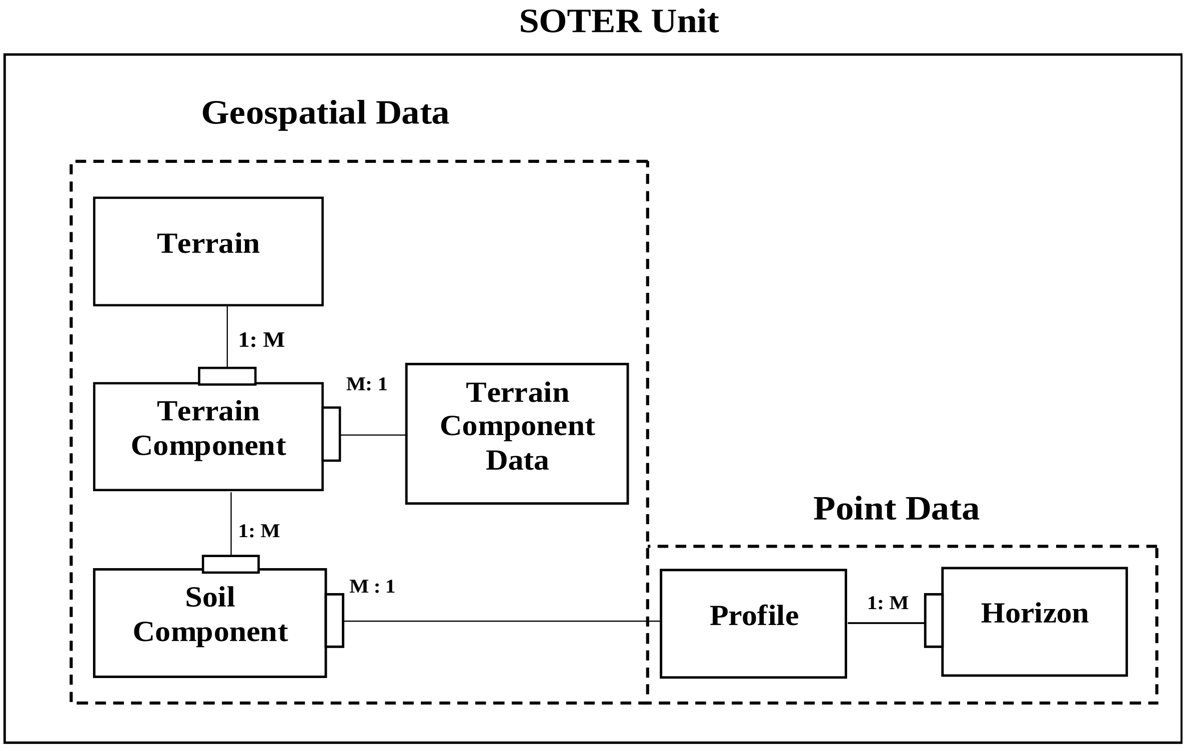


Fig. 1. SOTER attribute database structure with area and point data (1:M = one to many, M:1 = many to one relations) (adapted and modified from Van Engelen and Wan 1995).

Geo-referenced soil information systems and the SOTER database can be used for many applications. Terrain parameters are most commonly used as extensively mapped secondary and auxiliary variable to improve spatial prediction of soil-scapes and soil physical properties like thickness of horizon and physical properties. Soil information systems can be combined with digital elevation models and satellite radiometric data for regional soil mapping. The database has been successfully used to refine the agro-ecological sub-region map of India (Mandal *et al.* 2014) which will help to determine and demarcate the crop efficiency zones. The digital soil resource database along with climate and plant requirement can be combined to evaluate and categorise the land for different uses. The geo-referenced database has been used to evaluate the soils of the BSR and the IGP for the cotton and soybean systems and the rice-wheat system, respectively (Chatterji *et al*. 2014) in benchmark spots. The database along with ancillary datasets are also used for predicting the yield of cotton and rice in the BSR and IGP soils respectively (Venugopalan *et al*. 2014). It will also help in assessing the soil and evolving land quality parameters and evolving strategies to improve the quality and health of soils for better use on a sustainable basis (Ray *et al*. 2014; Bhattacharyya *et al*. 2014a,b). The primary database has also been widely used to develop pedotransfer functions for estimating physical properties like bulk density (BD) and saturated hydraulic conductivity (sHC) of the soils (Tiwary *et al*. 2014) which are seldom available in routine soil survey reports.

Methods

The GeoSIS is based on the client-server paradigm commonly used and implemented in the IT world. A conceptual framework of the WebGeoSIS is illustrated in figure 2. The major components of the system are:

- One or more geospatial and non-geospatial database servers to hold past, present and future soil and related datasets.
- One or more GIS Server instances to serve soil and related geospatial and non-geospatial datasets to multiple client applications.

- A web client application that interacts with GIS Server and provides a map based interface to the user

The communication between the web client application and GIS Server can take place over a Hypertext Transfer Protocol Secure (HTTPS) connection, with token based server side security provided by GIS Server. Therefore, security roles and users in GIS Server and their mapping with GIS map services will need to be defined. When users interact (via the web client) with GIS Server, all services will challenge the client for a secure token, which the client must provide in order to access ArcGIS services. Absence of token on part of the client will result in ArcGIS Server rejecting client requests for data. A high level of WebGeoSIS architecture shown in figure 2 may be dynamic depending on various phases of the concept (Table 2).

Table 2. Technical activities in web-based geo-referencing soil information system

Sl. No.	Technical activities
1	Creating data model for Soil Benchmarks and related entities, including normalization of Benchmark data currently residing in shapefiles and excel sheets
2	Integration of schema of datasets owned by NBSS into the data model
3	Creation of relational database to implement BSR and IGP data models, using Postgres
4	Creation of spatial database using Postgres and any GIS server based tools that can be used for accessing and managing the data within relational databases
5	Loading BSR and IGP data from shapefiles and excel sheets into the GIS environment
6	Building a map document to include spatial and non-spatial data
7	Publishing map document as a map service on GIS Server

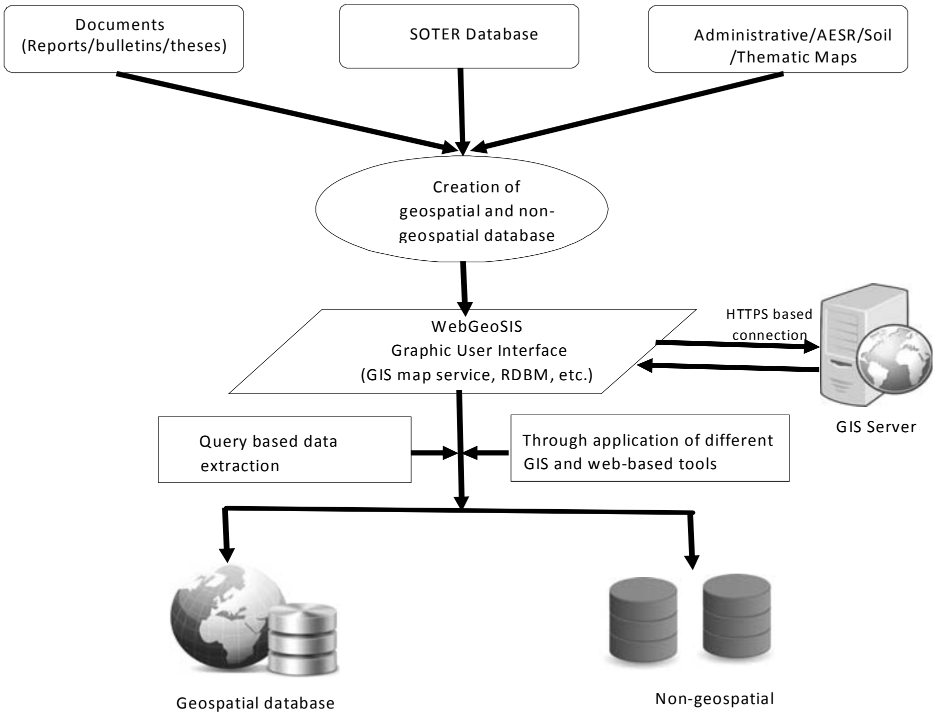


Fig. 2. **Schematic diagram showing web-based georeferenced soil information system and its structural framework.**

User Interface

The GeoSIS user interface is a map-based web application which provides a user-friendly view of Black Soil Region (BSR) and Indo-Gangetic Plains (IGP) soil data along with other related data. The application primarily consists of a map depicting the geographically distributed benchmark points. The map also includes layers of other data such as climate, land use, AER, and AESR, terrain and administrative boundaries, which can be turned on/off by the user. The user will be able to interact with the following three map layers in the manner described below:

1. *The soil information layer that contains benchmark points*: When user clicks on a benchmark point on the map, information for the selected point from related datasets such as climate, land use, terrain, AER and AESR will be pulled and displayed in the tab based information panel at the bottom on the window.
2. *The soil polygons*: When user clicks on a soil polygon, information related to that polygon alone will be displayed on the map as a pop-up.
3. *The administrative (district) polygons*: When a user clicks on a district, information related to soil benchmark points and other relevant datasets will be pulled in and displayed in the information panel at the bottom.

The application may also provide standard map functionalities such as pan, zoom in, and zoom out. It will also provide controls to modify transparency of all layers, for better visual experience. Based on this functionality, the following technical activities would be included for creation of the web application:

- Development and deployment of Javascript-based web application that will consume GIS Server services.
- Retrieve appropriate information for selected dataset

The data model

The following BSR and IGP data entities may be stored in the database in the form of i) Benchmark points, ii) Soil regions, iii) Land Use, Climate, iv) Terrain, v) Administrative Boundaries, vi) AER, and vii) AESR . Out of the data entities listed above, several are currently stored in separate files (shapefiles and excel sheets) (Fig. 3a,b). This requires that when there is a need to extract meaningful related information, linking between such separate files must be done manually. This quickly becomes time consuming and error prone. For example, data for benchmark points reside in shapefiles as well as excel sheets. The geographical aspect resides as a shape file, but the non-geographical one resides as separate excel sheets. There are indeed common attributes that tie up these separate parts, but values of these attributes need to be manually collated every time related data elements needs to be explored, rendering the data extraction and usage slow and tedious. GeoSIS proposes that such dispersed data must be reorganized, wherever necessary, and its schema re-evaluated for suitability and validity, keeping in mind the broader concepts of the science of soil and soil surveys. To reuse the example of benchmark points, a benchmark point has several weighted means and horizons elements. GeoSIS would first bring together the various shape files and excel sheets that make up a benchmark point as one entity (in a relational database) and then normalize it into separate tables for benchmark points, weighted means and horizons respectively, tying all of them together with above mentioned common attributes.

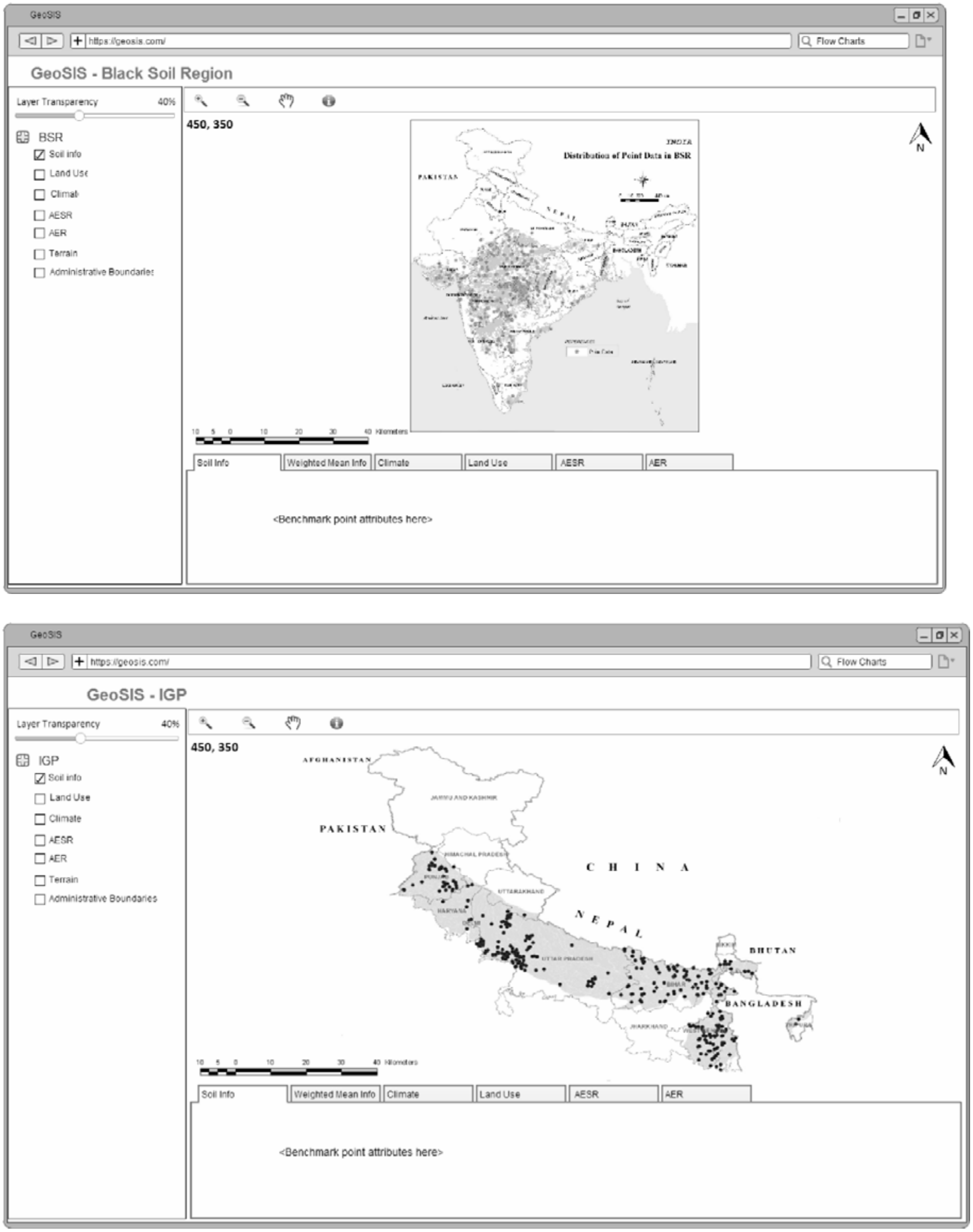
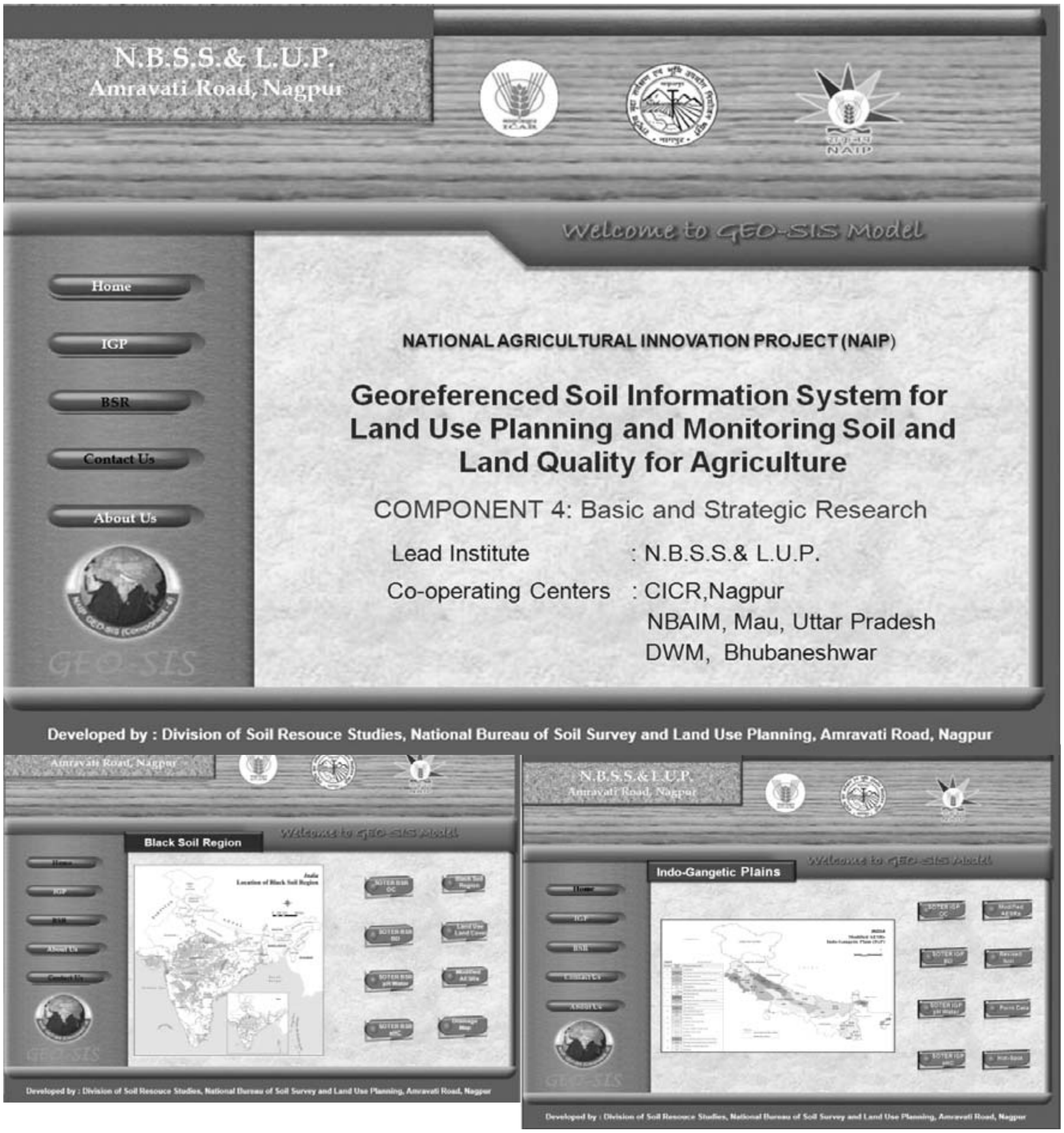


Fig. 3a&b. **Graphic User Interface of web-geosis (a) GeoSIS-BSR; (b) GeoSIS-IGP.**



NATIONAL AGRICULTURAL INNOVATION PROJECT (NAIP)

Georeferenced Soil Information System for Land Use Planning and Monitoring Soil and Land Quality for Agriculture

COMPONENT 4: Basic and Strategic Research

Lead Institute : N.B.S.S.& L.U.P.
Co-operating Centers : CICR,Nagpur
NBAIM, Mau, Uttar Pradesh
DWM, Bhubaneshwar

Developed by : Division of Soil Resouce Studies, National Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur

Fig.4. Graphic User Interface of webGeoSIS (a) home page (b) GeoSIS-IGP and (c) Geo-SIS-BSR

Thus, GeoSIS provides an opportunity to adopt data organization, storage and management-based practices for data that is currently available and owned by NBSS. Such adoption and experience gained during this phase could be extended later to other projects. This will not only open up use of standard relational database tools to easily link, access and maintain this data, but also provide an opportunity to standardize tools for enforcing organization wide security and centralized access controls over it. This phase also proposes that other related datasets such as land use, climate and administrative boundaries that will need to be procured from other organizations be covered by Service Level Agreement (SLAs). Such SLAs would, at the least, need to clarify the schema, quality, availability schedules and legal restrictions (if any) on shared datasets (Fig. 4).

Conclusion

(Mentioned in abstract and introduction) GeoSIS facilitates a holistic view of the land by recognizing that soil data are not self-sufficient information islands, but elements that are strongly connected with other data such as climate, land use, agro-ecoregion (AER), and agro-eco subregion (AESR). WebGeoSIS also recognizes the inherently location-based nature of soil information and therefore provides both geographic as well as non-geographic perspectives for data access, analysis and visualization. WebGeoSIS can enable collaboration between different agencies, facilitating better communication and can save time by avoiding repeatative research. This exercise can open new vistas for participatory research programmers involving common people and related organisations and can, therefore, keep space for revising database for monitoring soil health and changing land use pattern.

Acknowledgement

This is an extension of the basic concept of sharing data output on a NAIP (Component-4)sponsored project on “Georeferenced Soil Information System for Land Use Planning and Monitoring Soil and Land Quality for Agriculture”. The financial assistance is acknowledged.

References

Batjes, N.H. and Dijkshoorn, I.A. (1999). Carbon and nitrogen blocks in the soils of the Amazon region. *Geoderma* **89**: 273-286.

Batjes, N. H. et al. (2007). Preparation of consistent soil datasets for modelling purposes: secondary SOTER data for four case study areas. *Agriculture Ecosystem Environment* **122**: 26–34.

Bhattacharyya, T. and Mandal, B. (2009). Soils Information System of the Indo-Gangetic Plains for resource management. ISSS special session on Land Use Planning, *Journal Indian Soc. Soil Sci.,* Platinum Jubilee Symposium – Proceedings, 1-19.

Bhattacharyya, T., Pal, D.K., Mandal, C., Chandran, P., Ray, S.K., Sarkar, Dipak, Velmourougane, K., Srivastava, A., Sidhu, G.S., Singh, R.S., Sahoo, A.K., Dutta, D., Nair, K.M., Srivastava, R., Tiwary, P., Nagar, A.P. and Nimkhedkar, S.S. (2013). Soils of India: Their Historical Perspective, Classification and Recent Advances in Knowledge: A Review. *Current Science* **104:** 1308-1323.

Bhattacharyya, T., Sarkar, D., Ray, S.K., Chandran, P., Pal, D.K., Mandal, D.K., Prasad, J., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Mandal, C., Srivastava, R., Sen, T.K., Chatterji, S., Obireddy, G.P., Patil, N.G., Mahapatra, S.K., Anil Kumar, K.S., Das, K., Singh, A.K., Reza, S.K., Dutta, D., Srinivas, S., Tiwary, P., Karthikeyan, K., Venugopalan, M.V., Velmourougane, K., Srivastava, A., Raychaudhuri Mausumi, Kundu, D.K., Mandal, K.G., Kar, G., Durge, S.L., Kamble, G.K., Gaikwad, M.S., Nimkar, A.M., Bobade, S.V., Anantwar, S.G., Patil, S., Sahu, V.T., Gaikwad, K.M., Bhondwe, H., Dohtre, S.S., Gharami, S., Khapekar, S.G., Koyal, A., Sujatha, Reddy, B.M.N., Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N., Halder, A.S., Basu, R., Singh, R., Jat, B.L., Oad, D.L, Ola, N.R., Wadhai, K., Lokhande, M., Dongare, V.T., Hukare, A., Bansod, N., Kolhe, A., Khuspure, J., Kuchankar, H., Balbuddhe, D., Sheikh, S., Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal ,R.S., Sahu, A., Mahapatra, S., Puspamitra, S., Kumar, A., Gautam, N., Telpande, B.A., Nimje, A.M., Likhar, C. and Thakre, S. (2014a). Georeferenced Soil Information System : assessment of database. *Current Science* **107(9)**: 1400-1419.

Bhattacharyya, T., Sarkar, D., Ray, S.K., Chandran, P., Pal, D.K., Mandal, D.K., Prasad, J., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Mandal, C., Srivastava, R., Sen, T.K., Chatterji, S., Obireddy, G.P., Patil, N.G., Mahapatra, S.K., Anil Kumar, K.S., Das, K., Singh, A.K., Reza, S.K., Dutta, D., Srinivas, S., Tiwary, P., Karthikeyan, K., Venugopalan, M.V., Velmourougane, K., Srivastava, A., Raychaudhuri Mausumi, Kundu, D.K., Mandal, K.G., Kar, G., Durge, S.L., Kamble, G.K., Gaikwad, M.S., Nimkar, A.M., Bobade, S.V., Anantwar, S.G., Patil, S., Sahu, V.T., Gaikwad, K.M., Bhondwe, H., Dohtre, S.S., Gharami, S., Khapekar, S.G., Koyal, A., Sujatha, Reddy, B.M.N., Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N., Halder, A.S., Basu, R., Singh, R., Jat, B.L., Oad, D.L., Ola, N.R., Wadhai, K., Lokhande, M., Dongare, V.T., Hukare, A., Bansod, N., Kolhe, A., Khuspure, J., Kuchankar, H., Balbuddhe, D., Sheikh, S., Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal ,R.S., Sahu, A., Mahapatra, S., Puspamitra, S., Kumar, A., Gautam, N., Telpande, B.A., Nimje, A.M., Likhar, C. and Thakre, S. (2014b). Soil information system : use and potentials in humid and Semi-Arid Tropics. *Current Science* **107(9)**: 1550-1564.

Chandran, P., Tiwary, P., Bhattacharyya, T., Mandal, C., Prasad, J., Ray, S.K., Sarkar, D. , Pal, D.K., Mandal, D.K., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Srivastava, R., Sen, T.K., Chatterji, S., Obireddy, G.P., Patil, N.G., Mahapatra, S.K., Anil Kumar, K.S., Das, K., Singh, A.K., Reza, S.K., Dutta, D., Srinivas, S., Karthikeyan, K., Venugopalan, M.V., Velmourougane, K., Srivastava, A., Raychaudhuri, M., Kundu, D.K., Mandal, K.G., Kar, G.,Dijkshoorn, J.A., Batjes, N.H.,Bindraban, P.S., Durge, S.L. , Kamble, G.K.,Gaikwad, M.S., Nimkar, A.M., Bobade, S.V., Anantwar, S.G., Patil, S., Gaikwad, M.S., Sahu, V.T. , Bhondwe, H., Dohtre, S.S., Gharami, S., Khapekar, S.G., Koyal, A., Sujatha, K., Reddy, B.M.N., Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N. , Halder, A.S., Basu, R., Singh, R., Jat, B.L., Oad, D.L., Ola, N.R., Wadhai, K. , Lokhande, M., Dongare, V.T., Hukare, A., Bansod, N., Kolhe A.H., Khuspure, J., Kuchankar, H., Balbuddhe, D., Sheikh, S., Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal, R.S., Sahu, A., Mahapatra, S., Puspamitra, S., Kumar, A., Gautam, N., Telpande, B.A., Nimje, A.M. , Likhar, C. and Thakre, S. (2014). Development of SOTER database for major foodgrowing regions of India for resource planning. *Current Science* **107(9)**: 1420-1430.

Chatterji, S., Tiwary, P., Sen, T.K., Prasad, J., Bhattacharyya, T. , Sarkar, D., Pal, D.K., Mandal, D.K. , Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Mandal, C. , Srivastava, R., Chandran, P., Ray, S.K. , Obireddy, G.P., Patil, N.G. , Mahapatra, S.K., Srinivas, S., Das, K., Singh, A.K., Reza, S.K., Dutta, D., Anil Kumar, K.S., Karthikeyan, K., Venugopalan, M.V., Velmourougane, K., Srivastava A., Raychaudhuri, Mausumi, Kundu, D.K., Mandal, K.G., Kar, G., Durge, S.L. , Kamble, G.K. , Gaikwad, M.S. , Nimkar, A.M., Bobade, S.V., Anantwar, S.G., Patil, S., Gaikwad, M.S., Sahu, V.T., Bhondwe, H., Dohtre, S.S., Gharami, S., Khapekar, S.G., Koyal, A., Sujatha, Reddy, B.M.N., Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N. , Halder, A.S., Basu, R., Singh, R., Jat, B.L., Oad, D.L., Ola, N.R., Wadhai, K., Lokhande, M., Dongare, V.T., Hukare, A., Bansod, N., Kolhe, A., Khuspure, J., Kuchankar, H. , Balbuddhe, D. , Sheikh, S. , Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal, R.S., Sahu, A., Mahapatra, S., Puspamitra, S., Kumar, A., Gautam, N. , Telpande, B.A. , Nimje, A.M. , Likhar, C. and Thakre, S. (2014). Land evaluation for major crops. *Current Science* **107(9)**: 1502.

Mandal, C., Mandal, D.K. , Bhattacharyya, T. , Sarkar, D. , Pal, D.K., Prasad, J. , Sidhu, G.S. , Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Srivastava, R. , Sen, T.K. , Chatterji, S. , Chandran, P. , Ray, S.K. , Obireddy, G.P. , Patil, N.G. , Mahapatra, S.K., Anil Kumar, K.S., Das, K., Singh, A.K., Reza, S.K., Dutta, D., Srinivas,S., Tiwary, P. , Karthikeyan, K. , Venugopalan, M.V., Velmourougane, K., Srivastava, A., Raychaudhuri, Mausumi, Kundu, D.K., Mandal, K.G., Kar, G., Durge, S.L. , Kamble, G.K. , Gaikwad, M.S. , Nimkar, A.M. , Bobade, S.V. , Anantwar, S.G. , Patil, S. ,Gaikwad, K.M. , Sahu, V.T. , Bhondwe, H. , Dohtre, S.S. , Gharami, S. , Khapekar, S.G. , Koyal, A., Sujatha, Reddy, B.M.N., Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N. , Halder, A.S., Basu, R., Singh, R., Jat, B.L., Oad, D.L., Ola, N.R., Wadhai, K. , Lokhande, M. , Dongare, V.T. , Hukare, A. , Bansod, N. , Kolhe, A. , Khuspure, J. , Kuchankar, H. , Balbuddhe, D. , Sheikh, S. , Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal, R.S., Sahu ,A., Mahapatra, S., Puspamitra, S., Kumar, A., Gautam, N. , Telpande, B.A. , Nimje, A.M. , Likhar, C. and Thakre, S. (2014). Revisiting agro-ecological subregions of India – A case study of two major food production zones. *Current Science* **107(9)**: 1519-1536.

Ray, S.K., Bhattacharyya, T., Sarkar, D., Chandran, P., Pal, D.K., Mandal, D.K., Prasad, J., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Mandal, C., Srivastava, R., Sen, T.K., Chatterji, S., Obireddy, G.P., Patil, N.G., Mahapatra, S.K., Anil Kumar, K.S., Das, K., Singh, A.K., Reza, S.K., Dutta, D., Srinivas, S., Tiwary, P., Karthikeyan, K., Venugopalan, M.V., Velmourougane, K., Srivastava, A., Raychaudhuri Mausumi, Kundu, D.K., Mandal, K.G., Kar, G., Durge, S.L., Kamble, G.K., Gaikwad, M.S., Nimkar, A.M., Bobade, S.V., Anantwar, S.G., Patil, S., Sahu, V.T., Gaikwad, K.M., Bhondwe, H., Dohtre, S.S., Gharami, S., Khapekar, S.G., Koyal, A., Sujatha, Reddy, B.M.N., Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N., Halder, A.S., Basu, R., Singh, R., Jat, B.L., Oad, D.L., Ola, N.R., Wadhai, K., Lokhande, M., Dongare, V.T., Hukare, A., Bansod, N., Kolhe, A., Khuspure, J., Kuchankar, H., Balbuddhe, D., Sheikh, S., Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal, R.S., Sahu, A., Mahapatra, S., Puspamitra, S., Kumar, A., Gautam, N., Telpande, B.A., Nimje, A.M., Likhar, C. and Thakre, S. (2014). Soil and land quality indicators of the Indo-Gangetic Plains. *Current Science* **107(9)**: 1470-1486.

Soil Survey Staff (2006). *Keys to Soil Taxonomy*, United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC, 2006, 10th edn.

Tiwary, P., Patil, N.G., Bhattacharyya, T., Chandran, P., Ray, S.K., Karthikeyan, K., Sarkar, D., Pal, D.K., Prasad, J., Mandal, C.,Mandal, D.K., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Das, T.H., Singh, R.S., Srivastava, R., Sen, T.K., Chatterji, S., Obireddy, G.P., Mahapatra, S.K., Anil Kumar, K.S., Das, K., Singh, A.K., Reza, S.K., Dutta, D., Srinivas, S., Venugopalan, M.V., Velmourougane, K., Srivastava, A., Raychaudhuri, M., Kundu, D.K., Mandal, K.G., Kar, G.,Dijkshoorn, J.A., Batjes, N.H.,Bindraban, P.S., Durge, S.L., Kamble, G.K.,Gaikwad, M.S., Nimkar, A.M., Bobade, S.V., Anantwar, S.G., Patil, S., Gaikwad, M.S., Sahu, V.T. , Bhondwe, H., Dohtre, S.S., Gharami, S., Khapekar, S.G., Koyal, A., Sujatha, K., Reddy, B.M.N., Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N. , Halder, A.S., Basu, R., Singh, R., Jat, B.L., Oad, D.L., Ola, N.R., Wadhai, K. , Lokhande, M., Dongare, V.T., Hukare, A., Bansod, N., Kolhe A.H., Khuspure, J., Kuchankar, H., Balbuddhe, D., Sheikh, S., Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal, R.S., Sahu, A., Mahapatra, S., Puspamitra, S., Kumar, A., Gautam, N., Telpande, B.A., Nimje, A.M. , Likhar, C. and Thakre, S. (2014). Pedotransfer functions : A tool for estimating hydraulic properties of two major soil types of India. *Current Science* **107(9)**:1431-1439.

Venugopalan, M.V., Tiwary, P., Ray, S.K., Chatterji, S., Velmourougane, K., Bhattacharyya, T., Bandhopadhyay, K.K., Sarkar, D., Chandran, P., Pal, D.K., Mandal, D.K.., Prasad, J., Sidhu, G.S., Nair, K.M., Sahoo, A.K., Anil Kumar, K.S., Srivastava, A., Das, T.H., Singh, R.S., Mandal, C., Srivastava, R., Sen, T.K., Obireddy, G.P., Patil, N.G., Mahapatra, S.K., Das, K., Singh, S.K., Reza, S.K., Dutta, D., Srinivas, S., Karthikeyan, K., Raychaudhuri, Mausumi, Kundu, D.K., Mandal, K.K. , Kar G., Durge, S.L., Kamble, G.K., Gaikwad, M.S., Nimkar, A.M., Bobade, S.V., Anantwar, S.G., Patil, S., Gaikwad, M.S., Sahu, V.T., Bhondwe, H., Dohtre, S.S., Gharami, S., Khapekar, S.G., Koyal, A., Sujatha, Reddy, B.M.N., Sreekumar, P., Dutta, D.P., Gogoi, L., Parhad, V.N., Halder, A.S., Basu, R., Singh, R., Jat, B.L., Oad, D.L., Ola, N.R., Sahu, A., Wadhai, K., Lokhande, M., Dongare, V.T., Hukare, A., Bansod, N., Kolhe, A., Khuspure, J., Kuchankar, H., Balbuddhe, D., Sheikh, S., Sunitha, B.P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal, R.S., Mahapatra, S., Puspamitra, S., Kumar, A., Gautam, N., Telpande, B.A., Nimje, A.M. , Likhar, C. and Thakre, S. (2014). INFOCROP simulation model – its validation for Bt cotton and its application for land quality assessment for cotton cultivation. *Current Science* **107(9)**:1512-1518.

Van Engelen, V.W.P. and Wan, T.T. (Eds.) (1995). Global and National Terrain digital Database (SOTER) Procedure Manual (revised edition) International Soil Reference and Information Centre, Wageningen, The Netherlands.

Received : Oct, 2014 *Accepted : Dec, 2014*