Soil information system: web-based solution for agricultural land-use planning

Tapas Bhattacharyya[1,3,*], S. P. Wani[1], P. Chandran[2], P. Tiwary[2], D. K. Pal[2], K. L. Sahrawat[1] and M. Velayutham[2]

[1]International Crops Research Institute for Semi-Arid Tropics, Hyderabad 502 324, India
[2]National Bureau of Soil Survey and Land Use Planning, Nagpur 440 010, India
[3]Present address: Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli 415 712, India

The soil-forming factors, especially climate, vegetation and topography, act on a range of rock formations and parent materials leading to the development of different kinds of soils. Through concerted efforts, soil datasets generated earlier are used to develop maps and soil information systems at different scales. Progress in basic and fundamental research on the formation of Indian soils as related to climate, relief, organisms, parent materials and time has helped in developing the soil information system.

Keywords: Agriculture, information technology, land-use planning, soils.

IN a large country like India, soil grouping has always been generalized. The soil resource of the country has been mapped on 1 : 7 million scale at the sub-order level[1]. For sustainable resource management, large-scale mapping (soil) was initiated in 1986 using a three-tier approach comprising image interpretation, field mapping and laboratory analysis[1,2]. This was followed by cartography and printing of maps for all the States and Union Territories on 1 : 250,000 scale. One hundred and seventy-six false colour composite (FCC) and B/W infrared imageries on 1 : 250,000 scale were interpreted visually to prepare pre-field physiography-cum-photomorphic maps. Sikkim, Goa, Lakshadweep, and Andaman and Nicobar Islands were mapped on 1 : 50,000 scale using Thematic Mapper FCC (TM FCC). The map units have been described so as to be intelligible to most land-use planners using compiled soil information[3] (Table 1). Figure 1 *a* and *b* shows the major soil groups in India and their relative proportions.

The information on soils in India suggests a large diversity, caused by large variability in factors of soil formation. The generalizations about soils made so far are unlikely to have wider applicability in an agriculturally progressive country like India[4,5]. This requires developing an information system, including soils and landscapes.

*For correspondence. (e-mail: tapas11156@yahoo.com)

It has long been felt that the natural environment should be mapped and monitored with active participation of the agencies responsible for managing natural resources, industry groups and community organizations. Thus organized information forms a basis for storing soil and land database for the implementation and monitoring of various efforts on land resource management. The pedological information on soil and land resources is fundamental and the soil information system (SIS) plays a pivotal role in capturing. Information as soil and terrain digital database (SOTER; 1 : 1 M), for improved mapping, modelling and monitoring of changes in the world soil and terrain resources[1,2]. Pedological information has been generated and collated from different sources and at various scales to develop user-friendly datasets at different scales[1–3] (Table 1).

Global and national SOTER framework, developed at International Soil Reference and Information Centre (ISRIC) (The Netherlands) in collaboration with other international organizations, was used to create and maintain the digitized map units and their attributes, which can provide necessary data for improved mapping and monitoring of changes in soil and terrain resources. This approach resembles physiographic and land-system mapping, and the collated information is stored in the SOTER framework[2] which is linked to GIS to develop georeferenced soil information system (GeoSIS) for a wide range of applications. However, the present demand is to develop a link between basic and fundamental research (pedology) and its application (edaphology). This web-based technology can help bridge these two levels of soil datasets.

The use of improved agro-technology can be employed to reclaim physical conditions of soils[4]. Agro-ecological sub-region (AESR) maps can act as an agro-technology transfer wheel, using appropriate land evaluation methods. Soil and land-use/land-cover and AESR maps in conjunction with information on socio-economic and production systems are used in various steps of land evaluation, thereby facilitating land allocation based on agricultural land-use plans[3,4] (Figure 2). The framework for a district level can be downscaled at the block level using large-scale soil map at 1 : 10,000, with appropriate method of soil survey and mapping using expert pedological knowledge, to arrive at a decision support system (DSS) to develop AESR-based crop planning[1,6].

GeoSIS has been found to be useful for two case-study areas, namely the Indo-Gangetic Plains (IGP) and the black soil region (BSR) for various aspects as mentioned below.

Refining theme map boundaries: Earlier, a theme map of AESRs of the country was generated into 60 AESRs in 1994, by superimposing maps on natural resources like soils, climate and length of growing period (LGP) for crops and other associated parameters. With the passage

Table 1. Available soil and land information system – spatial hierarchy*

Land unit	Soil unit	Descriptive legends	Description of map unit	Map scale (million)
Level 1				
Country	Order	Soil order	Inceptisols, Entisols	1 : 25
State	Sub-order	Soil sub-order	Red and yellow soil, red loamy soil, mixed red and black soil	1 : 7
State	Old soil classification	Traditional soil name	Bengal plains, hot, sub-humid to humid LGP 210–300 days (AER 15)	1 : 4
State (region)	Old soil classification	AER	Bengal plains, hot, sub-humid to humid LGP 210–300 days (AER 15)	1 : 4.4
State (sub-region)	Old soil classification	Agro-ecological sub-region	Bengal basin and north Bihar plains, hot, moist, sub-humid with medium to high AWC and LGP (210–300 days; AER 15.1)	1 : 4.4
Country (sub-country)	Soil family	Soil family association	Total 1649 units in the country (IGP had 74 no. of units)	1 : 1
Level 2				
State (physiography)	Soil family	Soil family association	Soil units in the IGP showing association of dominant (60% average in polygon) and subdominant (40% in a polygon soils); and 50%, 30% and 20% where three soil families exist	1 : 0.25
District	Soil series	Soil series association	Soil units showing association of dominant and subdominant soil series with inclusions	1 : 0.05
Watershed	Soil series	Soil series association	Various soil series and map units in the watersheds	1 : 0.0024

*Source: Bhattacharyya *et al.*[1].
AER, Agro-ecological region; AWC, Available water-holding capacity; LGP, Length of growing period; IGP, Indo-Gangetic Plains.

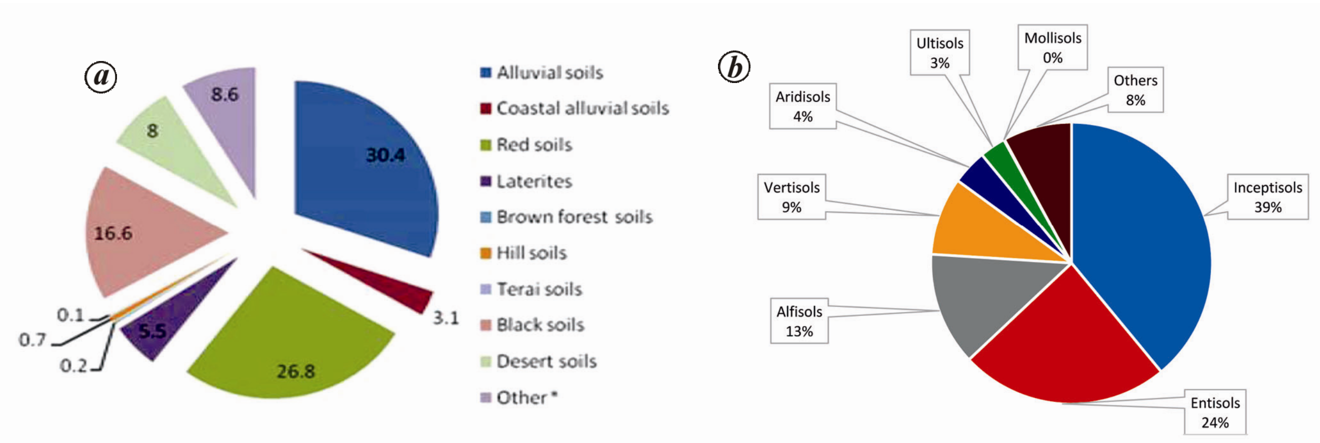

Figure 1. ***a***, Major soils of India (values expressed as per cent). ***b***, Various soil orders and their extent in India (source: Bhattacharyya *et al.*[5]).

of nearly two decades, and the advent of modern facilities of database management and improved knowledge base on natural resources such as GeoSIS, this theme map was revised from the existing 60 to 90 AESRs map.

Soil and land quality vis-à-vis minimum datasets: The minimum datasets (MDS) for soil quality of the IGP consists of clay, organic carbon (OC), saturate hydraulic conductivity (sHC), exchangeable sodium percentage (ESP), bulk density (BD), Ca/Mg (or exchangeable magnesium percentage, EMP), moisture retention at 1500 kPa, $CaCO_3$ equivalent and base saturation (BS). GeoSIS has been found to be extremely helpful in assessing soil and land quality indices (SQI, LQI) for the IGP, which was validated with the field conditions. The relationship between SQI and yield of rice ($R^2 = 0.57$) and wheat ($R^2 = 0.55$) indicate that the derived values of SQI are directly proportional to some major management goals. These types of information are useful in assessing the present cropping systems and also help in suggesting alternate cropping systems in a particular region. Information on soil and land quality is useful in assessing cropping systems and also to suggest alternate cropping systems in a particular region. The soils which are poor in quality generally belong to arid and semi-arid regions, where the major problem is related to poor drainage due to formation of pedogenic $CaCO_3$ and concomitant development of sodicity. Management interventions to

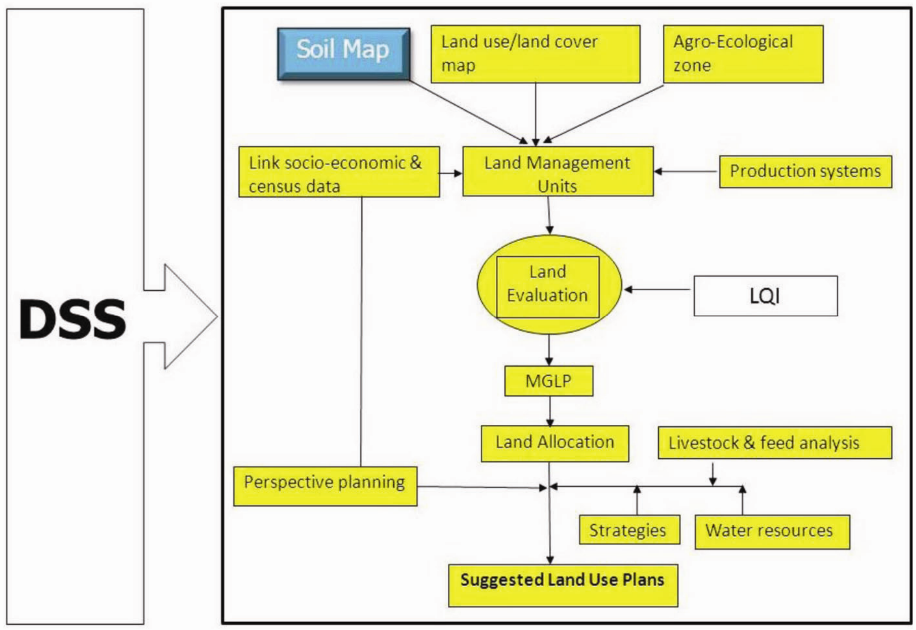

Figure 2. A proposed framework of decision support system (DSS) for developing land-use plans at district level – a framework (source: Bhattacharyya *et al.*). LQI, Land quality index; MGLP, Multiple goal linear programming.

reduce the effect of pedogenic $CaCO_3$ are vital for amelioration of these soils, for higher crop productivity.

Monitoring soil health: GeoSIS is structured for monitoring soil and land quality and to assess the impact of land-use changes. The baseline data generated through this project permit the use of changes in soil quality parameters in terms of soil organic carbon (SOC), soil inorganic carbon (SIC), BD and sHC. It has been found that a few selected dynamic properties of the soil such as SOC, SIC, BD and sHC change depending on the land-use system and time. There is an increasing concern about the declining soil productivity and impoverishment of soil nutrients caused by intensive agriculture, which affects the soil health. An overview of GeoSIS shows interface between information system, land evaluation and threshold limits of the land quality index, that ultimately culminates in a SIS structure to store various reports, tools and utilities in order to arrive at the DSS (Figure 2).

GeoSIS provides datasets over different time intervals. Soil carbon (both organic and inorganic) has been considered as one of the most important soil quality parameters. Therefore, soil carbon stock and its changes over time can serve as important datasets for monitoring soil quality and health. We compared soil carbon stock data and found that a quasi-equilibrium stage of SOC after a lapse of 30 years has been reached in the IGP. On the other hand, in the BSR, a marginal decrease in arid and 80% increase in semi-arid bioclimatic system is observed.

Simulation of crop yield: GeoSIS is also used in arriving at land quality parameters for assessing land quality through crop simulation models which have emerged as powerful tools for estimating yield gaps, forecasting production of agricultural crops, and analysing the impact of climate change. In this study, the genetic coefficients for *Bt* hybrids established from field experiments were used in the InfoCrop-cotton model, which was calibrated and validated earlier to simulate cotton production under different agro-climatic conditions. The model-simulated results for *Bt* hybrids were satisfactory with an R^2 value of 0.55 ($n = 22$), d value of 0.85, and a root mean square error of 277 kg ha^{-1}, which was 11.2% of the mean observed. Relative yield index (RYI), defined as the ratio between simulated rainfed (water-limited) yields to potential yield, was identified as a robust land quality index for rainfed cotton, and GeoSIS was utilized for deriving RYI for selected representative benchmark (BM) locations of the BSR from long-term simulation results of InfoCrop-cotton model (based on 11–40 years of weather data). The model could satisfactorily capture subtle differences in soil variables and weather patterns prevalent in the BM locations spread over 16 AESRs, resulting in a wide range of mean simulated rainfed cotton yields (482–4393 kg ha^{-1}).

Soil microbiology: GeoSIS helps to study the depth-wise distribution and factors (bio-climates, cropping systems, land use, management practices and soil properties) influencing the microbial population in soils. The microbial population declined with depth, and maximum activity

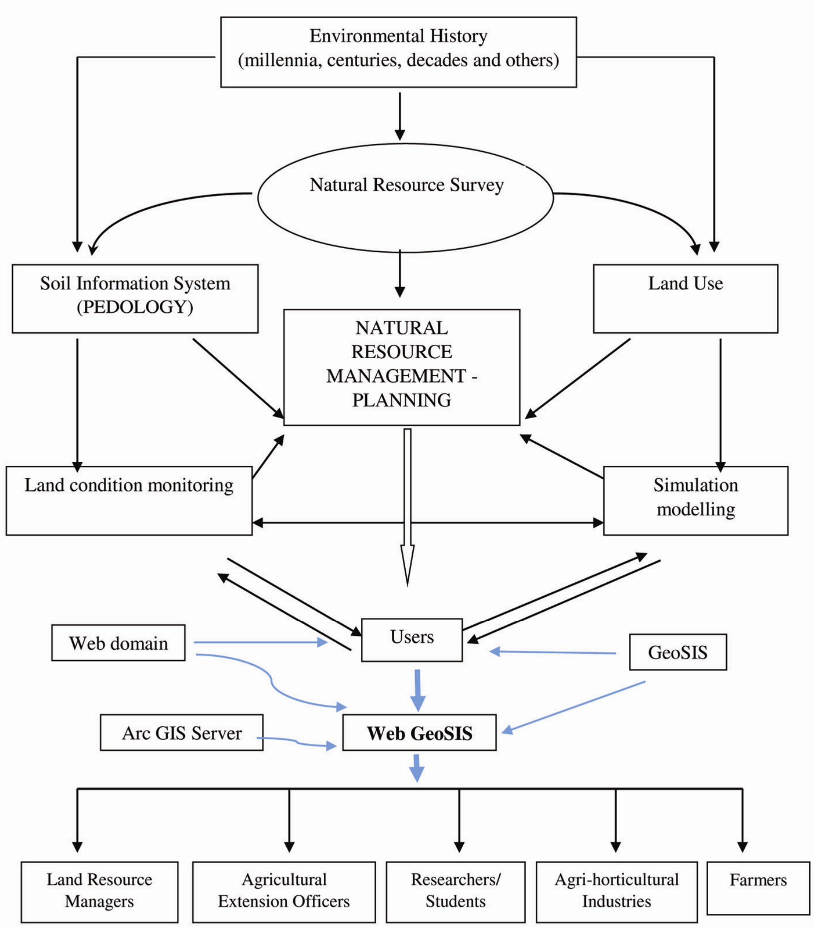

Figure 3. Mapping, monitoring and modelling, as complementary activities, to update geo-referenced soil information system (GeoSIS) with pedological inputs for web-based GeoSIS. (Source: Bhattacharyya *et al.*[1]); also see www.naip.icar.org.in, geosis-naip-nbsslup.org, www.currentscience.ac.in.

was recorded within 0–30 cm soil depth. The average microbial population (log10 cfu g^{-1}) in different bio-climates is in decreasing order: SHm > SHd > SAd > arid. Within cropping systems, legume-based system recorded higher microbial population (6.12 log10 cfu g^{-1}) followed by cereal-based system (6.09 log10 cfu g^{-1}). The mean microbial population in different cropping systems in decreasing order is: legume > cereal > sugarcane > cotton. Significantly, higher ($P < 0.05$) microbial population has been recorded in high management (6.20 log10 cfu g^{-1}) and irrigated agro-systems (6.33 log10 cfu g^{-1}), compared to low management (6.12 log10 cfu g^{-1}) and rainfed agro-systems (6.17 log10 cfu g^{-1}). The pooled analysis of data inclusive of bio-climates, cropping systems, land use, management practices and edaphic factors indicates that the microbial population is positively influenced by a host of physical and chemical parameters.

Judging by the tremendous scope of utility of GeoSIS the present study establishes a link between pedology and edaphology of Indian soils ultimately which may help prepare a handbook on Indian soils to facilitate their improved management for optimizing crop productivity. Realizing the inherent capacity of tropical soils, Kellog[1] envisaged that in future the most productive agriculture of the world would be mostly in the tropics, and this will depend on how rapidly institutions of education, research, and the other public and private sectors engaged in agriculture develop. For the renaissance in soil science, there will be a massive demand to appropriately manage tropical and subtropical soils for their restoration and preservation. In case soils are not properly managed, the crops will not be able to optimize the use of even assured rainfall for agricultural production[1,7].

Web technology has facilitated preparing web-based publications that are used for disseminating georeferenced soil information system (web GeoSIS) in an electronic format (Figure 3). This enables the users to access information/datasets for various purposes, including land resource inventory and management. Query-based information on soil and land use along with their spatial distribution can also be accessed for a specific purpose. Web GeoSIS enables collaboration among different agencies, facilitating better communication and avoiding duplication of efforts. Web GeoSIS 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. Such a strategy can facilitate participatory research for revising the database for monitoring soil health relative to land-use change[1,7].

The role of soils in maintaining ecosystem and climate regulation is increasingly gaining recognition. This demands relevant and useful information on soils throughout the world. The need for relevant and pertinent datasets to develop a SIS at the country, state, and farm level is a dynamic process. This is more so since the soil has many dynamic parameters which control its health affecting crop performance. Digital soil maps have been useful in providing information on dynamic soil properties. These can be generated for the Indian scenario as well following the scheme discussed in the present communication. Linking datasets of natural resources for web-based solutions requires team-work. With the changing global scenario at present we need expertise with sufficient knowledge on agriculture and allied sciences. Such experts would find GeoSIS and the proposed DSS useful to analyse issues like land degradation, soil diversity, agricultural land-use planning in different AESRs, and change in soil and land quality parameters as influenced by land-use and/or climate change.

1. Bhattacharyya, T., Pedology: the grammar of soil science, The 32nd Prof. J. N. Mukherjee – ISSS Foundation Lecture, Acharya N.G. Ranga Agricultural University, Hyderabad, 2014.
2. Chandran, P. *et al.*, Development of SOTER database for major food growing regions of India for resource planning. *Curr. Sci.*, 2014, **107**(9), 1420–1430.
3. Bhattacharyya, T., Sarkar, D., Sehgal, J. L., Velayutham, M., Gajbhiye, K. S., Nagar, A. P. and Nimkhedkar, S. S., Soil taxonomic database of India and the States (1 : 250,000 scale), NBSSLUP Publ. 143, National Bureau of Soil Survey and Land Use Planning, Nagpur, 2009, p. 266.
4. Bhattacharyya, T. *et al.*, Soils of India: their historical perspective, classification and recent advances in knowledge: a review. *Curr. Sci.*, 2013, **104**, 1308–1323.
5. Velayutham, M. and Pal, D. K., Classification, Indian. In *Encyclopedia of Soil Science* (ed. Lal, R.), Marcel Dekker, New York, 2004, pp. 1–3.
6. Tiwary, P. *et al.*, Pedotransfer functions: a tool for estimating hydraulic properties of two major soil types of India. *Curr. Sci.*, 2014, **107**(9), 1431–1439.
7. Bhattacharyya, T. *et al.*, Processes determining the sequestration and maintenance of carbon in soils: a synthesis of research from tropical India. *Soil Horizon*, 2014; doi: 10.2136/sh14-01-0001.

Received 20 April 2015; revised accepted 1 August 2015

doi: 10.18520/cs/v110/i2/241-245

An efficient method for digital imaging of ancient stone inscriptions

G. Bhuvaneswari[1,]* and V. Subbiah Bharathi[2]

[1]Department of CSE, Anna University, Chennai 600 025, India
[2]Easwari Engineering College, Ramapuram, Chennai 600 089, India

Ancient stone inscription is one of the most important primary sources to know about our ancient world such as age, art, politics, religion, medicine, etc. Image acquisition is the first stage for digitizing and preserving the stone inscriptions for further reference. The traditional method of wet paper squeezes is still being used, that will be digitized and preserved for recognition. In this communication, we propose a new image acquisition method called shadow photometric stereo method for upgrading the image for recognition. The efficiency of the proposed acquisition method has been proved in image thinning process. Improving the thinning quality of the characters facilitates better feature extraction for character recognition. An experiment has been performed on two stone inscriptions that were in different places, one inside laboratory and other in its original place, i.e. outside the laboratory. Analyses were performed in terms of performance measures such as hamming distance and peak signal-to-noise ratio. Comparisons with the best available results are given to illustrate the best possible technique that can be used as a powerful image acquisition method.

Keywords: Ancient stone inscriptions, image processing, shadow photometric stereo method, thinning algorithm.

DIGITAL images play an important role in epigraphy which is a study of inscriptions on rocks, copper plates, temple walls and pillars that are important for tracing the cultural and historical heritage of a country[1]. Ancient stone inscriptions are one of the most important primary sources for getting information about the ancient world. These inscriptions preserve writings from ancient times and give us direct access to the past. The main difficulties in studying and interpreting the stone inscriptions are that they are inaccessible due to location or damage by various natural climatic conditions such as wind, rain, lightning and thunder. The traditional methods of wet paper squeezes, wax rubbings and scale drawings for image acquisition are still used in many countries.

Presently epigraphists take the impressions of stone inscriptions on wet paper called 'squeezes' by beating them using a brush against the rock surface[2]. The squeezes with inadequate legibility are scanned for digital preservation, dissemination and transcription. It is both time-consuming and laborious. The digitized image of a sample squeeze is given in Figure 1, which is not legible.

*For correspondence. (e-mail: gbhuvanaphd@gmail.com)