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. 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. This was followed by cartography and printing of maps for all the territories on 1:250,000 scale. One hundred and sixty-six false colour composite (FCC) and B/W infrared images 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 (Table 1). Figure 1a 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. This requires developing an information system, including soils and landscapes.

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

<table>
<thead>
<tr>
<th>Land unit (sub-country)</th>
<th>Level 1 Orth</th>
<th>Soil unit</th>
<th>Descriptive legends</th>
<th>Description of map unit</th>
<th>Map scale (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
<td>Order</td>
<td>Soil order</td>
<td>Inceptisols, Entisols</td>
<td>Total 1649 units in the country (IGP had 74 no. of units)</td>
<td>1 : 1</td>
</tr>
<tr>
<td>State</td>
<td>Sub-order</td>
<td>Soil sub-order</td>
<td>Red and yellow soil, red loamy soil, mixed red and black soil</td>
<td></td>
<td>1 : 7</td>
</tr>
<tr>
<td>State and State (region)</td>
<td>Old soil classification</td>
<td>Traditional soil name</td>
<td>Bengal plains, hot, sub-humid to humid LGP 210–300 days (AER 15)</td>
<td>1 : 4</td>
<td></td>
</tr>
<tr>
<td>State (sub-region)</td>
<td>Old soil classification</td>
<td>AER</td>
<td>Bengal plains, hot, sub-humid to humid LGP 210–300 days (AER 15)</td>
<td>1 : 4.4</td>
<td></td>
</tr>
<tr>
<td>Country (sub-country)</td>
<td>Soil family</td>
<td>Soil family association</td>
<td>Total 1649 units in the country (IGP had 74 no. of units)</td>
<td>1 : 1</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Bhattacharyya et al.\(^3\).
AER, Agro-ecological region; 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.\(^3\)).

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
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 depthwise 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 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.
was recorded within 0–30 cm soil depth. The average microbial population (log$10$ cfu g$^{-1}$) in different bio-climates is in decreasing order: SHm $>$ SHd $>$ SA$d$ $>$ arid. Within cropping systems, legume-based system recorded higher microbial population (6.12 log$10$ cfu g$^{-1}$) followed by cereal-based system (6.09 log$10$ 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 log$10$ cfu g$^{-1}$) and irrigated agro-systems (6.33 log$10$ cfu g$^{-1}$), compared to low management (6.12 log$10$ cfu g$^{-1}$) and rainfed agro-systems (6.17 log$10$ 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.\(^1\)

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.

An efficient method for digital imaging of ancient stone inscriptions

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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. 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, lighting 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. 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.

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