Development of soil and terrain digital database for major food-growing regions of India for resource planning

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Soil information system in SOTER (soil and terrain digital database) framework is developed for the Indo-Gangetic Plains (IGP) and black soil regions (BSR) of India with the help of information from 842 georeferenced soil profiles including morphological, physical and chemical properties of soils in addition to the site characteristics and climatic information. The database has information from 82 climatic stations that can be linked with the other datasets. The information from this organized database can be easily retrieved for use and is compatible with the global database. The database can be updated with recent and relevant data as and when they are available. The database has many applications such as inputs for refinement of agro-ecological regions and sub-regions, studies on carbon sequestration, land evaluation and land (crop) planning, soil erosion, soil quality, carbon and crop modelling and other climate change related research. This warehouse of information in a structured framework can be used as a data bank for posterity.

Keywords: Black soil region, database, Indo-Gangetic Plains, SOTER.

Introduction

INNOVATIVE methods are increasingly important to utilize existing soil information and in this context spatial soil information systems play an important role[1,2]. Soil is an important component of land use planning as it acts both as a source and sink of energy for many functions of the land. In general, all living and non-living things on earth get their energy for functioning from the soil in the form of nutrients, water and air. In the last 2–3 decades, soil information has become increasingly important to many disciplines to address the conflicting pressure on limited land resources. In addition to farming community, civil engineers and agricultural engineers, environmentalists, urban planners, disaster managers and policy makers also need soil information[3–5].

This recent spurt in demand for development of information systems on natural resources is primarily due to the widespread awareness of the need for protection and

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preservation of the natural environment. Thus, worldwide there is a renewed awareness on the need for information about soils in digital format to support efficient and wise use of this critical resource. Many countries are now focusing on updating and modernizing their soil resource databases[6]. In this renewed effort the role of geo-informatics has become central not only to storing the data, but also for a range of analytical tasks like manipulating and transforming basic data into a variety of quantitative soil information according to user requirement[7].

A wide range of soil information in India is available in scattered and unorganized format, but the modern-day information system of any natural resource requires its location in terms of time and space and exact referencing or georeferencing of important spots. Therefore, soil information with exact coordinates can be used for developing a such system. A geographic information system (GIS) is an important tool for georeferencing soil information system (GeoSIS).

The Indo-Gangetic Plains (IGP) as a food bowl of India, produces nearly 50% of the total food grains of the country. During the recent past, including the green revolution and beyond, the IGP has been subjected to major agricultural intensification and high population pressure; consequently, there are reports of decline in productivity and fertility due to adverse changes in some dynamic soil properties and overexploitation of available resources[8]. Contrary to this, the black soil region (BSR) is underutilized, primarily due to its inherent nature of the soil, climate and management-related constraints. The major part of this area is rainfed and climate varies from arid to sub-humid (dry). Therefore, agriculture in this region depends on rainwater storage and release characteristics of soils. There are reports of development of subsoil sodicity in some parts of the arid and semi-arid regions due to the development of pedogenic carbonates[9], while in some other areas there are reports of occurrence of the palygorskite, a mineral which on irrigation develops a net-like structure and retards water movement[10]. In contrast, natural modifiers such as zeolites and gypsum are a boon to farmers as they protect the soils against degradation by modifying hydraulic properties even in the presence of sodicity and palygorskite[11–13].

As mentioned earlier, although the information on soils is huge, it is scattered and therefore needs to be archived in a standardized format to provide georeferenced information in a spatial and digital domain for researchers, policy makers and other managers and users of natural resources. With this in mind, the present article describes the process of developing a georeferenced soil information system in SOTER (soil and terrain digital daabase) framework and is restricted to the IGP and BSR. The database developed can be utilized for resource planning, in general and for agriculture planning and activities, in particular.

Materials and methods

Methods

The global and national soil and terrain digital databases (SOTER) input software was developed at the International Soil Reference and Information Centre (ISRIC), The Netherlands in collaboration with other international organization, viz. FAO, UNEP and IUSS to create and maintain a global 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[14]. The collated information is stored in the SOTER framework which is linked to a GIS, permitting a wide range of applications[8,15–18]. The database allows periodic updating by removing obsolete or irrelevant data. SOTER is a combination of geographical and attribute data. Terrain information is a geographic component indicating the topology of SOTER unit and attribute data give spatial unit characteristics stored in a set of relational database management system (RDBMS) files. A SOTER unit is made by combining information on terrain and soil attributes (Figure 1). The database can also store climatic data, data sources, land use and other auxiliary data which are useful for many other land users. The basic data required for the construction of a SOTER unit are topographic, geomorphological, 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.

In SOTER, the units are given unique identification codes. In the attribute tables for terrain, terrain component and soil component, this identification code is completed with sub-codes for the terrain component and soil component. Both the above attributes are derived from

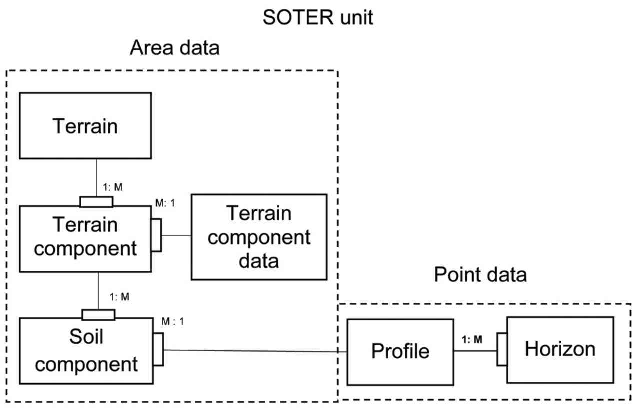

Figure 1. SOTER attribute database structure with area and point data (1: M = one to many, M: 1 = many to one relations)[14].

Table 1. Map details of the Indo-Gangetic Plains and black soil region*

Region	Source map-ID	Map title	Year	Scale (million)	Minimum latitude	Minimum longitude	Maximum latitude	Maximum longitude	UTM zone	Geodetic datum	Type of source map
India	Nil	Soils of India	2002	1 : 1	6°45′	67.7°	37°6′	97°25′	42–47 N	WGS 1984	Soil map
IGP	IN001	Soils of IGP	2010	1 : 1	21°30′	73°52′	32°15′	92°6′	43–45 N	WGS 1984	Soil map
BSR	IN002	Soils of BSR	2010	1 : 1	8°28′	68°24′	27°1′	89°2′	42–45 N	WGS 1984	Soil map

*Source: Refs 19 and 20. UTM, Universal Trans Marketer.

the site characteristics of each map unit. The soil component information is stored in three tables, viz. soil component, profile and horizon table. The profile and horizon tables hold attribute data for each profile with the exact location, morphological and laboratory data of each horizon and details of the laboratory. The SOTER structure has a link with each table in the database using primary keys. The database also stores information on laboratory methods followed for analysis and sources of information used for compilation of SOTER.

Materials

Geographic database for the IGP: Earlier, the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) developed a soil map of India on a 1 : 1 m scale[19] with distinct map units with information on landform, lithology, surface form, parent material and soil. Details of the source map developed for SOTER-IGP and BSR are given in Table 1. The soil map of IGP was derived from the 1 : 1 m soil map of India and this was used as a geographic database (Figure 2) for developing the SOTER IGP[20]. The IGP is situated between Gurudaspur district (Punjab) in the west and Jalpaiguri district (West Bengal) in the east, and to West Tripura district (Tripura) in the northeast extending from 21°45′ to 31°30′N lat. and 74°15′ to 91°30′E long. A recently revised area estimate of the IGP is 52.01 m ha (ref. 20). The plain is subdivided into 8 agro-ecoregions (AERs), 17 agro-ecological sub-regions (AESRs) and 6 bioclimatic regions depending upon major physiography, climate and length of the growing period[21–23]. The IGP has a nearly level physiography (plains) and the parent material is derived from the alluvial deposits of the river Ganga and its tributaries. Therefore, each soil map unit is considered as a separate terrain.

SOTER IGP has 348 map units showing association of soils as dominant and subdominant. As SOTER is a global database, the dominant soils occurring in the terrain are considered as its major soils. Soil attribute data were developed from profiles selected from the master database which contains information on 437 soil profiles[24,25], of which only 417 points were georeferenced in the map due to scale limitations. This point information was collated from different sources (Table 2) from the published reports and literature.

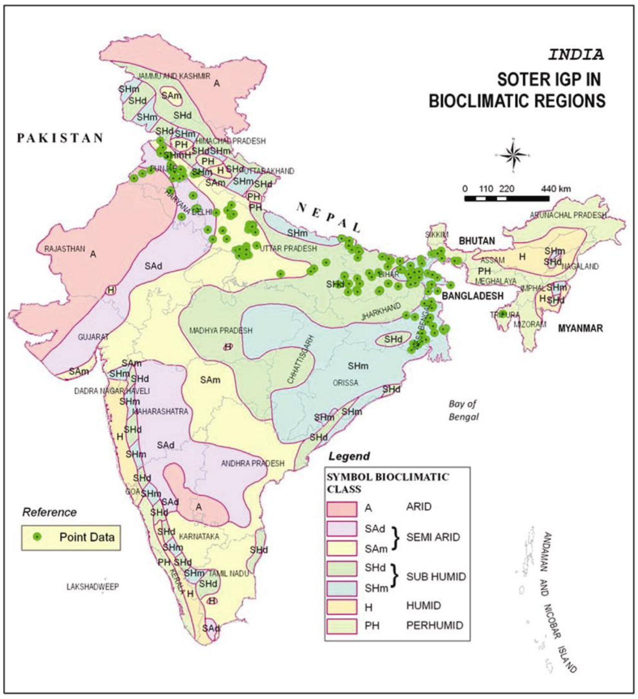

Figure 2. Georeferenced soil map of the Indo-Gangetic Plains developed for SOTER IGP.

Geographic database for BSR: The geometric database for SOTER BSR was derived from the 1 : 1 m soil map of India[19]. The revision of the BSR boundary was made using ASTER data and georeferenced soil information. The revised total area is 76.4 m ha (Figure 3), which is spread across in 36 AESRs of the country[21]. The BSR has 290 map units distributed mainly in eight states with some sporadic occurrence in non-traditional areas[26]. Each map unit in the BSR is considered as a separate terrain, as these soil map units were made taking into consideration the major physiography, landform and geology in addition to soil. The attribute database for SOTER BSR was developed by selecting representative profiles from the 448 profiles developed for this region (Table 3), of which 425 points were georeferenced in the map.

Procedure for development of SOTER IGP and SOTER BSR

Development of SOTER database: The attribute data table for terrain, terrain component and soil component

Table 2. Distribution of point data in states, agro-ecological regions (AERs), agro-ecological sub-regions (AESRs) and bioclimatic regions of IGP

State	No. of soil series	AERs	AESRs	Bioclimate*	Source
Punjab	53	2, 4, 9,14	2.1, 2.3, 4.1, 9.1, 14.2	SAd, SAm, A	44–47
Haryana	10	2, 4, 9,14	2.3, 4.1, 9.1, 14.2	SAd, SAm, A	45–47
Uttarakhand	1	9	14.5	SAm	47
Delhi	3	4	4.1	SAd	45, 46
Uttar Pradesh	177	4, 9, 13	4.1, 4.3, 4.4, 9.1, 9.2, 13.1, 13.2	SAm, SHd, SAd	48–57
Bihar	86	9, 13	9.2, 13.1	SHm, SHd	45–47, 57, 58
West Bengal	104	12, 13, 15, 16, 18	12.3, 13.1, 15.1, 15.3, 16.1, 16.2, 18.5	PH, SHm	24, 45–47, 49, 59, 60
Tripura	3	15, 17,	15.3, 17.2	PH	23, 24
Total	437 (417)**	10	17		

*PH, Perhumid; SHm, Sub-humid moist; SHd, Sub-humid dry; Sam, Semi-arid moist; SAd, Semi-arid dry; A, arid.
**No. of points georeferenced (many points overlapped due to scale limitation).

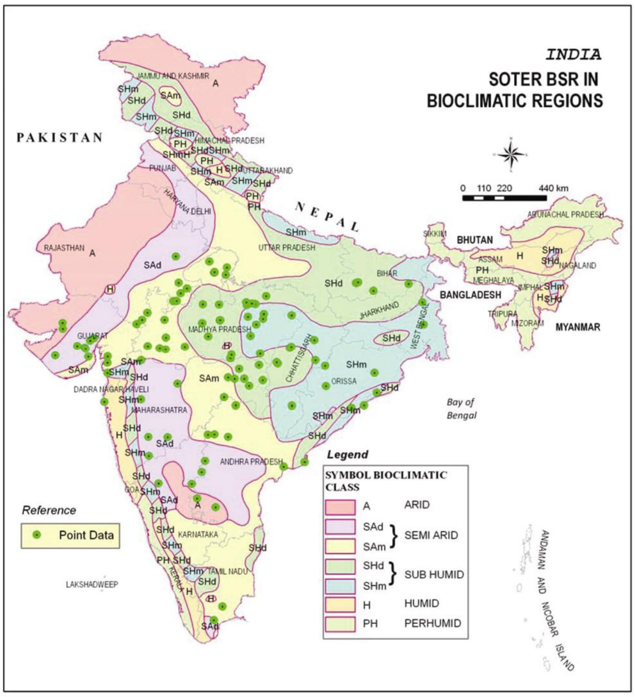

Figure 3. Georeferenced soil map of black soil region developed for SOTER BSR.

for the IGP and BSR were developed from the map and series information according to SOTER methodology[14]. The terrain and terrain component tables were developed from the soil map legend and site characteristics of soil profile cards. In the digitized soil map, locations of each series were georeferenced (Figures 2 and 3) and this map was used to link the attribute information to the soil map unit.

Some of the mandatory information required by SOTER such as bulk density (BD), moisture content at different tensions and saturated hydraulic conductivity (sHC) were not available in some of the published soil survey reports from which the series information was extracted. Therefore, pedo-transfer functions (PTFs) were developed[27] for water retention characteristics at different suctions, BD and sHC, in order to generate this information. Step-wise multiple regression technique in a statistical software (SPSS: version 18.0) was used to develop multiple regression models as PTFs. Scatter-plot diagrams were used to identify the variables and develop a working hypothesis about their relationships. The independent variables used for PTFs were selected considering the cause–effect relationship and correlation coefficient amongst the variables. Details of the procedures and variables selected are explained elsewhere[27]. The PTFs were validated separately for both the IGP and BSR with a set of available data on these parameters.

All pedon observations were coded in a format to identify the profile that is to be linked with the map (Figure 4). Thus 144 pedons from the IGP and 101 pedons from the BSR were linked to the map (Tables 4 and 5). These are distributed in 11 AESRs and five bioclimates of the IGP ranging from per-humid to arid through sub-humid and semi-arid. Thus the SOTER IGP and BSR cover 72 and 54% of the area of these regions respectively. In SOTER, there are provisions to upload the information when reliable data are available. However, the profile information collated so far can be utilized for the development of the SOTER database for different states on the 1 : 250,000 scale in future, wherein the map units will be greater in number. SOTER is a comprehensive database, which includes all soil and site characteristics, including climate and vegetation. Climate data for 82 climate stations, which were based on point observation, were compiled in the SOTER format and the link between soil and terrain information was made using geographical coordinates.

Application of SOTER database: An advantage of any database developed from the measured soil properties is that it includes data on which dependable decision relating to the most appropriate uses and management of soils can be made. Information synthesized on soils from a

Table 3. Distribution of point data in states, AERs, AESRs and bioclimatic regions of BSR

States	No. of soil series	AERs	AESRs	Bioclimate*	Source
Andhra Pradesh	57	3, 6, 7, 12, 18	3, 6.2, 7.1, 7.2, 7.3, 12.2, 18.3, 18.4	A, SAm, SAd, SHd	9, 45, 57, 61–65
Assam	2	15	15.2	PH, H, SHm, SHd	66
Bihar	4	9, 13	9.2, 13.1	SHd	58
Chhattisgarh	14	11, 12	11, 12.1	SHd, SHm	57, 67
Gujarat	33	2, 4, 5, 19	2.4, 4.2, 5.1, 5.2, 19.1	A, SAm, SAd, SHm	9, 45, 63, 65, 68
Karnataka	13	3, 6, 7	3, 6.1, 6.2, 6.4, 7.1, 7.2	SAd	9, 45, 63, 65, 69
Kerala	3	19	19.3	PH,H	70
Madhya Pradesh	86	4, 5, 10, 11, 12	4.3, 4.4, 5.2, 10.1, 10.2, 10.3, 10.4, 11.0, 12.2	SAm, SHd, SHm	9, 45, 63, 65, 71–73
Maharashtra	204	6, 10, 12, 19	6.1, 6.2, 6.3, 6.4, 10.2, 10.4, 12.1, 19.1	SAm, SAd, SHd, H	9, 63, 65, 73–88
Odisha	6	12, 18	12.1, 12.2, 18.4, 18.5	SHm	89
Punjab	1	2, 9	2.3	SAd, SAm, A	45
Rajasthan	14	2, 4, 5	2.1, 4.2, 5.2	SAd, SAm	9, 63, 90
Tamil Nadu	7	8, 18	8.1, 8.2, 8.3, 18.2	SAm	9, 57, 63, 65
Uttar Pradesh	1	4	4.3	SHm, SHd, SAm, SAd	45
West Bengal	3	15	15.1	SHm	45, 59
Jammu & Kashmir	–	14		A, SAm, SHd, SHm	
Total	448 (425)**		36		

*H, Humid; SHm, Sub-humid moist; SHd, Sub-humid dry; SAm, Semi-arid moist; SAd, Semi-arid dry, A, arid.
**No. of points georeferenced. (many points overlapped due to scale limitation)

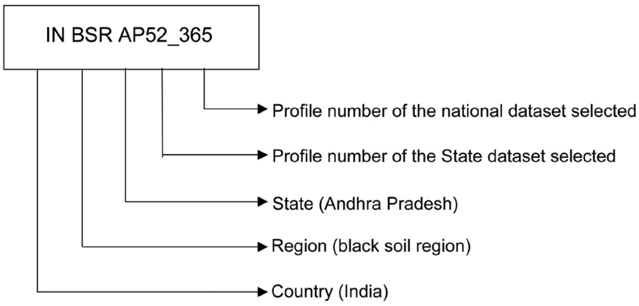

Figure 4. Keys for identification of profile from the master datasets in SOTER.

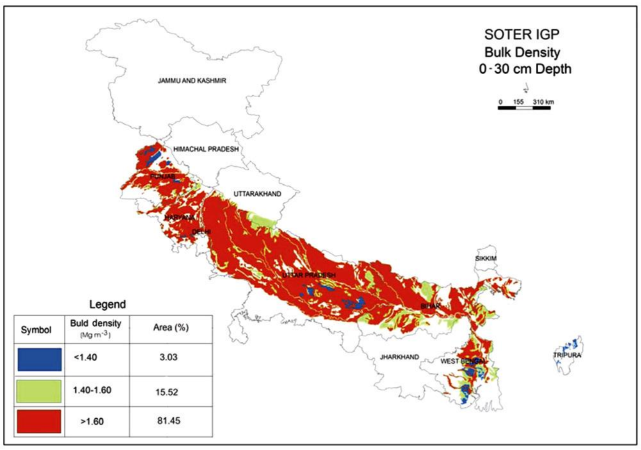

Figure 5. Soil bulk density (0–30 cm) map developed for the Indo-Gangetic Plains using SOTER datasets.

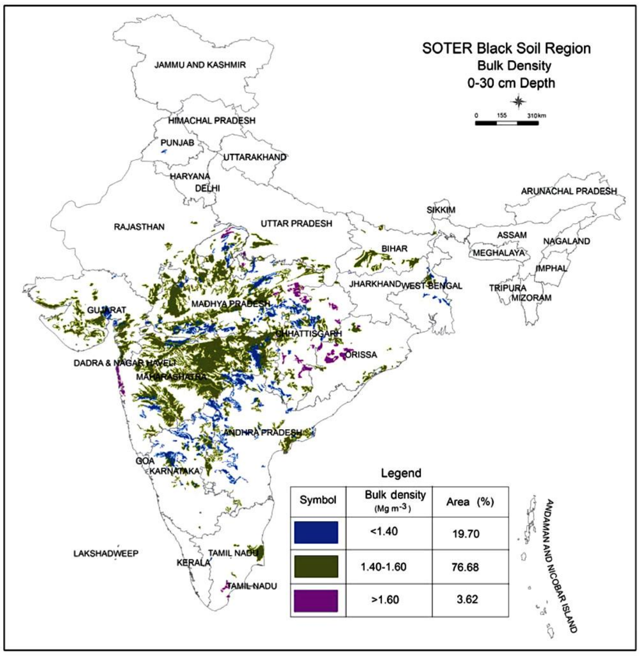

Figure 6. Soil bulk density (0–30 cm) map developed for black soil region using SOTER datasets.

map or stored in an information system, such as SOTER, can be used to make decisions for optimum utilization, planning and management of soil and land resources.

Using the base map of IGP and BSR and the corresponding attribute database, a number of thematic maps were prepared and a few of them are explained below.

Bulk density: BD is an important soil physical parameter which regulates the movement of water, air and roots into the soil and it depends on the texture and organic matter content of the soil. Management interventions, particularly cultural practices, have an impact on this

Table 4. Details of soil series selected from the master soil database to develop the SOTER IGP

State	No. of soil series	AESRs covered	Bioclimate*	Soil series
Punjab	20	9.1, 4.1, 2.3	SAd (8)	Balewal, Langrian, Phagunwala, Tulewal, Phaguwala, Kanjli, Tulewal, Patiala
			SAm (7)	Dhoda, Nabha, Gurudaspur, Fattu, Mund, Sadhu, Jagjitpur
			A (5)	Dewan-Khera, Nihal-Khera1, Nihal-Khera2, Panjgram Kalan, Fatehpur
Haryana	5	4.1, 9.1, 2.3	SAd (2)	Lukhi, Zarifa Viran
			SAm (2)	Shahazadpur, Berpura
			A (1)	Hisar
Uttarakhand	1	9.2	SAm (1)	Haldi
Delhi	3	4.1	SAd (3)	Daryapur, Kakra, Holambi
Uttar Pradesh	33	9.1, 4.1, 4.3, 9.2, 13.1	SAd (2)	Shergarh, Garhsauli
			SAm (26)	Shekhupur, Jauli, Mawana, Hirapur, Nandpur, Maktaura, Charpur, Allahpur, Tilhar, Saunda, Garcia, Bikranpur, Kabirpur, Gopalpur, Lajjanagar, Makhanpur, Nangla Bhagat, Sehud, Ajlapur, Chamkani, Nagaria, Bijaipur, Nagla Jola, Masuri, Parichhatgarh, Khanpur
			SHd (5)	Haderpur, Zikhripur, Jangipur, Tikarikhurd, Basiaram
Bihar	45	13.1, 9.2	SHm (15)	Darwabari, Dumri, Fatehpur, Bananiya, Bhawanipur, Belgachhi, Ganeshpur, Haldikhora, Karamwa, Khanua, Arraha, Bhargaon, Madhuban, Nirpur, Tikapatti
			SHd (30)	Bikramganj, Dullahpur, Baruna, Budhauli, Dadar, Datraul, korap, Dahiya, Katharain, Pokhrahi, Shivpur, Sarthua, Mathiya, Baswariya, Gandhrain, Ghoga, Qutubpur, Sagauli, Sangrampur, Walipur, Bahera, Parsouna, Pipra Naurangia, Narayanpur, Tarapur, Baratol, Hirapatti, Gaupur, Nanpur, Ekchari
West Bengal	35	12.3, 15.1, 16.2, 15.3, 13.1	SHm (27)	Majiara, Silampur, Balidanga, Ghoshat, Balia, Nampur, Alinagar, Salmara, Samaspur, Gangarampur, Barabarua, Sahazadpur, Tulsidanga, Ruisanda, Gopalpur, Balrampur, Chakprayag, Panchpota, Harinathpur, Jatikrishnapur, Jambani, Kanaidighi, Belar, Madhupur, Madhpur, Amarpur, Bansghata
			PH (8)	Singvita, Chunabhati, Daraboyjot, Berubari, Binnaguri, Matiarkuthi, Seoraguri, Mechpara
Tripura	2	17.2	PH (2)	Nayanpur, Khowai

*PH, Per-humid; SHm, Sub-humid moist; SHd, Sub-humid dry; SAm, Semi-arid moist; SAd, Semi-arid dry; A, arid; number of soil series is shown in parentheses.

property. In rice and potato-growing regions of West Bengal, an increase in BD immediately below the plough layer was observed, which has adversely affected the potato yield[28]. Similar observations were also reported in rice and wheat-growing soils of Punjab[29], some cotton-growing soils of Maharashtra (where subsoil sodicity is prevalent) and the soybean-wheat growing Vertisols of Madhya Pradesh[30]. Theme maps (Figures 5 and 6) for BD at different depths were developed for both the IGP and the BSR using SOTER. BD at the surface (0–30 cm depth) in soils of the IGP is > 1.6 Mg m^{-3} in 81% of the area, wherein the organic carbon is < 0.50%. This, low organic carbon is correlated with high BD, which adversely affects crop growth. High BD is the result of mechanized farming and the use of water with high salt content for many years. BD decreases with depth. The mechanized and intensive agriculture in these areas may form hard pans at the surface or subsurface layers and make the soil impervious to water, air and roots. In contrast, in the BSR, the occurrence of soils with BD > 1.6 Mg m^{-3} is negligible, indicative of low rate of adoption of intensive management practices in these areas.

Bhattacharyya *et al.*[30] reported an inverse relationship of BD with soil organic carbon (SOC) in soils of the semi-arid tropics, which increased in soils of drier bioclimates in accordance with the increase in soil inorganic carbon and subsoil sodicity. Therefore, proper rehabilitation measures are required to control BD, porosity and sHC, particularly in the rainfed areas.

Saturated hydraulic conductivity: The hydraulic properties of soils have important implications for management as they regulate water–air relationships and also nutrient availability. The soils of the IGP are well known for their rice–wheat cropping systems and recent reports indicate that production has plateaued or declined due to the emergence of some soil-related constraints. The rice crop of IGP requires standing water, unlike wheat. In contrast to this, cropping in major parts of BSR depends on the water stored in the profile during the monsoon and its

Table 5. Details of soil profiles (series) selected from the master soil database for development of the SOTER BSR

State	No. of soil series	AESRs covered	Bioclimate*	Soil series
Andhra Pradesh	10	3, 6.2, 7.2, 18.4	A (2)	Sollapuram, Tatireddipalle
			SAm (6)	Hugaluru, Amalapuram, Bhimavaram, Jammalamadugu, Pangidi, Nipani
			SAd (1)	Jajapur 1
			SHd (1)	Mummadivaram
Bihar	4	9.2, 13.1	SHd (4)	Barew, Bhadasi, Belsar, Dahiya
Chhattisgarh	7	11, 12.1	SHd (4)	Pendri Kalan, Hirawani, Boda, Bichanpur
			SHm (3)	Umariguda, Sirgeri, Khujji Kalam
Gujarat	12	2.4, 4.2, 5.1, 5.2, 19.2	A (2)	Bhimdevka, Sokhada1
			SAm (2)	Haldar, Mulad
			SHd (7)	Ratanvav, Arnej, Bhola, Chabhadia, Dholi, Jalia, Kumbhara
			SHm (1)	Eru
Karnataka	3	6.4, 7.1, 7.2	SAd (3)	Teligi, Achmatti, Raichur
Madhya Pradesh	33	4.4, 5.2, 10.1, 10.3, 10.4, 11.0, 12.2	SAm (11)	Loni, Bijapur Kalan, Gopalpur, Sarol, Namali, Shankarali, Baiharai, Digwar, Deorikalam, Bainar, Arsia
			SHm (9)	Gonditola, Tejgarh, Kheri, Gaintara, Semarar, Chhapratola, Chandranagar, Karloka, Makajhir
			SHd (13)	Savli, Nabibagh, Talgaon, Baroda Kalam, Mariyadar, Padariya, Madanpur, Sumariyakalam, Jamra, Amziri, Sundra, Rohana 2, Lalatora-1
Maharashtra	15	6.1, 6.2, 6.3, 10.2, 10.4, 12.1, 19.1	SAm (2)	Anjana, Bhugaon
			SAd (5)	Satgaon, Dhulgaon, Purandarwada, Masala, Nimone,
			SHd (7)	Boripani, Jamnapur, Bhisi, Sindewahi, Andhali, Bahadura, Lasanpur
			H (1)	Palghar
Odisha	4	12.1, 18.4, 18.5	SHm (4)	Birsinghasahi, Sanfafsi, Daiapalli, Nalibasant
Rajasthan	9	4.1, 5.2	SAd (1)	Datwasa
			SAm (8)	Sunel Chhoti, Khando, Raipur, Khanpur, Anta, Kushalgarh, Arnod, Jalawara
Tamil Nadu	2	8.1	SAm (2)	Kovilpatti, Salur
West Bengal	2	15.1	SHm (2)	Hanrgram, Gopalpur

*H, humid; SHm, Sub-humid moist; SHd, Sub-humid dry; SAm, Semi-arid moist; SAd, Semi-arid dry; A, Arid. Number of soil series is shown in parentheses.

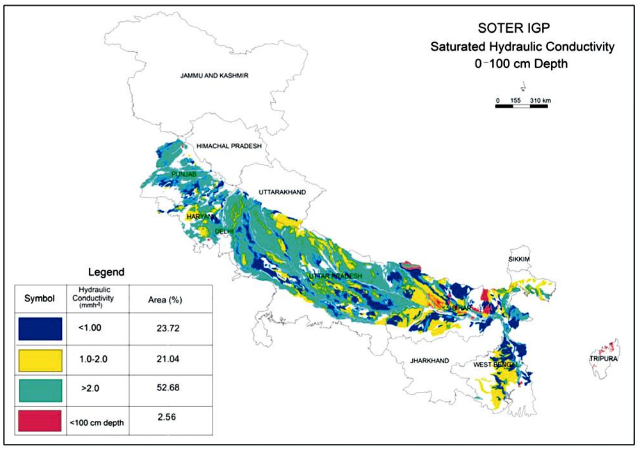

Figure 7. Saturated hydraulic conductivity (sHC) map for the Indo-Gangetic Plains.

release during the crop growth. Kadu *et al.*[31] observed that sHC can be considered as a robust parameter for the determination of the suitability of deep black soils for rainfed cotton and they reported a significant reduction in yield when sHC decreases to $< 10\ mm\ h^{-1}$. Therefore, theme maps for sHC are important from an agricultural crop growth point of view in both the IGP and BSR.

sHC (0-100 cm depth) in IGP soils is low ($< 2\ mm\ h^{-1}$) in major areas (45%; Figure 7), indicating poor drainage to favour rice crop which requires standing water. However, low sHC may pose a threat due to soil and water erosion and flooding during the monsoon and a low storage of soil water for post-rainy season.

In the BSR, the sHC map is presented for the entire 100 cm depth because the major part of the area is under rainfed conditions (Figure 8). Considering sHC of $10\ mm\ h^{-1}$ as threshold for good agricultural land, an area of 20% that has $< 10\ mm\ h^{-1}$, needs immediate management interventions to improve drainage. Some BSR areas have pedogenic $CaCO_3$ and subsoil sodicity[11,32]. The subsoil sodicity causes dispersion of clay (which is very high in Vertisols) and clogs the micropores and subsequently decreases hydraulic properties. However, the constant release of Ca^{2+} ions from zeolites and gypsum improves the sHC and overshadows the ill effects of sodium and magnesium[11,13] in the BSR under semi-arid and arid climates.

Soil organic carbon: The status of organic carbon in soil is considered as an indicator of soil quality in tropical soils because of its influence on soil properties and crop production[33]. Surface soils of IGP and BSR (Figures 9 and 10) indicate > 95% soils have organic carbon of < 1%, which is considered as a threshold value for a sufficient level in soils of tropical India[34]. Therefore, soils of IGP and BSR need immediate management intervention, particularly in those areas where organic carbon is < 0.5% (85% of area in the IGP and 38% of the area in BSR).

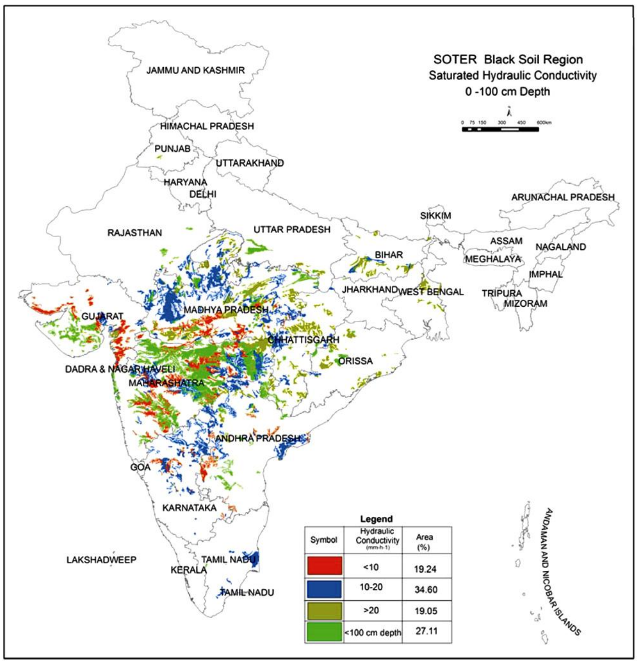

Figure 8. Saturated hydraulic conductivity map for the black soil region.

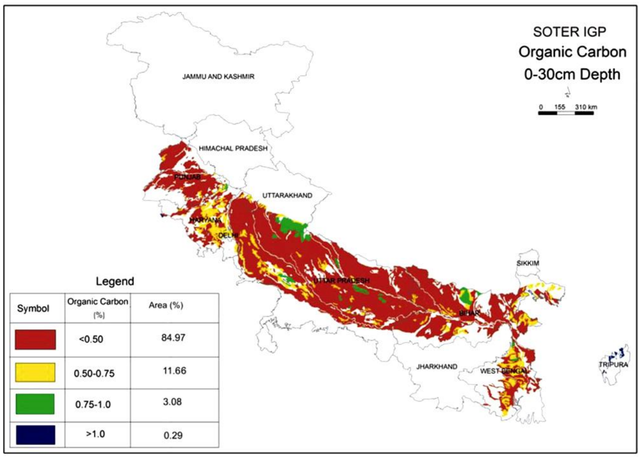

Figure 9. Soil organic carbon (0–30 cm) status map of the Indo-Gangetic Plains.

The climatic aridity and subsequent development of pedogenic carbonate in the major part of IGP, along with intensive agriculture with low organic inputs are the probable reason for their low organic carbon status. However, studies with limited datasets and carbon prediction models[23,35] indicate that there is a trend of increase in organic carbon stock in the soils of the IGP and BSR, which followed an initial decline during the post-green revolution period. Reports also indicate that soils of the arid and semi-arid climate, occupying more than one-third of the area of IGP, are prone to be calcareous and sodic due to low levels of organic carbon. Proper rehabilition programmes could make these soils resilient and thus improve their quality through carbon sequestration[11,23,36]. Vast areas of arid, semi-arid and sub-humid bioclimates of BSR are low in organic carbon, but have a high potential to sequester more organic carbon due to better substrate quality and thus can be prioritized for the sequestration of organic carbon. The thematic map developed through SOTER can be taken as a guide for selection of areas for the development of treatment plans on a priority basis.

Other applications: GeoSIS 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[37,38]. Soil information systems can be combined with digital elevation models and satellite radiometric data for regional soil mapping[39].

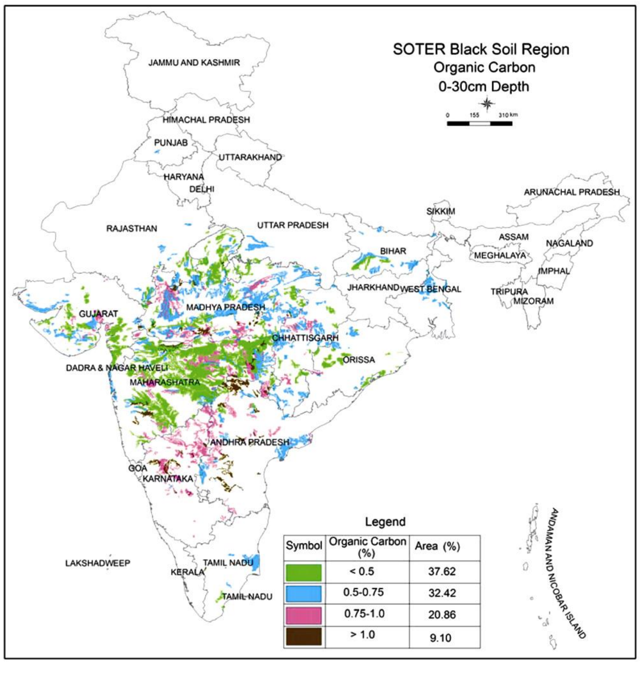

Figure 10. Soil organic carbon (0–30 cm) status of the black soil region.

The database has been successfully used to refine the AESR map of India[40], 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 categorize the land for different uses. The georeferenced database has been used to evaluate the soils of BSR and IGP for cotton and soybean systems and rice–wheat system respectively[41] in the benchmark spots. The database along with ancillary datasets are also used for predicting the yield of cotton and rice in BSR and the IGP soils respectively[42]. It will also help in assessing the soil and evolving land quality parameters and strategies to improve the quality and health of soils for better use on a sustainable basis[43]. The primary database has also been widely used to develop PTFs for estimating the physical properties like BD and sHC of soils[27], which are seldom available in routine soil survey reports. The other applications of SOTER include assessment of soil erosion, land degradation studies, conservation strategies, land productivity potential, spatial decision support system and environment protection studies.

Conclusions

A GeoSIS in the SOTER framework developed for the IGP and BSR forms a robust database which includes morphological, physical and chemical characteristics of soils along with the site characteristics and climate related information. The information from this organized database can be easily retrieved for use and is compatible with the global database. Although each map unit in the SOTER database can be linked with one profile information, the information collected can be utilized when we develop the SOTER for individual states on 1 : 2,50,000 scale. This warehouse of organized soil and land resource information would form the basis for the development of a SOTER database for the entire country. This can be updated with the recent and relevant data. It is expected that this robust database in a structured framework can be utilized by many users for future scientific and resource planning purposes and thus can remain as a national and international reference database.

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