Soil information system: use and potentials in humid and semi-arid tropics

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The articles presented in this special section emanated from the researches of consortium members of the National Agricultural Innovative Project (NAIP, Component 4) of the Indian Council of Agricultural Research (ICAR), New Delhi. These researches have helped develop a soil information system (SIS). In view of the changing scenario all over the world, the need of the hour is to get assistance from a host of researchers specialized in soils, crops, geology, geography and information technology to make proper use of the datasets. Equipped with the essential knowledge of data storage and retrieval for management recommendations, these experts should be able to address the issues of land degradation, biodiversity, food security, climate change and ultimately arrive at an appropriate agricultural land-use planning. Moreover, as the natural resource information is an essential prerequisite for monitoring and predicting global environmental change with special reference to climate and land use options, the SIS needs to be a dynamic exercise to accommodate temporal datasets, so that subsequently it should result in the evolution of the soil information technology. The database developed through this NAIP would serve as an example of the usefulness of the Consortium and the research initiative of ICAR involving experts from different fields to find out the potentials of the soils of humid and semi-arid bioclimatic systems of the country.

Keywords: Agricultural land-use planning, humid and semi-arid tropics, soil information system, soil information technology, temporal datasets.

Soil information system

THE soil information system (SIS) provides datasets on soils, landscapes and various parameters at different scales, collected and collated from primary and secondary sources. This organized information forms a basis for storing soil and land information for the implementation and monitoring of soil and land quality, to evaluate land for planning and suggesting appropriate land use in terms of various crops. In view of huge demands on natural resources like soil and water, constrained by environment and its protection, there is a need for better information on spatial variation and trends in the condition of soils and landscapes. It suggests the necessity to have a clear view of the status of information on various natural

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Table 1. Distribution of humid rainfed zones in India

AESR	Description	Location (state)	MAR (mm)	Area (m ha; of TGA)
14.3	Himalayas, warm humid to perhumid	Himachal Pradesh (Part)	2000–2500	1.0 (0.3)
14.4	Kumaon, warm humid to perhumid	Uttar Pradesh (Part)	2000–2500	0.5 (0.1)
14.5	Foothills of Kumaon Himalayas, sub-humid warm humid, perhumid	Uttar Pradesh (Part)	2000–2600	0.9 (0.3)
16.1	Foothills of Eastern Himalayas (Bhutan Hills), warm to hot, perhumid terrain region	West Bengal (Part)	2600–3000	0.3 (0.09)
16.2	Darjiling and Sikkim Himalayas, warm, perhumid	Sikkim, West Bengal (Part)	2500	1.1 (0.3)
17.1	Meghalaya Plateau and Nagaland Hills, warm to hot, moist humid to perhumid	Arunachal Pradesh, Meghalaya, Assam, Nagaland	2500	4.1 (1.3)
17.2	Purvachal (Eastern Range), warm to hot, perhumid ecosubregion	Manipur, Tripura, Mizoram	3000	5.5 (1.7)
19.1	North Sahyadris and Konkan coast, hot, humid	Maharashtra, Gujarat, UTs of Daman and Diu, and Dadar and Nagar Haveli	2000	2.2 (0.7)
19.2	Central and South Sahyadris, hot moist sub-humid to humid	Maharashtra, Karnataka, Goa, Kerala	2000–3000	6.9 (2.1)
19.3	Koumaon, Karnataka coastal plain, hot humid to perhumid	Kerala, Karnataka, Maharashtra, Goa	3000	2.0 (0.6)

MAR, Mean annual rainfall.

Table 2. Distribution of humid irrigated areas of the Indo-Gangetic Plains

Old AESR (LGP, in days)	Revised AESR	Area (m ha)	Soils	Criteria for modification[a]	MAR (mm)	Bioclimate[b]
13.1 (180–210)	13.1 a	6.12	Imperfectly to poorly drained, loamy (at places clay) soils, pockets of moderate flooding and slight salinity	Soils and drainage	1200–1500	SHm
	13.1 b	2.82	Well-drained, loamy soils			
13.2 (180–210)	13.2	1.33	Well-drained, loamy soils	No changes were made	1400–1500	SHm
15.1 (210–240)	15.1 a	4.32	Imperfectly to poorly drained, loamy/clay soils with moderate flooding	Soils and drainage	1300–1600	SHm–H
	15.1 b	0.44	Poorly drained, loamy soils with severe flooding			
18.5 (240–270)	18.5 a	0.83	Poorly drained, clay loamy soils, severe loamy, severe flooding, salinity	Soils and drainage	1800–2100	H
	18.5 b	0.36	Imperfectly to poorly drained loamy/clay soils with moderate flooding and salinity			
15.3 (270–300)	15.3 a	0.57	Poorly to imperfectly drained soils with occasional flooding	Soils and drainage	2000–3200	H–PH
	15.3 b	0.79	Well-drained with patches of poorly drained soils			

[a] LGP, Length of growing period. Criteria as soils indicate various soil properties, viz. colour, texture, depth, soil drainage, LGP, etc.
[b] SHm, Sub-humid moist; H, Humid; PH, Perhumid.

resources, with special reference to soils. Such information would not only store the datasets for prosperity, but will also improve our understanding of biophysical processes in terms of cause–effect relationship in the pedo-environment. Information on soils and land resources is thus fundamental, where the SIS plays a pivotal role[1,2].

Humid rainfed zones – defined

In India, 24.5 m ha is humid to perhumid rainfed area covering most of the northeastern region (including Sikkim) and other states (Uttarakhand, Himachal Pradesh and parts of Maharashtra, Gujarat, Karnataka, Goa, Kerala and West Bengal) (Table 1). The mean annual rainfall (MAR) ranges from 2000 to 3000 mm and in spite of such high rainfall, these areas cannot hold enough moisture in the soils to support *rabi* crops, due to terrain conditions effecting huge run-off loss. Such areas, therefore, also require conservation agriculture for which the SIS plays an important role in determining the agricultural prosperity of these areas.

Humid irrigated zones

Many areas in the lower Indo-Gangetic Plains (IGP) experience sufficient rainfall to be classified as humid zones. Table 2 shows these areas which are being studied, as illustrated in the following sections. These areas are under intensive agricultural land use and often support more than two crops in a year with canal/well irrigation. This agricultural practice has caused secondary salinization of soils with soluble carbonate and bicarbonate ions. Such soils have become saline–sodic in nature[3].

Semi-arid tropics defined

Despite increase in food production due to modern agricultural management, many parts of the world continue to face food insecurity. About 60% of the world's population facing food insecurity resides in South Asia and sub-Saharan Africa. Most of these areas are rainfed and there are several challenges in terms of area, extent and future prospects to improve the livelihood. Rainfed areas vary from region to region, and yet these are the zones where food is produced mostly for the poor communities. Rainfed agriculture in the semi-arid tropics (SAT) area is fragile, in view of spatial and temporal variation of rainfall. The total rainfall in these areas is received within a short span of three to five months[4]. Besides, as the rainfall is of high intensity and of short duration, huge amount of soil erosion and often flash flooding occurs in SAT. It has been established that SAT conditions induce formation of pedogenic calcium carbonate (PC) with concomitant subsoil sodicity, making the soil extremely impervious to air and rainwater, which in turn leads to flooding[5–7]. It is reported that there is an increase in the frequency of extreme events like drought, floods and hurricanes due to climate change. Many scenarios indicate loss of rainfed production areas (10–20%), which expectedly will affect nearly 1.2 billion people by 2080 (ref. 8). Climate change has been reported to adversely affect the water availability and food production. As a consequence land degradation, poverty and food insecurity are expected to grow to menacing proportions[9,10].

Hunger, poverty and vulnerability of livelihood in response to natural and other disasters will continue to be extremely important factors in the rural tropical areas of Africa and Asia. These challenges are further influenced by climatic aberration, population growth, degrading natural resources, poverty and other health-related problems[11]. Majority of the poor in developing countries live in rural areas. Their livelihood depends on agriculture and over-exploitation of the natural resource base, making the situation even worse. The rainfed agriculture is also associated with disproportionate food distribution between men and women[12]. It has been reported that every 1% increase in agricultural yield translates to a 0.6–1.2% decrease in the population of the absolute poor[13]. On an average, sub-Saharan (Africa) agriculture constitutes 35% of the Gross Domestic Product (GDP) and employs 70% of the total population and more than 95% of the agriculture area is in rainfed region[10].

In Africa and South Asia, agriculture will continue to remain the backbone of the economy in future. Most of the poor people are farmers and landless labourers. Therefore, strategies have to focus on generating more income to reduce poverty and its related problems. Substantial gains in land, water and labour productivity along with the careful natural resource management are essential to combat soil degradation, maintain sustainable crop production and ultimately to bring better lifestyle to the rural poor.

Out of 142 m ha of the net sown area in India, irrigated (rainfed) agriculture is practised in over 90 m ha. Nearly 67 m ha of rainfed area falls in the sector with mean annual precipitation in the 500–1500 mm range. Productivity and stability in rainfed areas are low. Although rainfed agriculture occupies about 63% of the total cropped area in India, it contributes only 45% of the country's agricultural production. Major rainfed crops grown in India comprise coarse grains, particularly pearl millet and sorghum, pulses, oilseeds and cotton. Not only the yields of these crops are low (average yield of coarse grains being just about 880 kg ha^{-1}), but also the technology transfer gap is wide. The region is characterized by erratic and often low rainfall, low soil fertility and harsh temperature regime[14]. Later estimates showed that the area under dry land agriculture in India is 100–105 m ha, of which Alfisols, Vertisols and Entisols occupy 30%, 35% and 10%, respectively[15]; besides some areas are under Inceptisols.

In India, rainfed areas include part of sub-humid dry (SHd), semi-arid moist (SAm), semi-arid dry (SAd) and arid bioclimatic systems (Table 3). Recent studies indicate that nearly 155.8 m ha of the country requires priority for better natural resources management in the form of organic carbon sequestration to bring back the soils to normal state[16]. Earlier, arid and semi-arid areas were designated as dry lands[17]. Our recent observation indicates that there are areas under sub-humid bioclimatic systems which also experience drought and should therefore be included in the dry tracts of the country[16,18].

In India, out of 60 agro-ecological sub-regions (AESRs)[19], 29 represent relatively dry tracts, showing arid, semi-arid, sub-humid bioclimates and cover an area of 168.1 m ha (nearly 56% total geographical area (TGA) of the country) (Table 3).

In the dry ecosystem, climatic variability [in terms of MAR and mean annual temperature (MAT)] results in the regressive pedogenic processes[6,7,20] which modify the physical, chemical and biological properties of soils to affect crop performance. The water deficiency in the soils is unfavourable for growth and development of rainfed crops and often leads to low crop yield[21]. The effective cropping season is restricted, both by the quantity and distribution of rainfall, thereby, setting the limits on the choice of crops, cultivars and cropping systems. Besides, knowledge on the soils and their modifiers (zeolites,

Table 3. Areas showing AESRs in rainfed semi-arid tropics of India

AESR no.	Description	Location (state)	Area (m ha; % of TGA)
2.1	Marusthali plains, hot hyper-arid, very low AWC, LGP < 60 days	Punjab, Rajasthan	12.3 (3.7)
2.3	Kachch Peninsula, hot hyper-arid	Punjab, Haryana	
3.1	Karnataka Plateau, hot arid with moderately well-drained, clayey mixed black and red soils, LGP 90–120 days	Karnataka	2.79 (0.9)
3.2	Karnataka Plateau, hot arid with moderately well-drained, loamy mixed red soils, LGP < 90 days	Karnataka, Andhra Pradesh	2.11
4.1	North Punjab Plain, Ganga–Yamuna Doab, hot semi-arid, medium Moga, Faridkot and Ferozepur, AWC, LGP 90–120 days	Punjab, Haryana, Uttar Pradesh	11.8 (3.5)
4.2	North Gujarat Plain (inclusive of Aravalli range and Eastern Rajasthan Uplands) hot, dry semi-arid eco-subregion	Gujarat, Rajasthan	7.6 (2.3)
4.3	Ganga–Yamuna Doab, Rohilkhand and Avadh Plain, hot moist semi-arid, medium to high AWC, LGP 120–150 days	Uttar Pradesh, Madhya Pradesh	6.9 (2.0)
4.4	Madhya Bharat Pathar and Bundelkhand Uplands, hot, moist semi-arid eco-subregion	Uttar Pradesh, Madhya Pradesh	5.9 (1.7)
5.1	Central Kathiwar Peninsula, hot, dry semi-arid eco-subregion	Gujarat	2.7 (0.8)
5.2	Madhya Bharat Plateau, Western Malwa Plateau, Eastern Gujarat Plain, Vindhyan and Satpura range and Narmada valley, hot, mosit semi-arid ecoregion	Madhya Pradesh	14.0 (4.3)
5.3	Coastal Kathiwar Peninsula, hot, moist semi-arid eco-subregion	Gujarat	0.9 (0.3)
6.1	Southwestern Maharashtra and North Karnatak Plateau, hot, dry, semi-arid ecosubregion	Maharashtra, Karnataka	7.6 (2.3)
6.2	Central and westrn Maharashtra Plateau and North Karnataka Plateau and North Western Telangana Plateau, hot, moist semi-arid ecoregion	Maharashtra, Andhra Pradesh	12.6 (3.8)
6.3	Eastern Maharashtra Plateau, hot, moist semi-arid eco-subregion	Maharashtra	5.4 (1.6)
6.4	North Sahyadris and Western Karnataka Plateau, hot, dry sub-humid eco-subregion	Maharashtra, Karnataka	5.4 (1.6)
7.1	South Telangana Plateau (Rayalseema) and Eastern Ghats, hot, dry semi-arid eco-subregion	Andhra Pradesh	3.9 (1.2)
7.2	North Telangana Plateau, hot, moist semi-arid eco-subregion	Andhra Pradesh	9.2 (2.8)
7.3	Eastern Ghat (South), hot, moist semi-arid/dry-subhumid eco-subregion	Andhra Pradesh	3.4 (1.0)
8.1	Tamil Nadu Uplands and Leeward Flanks of South Sahyadris, hot, dry semi-arid eco-subregion	Tamil Nadu	3.7 (1.1)
8.2	Central Karnataka Plateau, hot, moist semi-arid eco-subregion	Karnataka	6.5 (2.0)
8.3	Tamil Nadu Uplands and Plains, hot, moist semi-arid eco-subregion	Andhra Pradesh, Tamil Nadu	8.9 (2.7)
9.1	Punjab and Rohilkhand Plains, hot/dry moist sub-humid transition, medium AWC and LGP 120–150 days	Jammu & Kashmir, Himachal Pradesh, Punjab, Haryana, Uttar Pradesh	3.9 (1.2)
9.2	Rohilkhand, Avadh and south Bihar Plains, hot dry sub-humid, medium to high AWC and LGP 150–180 days	Uttar Pradesh, Bihar	8.3 (2.5)
10.1	Malwa Plateau, Vindhyan Scarpland and Narmada valley, hot dry subhumid eco-subregion	Madhya Pradesh	8.1 (2.5)
10.2	Satpura and Eastern Maharashtra Plateau, hot dry sub-humid eco-subregion	Madhya Pradesh, Maharashtra	2.8 (0.8)
10.3	Vindhyan Scarpland and Bagelkhand Plateau, hot, dry sub-humid ecosubregion	Madhya Pradesh	5.8 (1.8)
10.4	Satpura range and Wainganga Valley, hot, moist sub-humid eco-subregion	Madhya Pradesh, Maharashtra	5.6 (1.7)

gypsum, calcium carbonate, palygorskite) for each AESR is necessary, because the presence of modifiers immensely affects the soil–water relations[5,7,22–26], especially in post-rainy season, which in turn influences the crops that are grown on conserved rainwater.

Role of soils and SIS in humid areas of India

As shown in Table 1, most of the northeastern region and the Himalaya experience heavy to very heavy rainfall. These areas are generally under monocrop and agriculture is practised under rainfed conditions. The lower IGP is humid, but practices irrigated agriculture. Therefore, humid areas under both rainfed and irrigated ecosystems are important and require detailed information on soils.

SIS in humid rainfed ecosystems

Case studies of Tripura: Soils of Tripura and their usefulness indicate the application of SIS in soil degradation, conservation measures, suitability of different land uses, crop suitability and soil health[2]. The SIS of Tripura integrates outputs from various sources and is useful for monitoring natural resources, modelling soil physiographic relation, finding crop suitability, modelling of soil carbon and crop performance to comprehend the soil health[27–29]. All this information in combination, provides a meaningful tool to address various issues detailed in Figure 1.

Case studies of the lower IGP: The AESRs 13.1, 13.2, 15.1, 15.3 and 18.5 are characterized by imperfectly to poorly drained soils due to occasional to severe flooding in the low-lying areas. These AESRs (except 13.2) were revisited to modify their boundaries, as shown in Table 2. Since most of the areas is under irrigation, the concept of length of growing period (LGP), does not hold good for these areas[30,31]. The physiography, soils and their parameters were utilized to revise the AESR boundaries. For this purpose, the most important source was soil resource map of West Bengal, Bihar and Uttar Pradesh at 1 : 250,000 scale[32–34]. The hierarchy for the entire IGP is shown in Table 4. Soil information is documented from different sources and at various scales. The earlier attempts to collect datasets of the IGP were through GEFSOC project[28,35]. The hierarchy of land units and description of legends at various scales of soil, and land use survey efforts made so far, are shown in Table 4. The SIS IGP is routed through level 1 starting from 1 : 7 million to the revised soil map of IGP in 1 : 1 million through this project. The level-2 information reported earlier[36] will be revised after the land resource inventory of the IGP is developed at 1 : 10,000 scale.

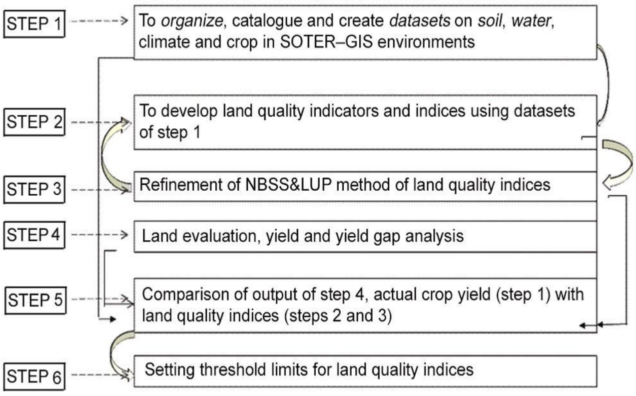


Figure 1. Schematic diagram showing steps to arrive at the threshold values of land quality parameters.

Level-1 SIS distinguishes major physiography, agro-ecological regions (AERs) and AESRs in the IGP. It provides information on selected climatic parameters such as temperature and rainfall and a few soil properties. The climate and soil data also estimate the length of growing period in each region to select crops[26].

Role of soil and SIS in SAT

The black soils in the central, western and southern parts of the country are generally rainfed and represent SAT. Besides, the upper and part of middle IGP also represent SAT, but are mostly irrigated. We present SIS of these two regions representing irrigated and rainfed dry areas in the following.

Case studies from upper and middle IGP (irrigated dry areas)

The AESRs 2.1, 2.3, 4.1, 4.3, 9.1 and 9.2 are characterized by relatively low rainfall and are designated as relatively dry compared to the humid part of the IGP (Table 5). SIS generated through the NAIP project was used to revise the AESR boundaries. The soil resource maps of Uttar Pradesh, Punjab, Haryana and Rajasthan at 1 : 250,000 scale were used to generate SIS of these regions[34,37–39]. A comparative status shows the datasets in the present effort for generating IGP soil map (Table 6). The hierarchy of land units and description of legends at various scales are shown in Table 4. Details of the soil information are given elsewhere[40,41].

Case studies from the black soil region (BSR)

Black soils are common in SAT in India, although their presence is reported in the humid and arid bioclimatic systems also[16,21]. These soils are spatially associated with red soils and thus form a major soil group of India, occurring on various parent materials and in different climate zones. They have been reported in various physiographic positions as, for example, red soil on the hills and black soils in the valleys[42]. Interestingly, these soils have also been reported in juxtaposition in Tamil Nadu, Maharashtra and Andhra Pradesh under similar topographic conditions[43–45]. Reports indicate presence of Ca-rich zeolites in basaltic landscape[7,22,23,46,47]. Zeolites have the ability to hydrate and dehydrate reversibly and to exchange some of their constituent cations to influence the pedochemical environment during the formation of soils. Significance of these zeolites has been realized in the formation of the soils and also in controlling soil moisture retention[48]. Table 7 details the spatial hierarchy in BSR. Earlier

Table 4. Available soil and land information system – spatial hierarchy in IGP

Level	Land unit	Soil unit	Descriptive legends	Description of map unit[+]	Map scale (million)	Source/comments
1	Country	Order[+]	Suborders	Inceptisols, Entisols	1 : 25	NRCS[63]
2	State	Suborder[+]	Soil suborders		1 : 7	NBSS&LUP[64] (map printed by NBSS&LUP, Nagpur)
3	State	Old soil classification	Traditional soil names	Red and yellow soils, red loamy soils, mixed red and black soils	1 : 4	Govinda Rajan[65]
4	State (region)	–	Agro-ecological region (AER)	Bengal plains, hot sub-humid to humid LGP 210–300 days (AER 15)	1 : 4.4	Sehgal *et al.*[66] (map printed by NBSS&LUP, Nagpur)
5	State (sub-region)	–	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	Velayutham *et al.*[19] (map printed by NBSS&LUP, Nagpur); Govinda Rajan[65]
6	Country	Soil great group	Soil great group association	Total 1649 units in the country – the IGP had 74 no. of units	1 : 1	NBSS&LUP[67] (printed by NBSS&LUP)
7.	Sub-country (the IGP)	Soil sub-group[+]	Soil sub-group association	Total 74 no. of units for the IGP	1 : 1 (based on 1 : 250,000 m scale information)	Bhattacharyya *et al.*[5,28], Batjes *et al.*[35]
8.	Sub-country level (the IGP)	Soil sub-group[+]	Soil sub-group association	Total 122 no. of units for the IGP	1.1	GeoSIS, NAIP soil map of the IGP, India[68] (draft prepared)

[+] USDA Soil Taxonomy[69]; [++] AWC, Available water holding capacity. Source: Revised from Bhattacharyya and Mandal[36].

Table 5. Agro-ecological sub-regions in the semi-arid irrigated areas in IGP

Old AESR (LGP, in days)	Revised AESR	Area (m ha)	Soils	Criteria for modification[a]	MAR (mm)	Bioclimate[c]
2.1 (<60)	–	0.13	Well to excessively drained sandy soil	b	100–300	Arid
2.3 (60–90)	2.3 a	2.49	Well-drained to excessively drained sandy soil	Soils and drainage	300–450	Arid
	2.3 b	0.16	Highly calcareous sandy soils			
4.1 (90–120)	4.1 a	4.08	Well-drained with pockets of imperfectly drained soils	Soils/drainage/salinity/ sodicity	600–800	SAd
	4.1 b	2.83	Well-drained loamy soils with salinity and sodicity			
	4.1 c	2.54	Well-drained sandy soils			
4.3 (120–150)	4.3 a	0.79	Dominantly black soils, well-drained	Soils	700–900	SAd
	4.3 b	6.32	Well-drained loamy soils, at places imperfectly drained			
9.1 (120–150)	9.1 a	2.10	Well-drained, loamy soils	Soils and drainage	700–1000	SHd
	9.1 b	0.55	Loamy, well-drained with pockets of imperfectly drained soils			
	9.1 c	1.66	Sandy, well-drained soils			
9.2 (150–180)	9.2 a	2.09	Well-drained, loamy, alluvial soils	Soils and drainage	1000–1200	SHd
	9.2 b	4.17	Well-to-imperfectly drained, loamy alluvial soils			
	9.2 c	2.64	Imperfectly to poorly drained, alluvial soils			
	15.3 b	0.79	Well-drained with patches of poorly drained soils			

[a] Criteria as soils indicate various soil properties, viz. colour, texture, depth, soil drainage, LGP, etc.

[b] For these AESRs boundaries of the polygons were revised keeping in view the administrative boundaries and at places physiography. Lack of enough soil data these AESRs were not further subdivided.

[c] SAd, Semi-arid dry; SHd, Sub-humid dry.

Table 6. Comparison of two levels of datasets generated to produce soil map IGP

Particulars	IGP map (1988)*	IGP map (2014)**
Map scale (m)	1.1	1 : 1 (based on 1 : 250,000 scale input)
Total area (m ha)	43.7	52.01
No. of soil associations	74	122
No. of polygons	–	349
Soil classification	Soil subgroup	Soil subgroup
Mapping legend	• Soil depth • Slope • Texture • Erosion • Salinity • Sodicity • Flooding	• Soil depth • Slope • Texture • Erosion • Salinity • Sodicity • Flooding
No. of benchmark spots	40	417
Frequency of observation (per m ha)	0.9	8.1
Soils	• Entisols • Alfisols • Inceptisols	• Entisols • Alfisols • Inceptisols • Vertisols

*Bhattacharyya *et al.*[5,28]; Batjes *et al.*[35]. **NBSS&LUP[68].

Table 7. Available soil and land information system – spatial hierarchy in the black soil regions

Level	Land unit	Soil unit	Descriptive legends	Description of map unit[+]	Map scale (million)	Source/ comments
1	Country	Order[+]	Suborders	Inceptisols, Entisols	1 : 25	NRCS[63]
2	State	Suborder[+]	Soil suborders		1 : 7	NBSS&LUP[64] (map printed by NBSS&LUP, Nagpur)
3	State	Old soil classification	Traditional soil names	Red and yellow soils, red loamy soils, mixed red and black soils	1 : 4	Govinda Rajan[65]
4	State (region)	–	Agro-ecological region	Bengal plains, hot subhumid to humid LGP 210–300 days (AER 15)	1 : 4.4	Sehgal *et al.*[66] (map printed by NBSS&LUP, Nagpur)
5	State (sub-region)	–	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	Velayutham *et al.*[19] (map printed by NBSS&LUP, Nagpur); Govinda Rajan[65]
6	Country	Soil great group[+]	Soil great group association	Total 1649 units in the country	1 : 1	NBSS&LUP[67] (printed by NBSS&LUP)
7	Sub-country (BSR)	Soil great group[+]	Soil great group association	Total 53 no. of units for the BSR	1 : 1 (based on 1 : 250,000 m scale information)	Sehgal *et al.*[70]
8.	Sub-country (BSR)	Soil great group[+]	Soil great group association	Total 50 no. of units for the BSR	1 : 1 (based on 1 : 1 m scale information)	NBSS&LUP Nagpur; BSR, India[71] (draft prepared)

[+] USDA Soil taxonomy[43]; Source: Revised from Bhattacharyya and Mandal[36].

Table 8. Comparison of two levels of datasets generated to develop the revised BSR map

Particulars	BSR map (1988)*	BSR map (2014)**
Map scale	1 : 4 million (based on 1 : 1 m map)	1 : 1 (based on 1 : 250,000 scale)
Total area (m ha)	70.0	76.4
No. of soil associations	50	53
No. of polygons	–	282
Soil classification	Great group association	Great group association
Mapping legend	Soil depth Slope	Soil depth Texture Soil erosion Flooding Salinity Sodicity Drainage Slope
No. of benchmark spots	33	425
Frequency of observation	0.47 per m ha	5.6 per m ha
Soils		
Vertisols	26.3	27.4
Inceptisols	28.2	39.8
Entisols	14.2	4.3
Alfisols (others)	1.3	4.9

*Sehgal *et al.*[70]; **NBSS&LUP[71].

attempts to prepare the black soil map in India have been revised taking into account the occurrence of black soils in non-traditional areas[49] through this project[31]. A relative comparison of these two efforts is shown in Table 8.

In BSR, the soils were selected from the established benchmark (BM) sites, the reason being that each soil would cover an extensive area in the landscape and monitoring these BM soils would be easy. In order to make meaningful comparison, the soils were chosen such that their substrate quality remains similar. Therefore, the study area and the soil series were selected mostly from the cultivated fields represented by Vertisols and their verticinter grades. Revised estimation indicates that black soils occupy nearly 76.4 m ha mostly in Maharashtra, Madhya Pradesh, Gujarat[31] and other states. Reports also show the presence of Vertisol in the IGP[50]. Black soils are also reported from Kerala, Jammu and Kashmir and Andaman and Nicobar Islands[49].

Discussion

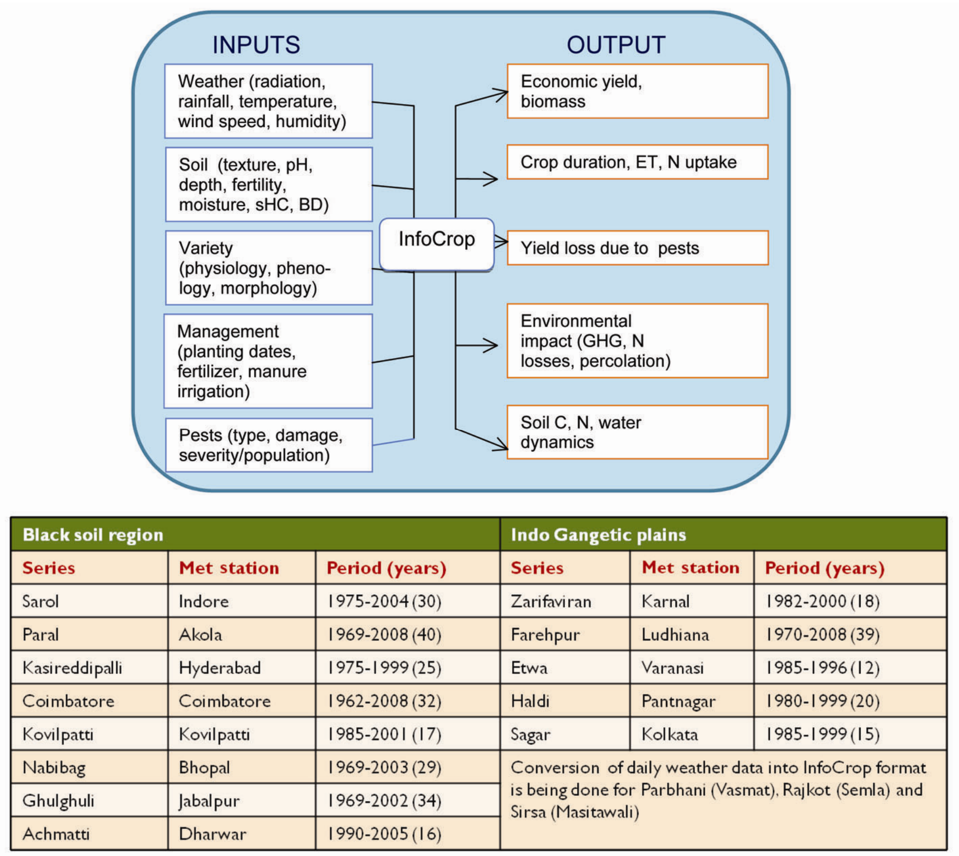
SIS stored in SOTER framework can be used for monitoring the quality of soil and land resources by different stakeholders to address the issues of environment with special reference to climate change and global warming[28,35,51], refining AESR boundaries to focus on agriculture land-use planning[31,48,52]. Revised agro-ecological map is a useful tool for crop planning[31]. SIS has been successfully used to evaluate potentiality of land[53] using principal component analysis to arrive at minimum datasets and threshold values of the land quality parameters (Figure 1). Crop yield of cotton and soybean in the BSR and rice and wheat in the IGP have been simulated using InfoCrop model[54] (Figure 2). Georeferenced soil information system (GeoSIS) is structured for monitoring soil and land quality and to assess the impact of land-use changes (Figure 3).

The baseline data generated through this project[40,41] permits to use changes in soil quality parameters in terms of soil organic carbon (SOC), soil inorganic carbon (SIC), bulk density (BD) and saturated hydraulic conductivity (sHC). It is realized that a few selected dynamic properties of 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. Earlier, the National Bureau of Soil Survey and Land Use Planning (Indian Council of Agricultural Research), through organized research initiative, developed two time series datasets for 1980 and 2005 to assess changes in the levels of carbon in soils in IGP and BSR[55] (Table 9). Soil carbon stock depends largely on the areal extent besides other factors such as carbon content, depth and BD of the soil. Even with a small amount of SOC (0.2–0.3%), the arid and semi-arid tracts show high SOC stock due to large area of these two bioclimatic systems[18]. To avoid such illusion, we express the changes in carbon stock per unit area (Table 9), to interpret the influence of soil and/or management parameter for sequestration of both SOC and SIC in the soil[55]. In the semi-arid bioclimatic system of the IGP, SOC stock is increased with Zarifa Viran as an exception; in sub-humid bioclimate a marginal increase indicates attainment of a near quasi equilibrium (QE) of SOC[55]. In humid climate a marginal decrease in SOC stock during 2010 over 1980, also

Table 9. Three different time series data to show the changes in soil organic (SOC) and soil inorganic (SIC) carbon stock in soils of the IGP and BSR

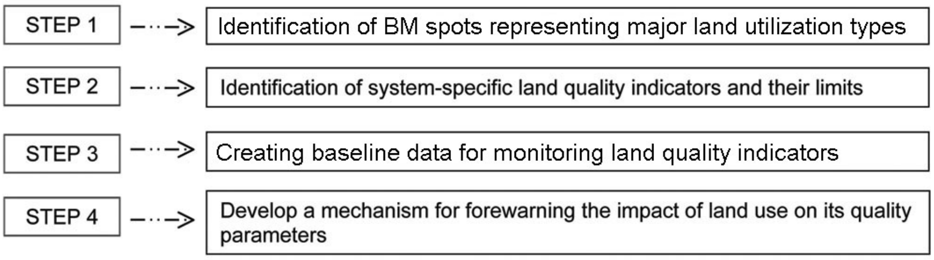
Bioclimatic systems	Soil series	SOC stock (Tg/lakh ha) 1980*	SOC stock (Tg/lakh ha) 2005*	SOC stock (Tg/lakh ha) 2010	SOC change over 1980 (%)	SIC stock (Tg/lakh ha) 1980*	SIC stock (Tg/lakh ha) 2005*	SIC stock (Tg/lakh ha) 2010	SIC change over 1980 (%)
Indo-Gangetic Plains									
Semi-arid	Zarifa Viran	4.13	5.38	3.24	–22	22.36	16.98	15.69	–30
	Fatehpur	1.11	5.50	4.44	300	0	58.30	3.33	–
	Sakit	4.05	8.55	8.10	100	51.03	5.37	5.18	–90
Sub-humid	Haldi	8.55	6.28	9.48	11	0	2.84	4.19	–
Humid	Madhpur	3.99	4.97	3.67	–8	4.03	15.98	4.13	3
Black Soil Regions									
Arid	Sokhda	11.19	9.20	9.24	–17	23.63	60.92	53.13	125
Semi-arid	Teligi	7.41	15.20	13.31	80	21.01	29.60	28.45	35

*Bhattacharyya *et al.*[55].



Black soil region			Indo Gangetic plains		
Series	**Met station**	**Period (years)**	**Series**	**Met station**	**Period (years)**
Sarol	Indore	1975-2004 (30)	Zarifaviran	Karnal	1982-2000 (18)
Paral	Akola	1969-2008 (40)	Farehpur	Ludhiana	1970-2008 (39)
Kasireddipalli	Hyderabad	1975-1999 (25)	Etwa	Varanasi	1985-1996 (12)
Coimbatore	Coimbatore	1962-2008 (32)	Haldi	Pantnagar	1980-1999 (20)
Kovilpatti	Kovilpatti	1985-2001 (17)	Sagar	Kolkata	1985-1999 (15)
Nabibag	Bhopal	1969-2003 (29)	Conversion of daily weather data into InfoCrop format is being done for Parbhani (Vasmat), Rajkot (Semla) and Sirsa (Masitawali)		
Ghulghuli	Jabalpur	1969-2002 (34)			
Achmatti	Dharwar	1990-2005 (16)			

Figure 2. Simulation of yields of different crops grown in the IGP and BSR using the InfoCrop model.


STEP 1 → Identification of BM spots representing major land utilization types

STEP 2 → Identification of system-specific land quality indicators and their limits

STEP 3 → Creating baseline data for monitoring land quality indicators

STEP 4 → Develop a mechanism for forewarning the impact of land use on its quality parameters

Figure 3. Schematic diagram showing steps for assessment of impact of land use change in IGP and BSR.

Table 10. Three different time series data to show the changes in bulk density (BD) and saturated hydraulic conductivity (sHC) in soils of IGP and BSR (0–150 cm)

Bioclimatic systems	Soil series	BD ($Mg\ m^{-3}$) 1980	2005	2010	BD change at 2010 over 2005 (%)	sHC ($cm\ h^{-1}$) 1980	2005	2010	sHC change over 2005 (%)
Indo-Gangetic Plains									
Semi-arid	Zarifa Viran	1.50	1.66	1.66	0	0.001**	2.030	0.390	–81
	Fatehpur	1.40	1.71	1.48	–13	1.497	2.190	2.100	–4
	Sakit	1.62*	1.70	1.38	–19	0.001**	0.230	0.020	–91
Sub-humid	Haldi	1.51	1.60	1.47	–8	0.001**	3.770	0.680	–82
Humid	Madhpur	1.73	1.86	1.53	–18	0.001**	1.550	0.080	–95
Black Soil Regions									
Arid	Sokhda	1.40	1.76	1.54	–13	0.001**	2.58	2.39	–7
Semi-arid	Teligi	1.40	1.43	1.74	22	0.001**	0.55	0.07	–87

*Derived from PTF[52]. **Very high ESP values produce (–ve) values of sHC when PTFs are used[52] so we presented a value of 0.001.

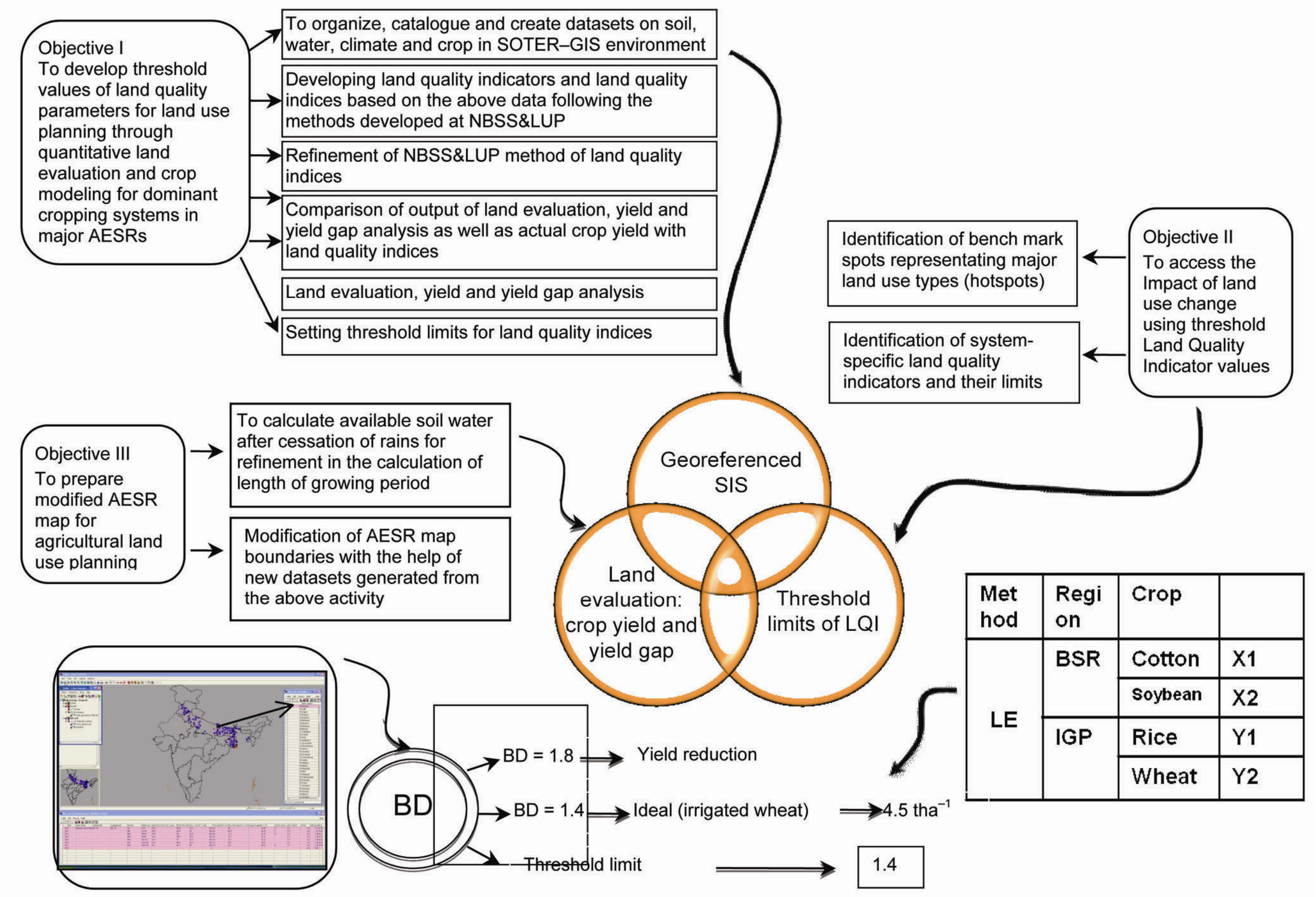


Figure 4. Schematic diagram showing an overview of the georeferenced soil information system (GeoSIS).

suggests a quasi equilibrium stage of SOC, after the lapse of 30 years. In BSR, a marginal decrease in arid and 80% increase in semi-arid bioclimatic system is observed. It is interesting to note that when we compare SOC stock in 2005 and 2010 at seven BM spots, we find, most of them show a tendency towards quasi equilibrium of SOC, with few exceptions. It has been earlier reported that in agriculture systems the SOC values tend to attain QE over a period of 30–50 years[56,57]. The SIC stock generally shows a decreasing trend in the IGP, with Madhpur as an exception. The increasing trend in SIC stock in the BSR is a warning signal for potential soil degradation in spite in increase in SOC stock (Table 9)[36]. Table 10 shows changes in BD and sHC in seven BM spots in the IGP

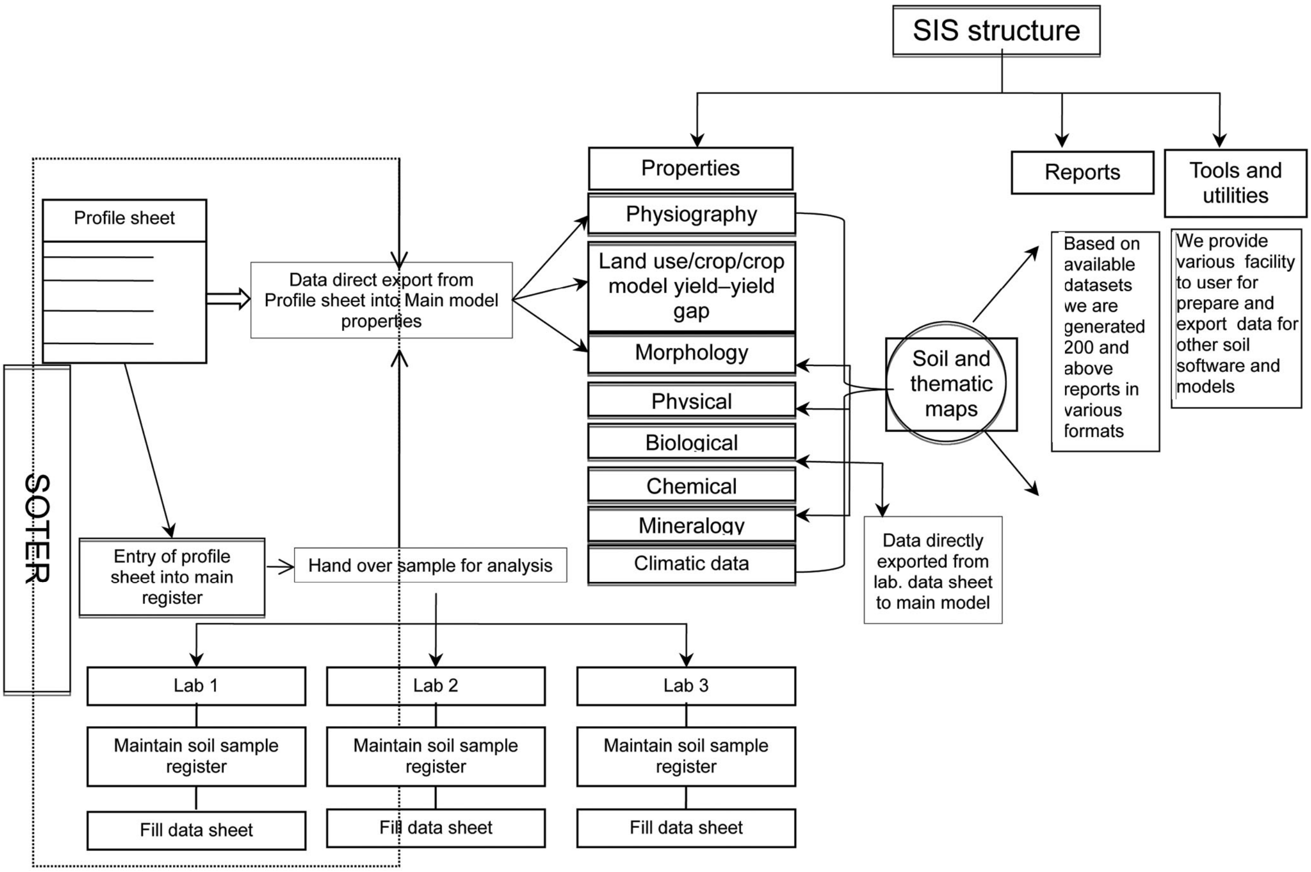


Figure 5. Schematic diagram showing soil information system and its usefulness for natural resources management.

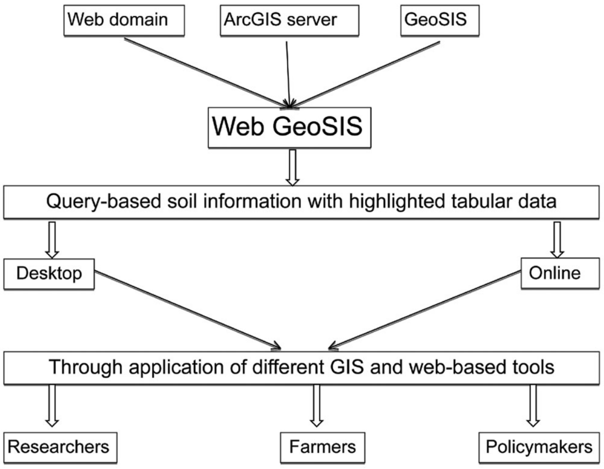


Figure 6. Schematic diagram showing web-based georeferenced soil information system and its structural framework.

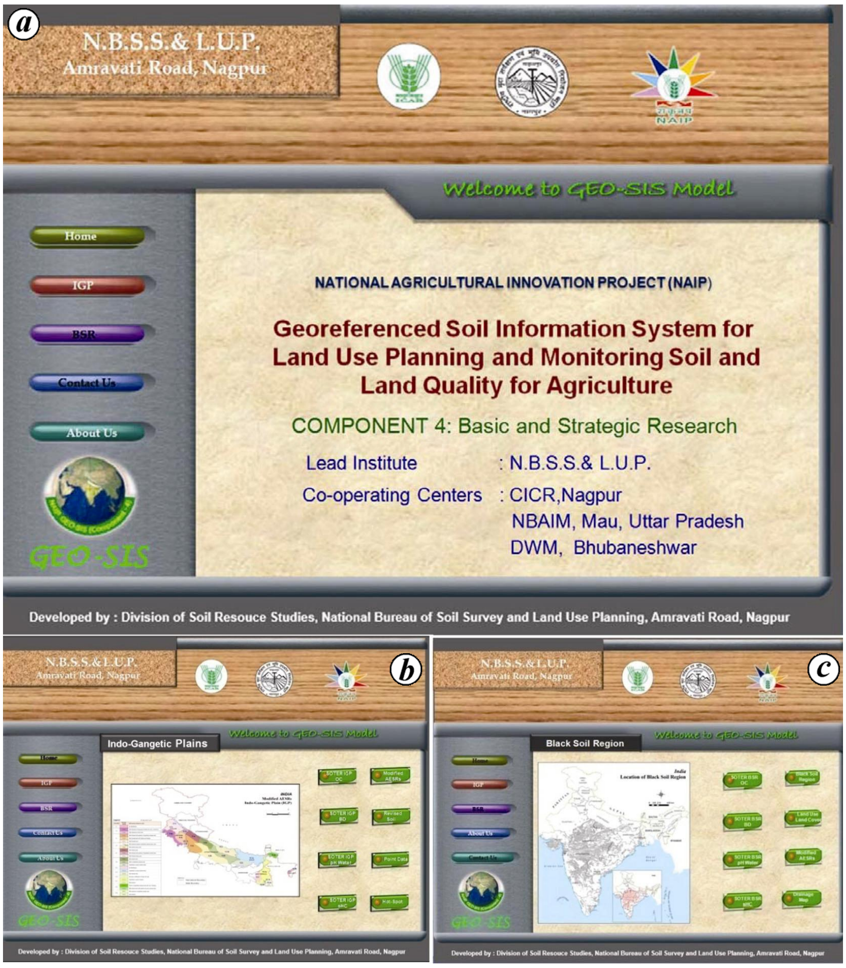
and BSR. Compared to 2005, BD shows a lower value in most of the soils, with Zarifa Viran and Teligi as exceptions. It may be mentioned that increase in BD with depth below the surface layer has been reported from the IGP as well as in BSR[58,59]. Table 10 shows the changes of weighted mean averages of BD and sHC. Interestingly, soil drainage is affected in all the soils, within IGP soils being the worst affected. Sidhu *et al.*[59] indicated various factors which control increase in BD value. Decrease in sHC values indicates that these soils are gradually becoming less porous and require immediate attention.

An overview of GeoSIS is shown in Figure 4, which shows interface between GeoSIS, land evaluation and threshold limits of the land quality index that ultimately culminates in a SIS structure to store various reports, tools and utilities (Figure 5). The present SIS is characterized by the introduction of soil microbiological information[60,61]. An effort has been made through this project to study depth-wise distribution and factors influencing the urease, dehydrogenase, microbial biomass carbon and microbial activity and their diversity in the soils of the selected BM spots representing the IGP and BSR. The information generated on the soil biological properties will improve Indian SIS, which will be useful for the assessment of soil/land quality and changes in the soil quality indicators for sustainable land resource management. The major deliverables of the present project are GeoSIS through SOTER GIS, land quality indices, threshold values of the datasets important for soil and land quality, revised maps of IGP and BSR soils and IGP and BSR AESR maps (Table 11).

Table 11. Deliverables and innovations through soil information system in IGP and BSR

Deliverables	Innovations
Georeferenced Soil Information System (GeoSIS)	GeoSIS of ~ 900 soil profiles having information on physical, chemical and microbiological properties of soil at three depths (0–30, 0–50 and 0–100 cm) in SOTER-GIS[a].
Datasets on land quality indicators and land quality indices	Included microbiological and hydrological properties to develop soil quality indices[b].
Improved methodology to estimate land quality indices	Modified land evaluation method is used to identify the land soil quality parameters[c].
Yield gap in dominant cropping system	For yield-gap analysis, InfoCrop model is being used. The soil information as input parameter is arranged in two formats. Also, InfoCrop model is being improvized to include some important soil information[d].
Threshold values and classes of land quality indices	Threshold values of sHC have been fixed for soils of the BSR in computation of plant available water content[e].
Pedotransfer functions for saturated hydraulic conductivity, bulk density and water retention	Pedotransfer functions were developed considering ESP, ECP and EMP, which are the important parameters influencing sHC and water retention–release behaviour[f].
New set of length of growing period values	Antecedent moisture content is being considered for LGP calculation[g].
Improved boundaries of agro-ecological sub-regions map	Based on LGP, total 17 AESRs were modified to 29 in the IGP and 27 modified to 45 in BSR[h].

[a]Chandran *et al.*[72]; [b]Velmourougane *et al.*[60]; [c]Ray *et al.*[73]; [d]Venugopalan *et al.*[54]; [e,g,h]Mandal *et al.*[31]; [f]Tiwary *et al.*[52].



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

Figure 7. Graphic user interface of web-GeoSIS. ***a***, Home page; ***b***, GeoSIS–IGP; ***c***, GeoSIS–BSR.

Way forward

Web publication

GeoSIS developed for the IGP and BSR is presented, discussed and disseminated through different means in the form of hard copy publications[62] (www.geosis-naip-nbsslup.org). Such publications have their own value as well as limitations. Since most of these datasets are available as hard copy (maps), the stakeholders, users and readers are unable to understand these maps and extract the auxiliary information, viz. soil, landscape, land use and climatic parameters from them. This necessitated to adopt more user-friendly approach to publish the information that could be interactive, more visible and easy to understand. The advent of modern information and web-based technology has made it easier to bring out web-based publication of georeferenced soil and other information. The project output is being showcased in the website of NAIP as web GeoSIS (Figure 6). Through web-based GeoSIS, the datasets – information on soil, land use, crop, climate, physiography, SOTER, etc. along with the associated maps can be accessed from any web-enabled equipment (Figure 7). Maps on the web provide a new paradigm to access and use soil information by the stakeholders at any time and from anywhere. This will enable the users to access information/datasets for various purposes, including land resources inventory and management. Query-based information (e.g. soils of IGP with BD more than 1.6) on soil, land use, etc. along with their spatial distribution can also be accessed for a specific purpose. Web GeoSIS can enable collaboration between different agencies, facilitating better communication and can save time to stop repetition of research activities. This exercise can open a new vista for participatory research programmers using common people and other organizations, and can therefore provide scope for revising the database for monitoring soil health and changing land use pattern.

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