Georeferenced soil information system: assessment of database

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Land-use planning is a decision-making process that facilitates the allocation of land to different uses that provide optimal and sustainable benefit. As land-use is shaped by society–nature interaction, in land-use planning different components/facets play a significant role involving soil, water, climate, animal (ruminant/non-ruminant) and others, including forestry and the environment needed for survival of mankind. At times these components are moderated by human interference. Thus land-use planning being a dynamic phenomenon is not guided by a single factor, but by a complex system working simultaneously,which largely affects the sustainability. To address such issues a National Agricultural Innovation Project (NAIP) on 'Georeferenced soil information system for land-use planning and monitoring soil and land quality for agriculture' was undertaken to develop threshold values of land quality parameters for land-use planning through quantitative land evaluation and crop modelling for dominant cropping systems in major agro-ecological sub-regions (AESRs) representing rice–wheat cropping system in the Indo-Gangetic Plains (IGP) and deep-rooted crops in the black soil regions (BSR). To assess the impact of land-use change, threshold land quality indicator values are used. A modified AESR map for agricultural land-use planning is generated for effective land-use planning.

Keywords: Agriculture, georeferenced soil information system, land-use planning, spatial database.

Introduction

MAPPING and monitoring of the natural resources with the active participation of agencies responsible for their protection, including scientists, industry groups and community organizations are important activities. This organized information forms a basis for storing soil and land databases for implementation and monitoring of various efforts on land resource management. In view of huge demands on natural resources like soil and water, with special reference to the environment and its protection, there is a need for better information on spatial variation and changing trends in the conditions of soils and landscapes. It suggests the necessity to have a clear view of the status of information on various natural resources with special reference to soils. Such information would not only store the datasets for posterity, but will also improve our understanding of biophysical processes in terms of cause–effect relationship in the pedo-environment. Information on soil and land resources is thus

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fundamental, where the soil information system (SIS) plays a pivotal role[1].

In view of immediate concern about the use of soil map information for land-use planning, the National Agricultural Innovation Project (NAIP) on 'Georeferenced soil information system for land-use planning and monitoring soil and land quality for agriculture' was taken up to equip ourselves with Georeferenced Soil Information System (GeoSIS)[2]. This provides a robust platform for monitoring the changes in soil properties induced by dynamic land-use changes. This fact assumes added importance to agricultural land-use planning in view of the declining trends in factor productivity. As of today, in spite of having excellent repository of various soil maps at both large and small scales, they are unable to provide geo-referenced information to their spatial domain for researchers engaged in natural resource management, crop and environment modelling. Considering the multitude of key agricultural, environmental, economic, social and cultural functions performed by soils, it is necessary to develop a land information system for monitoring land-use and land-use changes after land quality parameters. Identification of relevant indicators and fixing baseline (reference levels) will help in forewarning the consequences of non-compatible land-uses on land quality. The most important link between farming practices and sustainable agriculture is the health of soils, which needs regular monitoring. Land quality is conceptualized as the major link between the strategies of conservation management practices and achievement of major goals of sutainable agriculture. Assessment of land quality and the direction of change with time are the primary indication of sustainable land management.

In the changing scenario of better awareness on climate change and its implication on natural resources, the demand for development of information systems on natural resources has increased. Thus development of a systematic and organized information system on spatial variations and trends is necessary. Such information not only stores the datasets for posterity, but also improves our understanding of biophysical processes in terms of relationship among them in the pedo-environment. A wide range of information on soils is available in scattered and unorganized format, which needs to be georeferenced to understand their exact location in a map. Therefore, soil information with exact coordinates can be used for developing such systems. GIS has been an important tool for GeoSIS[1]. The present article is restricted to two important food-growing zones, viz. the Indo-Gangetic Plains (IGP) and the black soil region (BSR) to assess the datasets developed so far.

Materials and methods

The National Bureau of Soil Survey and Land-use Planning (NBSS&LUP) through an organized research initiative sponsored by the National Agricultural Technology Project (NATP) and Global Environment Facility Soil Organic Carbon (GEFSOC), monitored changes in soil quality in two timescales (during 1980 and 2005) in two important food production zones of India. In view of the already available datasets in these two zones (Figures 1 and 2) and to generate the third time-series data (2010), we selected the hotspots (selected benchmark spots) for the present study from the BSR (Figure 3) and IGP (Figure 4)[3–12]. The international pipette method was applied for particle size analysis for quantifying the sand, silt and clay fractions according to size segregation procedure[13]. Coefficient of linear extensibility (COLE) was determined according to Schafer and Singer[14]. Bulk density (BD) was determined by field/moist method using core samples (diameter 50 mm) of known volume (100 ml)[15,16]. Hydraulic conductivity (saturated) was measured by taking 200 g of soil, uniformly tapped and saturated overnight, following the procedure of Richards[17]. The other analyses were made following standard procedures[18].

Black soil region

Black soils are common in the semi-arid tropics (SAT) in India, although their presence has been reported in the humid and arid bioclimates also[9,19]. These soils are spatially associated with red soils and thus form major soil groups of India occurring on different parent materials and under different climates. They have been reported in

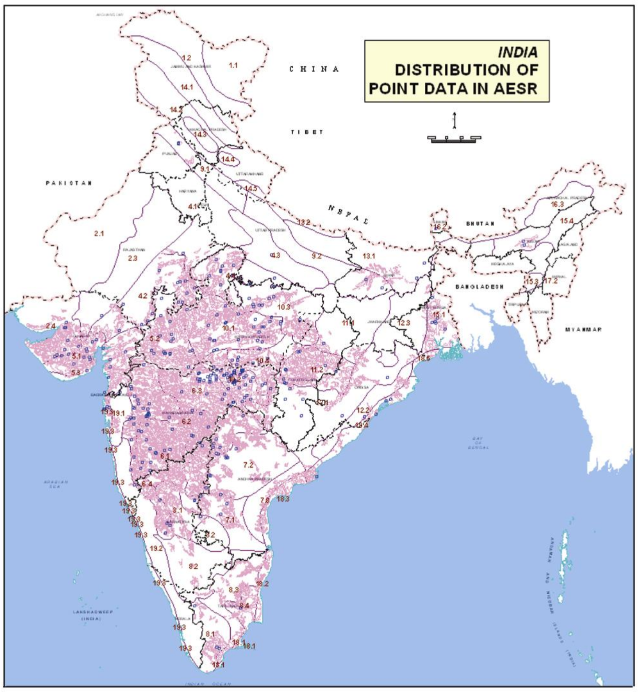

Figure 1. Distribution of available georeferenced benchmark soil spots in the black soil region (BSR).

the various physiographic positions such as red soils on the hills and black soils in the valleys in Maharashtra and Madhya Pradesh (MP)[19–21]. Besides, these soils have also been reported in juxtaposition in Tamil Nadu (TN), Maharashtra and Andhra Pradesh (AP)[22,23]. Exactly opposite situation was found in TN, where red soils are in the valleys while black soils are on the hills[24]. While black soils (Vertisols and their intergrades) are formed from basalts and other basic rocks[25], red soils are formed from various rock formations. Interestingly, spatially associated red and black soils can only be found in basalts, where part of these basalts contains amygdaloidal zeolites[3,26–29]. However, in some parts, basalts do not contain zeolites[24]. An account of zeolites and other cavity minerals has been given by Phadke and Khirsagar[29], while their utility in soils has been detailed elsewhere[4,19,28,30]. The black soils (Vertisols and their intergrades) represent a wide area and are potentially important crop production zones in the country. These are extensively spread in Uttar Pradesh, MP, Gujarat, Rajasthan, Maharashtra, AP, TN and Karnataka. Reports of Vertisols and their intergrades occur in many other states and their total acreage is 74.6 m ha, covering cover 36 agro-eco-subregions[4,31,32] (Figures 1 and 3). While selecting the soil sites, specific bioclimatic systems were identified taking into consideration rainfall (mean annual rainfall (MAR), mm). The rainfall variation in different bioclimatic systems in BSR and IGP is shown in Figure 5 *a* and *b* respectively.

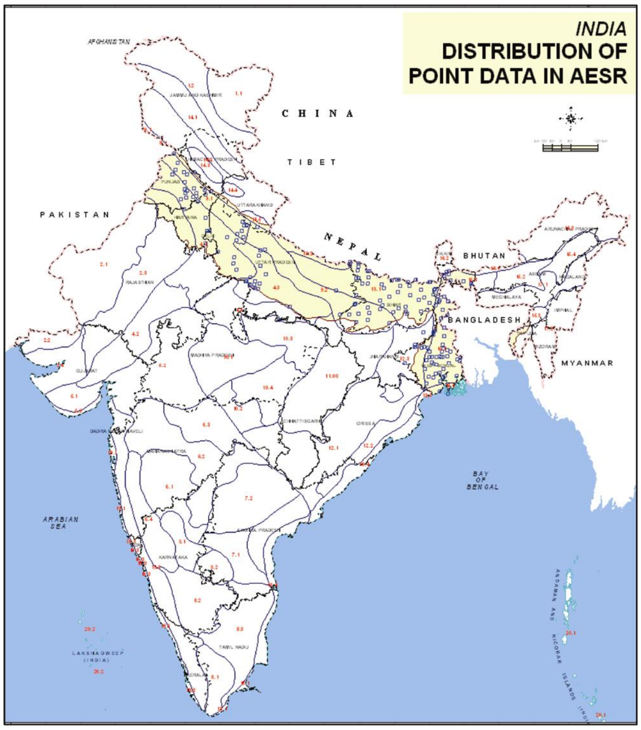

Figure 2. Distribution of available georeferenced benchmark soil spots in the Indo-Gangetic Plains.

The Indo-Gangetic Plains

The IGP ranks as one of the most extensive fluvial plains of the world. The deposit of this tract represents the last chapter of the earth's history in India. It came into existence due to the collision of the Indian and Chinese plates

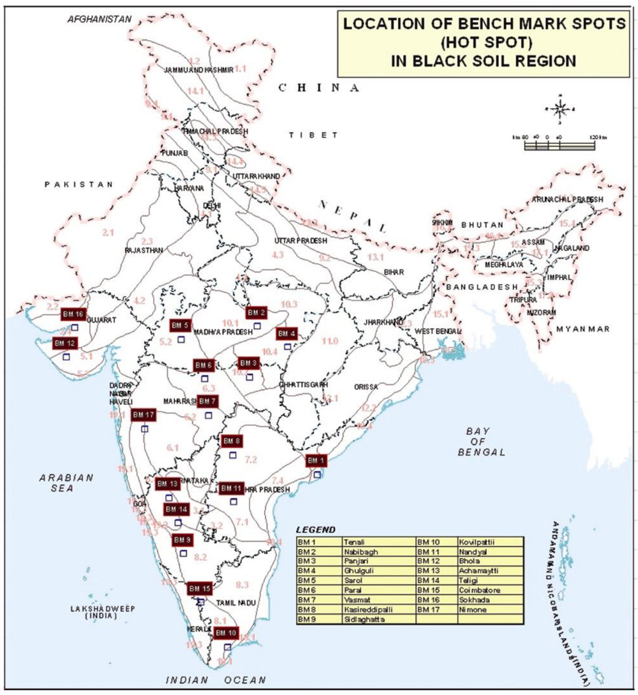

Figure 3. Location of hotspots in the black soil region.

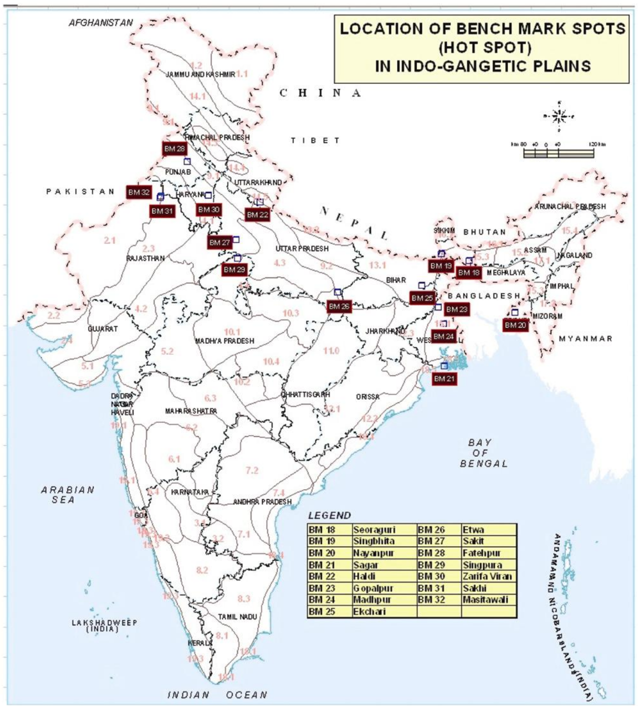

Figure 4. Location of hotspots in the Indo-Gangetic Plains.

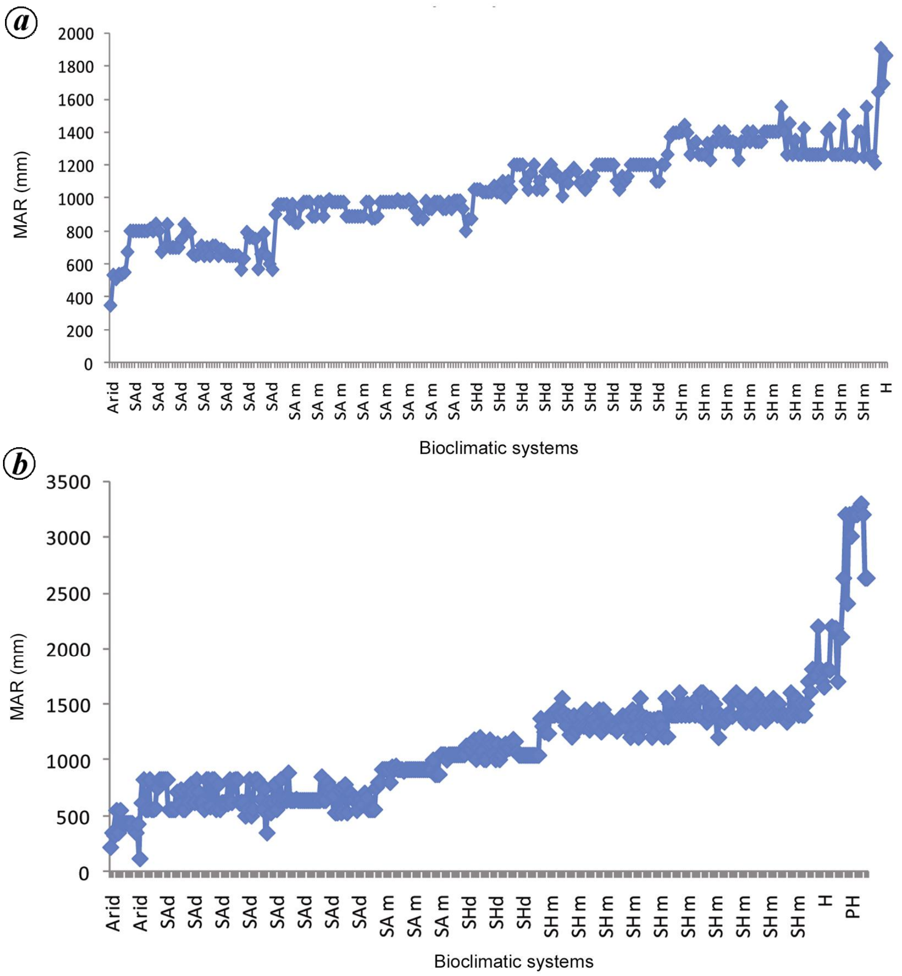

Figure 5. Rainfall variation in different bioclimatic systems: ***a***, BSR; ***b***, IGP. MAR, Mean annual rainfall.

during the Middle Miocene[33]. The fluvial deposits and landforms of IGP have been influenced by the stresses directed towards north and northeast. The major rivers of IGP have changed their courses and, at present, are flowing in southeast and easterly directions with convexity towards the southeast[34]. Thus, IGP shows a series of terraces, bars and meandering scars resulting in micro high and micro-low areas on apparently smooth topography[35,36]. IGP is still tectonically active and major sedimentation is taking place from large river systems. It has developed mainly by the alluvium of the Indus, Yamuna, Ganga and other rivers. The nature and properties of the alluvium vary in texture from sandy to clayey, calcareous to non-calcareous and acidic to alkaline. Though the overall topographic situation remains fairly uniform with elevations of 150 m amsl in the Bengal basin, and 300 m amsl in the Punjab plain, local geomorphic variations are significant[37]. The information of available soils in the IGP was used for developing SIS.

The soils were selected from the benchmark (BM) sites, so that they cover a widely extensive area in the landscape to facilitate easy monitoring of these sites. Though a few selected soils do not belong to the BM sites, it has been ascertained that each of these soil series covers an area larger than 20,000 ha (area required for any soil series to attain benchmark status)[38]. In order to make meaningful comparisons, the soils were so chosen that their substrate quality remains similar. This was the reason we selected Vertisols and their vertic intergrades in the BSR area. However, for the IGP we selected soils which have different substrate quality. A total of 17 BM spots were selected as hotspots. These include 34 pedon sites (P1–P34). Totally 15 soils in BSR belong to Vertisols and two to Inceptisols. Six are typical black soils (Typic Haplusterts). Kovilpatti soils are the only example of gypsiferous black soils. Out of 17 BM spots in the BSR, most of the pedons fall in semi-arid dry bioclimatic systems (Table 1). On the other hand, most of the spots represent humid to sub-humid bioclimatic systems in the IGP (Table 2).

Methodology for development of SIS

Global and National Soils and Terrain Digital Database (SOTER) framework, developed at ISRIC, The Netherlands

Table 1. Benchmark spots (hotspots) and their site characteristics in order of decreasing rainfall from sub-humid to arid bioclimatic systems in the black soil region (BSR)

Benchmark spots (hotspots)	AESR no.	Pedon no./ level of management	Soil series	State (district)	Mean annual rainfall (mm)	Soil taxonomy	Cropping system*
Sub-humid moist (SHm) bioclimatic systems							
BM1	7.3	P1/HM	Tenali	Andhra Pradesh (East Godavari)	1250	Very-fine, smectitic, isohyperthermic Sodic Haplusterts	Cotton–green gram//sorghum–maize//rice–sugarcane
		P2/LM				Very-fine, smectitic, isohyperthermic Sodic Haplusterts	Cotton–green gram//sorghum–maize//rice–sugarcane
BM2	10.1	P3/HM	Nabibagh	Madhya Pradesh (Bhopal)	1209	Fine, smectitic, hyperthermic Typic Haplusterts	Soybean–wheat
		P4/FM				Fine, smectitic, hyperthermic Typic Haplusterts	Soybean–wheat
Sub-humid dry (SHd) bioclimatic systems							
BM3	10.2	P5/HM	Panjri	Maharashtra (Nagpur)	1127	Very fine, smectitic, hyperthermic Typic Haplusterts	Cotton
		P6/FM				Fine, smectitic, hyperthermic Typic Haplusterts	Cotton
BM4	10.3	P7/HM	Ghulguli	Madhya Pradesh (Shahdol)	1100	Fine, smectitic, hyperthermic Typic Haplusterts	Rice–wheat/gram
		P8/LM				Fine, smectitic, hyperthermic Vertic Haplustepts	Rice–wheat/gram
BM5	5.2	P9/SW	Sarol	Madhya Pradesh (Indore)	1053	Fine, smectitic, hyperthermic Typic Haplusterts	Soybean–wheat
		P10/SO				Fine, smectitic, hyperthermic Typic Haplusterts	Soybean–chickpea//mango
Semi-arid dry (SAd) bioclimatic systems							
BM6	6.3	P11/HM	Paral	Maharashtra (Akola)	794	Very fine, smectitic, hyperthermic Sodic Haplusterts	Cotton–soybean/pigeonpea
		P12/LM		Maharashtra (Akola)		Fine, smectitic, hyperthermic Sodic Haplusterts	Cotton–soybean/pigeonpea
BM7	6.2	P13/HM	Vasmat	Maharashtra (Hingoli)	789	Very fine, smectitic, hyperthermic Typic Haplusterts	Sugarcane/sorghum, safflower
		P14		Maharashtra (Hingoli)		Very fine, smectitic, hyperthermic Typic Haplusterts	Sugarcane/sorghum, safflower
BM8	7.2	P15/HM	Kasireddipalli	Andhra Pradesh (Medak)	764	Fine, smectitic, isohyperthermic Typic Haplusterts	Soybean–pigeonpea/maize/safflower
		P16/TM		Andhra Pradesh (Medak)		Fine, smectitic, isohyperthermic Typic Haplusterts	Soybean–pigeonpea/maize/safflower
BM9	8.2	P17/HM	Sidlaghatta	Karnataka (Kolar)	661	Fine, smectitic, isohyperthermic Vertic Haplustepts	Rice–sugarcane/vegetables
		P18/LM		Karnataka (Kolar)		Fine, smectitic, isohyperthermic Vertic Endoaquepts	Rice–sugarcane/vegetables
BM10	8.3	P19/HM	Kovilpatti	Tamil Nadu (Tuticorin)	660	Very fine, smectitic, isohyperthermic Gypsic Haplusterts	Cotton–black gram
		P20/LM		Tamil Nadu (Tuticorin)		Very fine, smectitic, isohyperthermic Gypsic Haplusterts	Cotton–black gram

(*Contd*)

Table 1. (*Contd*)

Benchmark spots (hotspots)	AESR no.	Pedon no./ level of management	Soil series	State (district)	Mean annual rainfall (mm)	Soil taxonomy	Cropping system*
BM11	7.1	P21/HM	Nandyal	Andhra Pradesh (Kurnool)	650	Fine, smectitic, isohyperthermic Sodic Haplusterts	Cotton–sorghum/bajra//rice–groundnut/red gram
		P22/LM		Andhra Pradesh (Kurnool)		Fine, smectitic, isohyperthermic Sodic Haplusterts	Cotton–sorghum/bajra//rice–groundnut/red gram
BM12	5.1	P23/HM	Bhola	Gujarat (Rajkot)	650	Fine, smectitic, hyperthermic Vertic Haplustepts	Cotton–wheat/coriander
		P24/LM		Gujarat (Rajkot)		Fine, smectitic, hyperthermic Vertic Haplustepts	Cotton–wheat/sugarcane (fodder)
BM13	6.4	P25/HM	Achmatti	Karnataka (Dharwad)	638	Very fine, smectitic, isohyperthermic Sodic Haplusterts	Cotton–wheat/safflower/sorghum
		P26/LM		Karnataka (Dharwad)		Very fine, smectitic, isohyperthermic Sodic Haplusterts	Cotton–wheat/safflower/sorghum
BM14	3.2	P27/HM	Teligi	Karnataka (Bellary)	632	Fine, smectitic, isohyperthermic Sodic Haplusterts	Cotton–sorghum/pigeonpea/tobacco//paddy
		P28/LM		Karnataka (Bellary)		Very fine, smectitic, isohyperthermic Sodic Haplusterts	Maize–sorghum/Bengal gram
BM15	8.1	P29/HM	Coimbatore	Tamil Nadu (Coimbatore)	612	Very fine, smectitic, isohyperthermic Typic Haplusterts	Cotton–sorghum/pigeonpea//rice–sugarcane
		P30/LM		Tamil Nadu (Coimbatore)		Fine, smectitic, isohyperthermic Sodic Haplusterts	Cotton–sorghum/pigeonpea//rice–sugarcane
Arid (A) bioclimatic systems							
BM16	5.3	P31/HM	Sokhda	Gujarat (Rajkot)	533	Fine, smectitic (calcareous), hyperthermic Leptic Haplusterts	Cotton–bajra/jowar/castor/groundnut
		P32/FM		Gujarat (Rajkot)		Fine, smectitic (calcareous), hyperthermic Vertic Haplustepts	Cotton/bajra/castor-sesame
BM17	6.1	P33/HM	Nimone	Maharashtra (Ahmadnagar)	520	Very fine, smectitic, isohyperthermic Sodic Haplusterts	Soybean–wheat/gram
		P34/LM		Maharashtra (Ahmadnagar)		Very fine, smectitic, isohyperthermic Sodic Haplusterts	Soybean-jowar/sugarcane/gram

*/ 'or' // indicates 'new cropping system'. Perhumid: > 2000 mm MAR; Humid: 2000–1600 mm MAR; Sub-humid moist: 1600–1200 mm MAR; Sub-humid dry: 1200–1000 mm MAR; Semi-arid moist: 1000–850 mm MAR; Semi-arid dry: 850–550 mm MAR; Arid: < 550 mm MAR.

Table 2. Benchmark spots (hotspots) and their site characteristics in order of decreasing rainfall from perhumid to arid bioclimatic systems in the Indo-Gangetic Plains (IGP)

Benchmark spots (hotspots)	AESR no.	Pedon no./ level of management	Soil series	State (district)	Mean annual rainfall (mm)	Taxonomy	Cropping system*
Perhumid (PH) bioclimatic systems							
BM18	15.3	P35/HM	Seoraguri	West Bengal (Coochbehar)	3261	Clayey over loamy, mixed, isohyperthermic Typic Endoaqualfs	Rice
		P36/LM	Seoraguri	West Bengal (Coochbehar)		Clayey over loamy, mixed, isohyperthermic Typic Endoaqualfs	Rice
BM19		P37/HM	Singbhita	West Bengal (Darjilling)	2627	Fine-loamy, mixed, thermic, Umbric Endoaqualfs	Rice
		P38/LM	Singbhita	West Bengal (Darjilling)		Fine-loamy, mixed, thermic, Umbric Endoaqualfs	Rice
BM20		P39/HM	Nayanpur	West Tripura (West Tripura)	2178	Fine-loamy, mixed, hyperthermic Typic Endoaqualfs	Rice
		P40/LM	Nayanpur	West Tripura (West Tripura)		Fine-loamy, mixed, hyperthermic Typic Endoaqualfs	Rice
Humid (H) bioclimatic systems							
BM21	18.5	P41/HM	Sagar	West Bengal (24 Parganas)	1783	Fine, mixed, isohyperthermic Vertic Endoaqualfs	Rice
		P42/LM	Sagar	West Bengal (24 Parganas)		Fine, mixed, isohyperthermic Vertic Natraqualfs	Rice
BM22	13.2	P43/HM	Haldi	Uttarakhand (Pantnagar, Nainital)	1700	Coarse-loamy, mixed, hyperthermic Typic Hapludalfs	Maize/soybean–wheat
		P44/LM	Haldi	Uttarakhand (Pantnagar, Nainital)		Coarse-loamy, mixed, hyperthermic Typic Hapludalfs	Maize/soybean–wheat
BM23	12.3	P45/HM	Gopalpur	West Bengal (Birbhum)	1350	Fine, smectitic, hyperthermic Chromic Endoaquerts	Rice–potato/lentil/groundnut
		P46/LM	Gopalpur	West Bengal (Birbhum)		Fine, smectitic, hyperthermic Chromic Endoaquerts	Rice
BM24	15.1	P47/HM	Madhpur	West Bengal (Barddhaman)	1338	Fine, mixed, hyperthermic Vertic Endoaqualfs	Rice–mustard/potato
		P48/LM	Madhpur	West Bengal (Barddhaman)		Fine, mixed, hyperthermic Vertic Endoaqualfs	Rice
BM25	13.1	P49/HM	Ekchari	Bihar (Bhagalpur)	1105	Fine, smectitic, hyperthermic Vertic Endoaqualfs	Rice–maize/wheat
		P50/LM	Ekchari	Bihar (Bhagalpur)		Fine, smectitic, hyperthermic Vertic Endoaqualfs	Rice–maize/wheat

(*Contd*)

Table 2. (*Contd*)

Benchmark spots (hotspots)	AESR no.	Pedon no./ level of management	Soil series	State (district)	Mean annual rainfall (mm)	Taxonomy	Cropping system*
Sub-humid dry (SHd) bioclimatic systems							
BM26	9.2	P51/HM	Etwa	Uttar Pradesh (Varanasi Chanduli)	1003	Fine, mixed, hyperthermic Vertic Natraqualfs	Rice–wheat/barley/gram
		P52/LM	Etwa	Uttar Pradesh (Varanasi Chanduli)		Fine, mixed, hyperthermic Typic Natraqualfs	Rice–wheat/barley/gram
Semi-arid dry (SAd) bioclimatic systems							
BM27	4.3	P53/WL	Sakit	Uttar Pradesh (Etah)	782	Fine-loamy, mixed, hyperthermic Typic Natrustalfs	Rice–wheat
		P54/LM	Sakit	Uttar Pradesh (Etah)		Fine-loamy, mixed, hyperthermic Typic Natrustalfs	Rice–wheat
BM28	9.1	P55/HM	Fatehpur	Punjab (Ludhiana)	734	Coarse-loamy, mixed, hyperthermic Typic Haplusepts	Rice–wheat/bajra/mustard/pigeonpea/ soybean/gram
		P56/LM	Fatehpur	Punjab (Ludhiana)		Coarse-loamy, mixed, hyperthermic Inceptic Haplustalfs	Rice–wheat/bajra/maize/mustard/moong/ fodder
BM29	4.4	P57/HM	Singpura	Madhya Pradesh (Gwalior)	725	Fine-loamy, smectitic, hyperthermic Vertic Haplustalfs	Bajra–wheat/mustard/gram/urad
		P58/FM	Singpura	Madhya Pradesh (Gwalior)		Fine-loamy, smectitic, hyperthermic Vertic Haplustalfs	Bajra–wheat/arhar/moong/gram/mustard/ sesame/potato
BM30	4.1	P59/HM	Zarifa Viran	Haryana (Karnal)	705	Fine-loamy, mixed, hyperthermic Vertic Haplustalfs	Rice–wheat
		P60/LM	Zarifa Viran	Haryana (Karnal)		Fine-loamy, mixed, hyperthermic Vertic Natrustalfs	Rice–wheat
Arid (A) bioclimatic systems							
BM31	2.1	P61/HM	Sakhi	Rajasthan (Hanumangarh)	263	Coarse-loamy, mixed, hyperthermic Aridic Haplustepts	Cotton–wheat/mustard
		P62/LM	Sakhi	Rajasthan (Hanumangarh)		Coarse-loamy, mixed, hyperthermic Aridic Haplustepts	Cotton–wheat/mustard
BM32	2.3	P63/HM	Massitawali	Rajasthan (Sriganganagar)	221	Coarse-loamy, mixed, hyperthermic Aridic Haplustepts	Cotton–wheat/mustard/gram
		P64/LM	Massitawali	Rajasthan (Sriganganagar)		Coarse-loamy, mixed, hyperthermic Aridic Haplustepts	Cotton–wheat/mustard/gram

*/ 'or' // indicates 'new cropping system'. Perhumid: > 2000 mm MAR; Humid: 2000–1600 mm MAR; Sub-humid moist: 1600–1200 mm MAR; Sub-humid dry: 1200–1000 mm MAR; Semi-arid moist: 1000–850 mm MAR; Semi-arid dry: 850–550 mm MAR; Arid: < 550 mm MAR.

Table 3. Soil properties and parameters in the soil information system

Morphological properties		Physical properties	Chemical properties	Saturation extract
Horizon	Size	PSD	pH (H_2O)	Soluble cations
Depth	Grade	Total sand	pH (KCl)	Ca
Boundary	Volume	Very coarse sand	ΔpH	Mg
Distinctness	Presence/absence of krotovina	Coarse sand	EC	Na
Type	Presence/absence of animal faeces	Medium sand	$CaCO_3$	K
Diagnostic Horizon	Earth worm/insects, etc.	Fine sand	Carbonate clay	ECe
Matrix colour	Presence/absence of mollusc shells	Very fine sand	OC	Soluble anions
Dry	Effervescence	Silt	Exchangeable Ca	CO_3
Moist	Slight effervescence	Fine	Exchangeable Mg	HCO_3
Rubbed	Strong effervescence	Medium	Exchangeable Na	Cl
Mottle colour	Violent effervescence	Coarse	Exchangeable K	SO_4
Size	Other features: slickensides/pressure faces	Total clay	CEC	RSC
Grade	cracks	Coarse clay	BS	SAR
Abundance	Thickness depth (up to)	Fine clay	ECP	Saturation (%)
Texture	Soil taxonomy	BD	EMP	
Coarse fragments	National/local name	COLE	ESP	
Size		sHC	Zn	
Grade		WDC	Cu	
Volume		Moisture retention (kPa)	Mn	
Structure		33	Fe	
Granular		100	Exchangeable H	
Crumb		300	Exchangeable Al^{+3}	
Columnar		500	Total acidity ($BaCl_2$TEA)	
Prismatic		800	Carbonate equivalent (%)	
Platy		1000	Gypsum (%)	
Angular blocky		1500	Total carbon	
Sub-angular blocky			Total N	
Single grain			Total P	
Massive			Total K	
Consistence			Available N	
Wet			Available P	
Dry			Available K	
Moist			Available sulphur	
Porosity			Total sulphur	
Cutans			Fe (CBD)	
Nodules			Al (CBD)	
Conca			Al (ox)	
Conir			Mineralogy	
Conal				
Roots				

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 which is linked to GIS, permitting a wide range of applications. The SOTER methodology is detailed elsewhere[39].

Results and discussion

Soil information system of the IGP and BSR

Soil information system of the IGP: Details of information on geometric databases and attribute database in the form of soil profile and horizon information collated for the development of SISIGP and SISBSR in SOTER framework are given by Chandran *et al.*[39]. Earlier NBSS&LUP developed a soil map of India on 1 : 1 m scale[40] considering pattern of landforms, lithology, surface form and parent materials and soils. The map units are soil association at great group level[41] with description of dominant textural class, drainage class and soil characteristics. Soil map of the IGP was carved out from the 1 : 1 m map to use it as a geographic database for developing SOTER IGP. This soil map was digitized with different layers, viz. drainage, agroecoregions (AERs) and subregions (AESRs), and soils. The IGP is subdivided into eight AERs and 17 AESRs depending upon major physiography, climate and length of the growing period[31]. In SOTER IGP, physiography and lithology are the criteria used to differentiate terrain as detailed by Chandran *et al.*[39].

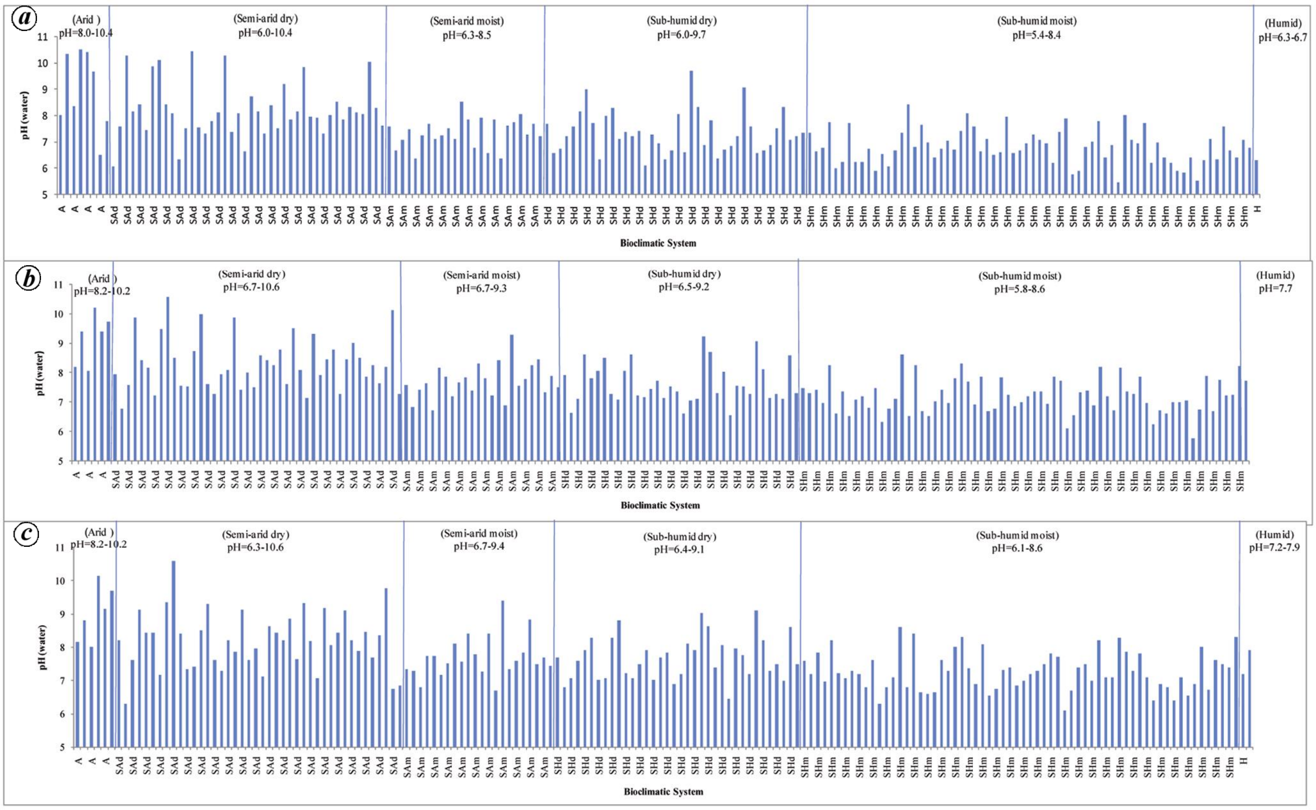

Figure 6. Variation of soil reaction (water pH) in IGP across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

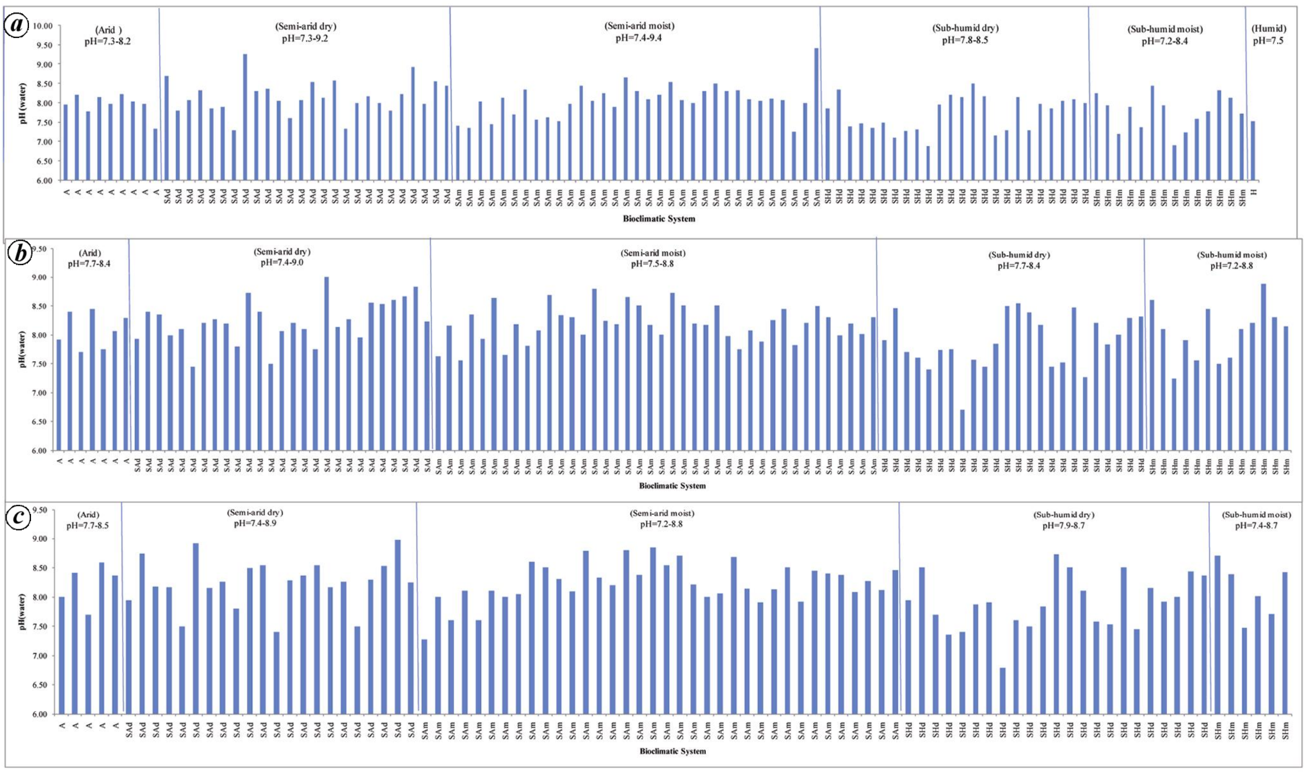

Figure 7. Variation of soil reaction (water pH) in BSR across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

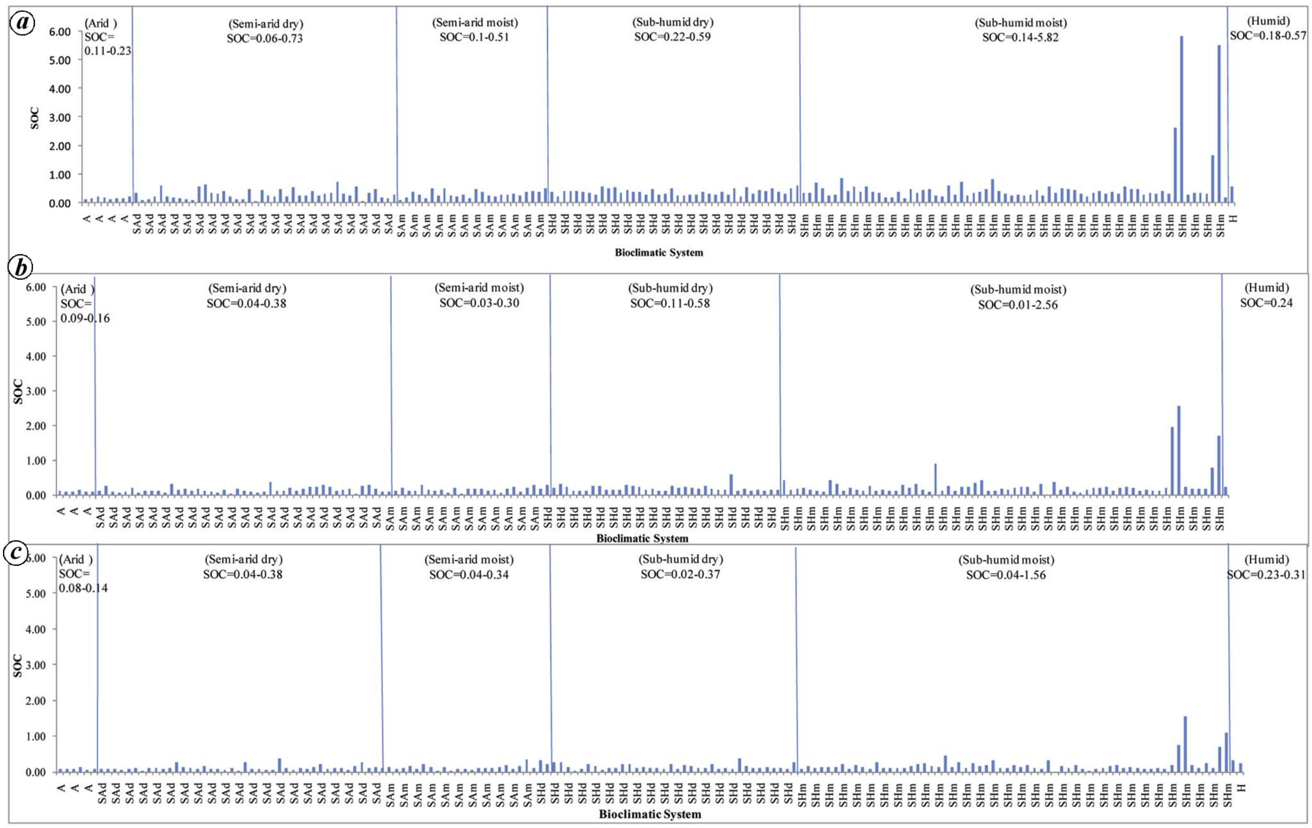

Figure 8. Variation of soil organic carbon (SOC) (%) in IGP across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

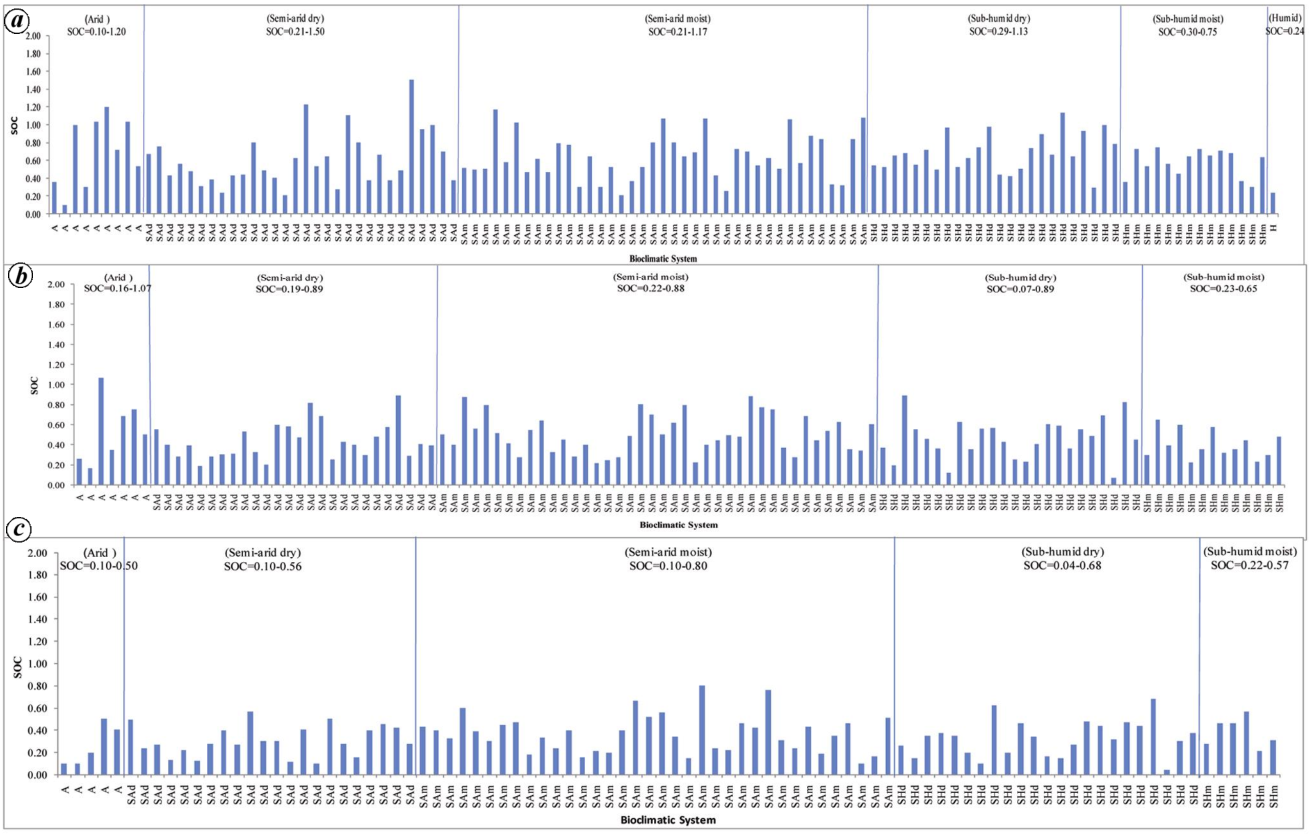

Figure 9. Variation of SOC (%) in BSR across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

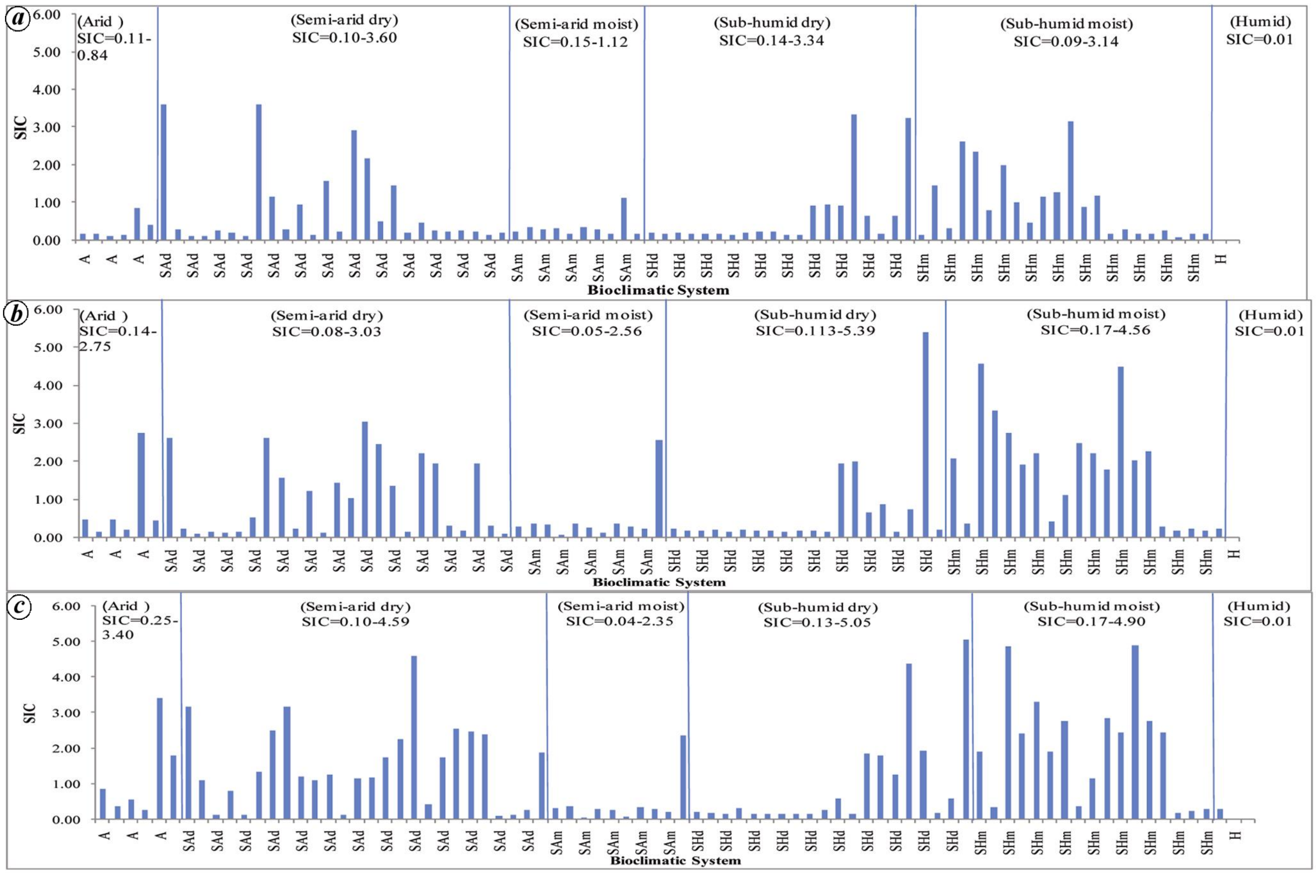

Figure 10. Variation of soil inorganic carbon (SIC) (%) in IGP across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

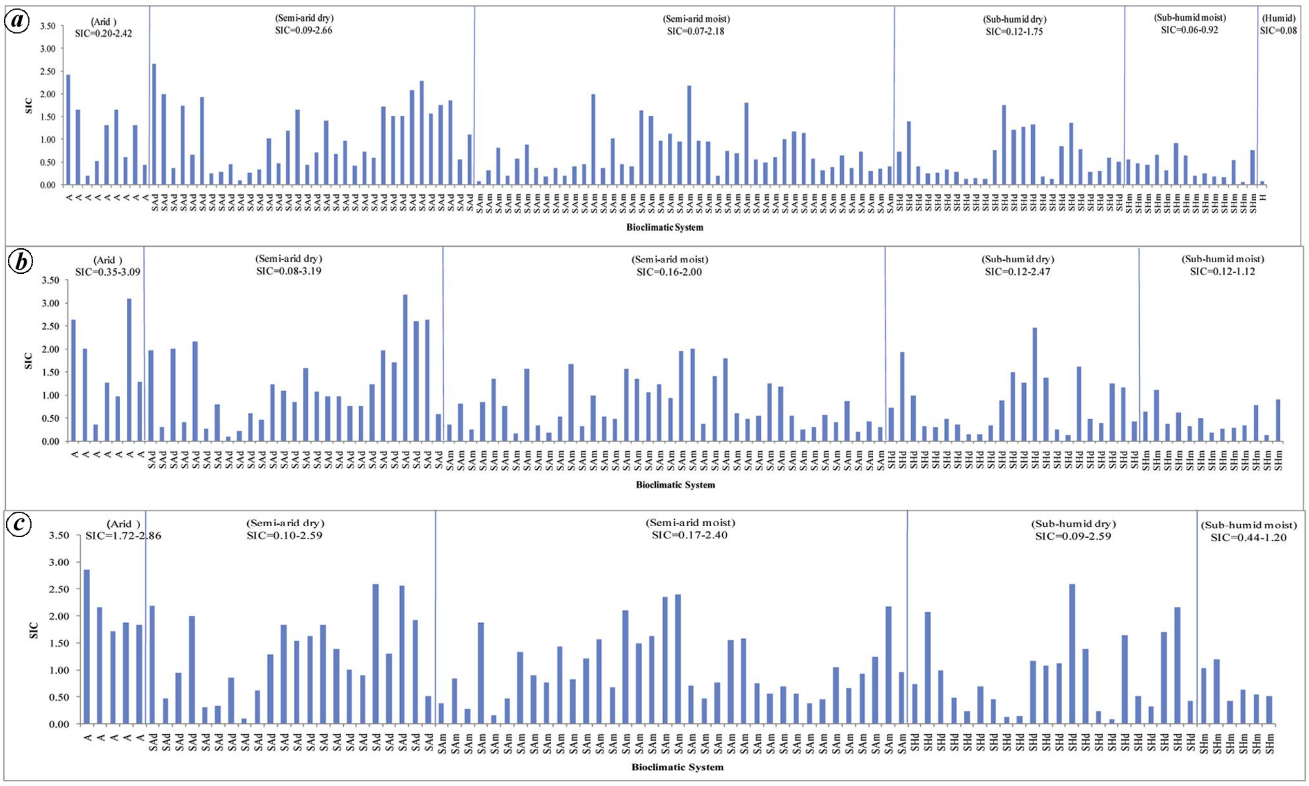

Figure 11. Variation of SIC (%) in BSR across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

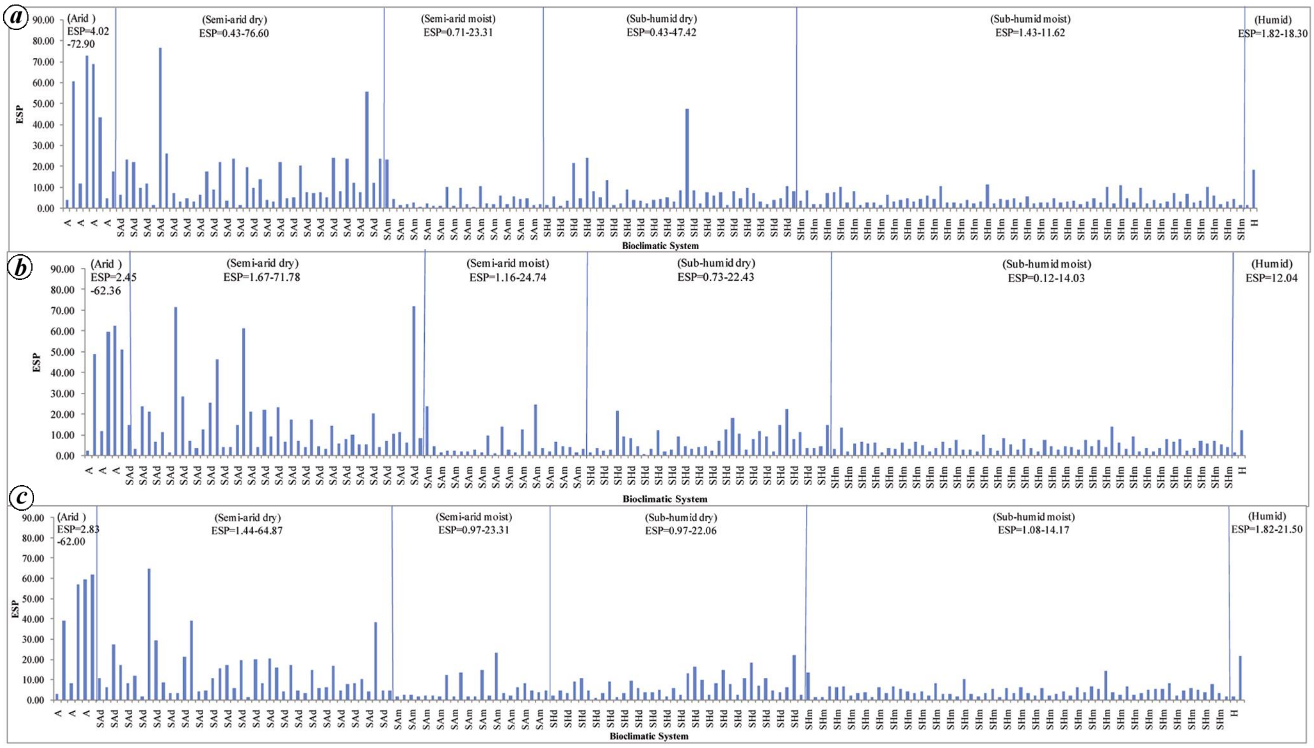

Figure 12. Variation of exchangeable sodium percentage (ESP) in IGP across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

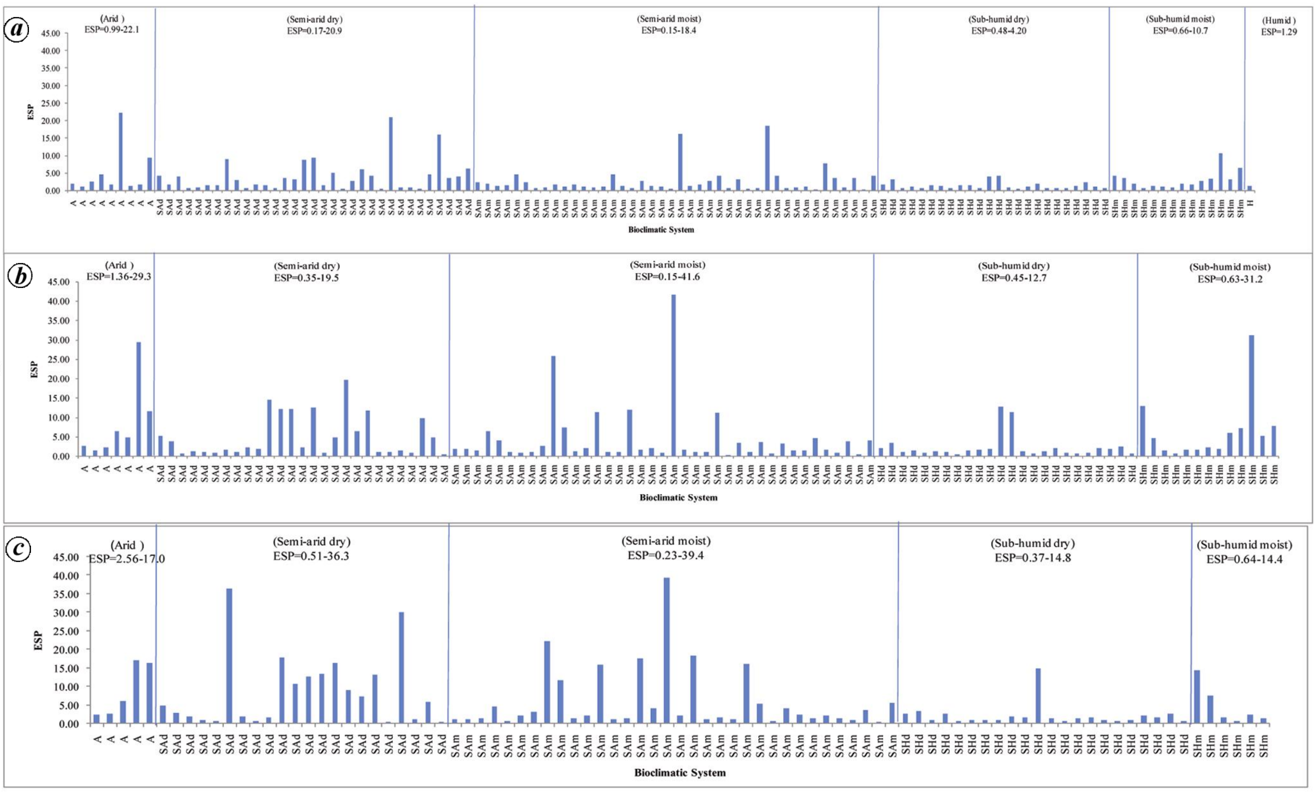

Figure 13. Variation of ESP in BSR across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

Soil information system of BSR: Black soils are generally confined to the Peninsular region. However, recent findings indicate their presence in the extra Peninsular areas of the country as well[42,43]. The importance of these soils for sustainable crop production necessitates assessing their spatial distribution. The SOTER BSR was developed

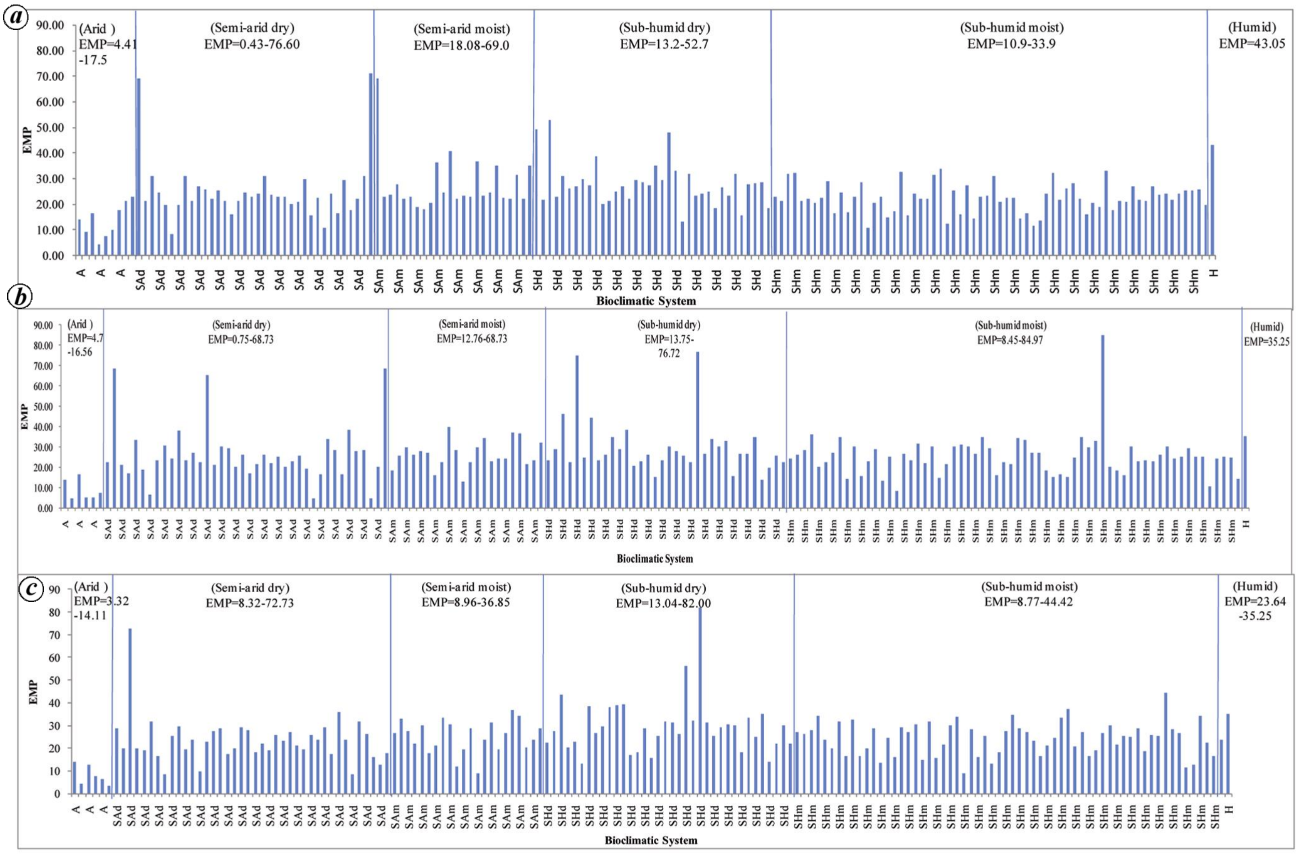

Figure 14. Variation of exchangeable magnesium percentage (EMP) in IGP across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

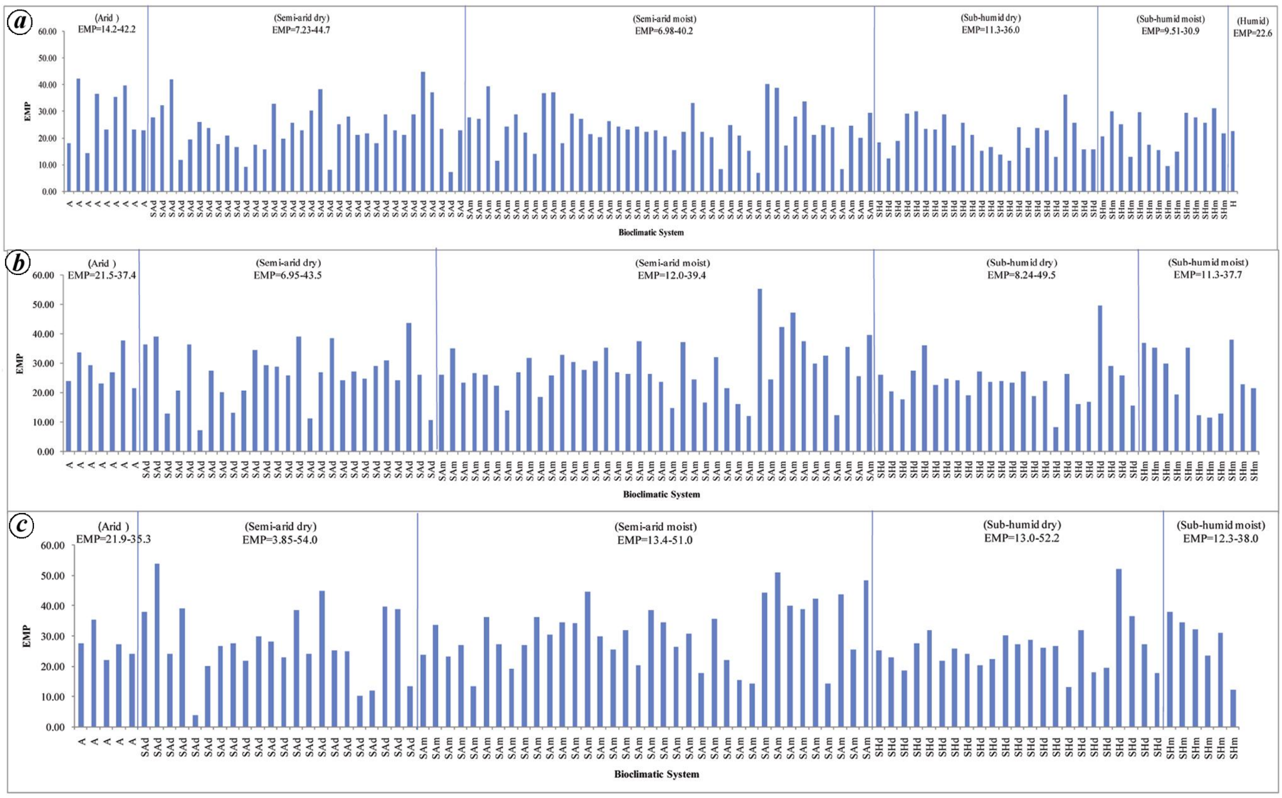

Figure 15. Variation of EMP in BSR across different bioclimatic systems: ***a***, 0–30; ***b***, 50–100; ***c***, 100–150 cm soil depth.

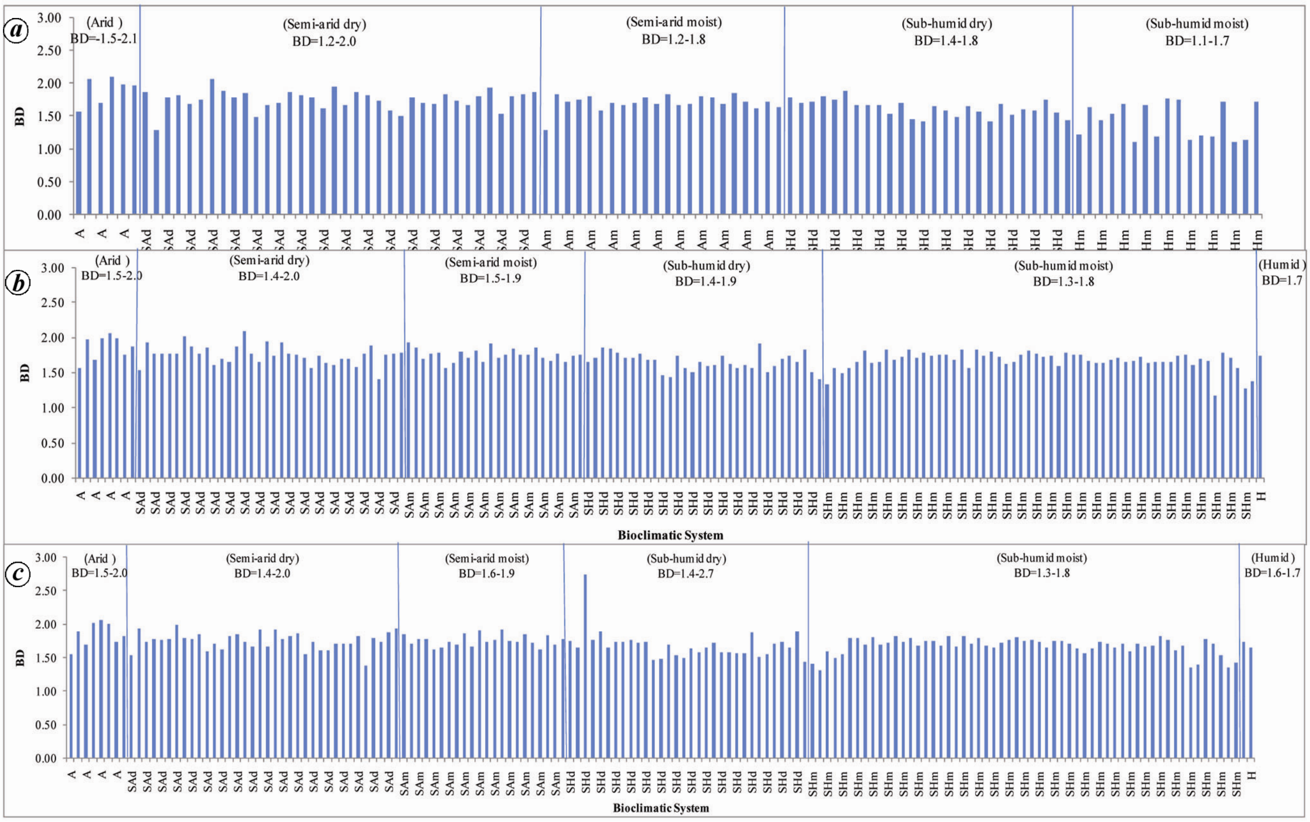

Figure 16. Variation of bulk density (BD) (mg m^{-3}) in IGP across different bioclimatic systems: ***a***, 0–30 cm; ***b***, 50–100 cm; ***c***, 100–150 cm soil depth.

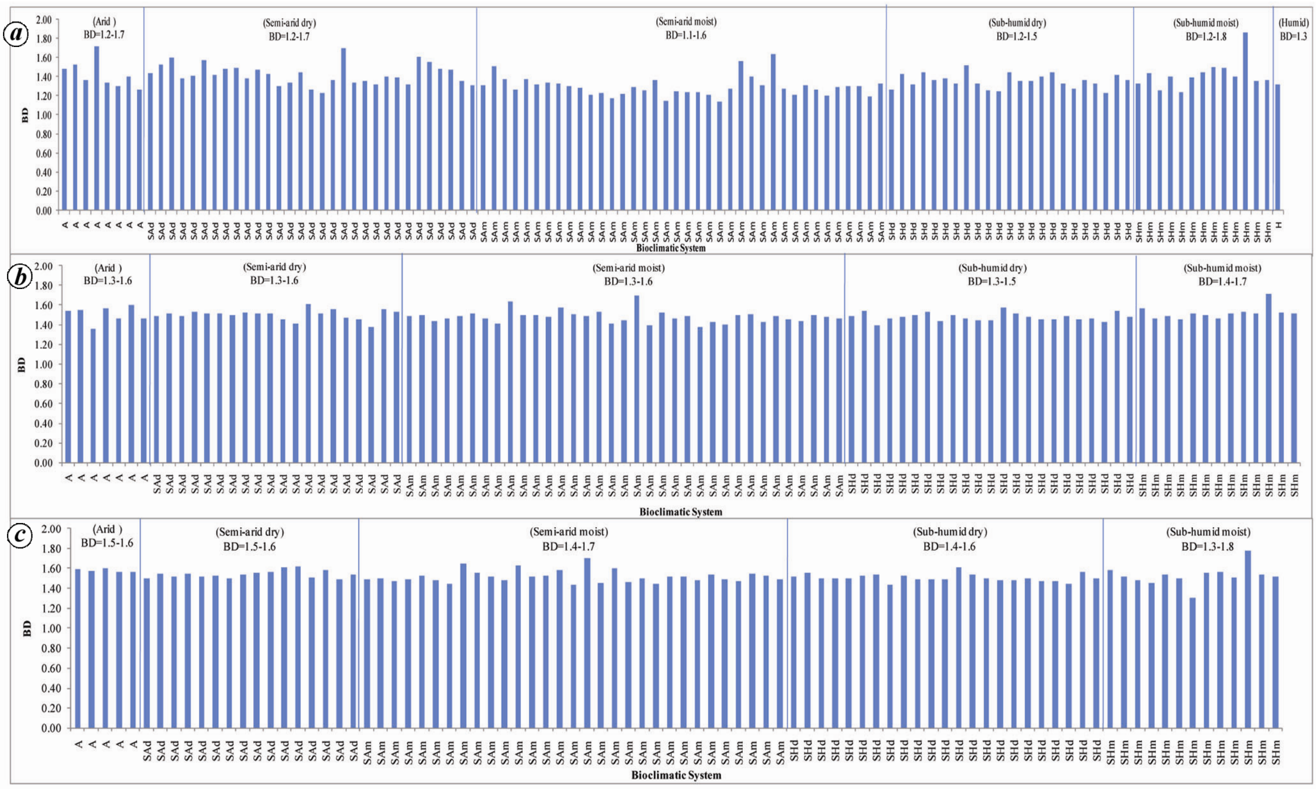

Figure 17. Variation of BD (mg m^{-3}) in BSR across different bioclimatic systems: ***a***, 0–30 cm; ***b***, 50–100 cm; ***c***, 100–150 cm soil depth.

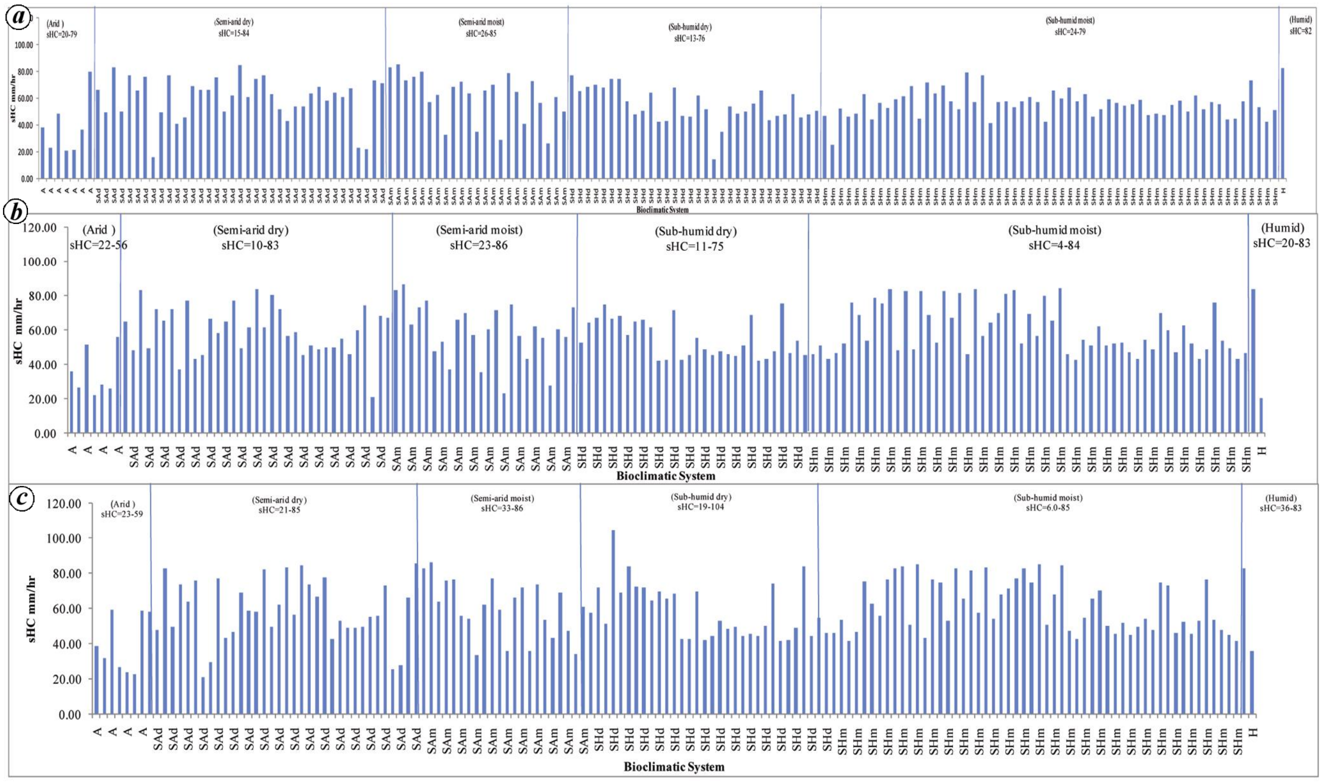

Figure 18. Variation of saturated hydraulic conductivity (sHC) (mm h^{-1}) in IGP across different bioclimatic systems: ***a***, 0–30 cm; ***b***, 50–100 cm; ***c***, 100–150 cm soil depth.

following the same methods as those of the SOTER IGP. A total of 101 soil series were placed in the SOTER BSR[39].

Assessment of database

The following sections assess the database generated from the IGP and BSR. Table 3 shows the strength and depth of the data generated. Since each soil pedon describes 129 parameters, it is difficult to describe all the parameters in this article. For brevity, we have selected a few datasets for both the IGP and BSR in different bioclimatic systems showing large variation in rainfall (Figure 5).

Soil reaction (pH)

Figure 6 shows the distribution of pH of soils in different bioclimatic systems for three different depths. In general, pH of sub-humid bioclimatic system is acidic, with some exceptions. Alkalinity of soil is common in sub-arid and arid climate. Soil pH gradually increases with depth. In BSR soil pH is generally alkaline for all depths and in all bioclimatic systems. Unlike the IGP, pH increase of the subsurface (50–100 and 100–150 cm) is more conscipuous (Figure 7).

Soil organic carbon

Soil organic carbon (SOC) decreases with soil depth. It also decreases in the dry semi-arid bioclimatic system. By and large, sub-humid dry, semi-arid moist and semi-arid dry bioclimatic systems store 0.6–0.73% of SOC in the IGP (Figure 8). The BSR, unlike the IGP, stores relatively more SOC on the surface (0–30 cm depth; Figure 9). This may be due to better substrate in the form of high smectite-rich clay in the black soils[44].

Soil inorganic carbon

Soil inorganic carbon (SIC), as reported earlier, increases with depth and also in the dry climatic zone. Figure 10 indicates appreciably high SIC at 100–150 cm depth. Depth distribution of SIC also shows greater increase below 30 cm soil depth in arid, semi-arid moist and sub-humid dry bioclimatic systems. Figure 11 shows distribution of SIC in BSR. In most cases, SIC is found to be less in the BSR than the IGP, irrespective of the bioclimatic system and soil depth.

Exchangeable sodium percentage

Exchangeable sodium percentage (ESP) in the IGP has been reported to be high, unlike the BSR (Figure 12).

Table 4. Database generated by the Indo-Gangetic Plains (figures indicate numbers only)

Properties	No. of observations		Morphological	No. of observations		Physical	No. of observations		Chemical	No. of observations		Saturated	No. of observations	
Site characteristics	IGP	BSR	properties	IGP	BSR	properties	IGP	BSR	properties	IGP	BSR	extract	IGP	BSR
Observation no	437	448	Horizon	2540	2221	Sand	2505	2162	pH	2458	2054	Saturation %	148	118
Toposheet no	437	448	Depth			Silt	2504	2141	EC	1713	1766	ECe	148	118
Photo no	437	448	Boundary	533		Clay	2502	2137	$CaCO_3$	1266	1553	Ca	148	118
Author and date of examination	437	448	Diagnostic horizon			BD	371	451	OC	2383	2089	Mg	148	118
Location (coordinates and other details)	437	448	Matrix colour	2125	1901	COLE	96	196	Exchangeable Ca	2181	2109	Na	148	118
Latitude and longitude	437	448	Mottle colour			Saturated hydraulic conductivity	1934	1673	Exchangeable Mg	2066	1986	K	148	118
Village	437	448	Texture	1273	1781	WDC	83	71	Exchangeable Na	2238	2036	Sum	148	118
Tehsil	437	448	Coarse fragments	127		Moisture retention	132	1913	Exchangeable K	2216	2033	CO_3	148	118
District	437	448	Structure	1071	2040				CEC	2342	2127	HCO_3	148	118
State	437	448	Consistence	982	2105				BS	1766	1961	Cl	148	118
Series and/or local name	437	448	Porosity						ECP	2181	1883	SO_4	148	118
Soil mapping legend	437	448	Cutans						EMP			SRC	148	118
API unit	437	448	Nodules						ESP	2220	1994			
Physiographic unit	437	448	Roots	776	2028									
Geology	437	448	Effervescence	514	1177									
Parent material	437	448	Other features: slickensides/pressure face											
Climate														
• Rainfall (mm)	333	314												
• Temperature (°C)	157	85												
• Relative humidity (%)														
Topography landform type	437	448												
Elevation amsl (m)	437	448												
Slope	437	448												
Erosion	437	448												
Run-off	437	448												
Drainage	437	448												
Groundwater	437	448												
Flooding	437	448												
Salt/alkali	437	448												
pH	437	448												
EC	437	448												
Stone size	437	448												
Stoniness	437	448												
Rock outcrops (distance apart m)	437	448												
Natural vegetation	437	448												
Crop yield (kg/ha)	437	448												
Present land use	437	448												
Classification	437	448												
Land capability classification	437	448												
Land irrigability class	437	448												
Remarks	437	448												

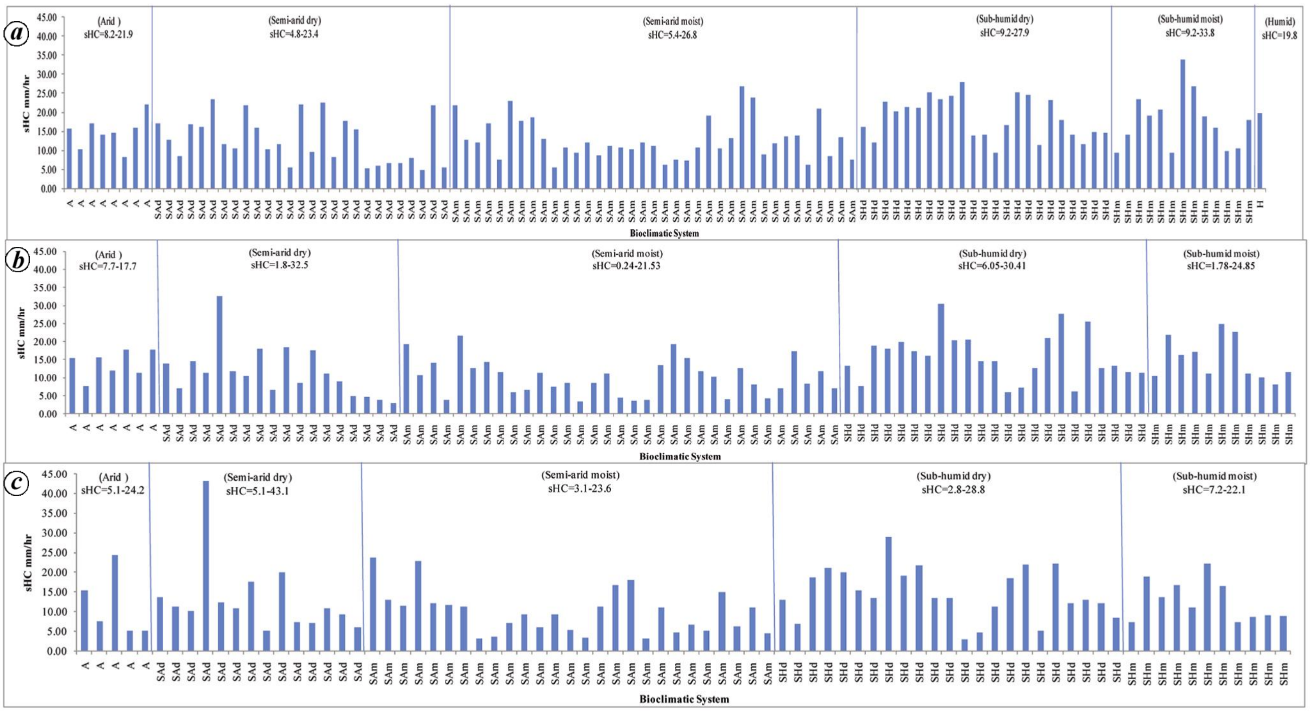

Figure 19. Variation of sHC in BSR across different bioclimatic systems: ***a***, 0–30 cm; ***b***, 50–100 cm; ***c***, 100–150 cm soil depth.

High ESP in semi-arid and arid tracts of the IGP is the major problem of these soils (Figure 12). In contrast, BSR rarely cross the limit of 15% in most cases (Figure 13). In many soils, the ESP values are even less. This is notwithstanding the fact, that at greater depths, a value of 40% ESP in a few soils is not uncommon in both the regions.

Exchangeable magnesium percentage

Exchangeable magnesium percentage (EMP) has often been considered to be a problem for soils. The EMP values, in general, increase from humid to dry bioclimate in IGP, although there are no definite trends with depth in a particular bioclimatic system. High EMP value nevertheless lead to similar problem like poor drainage caused by high BD and exchangeable sodium percentage (Figure 14). BSR in many cases have appreciable quantity of exchangeable magnesium as shown in Figure 15.

Bulk density

Figure 16 shows the variation in BD in IGP. In general, dry bioclimatic systems have a tendency to have more BD compared to areas receiving more rainfall (humid to subhumid). There is also an increase in BD with depth, cutting across different bioclimatic systems. This trend is also observed in BSR (Figure 17).

Saturated hydraulic conductivity

Figure 18 shows the saturated hydraulic conductivity (SHC) ranges, cutting across different bioclimatic systems. In IGP, the sHC values are relatively high when compared with those in BSR (Figures 18 and 19).

Conclusion

Assessment of the datasets shows that there are a few parameters which influence other parameters to control soil and land quality for agricultural land-use planning. These datasets have been utilized for quantifying soil drainage, relative crop yield index, land evaluation methods for land-use planning using minimum datasets to assess soil and land quality (Table 4), as described in the subsequent articles in this issue[32,45–48].

The need for relevant and pertinent datasets to develop a SIS for a particular state[49] and for a part of the Indian subcontinent has been earlier explained[1]. With the changing global scenario, the need at present is to produce a fresh group of expertise with sufficient knowledge on agriculture and allied sciences. These experts should be armed with the SIS developed through this project and will be able to analyse issues like land degradation, soil diversity, crop planning in different agroecological sub-regions and change in soil and land quality parameters as influenced by land-use and/or climate changes[1,49].

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