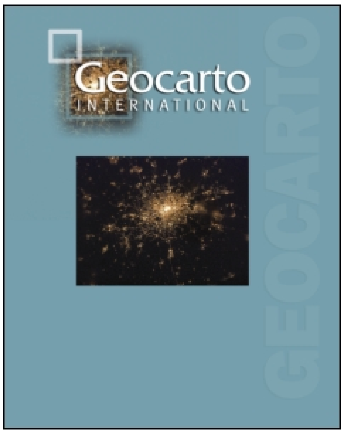

Geocarto International
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t759156373

Computerized database on salt affected soils in western and central India using GIS

A. K. Mandal [a]; R. C. Sharma [a]
[a] Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana, India

First Published:October2008

To link to this Article: DOI: 10.1080/10106040701207589
URL: http://dx.doi.org/10.1080/10106040701207589

Geocarto International
Vol. 23, No. 5, October 2008, 373–391

Computerized database on salt affected soils in western and central India using GIS

A.K. Mandal* and R.C. Sharma

Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana, India 132001

(*Received 15 January 2007; final version received 15 November 2007*)

Salt affected soils occupy significant areas in western and central India manifested by the arid and semiarid climate, sandy/clayey soil texture, absence of natural drainage, and inadequate infrastructure and irrigation development. These soils are productive following reclamation and appropriate management. The National Remote Sensing Agency, Hyderabad (India) published state-wise maps of salt affected soils in India on 1:250,000 scale using a legend that includes physiography, soil characteristics, and the aerial extent of the mapping units. In the analogue form, voluminous data contained in such maps were difficult to handle by users of varied backgrounds. An attempt was made to prepare a computerized database of salt affected soils for easy access, retrieval, and manipulation of spatial and attribute data useful for management of salt affected soils. The salt affected soils maps were prepared, for Rajasthan, Gujarat, Madhya Pradesh, and Maharashtra states, overlaying digitized layers of SAS polygons and the Survey of India basemap using the ILWIS (Integrated Land and Water Information System) software. GIS was used to prepare a composite (master) database of western and central India that showed the extent and distribution of salt affected soils. A relational database was prepared combining the digitized polygons with soil characteristics such as nature and degree of salinity (presence of higher concentration of neutral salts and neutral soil reaction), sodicity (presence of higher concentration of basic salts and alkaline reaction) and ground coverage. The regional and zonal databases of salt affected soils were prepared at a suitable scale overlaying agro-climatic regions agro-climatic zones. Spatial relation of salt affected soils with physiography, climate, geology, and agro-eco-sub-regions were evaluated employing map calculations in GIS. Saline soils were prevalent in Gujarat, and Rajasthan while sodic soils were dominant in Maharashtra and Madhya Pradesh. These were distributed primarily in the arid (B) plain of Rajasthan, alluvial (A) and coastal (D) plains of Gujarat, and peninsular plain (F) of Maharashtra and Madhya Pradesh. It occupied 2,596,942 ha (78%) in the western (Rajasthan and Gujarat) and 733,608 ha (22%) in the central (Madhya Pradesh and Maharashtra) regions. The SAS occupied 3.3 million ha in the western and central region constituting 50% of the total salt affected soils in India. The saline and sodic soils occupied 2,069,285 ha (62%) and 1,261,266 ha (38%), respectively.

Keywords: salt affected soils; saline soil; sodic soil; agroclimatic region; agroclimatic zone; database; GIS

1. Introduction

Salt affected soils are important ecological entities occupying 6% of the global land surface and 2% of the geographical area in India (Yadav 2003). The significant occurrence

*Corresponding author. Email: akmondal@cssri.ernet.in

ISSN 1010-6049 print/ISSN 1752-0762 online

DOI: 10.1080/10106040701207589
http://www.informaworld.com

of salt affected soils lies in the arid and semiarid regions reducing considerably (7–8%) the productive capacity of the land surface in the world. To mitigate the increasing demand for food production with increasing population growth, these soils with moderate production capacity need to be brought under cultivation. Sharma (1999) showed that grain yield of wheat increased from 0.1 tons/ha to 5.7 tons /ha in alkali soils with an increase of the productivity index from 15 to 62 following reclamation while artificially drained saline soils showed the grain yield of wheat increased from less than 0.1 tons/ha to 5.1 tons/ha with an increase in the productivity index to 43.

Agro-climatic regions (ACR) and zones (ACZ) were delineated by the Planning Commission of India for agricultural development under the National Agricultural Research Programme (NARP) based on the climate, soil types and physiographic features (Ghosh 1991, Basu and Guha 1996). The characteristics of salt affected soils vary with respect to the physiographic condition, climate, parent material, and salt composition. Specific management is required for soils developed under the influence of micro-climate, topography, salt concentration, and other local conditions. Regional and zonal databases are therefore necessary with appropriate scale to provide information on the characteristics, distribution, and extent of salt affected soils for micro-level planning in salinity management.

With the advent of computerized information technologies using the GIS, analogue maps were converted to digital format for easy access, retrieval, and manipulation of voluminous information on soil and related parameters. It facilitates linking spatial and attributes data stored in a GIS frame work for parallel visualization. Numerous databases are available at the global and national level that show systematic entry of data in appropriate scale for planning management of soil resources. The FAO (Food and Agriculture Organization of the United Nations) Soil Map of the World (FAO 1996) is a unique database used as a source of soil information at continental, global, and national scale. While GLASOD (Global Assessment of the status of Human-induced Soil Degradation), SOTER (World Soils and Terrain Digital Database), WISE (World Inventory of Soil Emission Potential), and ISIS (ISRIC Soil Information System) are important databases at the global level (Oldeman and Van Englen 1993, King *et al.* 1994, Batges 1996, Stolbovoi *et al.* 2001), SSURGO (Soil Survey Geographic Database), STATSGO (State Soil Geographic Database), NATSGO (National Soil Geographic Database) of the USA (Lytle 1993), CanSIS (Canadian Soil Information System), NSDB (National Soil Database), AAFC (Agriculture and Agri-Food Canada) of Canada (Coote and MacDonald 2000), and ASRIS (Australian Soil Resource Information System) of CSIRO, Australia (Johnston *et al.* 2003), are some of the national databases prepared at suitable scales to aid in the management of natural resources. The global network on the integrated soil management for sustainable use of salt affected soils under the Land and Plant Nutrition Management Services of FAO created databases on the nature and distribution of salt affected soils at the global and regional scale.

The National Remote Sensing Agency (Department of Space) Hyderabad, prepared state-wise the salt affected soils map of India (NRSA 1997) on 1:250,000 scale using remote sensing (LANDSAT) data and ground truth jointly with the Central Soil Salinity Research Institute, Karnal (ICAR), National Bureau of Soil Survey and Land Use Planning, and Nagpur (NBSS & LUP, ICAR). The database contains voluminous data comprised of maps showing physiographic features, distribution and extent of salt affected soils supported by a basemap with latitude/longitude coordinates, and a descriptive dataset showing nature and degree of salinity/sodicity. In the analogue form it is extremely difficult for users to retrieve the desired data. Such data entered in GIS format produce thematic layers and facilitate overlay and map calculations required for planning and management of land degradation.

Mandal and Sharma (2006) used GIS to integrate salt affected soil maps for a composite database of the Indo-Gangetic Plain in India and derived information on the extent and distribution of salt affected soils for agro-climatic regional and zonal planning. Integrated GIS overlays of multiple thematic layers were used to generate a State map of SAS (Mandal and Sharma 2005). A relational database was prepared integrating spatial and attribute datasets for salt affected soils using GIS. Mandal and Sharma (2001) showed integrated GIS overlay of topology with the spatial and non-spatial information on salt affected soils derived from remotely sensed data to manage soil salinity in irrigated agriculture. Sharma (2002) demonstrated the use of GPS in farm level mapping of SAS.

The widespread occurrence of salt affected soils is a common phenomenon of the arid and semi-arid regions in Rajasthan, Gujarat, Madhya Pradesh and Maharashtra states located in western and central India. Aridity, poor ground water quality, lack of infrastructure for irrigation, and absence of natural surface drainage caused development of salt affected soils, rendering vast areas unproductive. This objective of the present study is to develop a computerized database of salt affected soils using GIS that can be used for agro-climatic planning in western and central India.

2. Materials and methods

2.1 *Description of the study areas*

The study area lies between 15°30′ and 30°12′N and 68°04′ and 84°30′ E comprised of four states viz Rajasthan, Gujarat, Madhya Pradesh, and Maharashtra (Figure 1). Six ACRs viz VII, VIII, IX, XII, XIII and XIV and 36 ACZs were identified by the Planning Commission of India (Ghosh 1991) for regional planning (Table 1). The arid and semi-arid climate and limited irrigation account for 14–22% of the gross cropped area in this region. The poor drainage conditions coupled with arid climate, poor quality of ground water, and lack of adequate infrastructure and irrigation in arid and black soil regions caused development of salt affected soils.

The State of Rajasthan, located between 69°30′ to 78°12′E and 23°30′ to 30°12′N covering 34.2 M ha, is comprised of two broad physiographic units (Western Plain and Central Highlands) and three geological regions (viz aeolian sands, alluvium, and Aravalli). The northern and western parts show semi-arid to arid climate under desert conditions, while semi-arid to sub-humid climate is prevalent in the southern and eastern parts of the state. On the basis of the rainfall, temperature, soil types, and existing cropping pattern, nine ACZs were identified in the state by the Planning Commission of India (Ghosh 1991). On the basis of the climate, evapotranspiration (PE), actual evapotranspiration (AE), and length of growing period (LGP) for a normal cropping system, four agro-ecological sub-regions (Shyampura and Sehgal 1995) were identified for state level regional planning. The agricultural situation showed that the extent of the cultivated area is 13.4 million hectares and the irrigation potential is 3.1 million hectares. The estimated food grain production is 6.0 million tonnes. Principal crops are rice, barley, jowar, millet, maize, gram, wheat, oilseeds, pulses, cotton, and tobacco.

The Gujarat State, located between 20°01′ to 24°07′N and 68°04′ to 74°04′E covering 19.6 M ha, is comprised of three major physiographic units including Central Highlands, Western Hills, and West Coast and three geological formations including Pre-Cambrian, Archeans, and Aravallis. The climate varies widely from semi-arid in the northwest to sub-humid tropical monsoonal in the southeastern parts. Eight agro-eco-sub-regions (Sharma

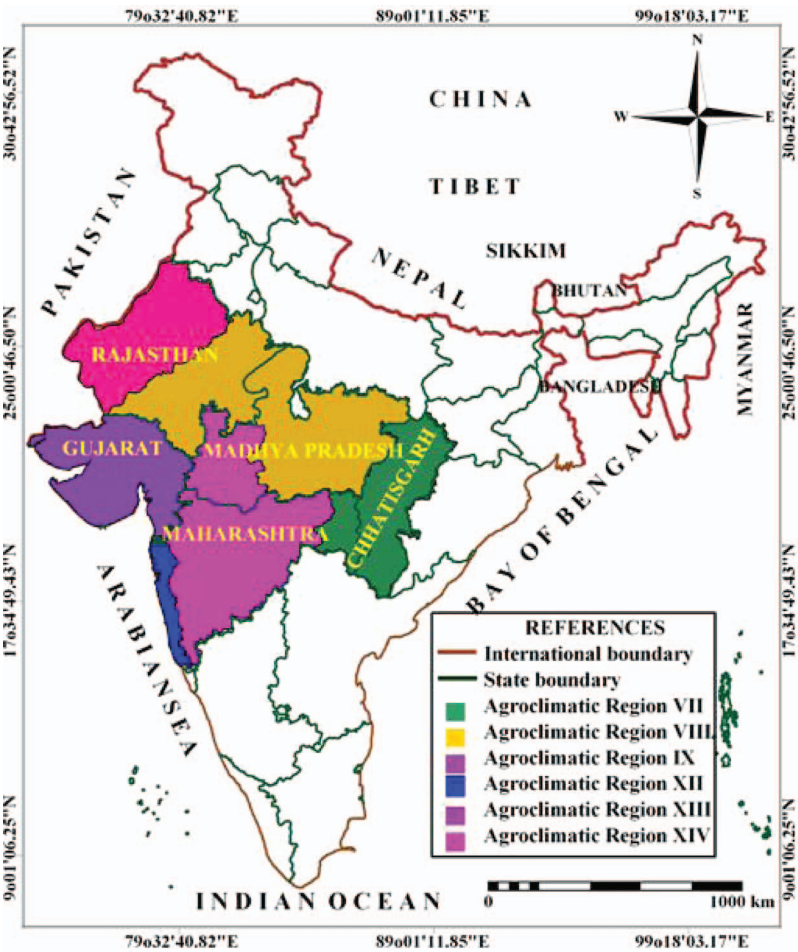

Figure 1. Location of the study area and distribution of ACRs. Available in colour online.

et al. 1994) and nine ACZs (Ghosh 1991) were identified for agricultural planning. The state occupies a significant position as a producer of tobacco, cotton, and groundnuts in the country. The total irrigation potential is 3.5 million hectares (Dubey *et al.* 1995).

The Madhya Pradesh State, located between 18°05′to 26°01′N and 72°05′ to 84°30′E covering 44.34 M ha, is comprised of three major physiographic regions including the North-Deccan plateau, Central Highlands, and Eastern Plateau and three geological formations comprised of archaeans, metamorphic to sub-recent, and recent alluvium. The climate varies from semi-arid in north-western to sub-humid to humid tropical in southeastern parts. Eight ACZs (Ghosh 1991) and nine agro-eco-sub-regions (Tamgadge *et al.* 1996) were identified in the state. Agriculture is the primary occupation of the 73% of the population in the state. About 49% of the state is cultivable. The foodgrain production is 14.9 million metric tonnes. Major crops include wheat, rice, and pulses. The net area under irrigation is 5.6 million hectares.

The Maharashtra State, located between 15°36′ to 21°48′N and 72°27′ to 81°07′E covering 30.7 M ha, is comprised of three physiographic regions (Coastal, Ghats, and

Table 1. Agro-climatic regions and zones in western and central India.

Name of the state	Name of the Agro-climatic region (ACR)	Name of the Agro-climatic zone (ACZ)
Gujarat	ACR XIII: Gujarat Plains and Hills Region	ACZ 1: South Gujarat Heavy Rainfall Zone
		ACZ 2: South Gujarat Zone
		ACZ 3: Middle Gujarat Zone
		ACZ 4: North Gujarat Zone
		ACZ 5: North Saurashtra
		ACZ 6: Bhal and Coastal Area
Rajasthan	ACR XIV: Western Dry Region	ACZ 1: Arid Western Zone
		ACZ 2: Irrigated North West Plain Zone
		ACZ 3: Transitional Plain of Inland Drainage Zone
		ACZ 4: Transitional Plain of Luni Basin Zone
		ACZ 5: Semi Arid Eastern Plain Zone
	ACR VIII: Central Plateau and Hills Region	ACZ 6: Flood Prone Eastern Plain Zone
		ACZ 7: Sub Humid Southern Plain Zone
		ACZ 8: Humid Southern Plain Zone
		ACZ 9: Humid South East Plain Zone
Maharashtra	ACR XII: West Coast Plains and Hills Region	ACZ 1: South Konkan Coastal Zone
		ACZ 2: North Konkan Coastal Zone
		ACZ 3: Western Ghat Zone
	ACR IX: Western Plateau and Hills Region	ACZ 4: Sub-montane Zone
		ACZ 5: Western Maharashtra Plain Zone
		ACZ 6: Western Maharashtra Scarcity Zone
		ACZ 7: Central Maharashtra Plateau Zone
	ACR VII: Eastern Plateau and Hills Region	ACZ 8: Central Vidarbha Zone
		ACZ 9: Eastern Vidarbha Zone
Madhya Pradesh	ACR VII: Eastern Plateau and Hills Region	ACZ 1: Chattisgarh Plain Zone
		ACZ 2: Bastar Plateau Zone
		ACZ 3: North Hill Zone of Chattisgarh
	ACR VIII: Central Plateau and Hills Region	ACZ 4: Kymore Plateau and Satpura Hill Zone
		ACZ 5: Vindhya Plateau Zone
		ACZ 6: Central Narmada Valley Zone
		ACZ 7: Gird Zone
		ACZ 8: Bundelkhand Zone
		ACZ 9: Satpura Plateau Zone
	ACR IX: Western Plateau and Hills Region	ACZ 10: Malwa Plateau Zone
		ACZ 11: Nimar Valley Zone
		ACZ 12: Jhabua Hills Zone

Plateau) and two geologic zones (alluvium and Deccan trap). The climate varies from semiarid in the central and south-central to humid tropical in the north and eastern parts of the state. Three agro-eco-sub-regions (Challa *et al.* 1995) and six ACZs (Ghosh 1991) were identified for regional planning in the state. Agriculture is the principal occupation of 65% of the population. The net irrigated area is 2.97 million hectares. Principal crops are rice, jowar, bajra, wheat, tur, mung, urad, gram, and other pulses.

2.2 *Data, software and equipment used*

Salt affected soil maps of India on 1:250,000 scale were used for digitization. ILWIS software (version 3.3) was used for geo-referencing, digitization, entry, and storage of attribute data and map calculation operations. The Survey of India (Government of India) maps on 1,000,000 scale were used to generate thematic layers of administrative and political boundaries, infrastructure, irrigation/drainage, and settlements to prepare a basemap. The published maps of ACZs and regions (Ghosh 1991) were used to delineate boundaries of ACRs and ACZs. The boundaries of agroecosubregions, physiography, geology, and rainfall were delineated from the published maps of the National Bureau of Soil Survey and Land Use Planning, ICAR, New Delhi (Sharma *et al*. 1994, Challa *et al*. 1995, Shyampura and Sehgal 1995, Tamgadge *et al*. 1996). A Cal Comp (A0) digitizer, scanner, and printer attached to a Pentium (PIV) computer equipped with Microsoft Windows XP and Office (2000) were used for entry, editing, and analysis of map and attribute data and drawing printed outputs.

2.3 *Methodology*

2.3.1 *Development of the digitized layer of salt affected soils*

The salt affected soils maps of NRSA (NRSA 1997) on 1:250,000 scale were geo-referenced using UTM projection and digitized to prepare the salt affected soils polygons. The digitized segments of salt affected soils were properly edited to improve mapping accuracy. These were polygonized and converted to digital (raster) form. The codes and nomenclature of the segments and points were entered in a 'class domain' file and were linked to a coloured 'representation' file for visualization. An attribute table was prepared by entering the chemical properties of the soil units in columns with appropriate domains and linked with the SAS polygons to prepare a relational database. Statistical analysis was provided for the area enclosed by the polygons (Figure 2).

2.3.2 *Development of the survey of India maps*

Initially, the latitude–longitude coordinates of the Survey of India maps on 1:250,000 scale were transformed to a metric coordinate with UTM projection using ILWIS. These maps were registered by map referencing of four 'tic points' (corner coordinates) over the digitizer to calculate the affine transformation coefficients (sigma value) to assess the accuracy of georeferencing. Digitization of administrative and political (state/district) boundaries, irrigation and drainage, infrastructure (roads/railways), and settlements (state/district HQs) was done to generate digital thematic layers in GIS. These layers were overlaid to prepare a thematic layer of the basemap (Figure 3).

2.3.3 *Development of the salt affected soils maps at state, regional and zonal scale*

The digitized layers of salt affected soils and the basemap were superimposed to prepare the state maps salt affected soils. Georeferenced maps of Rajasthan, Gujarat, Madhya Pradesh, and Maharashtra states were integrated in GIS to prepare a composite (master) database of salt affected soils representing the arid and semiarid region of western and central India (Figure 3). The thematic information of the raster maps in multiple layers were overlaid to prepare an interactive database for spatial and attribute outputs that

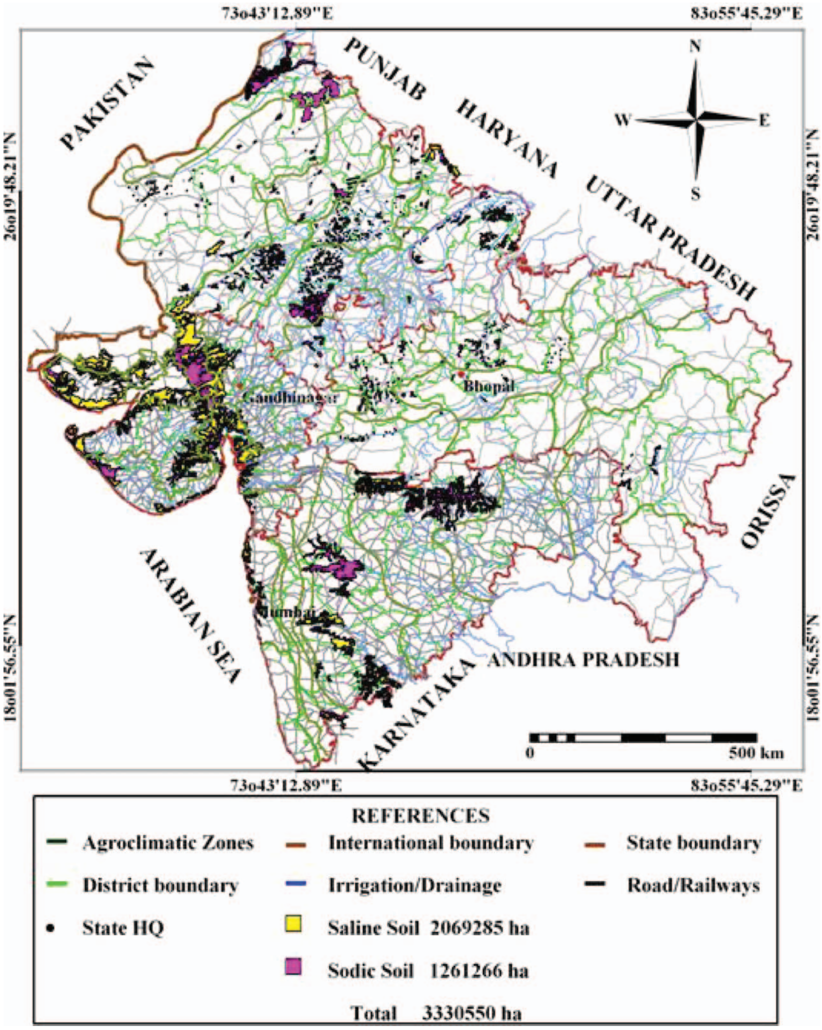

Figure 2. Distribution of salt affected soils in western and central India. Available in colour online.

provide information useful for management of soil resources. The analogue maps for agro-eco-sub-regions, physiography, rainfall, and geological zones were geo-referenced with tie points and digitized to prepare the segment maps which were polygonized, resampled, and rasterized to generate digital thematic layers. These layers were overlaid with SAS polygons using 'cross operation' in ILWIS. The outputs such as *crossed maps* and *crossed tables* showed spatial distribution and the area statistics of SAS in various agro-eco-sub-regions, geology, rainfall, and physiography zones (Tables 5–8). These were analysed and interpreted visually.

The boundaries of ACRs and zones (ACZ) (Ghosh 1991) were geo-referenced and digitized to prepare polygons of ACRs and ACZs. These were subsequently converted to raster form and overlaid the master database to prepare the regional and zonal database of salt affected soils using map calculations in ILWIS (Figure 3). The zonal and regional extent of SAS was calculated from the area statistics of the polygons (Tables 9–11).

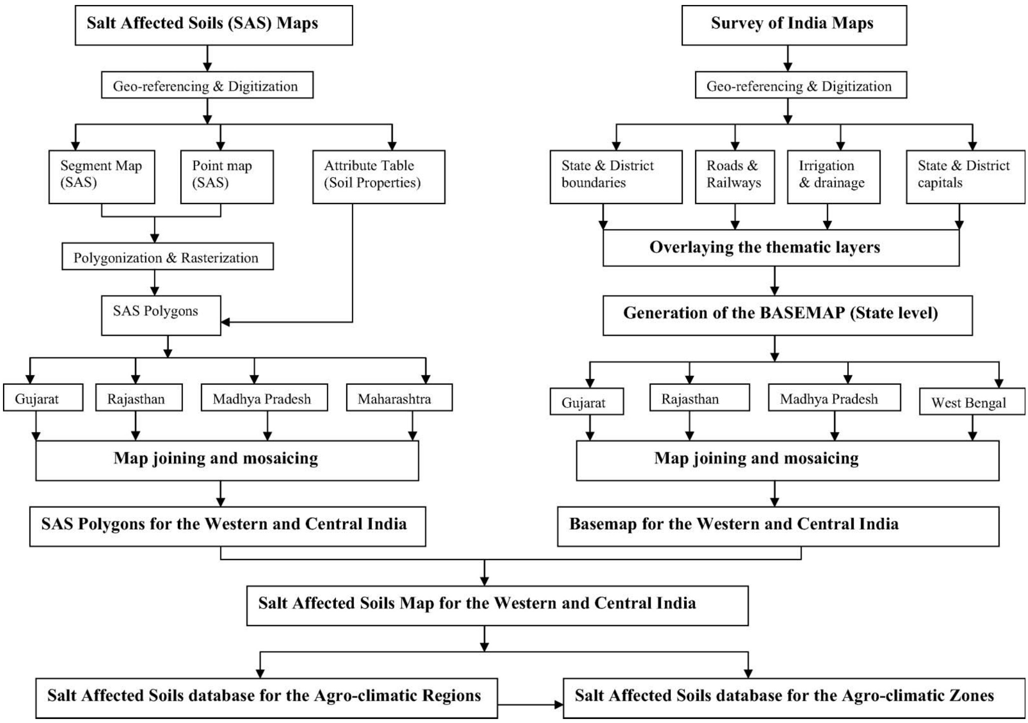

Figure 3. Flow chart (methodology) for computerized database of salt affected soils for the western and central India using GIS.

Thus, the computerized database of salt affected soils in digital format provides geo-referenced, easy to access, and retrievable, relational databases comprising thematic and attribute information. It facilitates superimposition with related datasets such as climate, geology, water quality, water table depth, etc and information extraction at the state, regional, and zonal scale, essentially required for planning reclamation and management.

2.4 *The legend used*

The legend for the salt affected soils map consists of codes and descriptions for soils depicting the nature of salt such as saline (s), sodic (n), and saline-sodic (sn); the degrees of salinity/sodicity such as slight (1), moderate (2), and strong (3); and the extent of area covered as $<1/3$, 1/3-2/3 and $>2/3$. The criteria for categorizing soil were the ranges of electrical conductance (ECe, dS m^{-1}) (4–8, 8–30 and >30 dS m^{-1}), soil reaction (pHs) (<8.5, 8.5–9.0 and >9.0), and exchangeable sodium percentage (ESP) (<15, 15–40 and >40) values. These classes were entered in the domain (class) item with a code and its description, such as As1n1 describing 'A' for Alluvial (physiographic unit), 's1' slightly saline, and 'n1' slightly sodic, and representation classes such as yellow, orange, and magenta colour to define the extent of area such as $<1/3$, 1/3-2/3 and $>2/3$ area covered by the mapping unit. Fourteen categories of soils (s1, s2, s3, n1, n2, n3, s1n1, s1n2, s1n3, s2n1, s2n2, s2n3, s3n1, s3n2, s3n3) were identified in six categories of physiographic units, viz alluvial (A), aeofluvial/aeolian/arid (B), coastal (D), deltaic (C), peninsular (F), and others/unclassified (H) in the study area (Tables 2 and 3). For management purposes, two categories, viz saline and sodic soils were considered.

3. Results and discussion

3.1 *Extent, distribution and characteristics of salt affected soils*

The extent, distribution and characteristics of SAS in Rajasthan showed that out of 3.75 lakh hectares of SAS in Rajasthan, a significant area (277,937 ha, 74%) was distributed in arid plains (B) while 6.5% (24,430 ha) and 19% (72,574 ha) were found in alluvial plains (A) and other (H) units (Table 3). Overlaying irrigation/drainage, infrastructure, and climate data with the SAS, it was found that low rainfall, high temperature, and lack of proper irrigation, drainage, and infrastructure may explain the higher extent of SAS in arid plains (Shyampura and Sehgal 1995). The soils of this region were saline (161,246 ha, 58%) and sodic (116,691 ha, 42%), which corroborates with the areas of saline (195,571 ha, 52%) and sodic (179,371 ha, 48%) soils in the state. Superimposing district boundaries and physiography zones over SAS, it was revealed that 39% of the SAS were distributed in Eastern Rajasthan Upland (Ce) covering Bhilwara, Tonk, Ajmer, Rajsamand, Udaipur, Bharatpur and Jaipur districts; 27% in Arid Transitional Plain (Wb) covering Pali, Nagaur, Jalor, and Barmer districts; 21% in the Arid Transitional Zone (Wa) covering Jaisalmer and Bikaner districts and 8% in the Aravalli landscape (Ca) covering Alwar district (Table 4). The distribution of SAS showed a higher extent in the irrigated areas of the northwest and the basin lands in southeast Rajasthan. A higher extent of SAS (33%) was found in the low rainfall zone (450 mm) than in the higher (1000 mm) rainfall zones (19%) (Table 4). The SAS was significantly higher (57%) in the

Table 2. Description of the soil characteristics used for legend development.

SAS code	Categories of SAS	ECe (dS m^{-1})	Salinity classes	pH range	ESP range	Sodicity classes
s1	Slightly saline	4.0–8.0	Slight	Low	Low	Low
s2	Moderately saline	8.0–30.0	Moderate	Low	Low	Low
s3	Strongly saline	>30.0	Strong	Low	Low	Low
n1	Slightly sodic	Low	Low	8.5–9.5	<15	Slight
n2	Moderately sodic	Low	Low	9.0–9.8	15–40	Moderate
s1n1	Slightly saline, slightly sodic	4.0–8.0	Slight	8.5–9.5	<15	Slight
s1n2	Slightly saline, moderately sodic	4.0–8.0	Slight	9.0–9.8	15–40	Moderate
s1n3	Slightly saline, strongly sodic	4.0–8.0	Slight	>9.8	>40	Strong
s2n1	Moderately saline, slightly sodic	Low	Low	8.5–9.5	<15	Slight
s2n2	Moderately saline, moderately sodic	8.0–30.0	Moderate	9.0–9.8	15–40	Moderate
s2n3	Moderately saline, strongly sodic	8.0–30.0	Moderate	>9.8	>40	Strong
s3n1	Strongly saline, slightly sodic	>30.0	Strong	8.5–9.5	<15	Slight
s3n2	Strongly saline, moderately sodic	>30.0	Strong	9.0–9.8	15–40	Moderate
s3n3	Strongly saline, strongly sodic	>30.0	Strong	>9.8	>40	Strong

Table 3. Extent, distribution and characteristics of salt affected soils.

		Rajasthan				Maharashtra					Gujarat					
Code	Category	Alluvial plain (A)	Aeofluvial/aeolian/arid plains (B)	Other (H)	Total area (ha)	Peninsular plain (F)	Coastal plain (D)	Mudflats/mangrove swamps (G)	Other (H)	Total area (ha)	Alluvial plain (A)	Aeofluvial/aeolian/arid plains (B)	Coastal plain (D)	Other (H)	Total area (ha)	Madhya Pradesh Peninsular plain (F)
s1	Slightly saline	12133	78143	–	90277	146893	–	–	–	146893	103663	286883	10058	32348	432953	8254
s2	Moderately saline	9404	75186	12787	97376	5136	26030	–	–	31166	13014	18076	95694	108837	219808	801
s3	Strongly saline	–	7917	–	7917	–	3324	2416	291	6031	–	–	–		–	–
n1	Slightly sodic	–	2215	4370	6585	6842	–	–	–	6842	–	–	–	–	–	29895
n2	Moderately sodic	–	–	440	440	–	–	–	–	–	–	–	–	–	–	962
s1n1	Slightly saline and slightly sodic	2893	34154	54977	92024	254400	–	–	–	254400	365073	77434	72728	81469	596704	45386
s1n2	Slightly saline and moderately sodic	–	2475	–	2475	6835	–	–	–	6835	–	–	–	–	–	11388
s1n3	Slightly saline and strongly sodic	–	12	–	12	154589	–	–	–	154589	–	–	–	–	–	–
s2n1	Moderately saline and slightly sodic	–	38505	–	38505	–	–	–	–	–	–	109228	68458	76526	252999	16657
s2n2	Moderately saline and moderately sodic	–	14714	–	14714	–	–	–	–	–	–	31017	91425	–	139466	10508
s2n3	Moderately saline and strongly sodic	–	–	–	–	–	–	–	–	–	–	9600	11461	379669	400730	2140
s3n1	Strongly saline and slightly sodic	–	22866	–	22866	–	–	–	–	–	–	–	–	114474	114474	859
s3n2	Strongly saline and moderately sodic	–	1033	–	1033	–	–	–	–	–	–	–	50236	–	50236	–
s3n3	Strongly saline and strongly sodic	–	717	–	717	–	–	–	–	–	–	–	14628	–	14628	–
Total (ha)		24430	277937	72574	374942	574695	29354	2416	291	606759	481750	532239	414686	793323	2222000	126849

alluvium and blown sand zones though considerable areas (18%) were distributed in the gneissic complex basic rocks zones (Table 4). The extent of SAS was higher (40%) in the hot semi arid central highland with low LGP (length of growing period) and decreased to 30% in the arid western plain, 23% in the hot arid western plain Marusthali and 4% in the semiarid Malwa highland with increasing rainfall and the LGP.

The SAS in Maharashtra was significantly (94%) distributed in the inland peninsular plain and a few pockets in the coastal region located in coastal (5%), mudflats/mangrove swamps (0.4%), and other units (Table 3). The soils were sodic (70%) in the peninsular plain and saline (30%) in the coastal region. The physiographic distribution showed that 63% of SAS were distributed in the Lower Maharashtra (Deccan) Plateau covering Satara, Kaohlapur, Sangli, and Solhapur districts: 27% in the Upper Maharashtra

Table 4. Extent and distribution of salt affected soils in agro-eco-sub-region, geology, rainfall, physiographic zones in Rajasthan State.

Code	Description of agro-eco-region, geology, rainfall and physiographic zones	Area (ha)
Agro-eco-sub-region		
1	Hot Arid Western plain Marusthali	87576
2	Arid Western Plain	115934
3	Hot Semi Arid Central Highland	156218
4	Semi Arid Malwa Highland	15213
Geology		
1	Alluvium and Blown Sand	215894
2	Sand Stone and Conglomerate	474
3	Abur Beds	3712
4	Jurassic Formation	5887
5	Bap Beds	585
6	Vindhya Supper/Undifferentiated	29417
7	Malani Jalore/Siwana Granite	1405
8	Eranpura Granite/Ultrabasic Intrusive	4154
9	Delhi Supper Group	5754
10	Raialo Series	531
11	Granite/Niphe, Lime Syenite	2748
12	Aravalli Supper Group, Basic Ultrabasic Rocks	26466
13	Granite	8763
14	Gneissic Complex Basic Rocks	69150
Rainfall		
1	Rainfall 150 mm	3234
2	Rainfall 300 mm	49538
3	Rainfall 450 mm	124646
4	Rainfall 600 mm	46550
5	Rainfall 750 mm	78838
6	Rainfall 1000 mm	71540
7	Rainfall $>$ 1000 mm	596
Physiography		
Wa	Arid Transitional Zone	80270
Wb	Arid Transitional Plain	100653
Ca	Aravalli Land Scape	29728
Ce	Eastern Rajasthan Upland	149181
Cp	Pathar and Bundelkhand Upland	12120
Cm	Malwa Plateau	2989

(Deccan) Plateau covering Jalgaon, Nasik, Ahmadnagar, and Pune districts and 9% in the West Konkan Coast covering Thane and Mumbai districts (Table 5). The unfavourable physiography and rainfall, presence of black (vertisol) soil, absence of natural drainage (Balpande *et al.* 1996), and lack of proper infrastructure and irrigation facilities may explain the higher extent of salt affected soils in the Deccan Plateau (Challa *et al.* 1995). The distribution of rainfall and SAS in Maharashtra showed that 46% of SAS occurred in the rainfall zone of 600 mm decreasing to 34% in the rainfall zone of 800 mm and 11% in the rainfall zone of 1000 mm. Similar studies with the agroecosubregions showed that 90% of the SAS occurred in the Deccan plateau, hot semiarid, shallow, medium, deep black soils zone with low LGP (90–150 days) and the extent decreased with increasing LGP. Among the geology zones, the SAS occurred significantly more (83%) in the Deccan Trap with inter trappen beds than the alluvium (Table 5).

In Gujarat, salt affected soils occupied 22.2 lakh hectares and were distributed primarily in the coastal (18%), arid (24%), and alluvial (22%) plains, and other units (36%). The soils were saline (76%) and sodic (24%) in nature (Table 3). Physiographic distribution showed that these soils were primarily (34%) located in the West Coast (Gujarat Plain) covering Banaskantha, Ahmadabad, Bharuch, and Surat districts; Kathiawar Peninsula (31%) covering Surendranagar and Junagadh districts; the Kachchh Peninsula (29%) covering Kachchh district; and the Rann of Kachchh (5%) covering Bhuj district (Table 6). The climatic distribution of SAS showed that 49% occurred in the rainfall zone of 800 mm, 32% in the rainfall zone of 400 mm, and 17% in the rainfall zone of 200 mm, accounting for 98%

Table 5. Extent and distribution of salt affected soils in agro-eco-region, geology, rainfall, physiographic zones in Maharashtra State.

Code	Description of geology, rainfall and physiographic zones	Area (ha)
Agro-eco-region		
19	Western Ghat and Coastal Plain, hot humid-per-humid, red, lateritic and alluvium derived soils, GP 210 + days	52280
I5	Central (Malwa) Highlands, Gujarat Plain and Kathiawar Peninsula, hot semiarid, medium and deep black soils, GP 90–150 days	4929
6:	Deccan Plateau, hot semiarid, shallow, medium and deep black soils, GP 90–150 days	549550
Geology		
1	Alluvium	104163
3	Deccan Trap with inter-Trappen Beds	502595
Rainfall		
I	Rainfall 600 mm	279304
II	Rainfall 800 mm	207981
III	Rainfall 1000 mm	66979
IV	Rainfall 1200 mm	216
V	Rainfall 2400 mm	14579
VI	Rainfall 3200 mm	31003
VII	Rainfall 4000 mm	6696
Physiography		
1	West Konkan Coast	52276
2	Western Ghats	2436
4	Upper Maharashtra Plateau (Deccan)	163888
5	Lower Maharashtra Plateau (Deccan)	388158

Table 6. Extent and distribution of salt affected soils in agro-eco-sub-regions, physiographic, geological and rainfall zones in Gujarat.

Code	Description of agro-eco-sub-regions, geological, physiographic and rainfall zones	Area (ha)
Agro-eco-sub-regions		
1	Arid Bunny and Rann	290002
2	Arid Kachchh, Kathiawar and North Gujarat	922743
3	Semiarid Bhal and Coastal Kathiawar	120209
4	Semiarid Central Gujarat	101956
5	Semiarid Central Highlands	19108
6	Semiarid Kathiawar	421703
7	Semiarid North Gujarat	304902
8	Subhumid North Sahyadris	41375
Geological zones		
I	Alluvium (Recent)	1707631
Vic	Basic Intrusive (Pre-cambrian)	777
IVb	Deccan Trap (Tertiary Mesozoic)	175281
IIIa	Dwarka Beds (Tertiary)	82532
IVa	Eocene Beds (Tertiary Mesozoic)	41794
IIIb	Gaj-Nari Series (Tertiary)	91573
II	Laterite (Recent Tertiary)	27354
Vc	Umia and Bhuj Beds	41287
	Rann of Kachchh	53769
Physiographic zones		
Phgr I	Rann of Kachchh	111266
Phgr III	The West Coast – Gujarat Plain	766214
Phgr IV	The West Coast – Kachchh Peninsula	647418
Phgr V	The West Coast – Kathiawar Peninsula	697101
Rainfall zones		
Rain IV	Rainfall 1200 mm	35338
Rain V	Rainfall 1600 mm	8273
Rain VI	Rainfall 1800 mm	106
Rain I	Rainfall 200 mm	371600
Rain II	Rainfall 400 mm	715884
Rain III	Rainfall 800 mm	1090796

of the total area in Gujarat (Table 6). Among the geology zones, 77% of the SAS was located in the alluvium, 8% in the Deccan Trap (Tertiary Mesozoic), 4% in the Gaj-Nari series (Tertiary), and 4% in the Dwarka Beds (Tertiary) which indicates a significant role of the secondary deposits in alluvium and the weathering of basic parent materials on the evolution of SAS (Sharma *et al.* 1994). The distribution of SAS in the agro-eco-sub-regions showed a higher (41%) extent in the arid Kachchh, Kathiwar, and North Gujarat decreasing to 19% in the Semiarid Kathiawar, 14% in the semiarid North Gujarat, 13% in the Arid Bunny and Rann, 5% in the semiarid Bhal and coastal Kathiawar, and 4% in the semiarid central Gujarat, indicating increasing area with decreasing rainfall and LGP (Table 6).

The salt affected soils of Madhya Pradesh state occupied 126,849 ha and were sodic (93%) and saline (7%) in nature. Physiographic distribution showed that 46% of SAS were distributed in the Central Highland, Pathar, and Bundelkhand upland covering Morena, Bhind, and Gwalior districts, and 39% in the central highland, Malwa plateau covering Vidisha, Shajapur, Ujjain, Indore, Ratlam, Dhar, Bhopal, and Sagar districts. The higher extent of SAS was found in the rainfall zone of 700–800 mm (37%) decreasing to 25% in the 800–900 mm zone and 16% in the 1200–1400 mm zone. The distribution of SAS in geology zones showed that 43% exist in the parent material of the Jurassic period while 23% exist in the Archean period and 12% in the Pleistocene period (Table 7).

Combining salt affected soils in four states, it was revealed that 3,330,550 ha of SAS were distributed in Central and Western India. The saline and sodic soils covered 2,069,285 ha (62%) and 1,261,266 ha (38%) in western and central India. The SAS occupied 2,596,942 ha (78%) in the western (Rajasthan and Gujarat) and 733,608 ha (22%) in the central (Madhya Pradesh and Maharashtra) region. The extent of sodic soils (540,465 ha, 74%) was higher than saline soils 193,144 ha (26%) in the central region while the saline soils (187,6141 ha, 72%) exceeded sodic soils (720,801 ha, 28%) in the western region (Table 8).

3.2 *Regional distribution of salt affected soils*

The ACRs and zones (ACZ) of the Planning Commission of India were used to prepare a salt affected soils database useful for salinity management at the regional scale (Figure 2). Two agoclimatic regions were identified in Rajasthan (ACR VIII and XIV) and three in Madhya Pradesh (ACR VII, VIII, IX), two in Maharashtra (ACR IX and XII), and one (ACR XIII) in Gujarat (Table 1).

The ACR VIII covered the southeast part of the Rajasthan and the adjoining areas of the Madhya Pradesh with similar agro-climatic conditions. These were primarily saline

Table 7. Extent and distribution of salt affected soils in geology, rainfall, physiographic zones in Madhya Pradesh State.

Code	Description of geology, rainfall and physiographic zones	Area (ha)
Geology		
1	Archean	29058
2	Dharwar	1773
3	Cuddapah	8058
4	Vindhyan	12788
6	Jurassic	240
8	Lower Deccan Trap	54862
11	Pleistocene	14914
12	Recent	5156
Rainfall		
RI	Rainfall under 600 mm	83
RII	Rainfall under 600–700 mm	4692
RIII	Rainfall under 700–800 mm	47214
RIV	Rainfall under 800–900 mm	31675
RV	Rainfall under 900–1000 mm	7580
RVI	Rainfall under 1000–1200 mm	12441
RVII	Rainfall under 1200–1400 mm	20328
RVIII	Rainfall under 1400–1600 mm	2834
Physiography		
1	Deccan Plateau, Satpura Range	879
2	Central Highland, Narmada Valley	2433
4	Central Highland, Malwa Plateau	49630
5	Central Highland, Pathar and Bundelkhand Upland	58297
6	Eastern Plateau, Bundelkhand Plateau	6576
7	Eastern Plateau, Mahanadi Basin	4250
8	Eastern Plateau, Dandakaranya Plateau	4784

(169,714 ha, 63%) and sodic (100,689 ha, 37%) in Rajasthan. The SAS occupied 79,032 ha in Madhya Pradesh. These were sodic (70,614 ha, 89%) and saline (8418 ha, 11%) nature (Table 9).

Table 8. State-wise extent of salt affected soils.

Name of the State	Categories of salt affected soils		Total area (ha)
	Saline	Sodic	
Gujarat	1680570	541430	2222000
Rajasthan	195571	179371	374942
Maharashtra	184089	422670	606759
Madhya Pradesh	9055	117795	126849
Total area (ha)	2069285	1261266	3330550

Table 9. Characteristics and distribution of salt affected soils in ACRs.

Code	Category	Rajasthan		Maharashtra		Madhya Pradesh			Gujarat
		ACR VIII	ACR XIV	ACR XII	ACR IX	ACR VII	ACR VIII	ACR IX	ACR XIII
s1	Slightly saline	84768	5508	–	146893	–	7617	637	432953
s2	Moderately saline	82271	15106	25906	5260	–	801	–	235621
s3	Strongly saline	2675	5240	6031	–	–	–	–	–
n1	Slightly sodic	4371	2214	–	6842	3972	20490	5433	–
n2	Moderately sodic	440	–	–	–	–	962	–	–
s1n1	Slightly saline, slightly sodic	71005	21019	–	254400	5116	10680	29590	604883
s1n2	Slightly saline, moderately sodic	2452	23	–	6837	–	8831	2557	–
s1n3	Slightly saline, strongly sodic	–	12	–	154589	–	–	–	–
s2n1	Moderately saline, slightly sodic	6509	31996	–	–	–	16144	513	254212
s2n2	Moderately saline, moderately sodic	1618	13096	–	–	–	10508	–	122441
s2n3	Moderately saline, strongly sodic	–	–	–	–	–	2140	–	400730
s3n1	Strongly saline, slightly sodic	13040	9825	–	–	–	859	–	114474
s3n2	Strongly saline, moderately sodic	1035	–	–	–	–	–	–	50236
s3n3	Strongly saline, strongly sodic	219	499	–	–	–	–	–	14628
Total area (ha)		270403	104538	31937	574821	9088	79032	38730	2222000

The ACR XIV covered northwest Rajasthan irrigated by the Indira Gandhi Nahar Pariyojona (IGNP) canal covering Ganganagar, Hanumangarh, Churu, Jaisalmer, Barmer, Nagaur, Jodhpur, and Bikaner districts. The soils were primarily sodic (78,684 ha, 66%) and saline (25,854 ha, 24%) in nature (Table 9).

Salt affected soils (31,937 ha) in ACR XII, were distributed in Thane, Mumbai, and Ratnagiri districts in the coastal region of Maharashtra. These soils were moderate (25,906 ha, 81%) and strongly (6031 ha, 19%) saline in nature (Table 9).

The ACR IX covered the north and central parts of Maharashtra and the southern part of Madhya Pradesh states. Sodic (422,668 ha, 74%) and saline (152,153 ha, 26%) soils were prevalent in the Maharashtra (Deccan) Plateau covering Nasik, Pune, Satara, Kolhapur, Ahmadnagar, Sangli, Jalgaon, and Akola districts. These soils were slightly saline (146,893 ha, 25%); slightly (261,242 ha, 45%) and strongly (154,589 ha, 27%) sodic in nature. The SAS in Madhya Pradesh were distributed in the Central Highland and Malwa Plateau covering Dhar, Ujjain, Dewas, Ratlam, Indore, and Shahjapur districts. These were saline (637 ha) and sodic (38,093 ha) in nature. The slightly (35,023 ha, 90%) and moderately sodic (3070 ha, 8%) soils were a common occurrence in this region (Table 9).

The ACR VII covered Eastern Plateau of Chhattisgarh region in Madhya Pradesh state. The SAS were distributed in Durg and Rajnandgao districts and commonly sodic (9088 ha) in nature (Table 9).

The SAS in ACR XIII was distributed in the Gujarat Plain, Kathiawar Peninsula (West Coast), and the Rann of Kachchh covering Banaskantha, Mehsana, Ahmedabad, Kheda, Surat, Bharuch, Valsad, Surendranagar, Bhavnagar, Jamnagar, Rajkot, Junagadh, Amreli, and Kachchh districts of Gujarat State. The soils were saline (1,680,570 ha) and sodic (541,430 ha) in nature (Table 9).

Thus, salt affected soils occupied 3,330,550 ha in western (2,358,475 ha, 71%) and central (972,074 ha, 29%) India (Table 10). These were distributed in ACR IX (613,551 ha, 18%), ACR VIII (349,435 ha, 10%), and ACR VII (9088 ha, 0.3%) of central India and ACR XIII (2,222,000 ha, 67%), ACR XIV (104,538 ha, 3%), and ACR XII (31,937 ha, 1%) India (Table 10).

Table 10. Extent of salt affected soils in ACRs.

Zone No	ACRs	Categories of salt affected soils		Total (ha)
		Saline soil	Sodic soil	
Central India				
VII	Eastern Plateau and Hills Region	–	9088	9088
VIII	Central Plateau and Hills Region	178132	171303	349435
IX	Western Plateau and Hills Region	152790	460761	613551
Sub-total		330922	641152	972074
Western India				
XII	West Coast Plain and Hills Region	31937	–	31937
XIII	Gujarat Plain and Hills Region	1680570	541430	2222000
XIV	Western Dry Region	25854	78684	104538
Sub-total (ha)		1738361	620114	2358475
Total (ha)		2069283	1261266	3330550

3.3 *Distribution of salt affected soils in agro-climatic zones*

The ACZ were useful for micro-level (zonal) planning and soil management prepared from climatic parameters and soil properties. The zonal maps (Figure 2) and estimates of SAS were prepared in GIS (Table 11). The salt affected soils were distributed in six ACZ in Gujarat, nine ACZ in Rajasthan, 12 ACZ in Madhya Pradesh and nine ACZ in Maharashtra state (Table 1). The SAS in Gujarat was significantly higher in the North West Zone (10,005,109 ha, 45%) and decreased in the Rann of Kachchh (298,661 ha, 13%), Bhal and Coastal region (296,100 ha, 13%), and North Saurashtra (295,247 ha, 13%) with increasing rainfall and soil condition (Sharma *et al.* 1994). The SAS in Rajasthan were higher in irrigated zones of Southern Plain Zone (103,003 ha, 27%) and North West Plain Zone (70,996 ha, 19%), lower in the rain-fed Transitional Plain of Luni

Table 11. Extent and distribution of salt affected soils in ACZs.

Code	Description of ACZs	Area (ha)
Gujarat		
1	South Gujarat Heavy rainfall area	19845
2	South Gujarat Zone	44531
3	Middle Gujarat Zone	9080
4	North Gujarat Zone	135571
5	North West Zone	1005109
6	North Saurashtra	295247
7	South Saurashtra	117853
8	Bhal and Coastal region	296100
9	Rann of Kachchh	298661
Rajasthan		
1	Arid Western Zone	45392
2	Irrigated North West plain Zone	70996
3	Transitional Plain of Inland Zone	24850
4	Transitional Plain of Luni Basin Zone	62115
5	Semi Arid Eastern Plain Zone	32043
6	Flood Prone Eastern Plain Zone	25192
7	Sub-humid Southern Plain Zone	103003
8	Humid Southern Plain Zone	10485
9	Humid South East plain Zone	863
Madhya Pradesh		
1	Chattisgarh Plain Zone	9113
4	Kymore Plateau and Satpura Hill Zones	118
5	Vindhya Plateau Zone	18942
6	Central Narmada Valley Zone	4309
7	Gird Zone	57703
8	Jhabua Hills Zone	3965
10	Malwa Plateau Zone	26826
11	Nimar Valley Zone	5871
Maharashtra		
1	Northern Konkan Coastal Zone	52280
2	Sub-montane Zone	3465
3	Western Maharashtra Plain Zone	20556
4	Western Maharashtra Scarcity Zone	321313
5	Central Maharashtra Plain Zone	207013
6	Central Vidarbha Zone	2130

Basin Zone (62,115 ha, 16%), Arid Western Zone (45,392 ha, 12%), Semi Arid Eastern Plain Zone (32,043 ha, 8%), Flood Prone Eastern Plain Zone (25,192 ha, 6%), and Transitional Plain of Inland Zone (24,850 ha, 6%). In Madhya Pradesh, higher SAS were found in the irrigated Gird Zone (57,703 ha, 45%), Malwa Plateau Zone (26,826 ha, 21%), and Vindhya Plateau Zone (18,962 ha, 15%). In Maharashtra, the SAS was higher in the semiarid irrigated Western Maharashtra Scarcity Zone (3,21,313 ha, 53%), Central Maharashtra Plain Zone (2,07,013 ha, 34%), than in the rain-fed North Konkan Coastal Zone (52,280 ha, 9%) and Western Maharashtra Plain Zone (20,556 ha, 4%).

4. Conclusion

A computerized database was prepared to show the distribution and extent of salt affected soils of arid and semiarid regions in India. A relational database was prepared linking SAS polygons and soil properties stored in an attribute table for parallel visualization. A composite (master) database was prepared to show the distribution of salt affected soils in western and central India. Two categories of salt affected soils, saline and sodic, were identified based on the soil characteristics. The regional and zonal maps of SAS were prepared to facilitate micro-level planning and soil management. Spatial relations were shown between SAS and related parameters such as physiography, rainfall, agro-eco-region, and geology using a GIS. The prominent salt affected areas were located in the alluvial and coastal plains in Gujarat, arid plain in Rajasthan, and peninsular plain in Maharashtra and Madhya Pradesh. The higher extent of SAS was associated with the agro-eco-sub-regions with low LGP and low rainfall. The sedimentary deposits like alluvium were a common occurrence in the salt affected areas of the western plain while basic parent materials were abundant in the peninsular plains of central India. An area of 3.3 million ha was affected in western and central India, which constitutes 50% of the total salt affected soils in India.

Acknowledgement

The authors thank Head, Soil and Crop Management Division, and Director, Central Soil Salinity Research Institute, Karnal (India) for providing financial support and encouragement to carry out this work.

References

Balpande, S.S., Deshpande, S.B., and Pal, D.K., 1996. Factors and processes of soil degradation in vertisols of Purna valley, Maharashtra, India. *Land Degradation and Development*, 17, 313–324.

Basu, D.N. and Guha, G.S., 1996. *Agro-climatic regional planning in India*. New Delhi: Concept Publishing Co. pp. 330.

Batges, N.H., 1996. The carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, 47, 151–163.

Challa, O., Vadivelu, S., and Sehgal, J., 1995. Soils of Maharashtra for optimizing land use. Executive Summary. NBSS Publ.54b, 96p + 6 sheets map.

Coote, D.R. and Mac Donald, K.B., 2000. The Canadian soil database. *In*: M. Sumner, ed. *Handbook of Soil Science*. New York: CRC Press, 41–51.

Dubey, D.D., Sharma, O.P., Sethi, M., and Gupta, R.K., 1995. Salt affected soils of Gujarat, extent, nature and management. Karnal, India: CSSRI, 95 p.

FAO, 1996. The digitized soils map of the World including derived soil properties. Rome: FAO.

Ghosh, S.P., 1991. *Agroclimatic zone specific research, Indian perspective under NARP*. New Delhi: Indian Council of Agricultural Research, 1–539.

Johnston, R.M., Barry, S.J., Bleys, E., Bui, E.N., Moran, C.J., Simon, D.A.P., Carlile, P., Mckengie, N.J., Henderson, B.L., Chapman, *et al.*, 2003. ASRIS: the database. *Australian Journal of Soil Research*, 41, 1021–1036.

King, D., Daroussin, J., and Travernier, R., 1994. Development of a soil geographic database from the soil map of the European Communities. *Catena*, 21, 37–56.

Lytle, D.T., 1993. Digital soil databases for the United States. *Environmental modeling with GIS*. New York: Oxford University Press, 386–391.

Mandal, A.K. and Sharma, R.C., 2001. Mapping of waterlogged and salt affected soils in IGNP command area. *Journal of the Indian Society of Remote Sensing*, 29, 229–235.

Mandal, A.K. and Sharma, R.C., 2005. Computerized database on salt affected soils in Haryana State. *Journal of the Indian Society of Remote Sensing*, 33, 447–455.

Mandal, A.K. and Sharma, R.C., 2006. Computerized database of salt affected soils for Agro-climatic regions in the Indo_Gangetic plain in India using GIS. *Geocarto International*, 21, 47–57.

NRSA, 1997. Salt-affected soils of India. National Remote Sensing Agency, Department of Space, Hyderabad, India.

Oldeman, L.R. and Van Enggelen, V.W.P., 1993. A world soils and terrain digital database (SOTER) – an improved assessment of land resources. *Geoderma*, 60, 309–325.

Sharma, J.P., Shyampura, R.L., and Sehgal, J., 1994. Soils of Gujarat: their kinds, distribution, characterization and interpretation for optimizing land use, executive summary. NBSS Publ. 29b, National Bureau of Soil Survey and Land Use Planning, Nagpur, India. 73p + 4 sheet soil map (1:500,000 scale).

Sharma, R.C., 1999. Soil suitability of reclaimed salt affected soils for wheat. *Agropedology*, 9, 59–62.

Sharma, R.C., 2002. *Use of GPS for farm level mapping of Salt Affected Soils. In: Asian GPS: Proceedings of the GPS in Agriculture*. New Delhi: IIC, pp. 1–3.

Shyampura, R.L. and Sehgal, J., 1995, Soils of Rajasthan for optimizing land use planning. Executive Summary. NBSS Publ No. 51, National Bureau of Soil Survey and Land Use Planning, Nagpur, India, 76p + 6 sheet soil map (1:500,000 scale).

Stolbovoi, V., Montanarella, L., Medvedev, V., Smeyan, N., Shiskov, L., Unguryan, V., Dovrovol, S.G., Jamgne, M., King, D., Rozov, V., *et al.*, 2001. Integration of data on the soils of Russia, Belarus, Moldova and Ukraine into the soil geographic database of the European community. *Eurasian Soil Science*, 34, 687–703.

Tamgadge, D.B., Gaikawad, S.T., Nagabhusana, S.R., Gajbhiye, K.S., Deshmukh, S.N. and Sehgal, J., 1996. Soils of Madhya Pradesh: their kinds, distribution, characterization and interpretation for optimizing land use, Executive Summary. NBSS Publ. 59, National Bureau of Soil Survey and Land Use Planning, Nagpur, India, 182p + 9 sheet soil map (1:500,000 scale).

Yadav, J.S.P., 2003. Managing soil health for sustained high productivity. *Journal of the Indian Society of Soil Science*, 51, 448–465.