Chapter 2
Scaling-up Agro-Technologies Using Agro-Eco Sub-Regions in the Target States

Tapas Bhattacharyya, Suhas P. Wani, and P. Tiwary

Abstract Agro Eco Regions/Sub-regions (AERs/AESRs) are near homogeneous area similar with respect to (a) broad soil groups, (b) overhead climate and (c) length of moisture availability period in relation to crop production. Efforts of zoning world soils /lands at global level has been tropicalized for minimizing the inadequacies of the concept and to suit the requirement of the Indian subcontinent using the revised length of growing period (LGP) with special reference to dryland agriculture. To address these inadequacies for developing agro-ecological zones/regions, LGP was taken as an index of crop production, since it considers soil-water balance as a direct function of moisture availability in a landform instead of the total annual rainfall. The map boundaries, depicting 20 (twenty) AERs in India were delineated by superimposing bio-climate and LGP on soil-scape. The LGP classes were further grouped into different feasible cropping systems in an agro-environment to delineate 60 (sixty) AESRs. For land use planning agro ecology concept has been considered as a vehicle for technology transfer to address the issues of agricultural land use planning, climate change, soil water availability and the livelihood of the farming community.

Keywords Agro-eco region · Dryland agriculture · Agricultural land use planning · LGP · Climate change

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S. P. Wani et al. (eds.), *Scaling-up Solutions for Farmers*,
https://doi.org/10.1007/978-3-030-77935-1_2

2.1 Importance of Understanding Agro-Ecologies for Agricultural Planning

Agricultural land use planning involves systematic and iterative processes to develop an appropriate and sustainable environment for acceptable utilization of land resources. These processes involve the physical, socio-economic, institutional and legal potentials and the constraints with respect to an optimal and sustainable use of land resources. In addition, it also empowers people to make informed decisions about how to allocate those resources for reaping maximum benefit. On the basis of an inventory of land resources, land management options are formulated keeping in view the biophysical limitations and potentials of resources to develop the agro-ecological zones/sub-regions (Bhattacharyya 2021a).

FAO (1978–1981) defined Agro Eco zone (AEZ) as a near homogeneous area similar with respect to (a) broad soil groups, (b) overhead climate and (c) length of moisture availability period in relation to crop production. The efforts of FAO were to concentrate on creation of broad crop feasibility zone based on FAO/UNESCO Global Soil and Terrain Map on 1:5 m scale by superimposition of climate and moisture availability period. The major drawback of AEZ of FAO so created is its limited utility for crop planning at regional sub-levels for Asia, Africa, Europe and Latin America.

2.2 Criteria for Delineating Agro-Ecological Zones (AEZs) and Agro-Ecological Regions (AERs) in India

2.2.1 Agro-Ecological Zones (AEZs) in India

AEZ provides a standardized framework for the characterization of climate, soil, and terrain conditions relevant to agricultural production. In this context, the concepts of “length of growing period” and of latitudinal thermal climates was applied in mapping activities focussing on zoning at various scales, from the subnational to the global level. Second, AEZ matching procedures are used to identify crop-specific limitations of prevailing climate, soil, and terrain resources, under assumed levels of inputs and management conditions. This part of the AEZ methodology provides estimates of maximum potential and agronomically attainable crop yields for basic land resources units. Third, AEZ provides the frame for various applications. The previous two sets of activities developed large database. The information contained in these data sets form the basis for a number of AEZ applications, such as quantification of land productivity, extents of land with rain-fed or irrigated cultivation potential, estimation of the land’s population supporting capacity, and multi-criteria optimization of the use and development of land resources.

The AEZ methodology uses a land resources inventory to assess, for specified management conditions and levels of inputs, all feasible agricultural land-use options and to quantify anticipated production of cropping activities relevant in the specific agro-ecological context. The characterization of land resources includes components of climate, soils, and landform. The recent availability of global digital databases of climatic parameters, topography, soil and terrain, and land cover have allowed for revisions and improvements in calculation procedures. Also permitted the expansion of assessments of AEZ crop suitability and land productivity potentials to temperate and boreal environments. This effectively enables global coverage for assessments of agricultural potentials. The AEZ methodologies and procedures have been extended and newly implemented to make use of these digital geographical databases, and to cope with the specific characteristics of seasonal temperate and boreal climates.

The concept of agro-ecological zone (AEZ) for improving the rainwater use efficiency, conservation of natural resource and practice of sustainable agriculture under rain-fed situation is essential. In this endeavour, the highest priority is given to assess land resources and their components such as soil, water and climate to create an integrated system to apply the best of scientific technology and knowledge for agricultural development. The main purpose for delineating AEZ was to create a near homogenous soil climatic region that is compatible for (i) potential genetic expression in terms of growth of a particular group of crops and cultivars and their sustenance, and (ii) the AEZ-based dissemination of agro-technology to reduce the recurring costs.

2.2.2 Agro-Ecological Regions (AERs) in India

To address the inadequacies for developing agro-ecological zones/regions, length of growing period (LGP) was taken as an index of crop production, since it considers soil-water balance as a direct function of moisture availability in a landform instead of the total annual rainfall. The map boundaries, depicting 20 AERs in India were delineated by superimposing bio-climate and LGP on soil-scape. The LGP classes were further grouped into different feasible cropping systems in an agro-environment.

FAO (1976, 1978) developed the concept of agro-ecological zones with strong emphasis on comparable agro-climatic parameters to delineate agriculturally potential areas suitable for particular genotype so that optimum production potential of the genotypes is achieved. With an urge to optimize land use for increased agricultural production on a sustainable basis, agro-ecologically comparable resource region was delineated for generating and transferring agro-technology to meet the country's ever-increasing food, fodder and fibre needs. Through several approximations using the parameters, such as, bio-climate, length of growing period, physiography and soils, the scheme outlined in Table 2.1, an agro-ecological region map of the country has been prepared and published (Sehgal et al. 1992). The climatic data of more than 1700 meteorological stations were used for preparing water balances which formed the base for the generalised climatic map and for preparing the Length of Growing Period (LGP) map. Therefore, in the present study, nine states, *viz.* Karnataka, Andhra Pradesh and Telangana, Odisha, Madhya Pradesh and Chhattisgarh, Madhya Pradesh, Bihar and Jharkhand, and Maharashtra have been identified as target states for delineating agro-ecologically based potential areas for agro-technology transfer. Mostly the drier areas of these states are selected except a few exceptions.

Table 2.1 Various levels of exercises to develop agro-ecological zones in India

S.No	Level	Criteria Used			
		Soil	Physiography	Bioclimate	Length of Growing Period
1.	Agroecological Regions of India (AER) (20 AER) (for resource planning at national level)	Soil great group association (1:7 m scale)	Broad (15 nos)	After Thornthwaite & Mather, 1955 water balance using Penman PET and climatic divisions are arid, semiarid, subhumid, humid, per humid	*<90 days; 90-150; 150-210; >210 and Normal LGP (annual) value
2.	Agroecological subregions of India (60 AESR) (for resource planning at regional level)	Soil sub group association (1:1 m scale)	Sub division of major physiography	arid — typic arid, hyper arid Semiarid — semiarid dry, semiarid moist Sub humid — dry, moist Humid perhumid	LGP value starting from <60 days and 30 days interval to >330 days and probability of occurrence of LGP (annual) at 50 percent level
3.	Agroecological zones at state level (for resource planning at state level)	Soil family association at (1:250,000 scale)	Landform	Bioclimate computation based on subdivision level rainfall data and PET based on pan evaporation data	LGP isolines at 15/30 days interval depending on the climate and LGP probability analysis on monthly basis
4.	Agroecological unit at district level (for resource planning at district level)	Soil series association (50,-000 scale)	Geomorphic unit	Bioclimate classification based on rainfall and pan evaporation data at block level	LGP isoline based on weekly or 10 days interval and LGP probability analysis at growth phases
5.	Agroecological unit at watershed level	Soil phase level 1:5,000 scale)	Details of geomorphic units	Effective rainfall at unit level and pan evaporation data at watershed level	LGP based on actual AWC of soil unit and LGP probability analysis at growth phases

*<90 days : *feasible for single short duration crop*
90-150 days : suitable for one medium duration crop or single short duration crop plus relay crop
150-210 days : feasible for one long duration crop or two single short duration crop
>210 days : feasible for double cropping

2.3 Ecoregions and Soils (Karnataka, Andhra Pradesh and Telangana, Odisha, Madhya Pradesh and Chhattisgarh, {Madhya Pradesh}, Bihar and Jharkhand {Bihar}, Maharashtra)

Soil data and its utility in land use planning and more so for agriculture have been discussed in many forums. For an effective and acceptable planning, the unit of land parcel for agro-technology transfer has also been discussed. For land use planning agro-ecology concept has been considered as a vehicle for technology transfer. Ideally, agro-ecology takes care of soil and land information while delineating different units. Therefore, information on soils need a special attention to sharpen the concept of agro-ecology.

2.3.1 Soils of Karnataka

Karnataka state covers an area of 19.1 million hectare and accounts for 5.8% of the total geographical area (TGA) of India. The state represents three major physiographic regions viz. south Deccan Plateau, the Western Ghats and the West Coast Plains with different climate, geology, and vegetation which influence a variety of soils in this state. It has a 350 km coast line which forms the western boundary. The important geological formations are Achaean group, Proterozoic, Mesozoic and Cainozoic rocks. The Achaeans are the oldest formation and covers 60% area of the state. The chief rocks are gneisses, granites, and charnockites. The climate varies from arid to semiarid in the plateau region, sub humid to humid tropical in the Ghats region and humid tropical monsoonic type in the west coast plains. The mean annual rainfall in main three regions of the state varies from a minimum of 350 mm to 5000 mm (Fig. 2.1). The mean annual temperature ranges from 20.3 °C to 27.6 °C, with the summer temperature ranging from 35 to 42 °C and winter temperature 13–23 °C. The soil moisture regime is ustic in most part of the state except Bellary, Raichur and Bijapur districts where it is dry and moisture regime is Aridic (Soil Survey Staff 2014). In west coast plains, aquic moisture regime is found in local patches. The soil temperature regime is isohyperthermic.

Based on physiography, soils, bio-climate and length of growing period (LGP), the state is divided into seven agro ecological sub regions (AESRs) (Sehgal et al. 1996). More soils and climatic information helped to revise the LGP and revise the AESRs (Mandal et al. 2014). Out of seven, nearly 80% areas in the state is under dry climate covering AESRs, 1, 2, 3, 4 and 5 (Fig. 2.2). Ecologically five types of forests are identified in this state. These are, dense evergreen, semi evergreen, moist deciduous, dry deciduous and miscellaneous.

Soils of Karnataka have been traditionally classified into soil groups namely red, laterite, black and alluvial soils. Other important soils are brown forest soils (Mollisols). The soil formation in South Deccan Plateau is influenced by parent material, topography, and climate resulting in the formation of Alfisols, Inceptisols, Entisols, Aridisols and Vertisols. In the Western Ghats Alfisols, Ultisols and Mollisols are formed by the influence of climate, vegetation and relief. Topography and parent material influence the Eastern Ghats to form Entisols and Inceptisols while in the East Coast by climate and topography forming Ultisols and Entisols. The soils belong to 7 orders, 12 suborders 27 greatgroups 47 subgroups and 96 families (Bhattacharyya et al. 2009). Alfisols are the dominant soils (28%: Fig. 2.3)

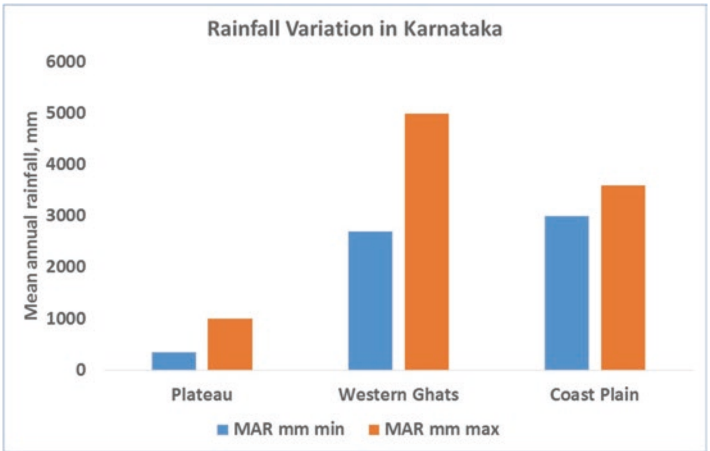
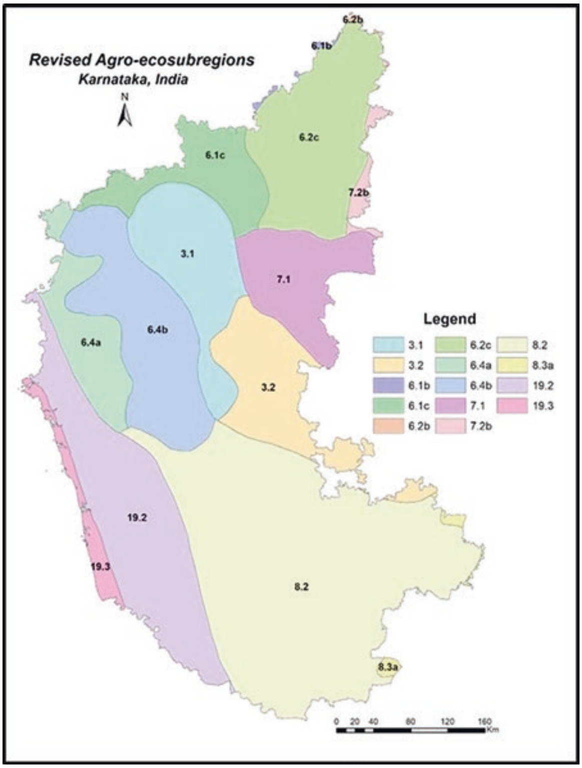


Fig. 2.1 Rainfall variations in Karnataka (min: Minimum rainfall; max: maximum rainfall)

Fig. 2.2 Agro-eco sub-regions (AESRs) in Karnataka, India



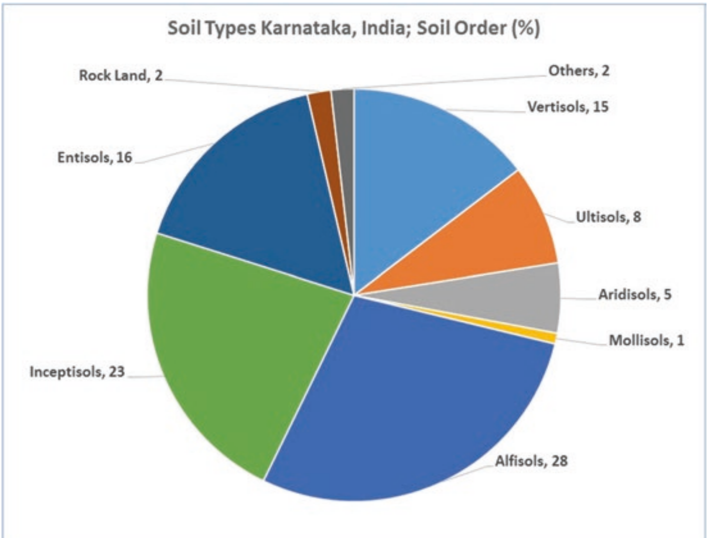


Fig. 2.3 Soil types of Karnataka, distribution of soil orders in percent

followed by Inceptisols, Entisols and Vertisols. About 2% of the total area is covered by others including rocky lands. Land use of Karnataka is governed by topography, climate, soils and food habits of people. About 53% of the state area is under cultivation (Fig. 2.4) of which 30% area is under irrigation (Anonymous 2008–2009). A representative soil of this state and its different parameters are shown in Tables 2.2 and 2.3.

2.3.2 *Soils of Andhra Pradesh and Telangana*

Andhra Pradesh state, located in the south eastern part of the subcontinent has an area of 162.97 lakh hectare. It is bounded by the Indian states of Tamil Nadu to the south, Karnataka to the southwest and west, Telangana to the northwest and north, and Odisha to the northeast. Andhra Pradesh has a long coastline of around 974 km. Telangana state is surrounded by Maharashtra and Chhattisgarh in the North, Karnataka in the West and Andhra Pradesh in the South and East directions and covers an area of 114.84 lakh ha. Details of land use of Telangana and Andhra Pradesh states are shown in Tables 2.4 and 2.5.

Both the states are museum of various geological formations including Achaean, Precambrian, Palaeozoic, Carboniferous, Triassic, Cretaceous, Mesozoic, Tertiary,

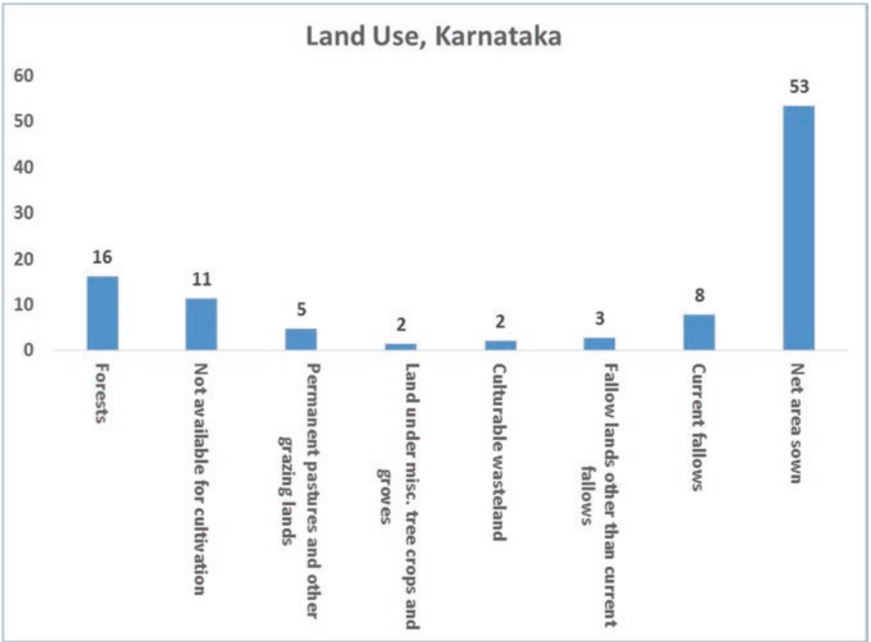


Fig. 2.4 Land use of Karnataka. (Source: Anonymous (2008–2009))

Table 2.2 Morphological properties of representative soils in the selected states

Horizon	Depth cm	Matrix colour Moist	Texture	Structure	Nodules (conca/conir/conmn) (%)	Effervescence[a] (dil HCl)	Other features	Cracks[b]
Karnataka: Achmatti: 600 m above MSL: MAR 660 mm: Very fine, smectitic, isohyperthermic Sodic Haplusterts								
Ap1	0–4	10YR 3/1	Clay	Granular	2	Strong	–	10–15 mm wide
Ap2	4–22	10YR 3/1	Clay	Sub-angular blocky and granular	5	Strong	–	10–15 mm wide
Bss1	22–54	10YR 3/1	Clay	Angular blocky	–	Strong	Intersecting slickensides	10–15 mm wide
Bss2	54–87	10YR 3/1	Clay	Angular blocky	–	Strong	Intersecting slickensides	10–15 mm wide
BCk1	87–152	10YR 4/2	Clay	Angular blocky	7	Violent	Intersecting slickensides	less than 10 mm wide
BCk2	152–170	10YR 3/1	Clay	Angular blocky	10	Violent	Slickensides	less than 10 mm wide
Andhra Pradesh: Kurnool: 254 m above MSL: MAR 740 mm: Fine, smectitic (calcareous), isohyperthermic Vertic Haplustepts								
Ap	0–18	10YR 3/2	Clay	Sub-angular blocky	–	Violent		–
Bw1	18–50	10YR 3/3	Clay	Sub-angular blocky	–	Violent	Pressure faces	–
Bss1	50–79	10YR 3/3	Clay	Sub-angular blocky	–	Violent	Non-intersecting slickensides	–
Bss2	79–109	10YR 3/3	Clay	Sub-angular blocky	–	Violent	Non-intersecting slickensides	–
Bss3	109–151	10YR 3/4	Clay	Sub-angular blocky	–	Violent	Non-intersecting slickensides	–
Telangana: Kasireddipalli: 540 m above MSL: MAR 760 mm: Fine, smectitic, isohyperthermic Typic Haplusterts								
Ap	0–8	10YR 3/2	Clay	Sub-angular blocky	Many lime nodules	Slight	–	
Bw	8–18	10YR 3/2	Clay	Sub-angular blocky	Many lime nodules	Slight	Pressure faces;	
Bss1	18–32	10YR 3.5/2	Clay	Angular blocky	Many lime nodules	Slight	Well-developed slickensides	
Bss2	32–44	10YR 3/2	Clay	Angular blocky	Many lime nodules	Strong	Well-developed slickensides	

Bss3	44–65	10YR 3/2	Clay	Angular blocky	Many lime nodules	Strong	Well-developed slickensides	
Bss4	65–87	10YR 3.5/2	Clay	Angular blocky	Many lime nodules	Strong	Well-developed slickensides	
Bss5	87–115+	10YR 4.5/4	Clay	Sub-angular blocky	Many lime nodules	Violent	Well-developed slickensides	
Odisha: Sunugarh: 18 m above MSL: MAR 1520 mm: Fine, mixed, hyperthermic Aquic Ustochrepts								
Ap	0–16	10YR 4/3	Silty clay	Massive	–	–	Prominent Mottles	20 mm wide cracks
BA	16–33	10YR 4/3	Clay	Angular blocky	–	–	Mottles	10–20 mm wide cracks
Bw1	33–58	10YR 4/2	Clay	Angular blocky	–	–	Mottles	10 mm wide cracks up to 41 cm depth
Bw2	58–81	10YR 5/2	Clay	Angular blocky	–	–	Mottles	
BC	81–150	10YR 5/1	Clay	Angular blocky	–	–	Mottles	
Bihar: Hirapatti: 60 m above MSL: MAR 1257 mm: Fine-loamy, mixed, hyperthermic family of Fluventic Haplustepts								
Ap	0–18	2.5Y 5/2 M	Silt loam	Massive		Slight		
Bw1	18–35	10YR 6/2	Silt loam	Sub-angular blocky	Iron manganese concretions	Slight		
Bw2	35–58	10YR 6/3	Silt loam	Sub-angular blocky	Iron and manganese concretions	Slight		
Bw3	58–71	10YR 6/3	Silt loam	Sub-angular blocky		slight		
Bw4	71–103	10YR 6/3	Silt loam	Sub-angular blocky		Slight		
BC	103–150	10YR 6/4	Silt loam	Massive		Slight		
Jharkhand: Pusaro: 125–500 m above MSL: MAR 1090 mm: Fine-loamy, mixed, hyperthermic Typic Paleustalfs								
A	0–9	5YR 4/6	Loam	Massive	Iron-manganese concretions	–		–
AB	9–30	5YR 4/4	Loam	Sub-angular blocky	Iron-manganese concretions	–		–

(continued)

Table 2.2 (continued)

Horizon	Depth cm	Matrix colour Moist	Texture	Structure	Nodules (conca/conir/conmn) (%)	Effervescence[a] (dil HCl)	Other features	Cracks[b]
BA	30–48	5YR 4/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–		–
Bt1	48–73	5YR 5/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
Bt2	73–91	5YR 5/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
Bt3	91–114	5YR 4/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
Bt4	114–141	5YR 4/6	Clay loam	Sub-angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
BC	141–186	5YR 5.5/6	Clay	Angular blocky	Iron-manganese concretions	–	Thick clay cutans	–
Madhya Pradesh, Arsia: 190 m above MSL: MAR 960 mm: Fine, smectitic, hyperthermic Typic Haplusterts								
Ap	0–20	7.5YR 3/2	Clay	Granular		Slight		20–30 mm wide cracks
B	20–73	7.5YR 3/2	Clay	Sub-angular blocky		Slight	Shiny pressure faces	20–25 mm wide cracks
2Bss	73–101	7.5YR 3/2	Clay loam	Angular blocky		Strong	Wedge-shaped peds with shiny pressure faces	10–20 mm wide cracks
2BC	101–118	7.5YR 5/4	Clay loam	Sub-angular blocky	5% lime nodules	Strong		
Chhattisgarh, Chaugel: 500–600 m above MSL: MAR 1400 mm: Fine-loamy, mixed, isohyperthermic Plinthustalfs								
A	0–11	10YR 4/3	Sandy clay loam	Sub-angular blocky	–	–	–	–
Bw1	11–34	10YR 5/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–

Bw2	34–49	10YR 5/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–
Bw3	49–71	10YR 5/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–
Btc1	71–104	10YR 5/4	Sandy clay	Sub-angular blocky	–	–	Thin clay cutans	–
Btc2	104–143	10YR 6/6	Sandy clay	Sub-angular blocky	–	–	Thin clay cutans	–
BC1	143–159	10YR 6/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–
BC2	159–172	10YR 6/6	Sandy clay loam	Sub-angular blocky	–	–	Thin clay cutans	–
Maharashtra: Linga: 300–320 m above MSL: MAR 1125 mm: Very fine, smectitic, hyperthermic Udic Haplusterts								
Ap	0–16	10YR 3/2	Clay	Sub-angular blocky		Slight		
Bss1	16–47	10YR 3/2	Clay	Angular blocky	Lime nodules	Strong	Intersecting slickensides	
Bss2	47–84	10YR 3/2	Clay	Angular blocky	Lime nodules	Strong	Intersecting slickensides	
Bss3	84–117	10YR 3/2	Clay	Angular blocky	Lime nodules	Strong	Intersecting slickensides	
BC	117–140	2.5Y 4/2	Clay	Angular blocky	Lime nodules	Violent	Intersecting slickensides	

[a]Matrix effervescence observed in 42–150 cm
[b]Cracks ~ 0.5 mm wide up to 20 cm

Table 2.3 Physical and chemical properties of representative soils in the selected states

Horizon	Depth cm	Sand %	Silt %	Clay %	Coarse fragments > 2 mm % of whole soil	Organic carbon (%)	Carbonate as $CaCO_3$ < 2 mm (%)	pH (1:2.5) H_2O	CEC NaOAc pH 8.2 cmol (p+)kg^{-1}	Exchangeable sodium (%)	Base saturation NaOAc (%)
Karnataka: Achmatti: 600 m above MSL: MAR 660 mm: Very fine, smectitic, isohyperthermic Sodic Haplusterts											
Ap1	0–4	23.5	21.9	54.6	12	1.25	16.2	8.3	59.4	4	109
Ap2	4–22	22.3	19.1	58.6	12	1.21	13.6	8.6	60.5	7	111
Bss1	22–54	13.2	18.8	68.0	5	1.27	12.8	8.7	71.5	14	111
Bss2	54–87	9.8	20.7	69.5	8	0.78	15.2	8.8	67.4	17	110
BCk1	87–152	9.8	20.1	70.1	13	0.71	15.0	8.9	66.1	20	114
BCk2	152–170	10.0	19.7	70.3	9	0.48	13.7	8.4	66.7	27	127
Andhra Pradesh: Kurnool: 254 m above MSL: MAR 740 mm: Fine, smectitic (calcareous), isohyperthermic, Vertic Haplustepts											
Ap	0–18	32.1	26.2	41.7	–	0.78	16	9.1	–	23	–
Bw1	18–50	17.3	28.0	54.7	–	0.37	20	9.8	–	37	–
Bss1	50–79	14.1	27.0	58.9	–	0.32	18	9.6	–	33	–
Bss2	79–109	12.2	28.2	59.6	–	0.16	17	9.6	–	33	–
Bss3	109–151	11.6	26.3	62.1	–	0.23	16	9.5	–	31	–
Telangana: Kasireddipalli: 540 m above MSL: MAR 760 mm: Fine, smectitic, isohyperthermic, Typic Haplusterts											
Ap	0–8	23.3	29.6	47.1	–	0.65	4.37	8.0	42.6	3	108
Bw	8–18	22.6	25.6	51.8	–	0.58	4.21	8.1	49.2	2	98
Bss1	18–32	21.2	25.9	52.9	–	0.42	4.14	8.2	50.4	2	106
Bss2	32–44	20.4	25.0	54.6	–	0.34	4.88	8.2	48.7	2	110
Bss3	44–65	17.0	24.4	58.6	–	0.3	4.25	8.1	57.4	2	94
Bss4	65–87	14.3	24.9	60.8	–	0.27	4.14	8.2	54.7	2	95
Bss5	87–115+	13.0	22.4	64.6	–	0.15	6.09	8.1	54.7	3	95
Odisha: Sunugarh: 18 m above MSL: MAR 1520 mm: Fine, mixed, hyperthermic Aquic Ustochrepts											
Ap	0–16	6.4	43.1	50.5		0.60	nd	6.2	30.8	8	70
BA	16–33	6.0	37.5	56.5		0.31	nd	6.4	30.8	8	68

Bw1	33–58	5.4	37.1	57.5		0.30	nd	6.5	31.5	8	62
Bw2	58–81	6.0	37.5	56.5		0.35	nd	6.6	31.5	8	66
BC	81–150	6.8	39.7	53.5		0.27	nd	6.7	30.8	8	71
Bihar: Hirapatti: 60 m above MSL: MAR 1257 mm: Fine-loamy, mixed, hyperthermic family of Fluventic Haplustepts											
Ap	0–18	9.2	70.9	19.9		1.14	3.8	7.9	9.0		94
Bw1	18–35	2.4	77.5	20.1		0.40	3.7	8.0	7.5		97
Bw2	35–58	0.8	75.3	23.9		0.51	4.0	8.0	9.6		97
Bw3	58–71	0.6	78.0	21.4		0.42	3.5	8.0	8.8		96
Bw4	71–103	12.8	62.2	25.0		0.42	3.1	7.7	10.3		92
BC	103–150	30.2	54.5	15.3		0.32	2.9	7.3	6.9		85
Jharkhand: Pusaro: 125–500 m above MSL: MAR 1090 mm: Fine-loamy, mixed, hyperthermic Typic Paleustalfs											
A	0–9	51.6	28.5	19.9	Tr	0.26		4.3	8.5	2	55
AB	9–30	43.7	29.7	26.6	Tr	0.23		5.0	8.8	1	70
BA	30–48	40.2	28.0	31.8	3	0.13		5.7	9.1	1	76
Bt1	48–73	40.8	26.7	32.5	3	0.10		5.9	9.6	2	90
Bt2	73–91	40.4	25.9	33.7	2	0.10		5.6	10.4	1	86
Bt3	91–114	42.1	24.0	33.9	5	0.08		5.7	11.4	1	82
Bt4	114–141	36.7	25.7	37.6	2	0.07		5.6	13.3	1	80
BC	141–186	33.6	25.8	40.6	2	0.05		5.5	14.3	2	82
Chhattisgarh, Chaugel: 500–600 m above MSL: MAR 1400 mm: Fine-loamy, mixed, isohyperthermic Plinthustalfs											
A	0–11	62.6	8.1	29.3	4	0.70		5.4	10.5	–	66
Bw1	11–34	60.3	11.6	28.1	2	0.60		5.0	13.6	–	51
Bw2	34–49	61.6	10.3	28.1	26	0.44		4.9	14.2	–	49
Bw3	49–71	59.8	9.3	30.9	8	0.38		4.9	17.7	–	36
Btc1	71–104	47.1	10.5	42.4	31	0.41		4.8	19.8	–	48
Btc2	104–143	47.1	11.3	41.6	7	0.28		5.1	23.3	–	43
BC1	143–159	51.4	14.3	34.3	37	0.16		5.3	16.2	–	57

(continued)

Table 2.3 (continued)

Horizon	Depth cm	Sand %	Silt %	Clay %	Coarse fragments > 2 mm % of whole soil	Organic carbon (%)	Carbonate as $CaCO_3$ < 2 mm (%)	pH (1:2.5) H_2O	CEC NaOAc pH 8.2 cmol (p+)kg^{-1}	Exchangeable sodium (%)	Base saturation NaOAc (%)
BC2	159–172	56.7	8.4	34.9	38	0.17		5.4	13.9	–	60
Madhya Pradesh, Arsia: 190 m above MSL: MAR 960 mm: Fine, smectitic, hyperthermic Typic Haplusterts											
Ap	0–20	20.3	30.4	49.3	13	0.27	2.0	7.5	45.2	6	96
B	20–73	20.4	29.5	50.1	13	0.17	1.0	7.4	46.2	10	93
2Bss	73–101	31.1	36.4	32.5	13	0.15	12.5	7.6	30.6	8	95
2BC	101–118	34.2	34.4	31.4	13	0.15	11.5	7.8	30.0	8	98
Maharashtra: Linga: 300–320 m above MSL: MAR 1125 mm: Very fine, smectitic, hyperthermic Udic Haplusterts											
Ap	0–16	4.8	20.6	74.6	2	0.51	1.9	8.3	59.3	8	8
Bss1	16–47	5.5	20.0	74.5	3	0.47	4.0	8.1	56.0	8	8
Bss2	47–84	9.7	16.5	73.8	4	0.42	5.6	8.1	64.2	7	7
Bss3	84–117	10.3	15.1	74.6	4	0.49	6.5	8.1	69.4	7	7
BC	117–140	10.1	19.0	70.9	8	0.27	8.5	8.1	65.1	6	6

Table 2.4 Land use and other details of Telangana sate, India

Sl No	Particulars	Lakh[a] ha	
1.	Total geographical area	114.84	
2.	Forest	27.43	23.9
3.	Barren and uncultivable land	6.15	5.4
4.	Land put to non-agri. uses		
5.	Water logged area	0.06	0.1
6.	Social forestry	0.07	0.1
7.	Land under still water	2.46	2.1
8.	Others	6.36	5.5
9.	Total Land put to Non-Agriculture Use (TLPNAU)	8.95	7.8
10.	Culturable waste	1.78	1.5
11.	Permanent pastures and other grazing lands	3.01	2.6
12.	Land under misc. tree crops, groves not included in net area sown	1.14	1.0
13.	Other fallow lands	7.17	6.2
14.	Current fallow lands	9.6	8.4
15.	Gross area sown	62.88	54.8
16.	Net area sown (including fish culture)	49.61	43.2
17.	Area sown more than once	13.27	11.6
18.	No. of farm holdings (Lakh Nos)	55.54	
19.	Average farm holding size (Ha)	1.12	
20.	Average annual rainfall (in mm)	906.8	
21.	Net irrigated area	17.74	15.4
22.	Gross irrigated area	31.64	27.6
	Cropping intensity (%)	127	
	Irrigation intensity (%)	138	

Source: Anonymous (2013–2014)
[a]10 lakh =1 million

Table 2.5 Land use in Andhra Pradesh, India

Sl No.	Particulars	*Lakh ha*[b]	*% of TGA*
1.	TGA	162.97	
2.	Forest	36.88	23
3.	Barren and uncultivable land	13.45	8
4.	Land put to non-agri. uses	20.55	13
5.	Culturable waste	4.14	3
6.	Permanent pastures and other grazing lands	2.09	1
7.	Land under misc. (Tree crops, groves)	1.55	1
8.	Other fallow lands	9.4	6
9.	Current fallow lands	14.43	9
10.	Net area sown[a]	60.48	37

[a]Net Area Sown under (i) Crops is 58.94 lakh ha (ii) Fish Ponds 1.54 lakh ha. (Source: Anonymous 2015–2016)
[b]10 lakhs = 1 million

Miocene, Pliocene, Pleistocene and Recent. The states represent a transition from tropical to subtropical monsoonic climate of semi-arid to arid in Telangana and humid to sub humid in the coastal regions. The average annual rainfall varies from 690 to 860 mm. The red soils are most common in both the states (Fig. 2.5) and most of these soils are categorised either as Alfisols and Inceptisols.

2.3.3 *Soils of Odisha*

The state of Odisha is surrounded by West Bengal, and Jharkhand to the north, Andhra Pradesh in the south, Chhattisgarh to the west and Bay of Bengal in the east. Odisha has a coastline of 485 km along the Bay of Bengal. The state covers an area

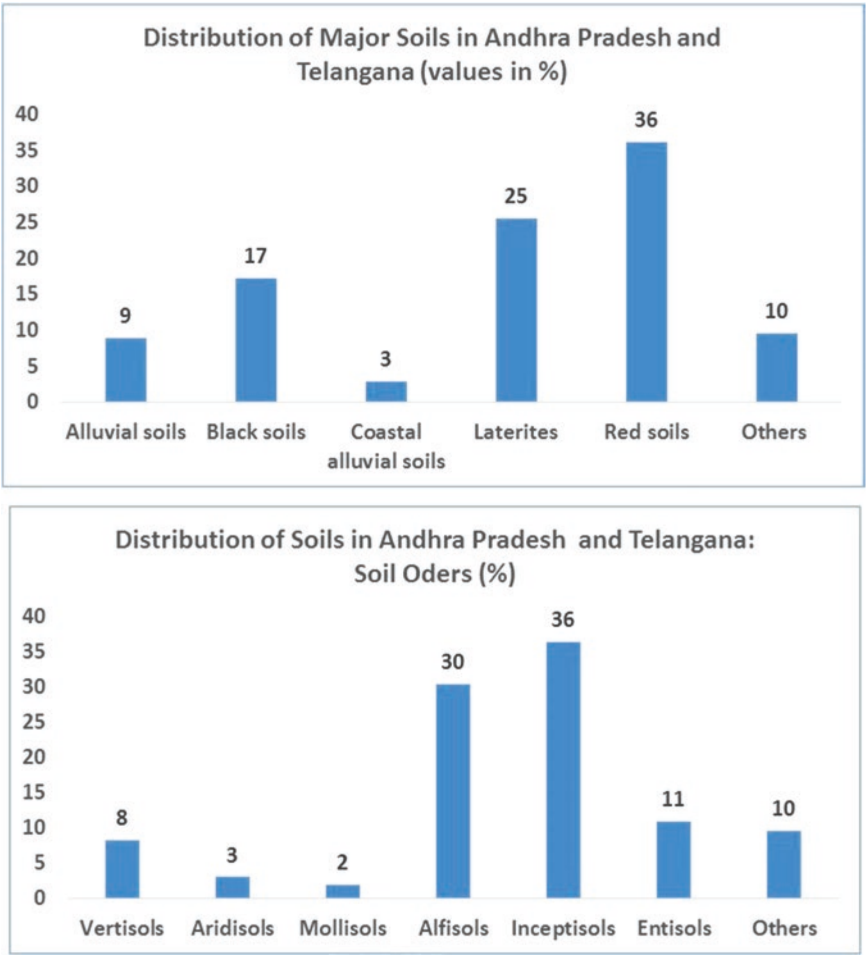


Fig. 2.5 Soils in Andhra Pradesh and Telangana in India

of 15.57 million hectares. Based on stratigraphy, tectonic history and relief features along with erosional processes, the state presents four broad physical regions (i) northern plateau, (ii) central table land, (iii) Eastern Ghats, and (iv) east coast plains. The present day landforms are the result of several cycles of denudation, sedimentation and igneous activities. The geological sequences responsible for the present topography are the Achaean to Pleistocene and Recent age. A group of lime stones, sandstones, and slates occurring in the bed of northern hilly regions belongs to Miocene age. Larger deposits of laterite are of the Pleistocene origin. The Deltaic sediments of the Mahanadi, Brahmini, and other rivers cover the Balasore, Cuttack and Puri districts of the coastal tract. The changing pattern of rainfall in the state causes both drought and flood. The state receives south west monsoon from June to September. The average annual rainfall is 1481 mm. The rainfall variation (Fig. 2.6), potential evapo-transpiration (PE), actual evapo-transpiration (AE) and soil data help estimating the length of growing period (LGP) to group the state into 6 agro-ecological sub regions (11.0,12.1,12.2,12.3,18.4, and 18.5) (Sehgal et al. 1992). The mean minimum temperature is ~12 °C and maximum of about 42 °C. The soils of this state belong to 4 orders, 9 suborders, 15 greatgroups, 35 sub-groups and 93 families (Bhattacharyya et al. 2009). Figures 2.7 and 2.8 show the distribution of different soils in Odisha. The major soils in the state are alluvial, black, coastal alluvial, laterites, red and hills. The land use of the state is shown in Fig. 2.9.

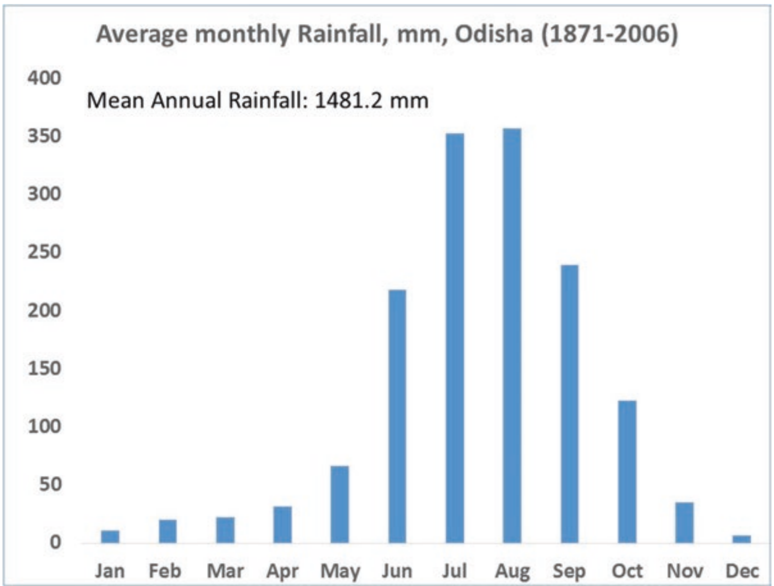


Fig. 2.6 Rainfall distributions in Odisha. (Source: Patra et al. 2012)

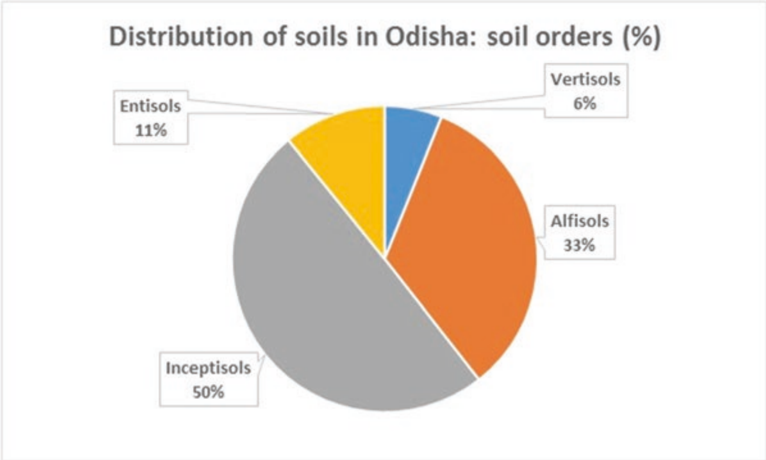


Fig. 2.7 Distribution of soil orders in Odisha

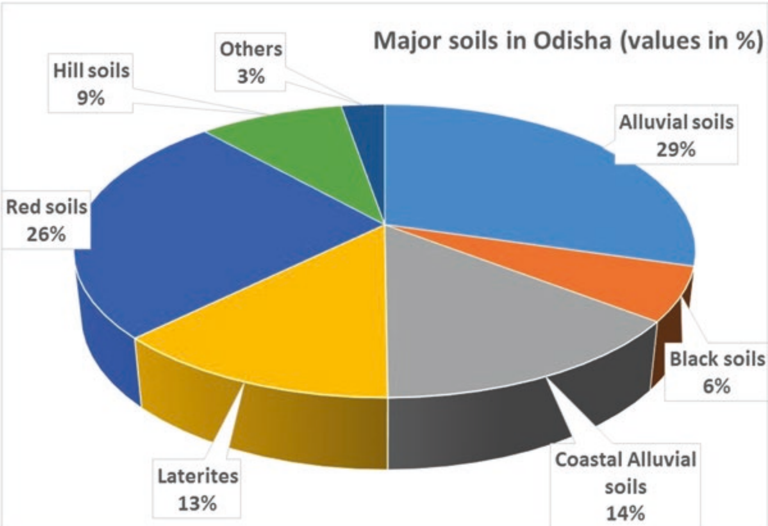


Fig. 2.8 Distribution of major soils in Odisha (others include rock outcrops and water bodies)

2.3.4 Soils of Bihar and Jharkhand

Bihar is situated in eastern part of India and is a part of the Indo-Gangetic Plains, India. It is contiguous with Uttar Pradesh to its west, Nepal to the north, the northern part of West Bengal to the east, and with Jharkhand to the south. The land use of Bihar is shown in Fig. 2.10. Jharkhand is situated in eastern part of India. The state shares its border with the states of Bihar to the north, Uttar Pradesh to the north

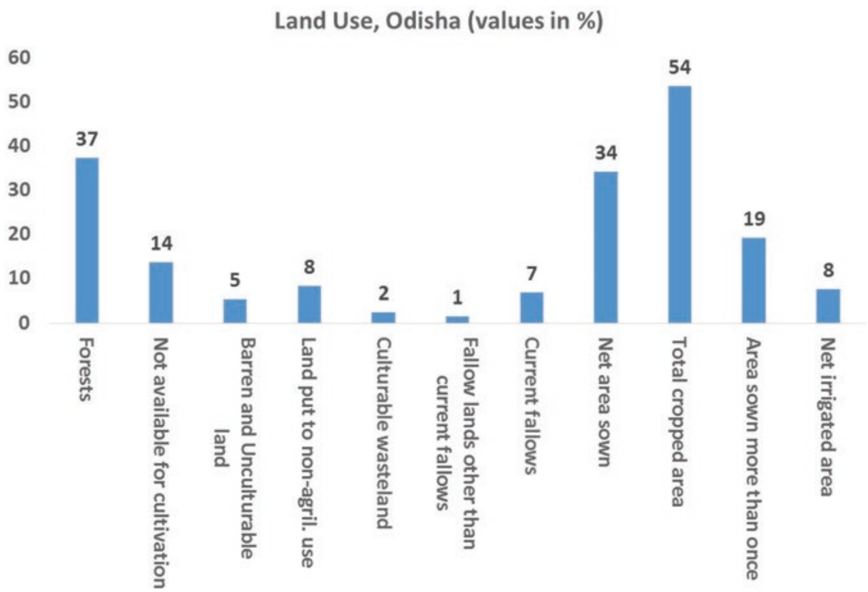


Fig. 2.9 Land use, Odisha. (Source: Dash et al. 2017)

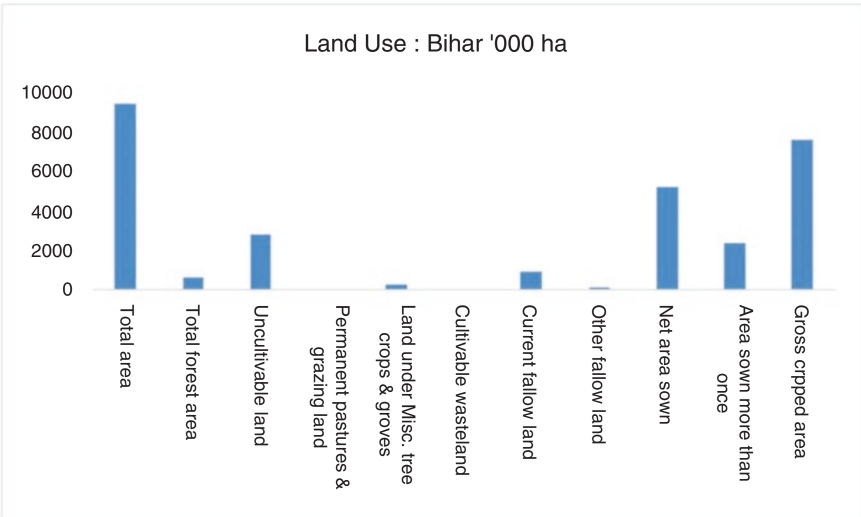


Fig. 2.10 Land use, Bihar. (Source: Anonymous 2015–2016)

west, Chhattisgarh to the west, Odisha to the south and West Bengal to the east. The land use of Jharkhand is shown in Fig. 2.11. The soils of Bihar and Jharkhand belong to 4 orders, 9 suborders, 19 greatgroups, 40 subgroups and 79 families (Bhattacharyya et al. 2009). Figures 2.12 and 2.13 show the distribution of different soils in these states. The major soils in the state are alluvial, black, and red.

2.3.5 *Soils of Madhya Pradesh and Chhattisgarh*

Madhya Pradesh (MP) is situated in central India and is a part of the peninsular plateau of India. It is bordered in the northeast by Uttar Pradesh, to its southeast by Chhattisgarh, to its south by Maharashtra, Gujarat to the west, and to its northwest lies Rajasthan. The Narmada Son valley defines its topography. Madhya Pradesh is positioned in the heart of India and spans an area of 30.8252 million ha. The land use of Madhya Pradesh is shown in Fig. 2.14.

Chhattisgarh is bounded by southern Jharkhand and Odisha in the east, Madhya Pradesh and Maharashtra in the west, Uttar Pradesh and western Jharkhand in the north and Andhra Pradesh in the south. Out of the geographical area of 13.79 million hectares, gross cropped area is about 35% of the total geographical area. *Kharif* (rainy season) is the main cropping season. Rice is the predominant crop of the state. Other important crops are maize, wheat, niger, groundnut and pulses. The state has one of the biggest collections of rice germplasm. Horticulture crops are grown in an

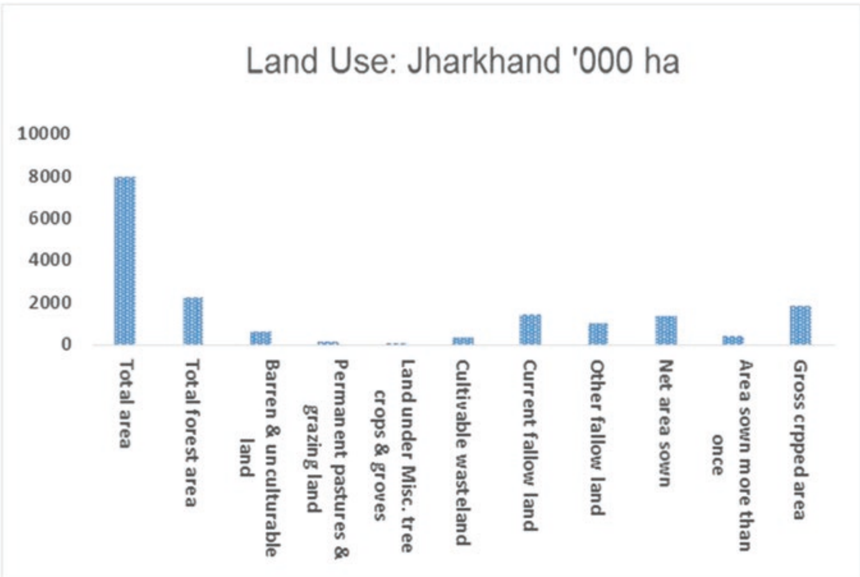


Fig. 2.11 Land use, Jharkhand. (Source: Anonymous 2015–2016)

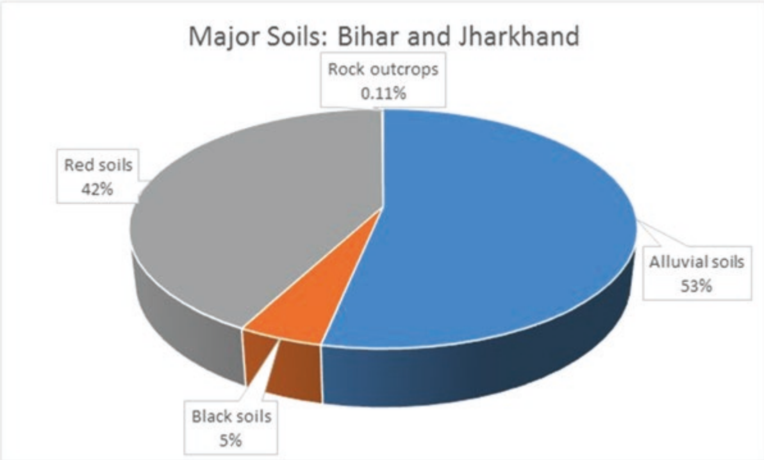


Fig. 2.12 Distribution of major soils in Madhya Pradesh and Chhattisgarh (others include rock outcrops and water bodies)

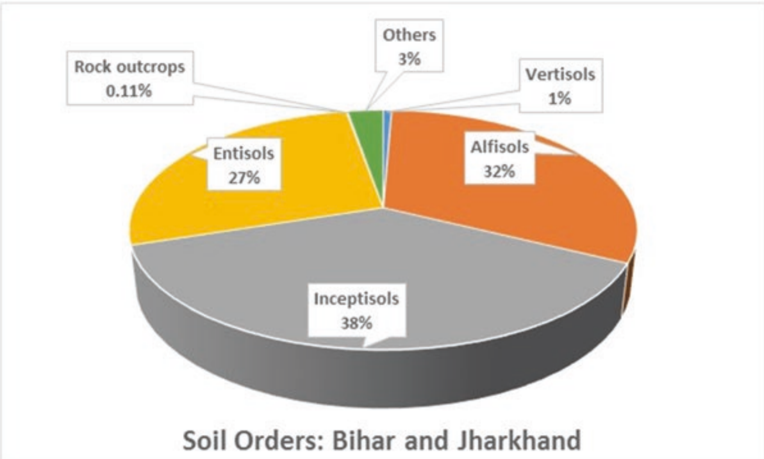


Fig. 2.13 Distribution of soil orders in Bihar and Jharkhand

area of about 540 thousand hectares. The state has 18.09 lakh hectare irrigated area. The land use of Chhattisgarh is shown in Fig. 2.15.

The soils of Madhya Pradesh and Chhattisgarh belong to 5 orders, 8 suborders, 11 greatgroups, 26 subgroups and 176 families (Bhattacharyya et al. 2009). Figures 2.16 and 2.17 show the distribution of different soils in these states. The major soils in the state are alluvial, black, and red.

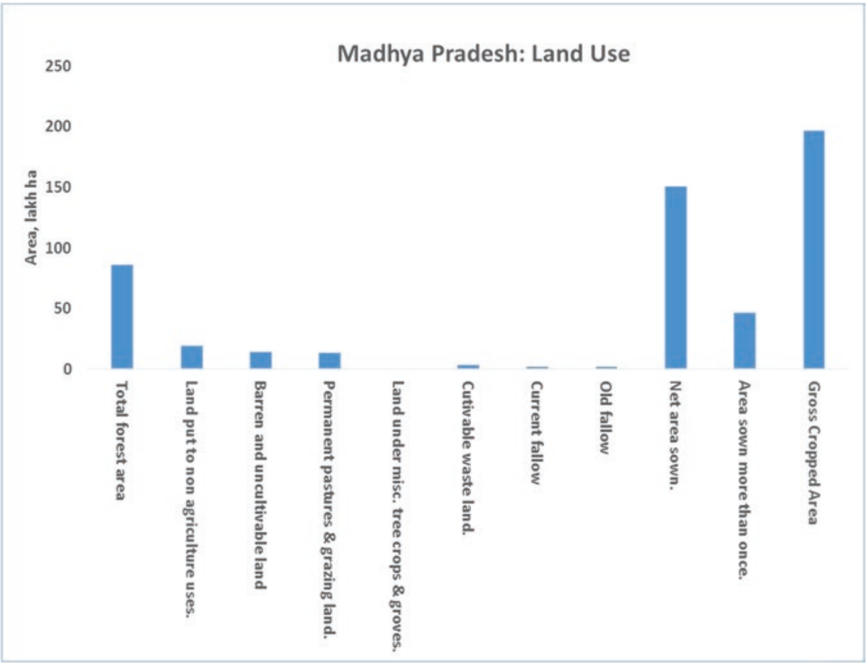


Fig. 2.14 Land use, Madhya Pradesh. (Source: Anonymous 2015–2016)

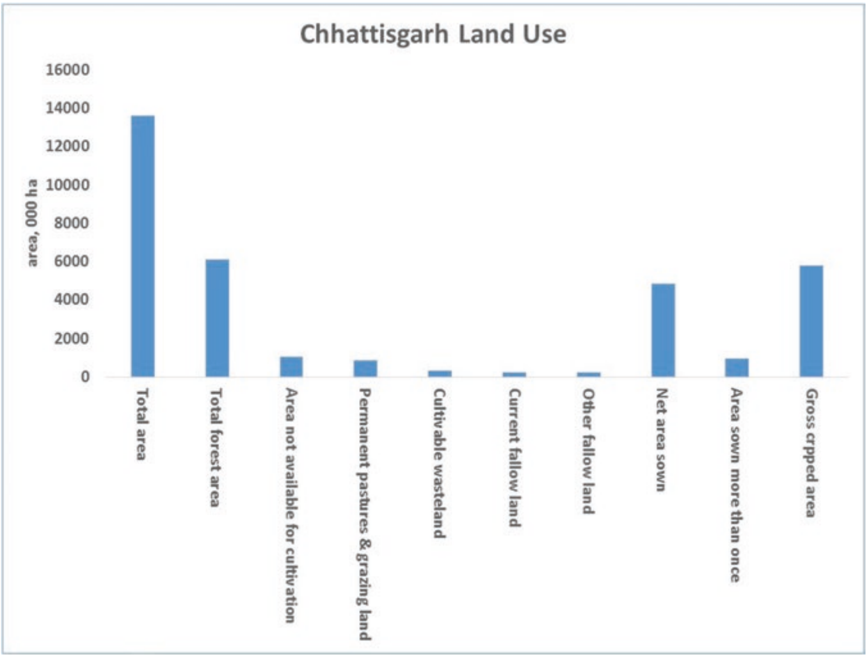


Fig. 2.15 Land use, Chhattisgarh. (Source: Anonymous 2015–2016)

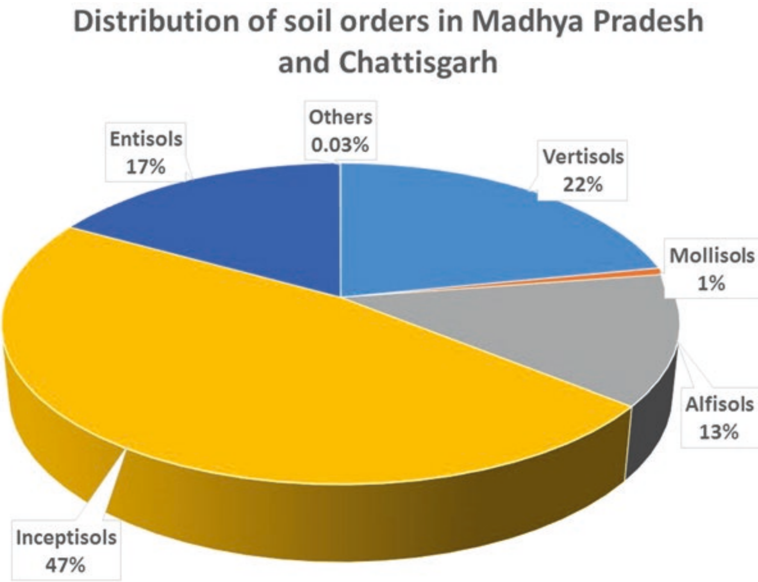


Fig. 2.16 Distribution of soil orders in Madhya Pradesh and Chhattisgarh

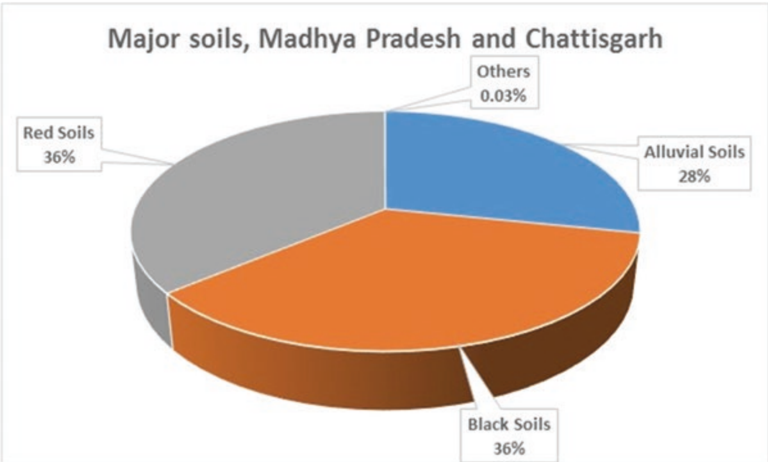


Fig. 2.17 Distribution of major soils in Madhya Pradesh and Chhattisgarh (others include rock outcrops and water bodies)

2.3.6 Soils of Maharashtra

Maharashtra is a state in the western peninsular region of India occupying a substantial portion of the Deccan Plateau. Maharashtra is bordered by the Arabian Sea to the west, the Indian states of Karnataka and Goa to the south, Telangana to the southeast and Chhattisgarh to the east, Gujarat and Madhya Pradesh to the north, and the Indian union territory of Dadra and Nagar Haveli and Daman and Diu to the northwest. The land use of Maharashtra is shown in Fig. 2.18

The soils of Maharashtra belong to 5 orders, 7 suborders, 8 great groups, 18 subgroups and 95 families (Bhattacharyya et al. 2009). Figures 2.19 and 2.20 show the distribution of different soils in these states. The major soils in the state are alluvial, black, and red.

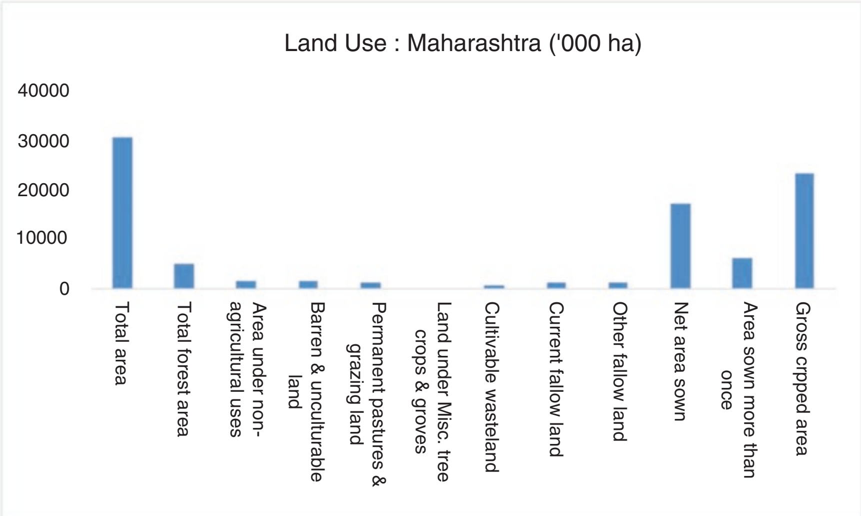


Fig. 2.18 Land use, Maharashtra. (Source: Anonymous 2015–2016)

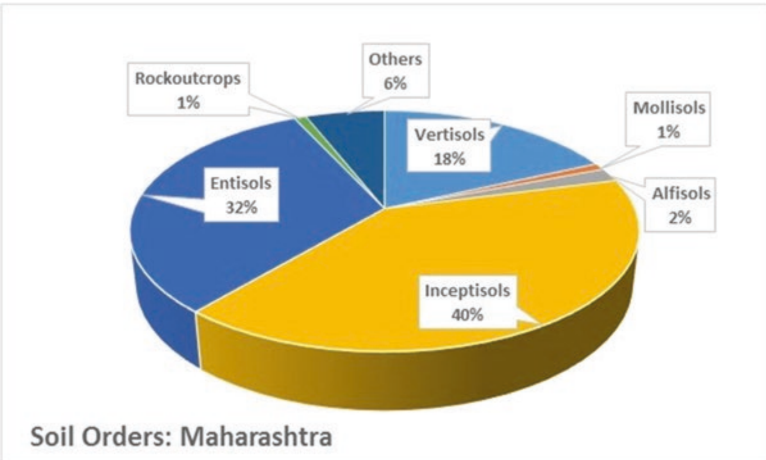


Fig. 2.19 Distribution of soil orders in Maharashtra

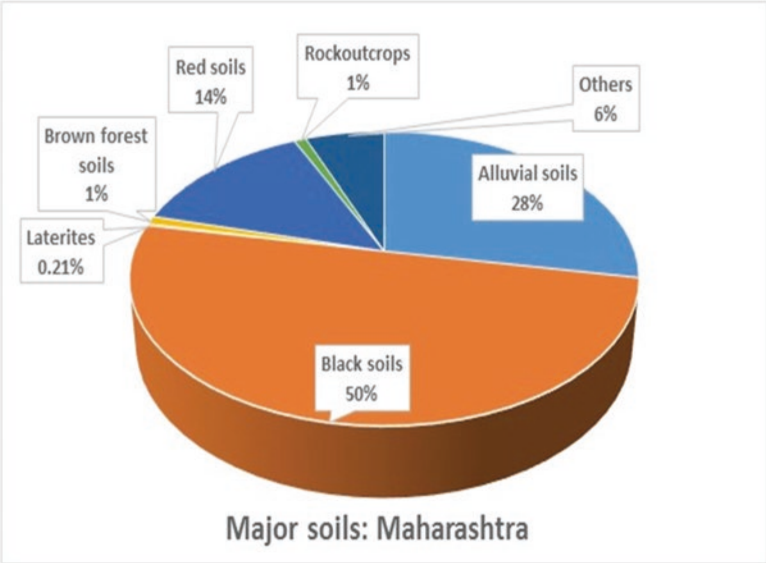


Fig. 2.20 Distribution of major soils in Maharashtra

2.4 Moisture Regimes and the Target Regions

2.4.1 Soil Moisture Regime

The term “soil moisture regime” refers to the presence or absence either of groundwater or of water held at a tension of less than 1500 kPa in the soil at different times of the year. Water held at a tension of 1500 kPa or more is not available to keep most mesophytic plants alive. Soil is considered moist when it is at moisture tension of < 1500 kPa (15 bar) and dry when the tension is ≥ 1500 kPa in the soil moisture control section (SMCS) (Figs. 2.21 and 2.22). The limits of SMCS are determined by the soil depth. Soil moisture regime is controlled by the soil parameters, most important of which, is soil texture. The textural class (Fig. 2.22) in terms of clay content and its quality fix the limit of soil moisture available for plants and trees.

Under natural conditions soils experience two different types of soil moisture regimes namely (i) saturated, and (ii) unsaturated. A soil may be continuously moist in some or all horizons either throughout the year or for some part of the year. It may be either moist in winter or dry in summer or the reverse. In the Northern Hemisphere, summer refers to June, July, and August and winter refers to December, January, and February (Soil Survey Staff 2014). The soil moisture regimes are defined in terms of the level of groundwater and in terms of the seasonal presence or absence of water held at a tension of less than 1500 kPa. There are five different classes of soil moisture regime viz. aquic, aridic or torric, udic, ustic, and xeric (Soil Survey Staff 2014).

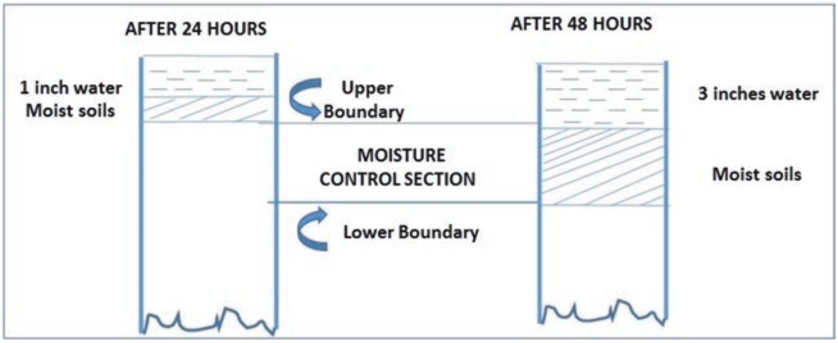


Fig. 2.21 Schematic diagram showing upper and lower boundaries of soil moisture control section (SMCS)

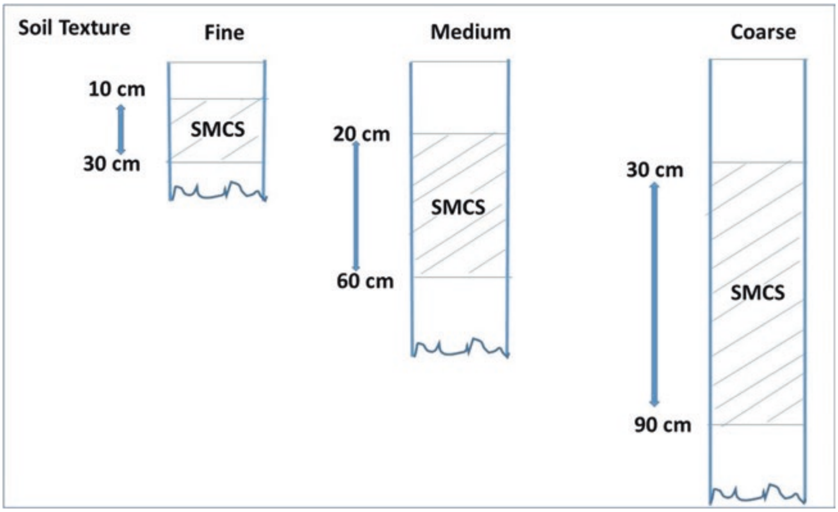


Fig. 2.22 Schematic diagram showing variation in soil moisture control section (SMCS) in different soil textures (Fine: fine silty to clayey), medium (fine loamy to coarse loamy) and coarse (sandy)

2.4.2 Soil Moisture Regimes in the Target Regions

The target states are Karnataka, Andhra Pradesh, Telangana, Odisha, Madhya Pradesh, Chhattisgarh, Madhya Pradesh, Bihar, Jharkhand, and Maharashtra. Mostly the drier areas of these states are selected for the present study except a few exceptions. The moisture regimes of these states belong to aquic, udic, ustic and aridic as detailed (Table 2.6; Figs. 2.23, 2.24, 2.25, 2.26, 2.27 and 2.28).

Table 2.6 Classes of soil moisture regime in the target states and their distribution in target states

States	Moisture regimes				
	Aquic	Udic	Ustic	Aridic	Torrid
Karnataka			17795.99	545.86	137.38
Andhra Pradesh and Telangana	122.63		23867.97	810.06	77.89
Odisha	3786.31		11146.13		
Madhya Pradesh & Chhattisgarh	12.9		43659.67		
Bihar & Jharkhand	5749.64	233.06	10916.16		
Maharashtra	108.07		28536.58		

Aquic: Aquic (L. aqua, water) soil moisture regime is a reducing regime in a soil that is virtually free of dissolved oxygen because it is saturated by water
Udic: Udic (L. udus, humid) soil moisture regime is one in which the soil moisture control section is not dry in any part for as long as 90 cumulative days in normal years
Ustic: Ustic (L. ustus, burnt; implying dryness) soil moisture regime is intermediate between the aridic regime and the udic regime
Aridic and torric (L. aridus, dry, and L. torridus, hot and dry): In the aridic (torric) soil moisture regime, the moisture control section is, in normal years: Moist in some or all parts for less than 90 consecutive days when the soil temperature at a depth of 50 cm below the soil surface is above 8 °C (Soil Survey Staff 2014)
Values in ‘000 ha

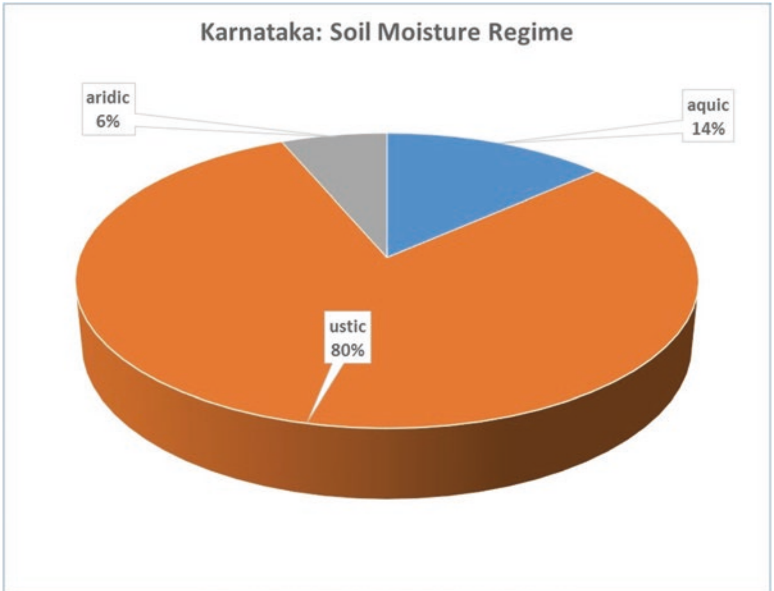


Fig. 2.23 Soil moisture regime in Karnataka

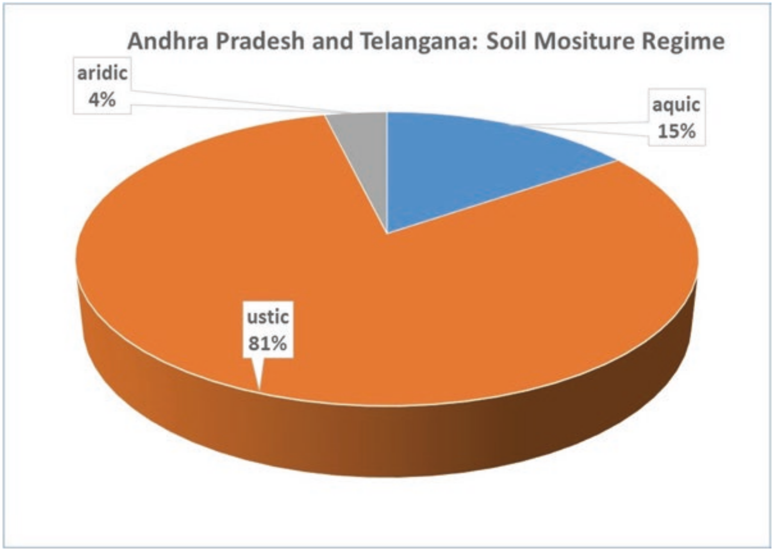


Fig. 2.24 Soil moisture regime in Andhra Pradesh and Telangana

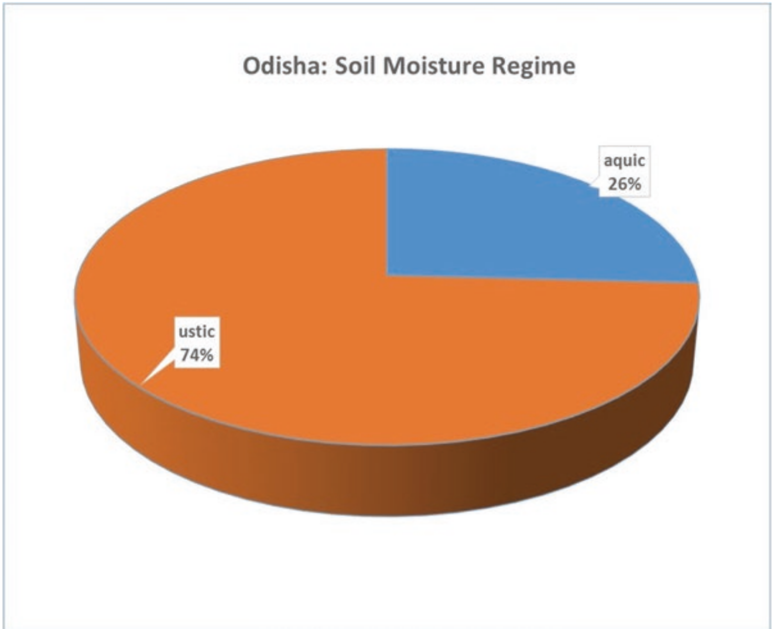


Fig. 2.25 Soil moisture regime in Odisha

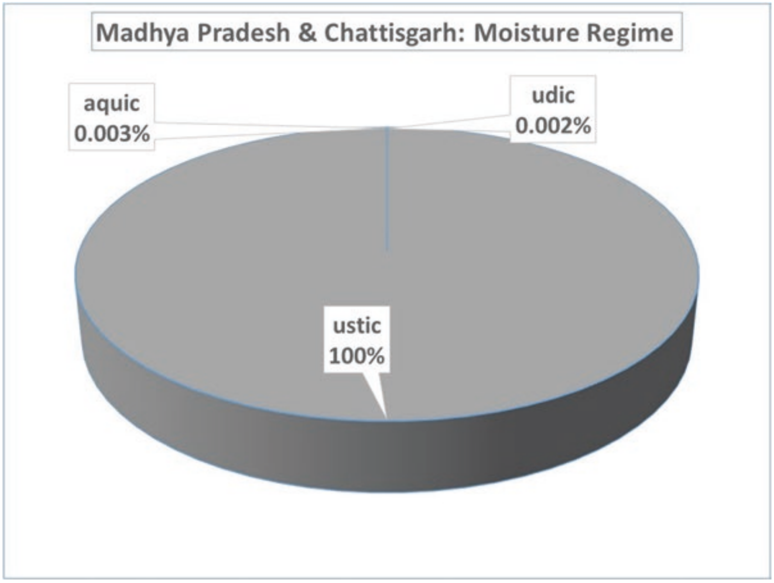


Fig. 2.26 Soil moisture regime in Madhya Pradesh and Chhattisgarh

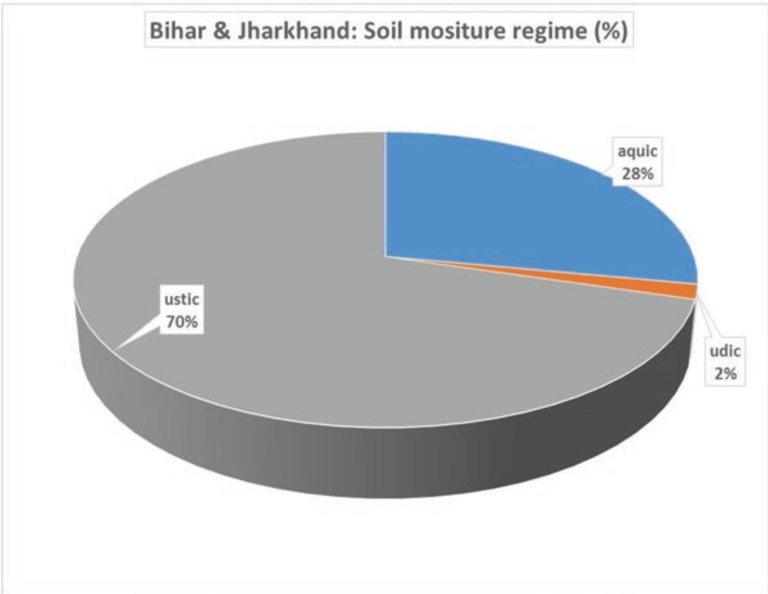


Fig. 2.27 Soil moisture regime in Bihar and Jharkhand

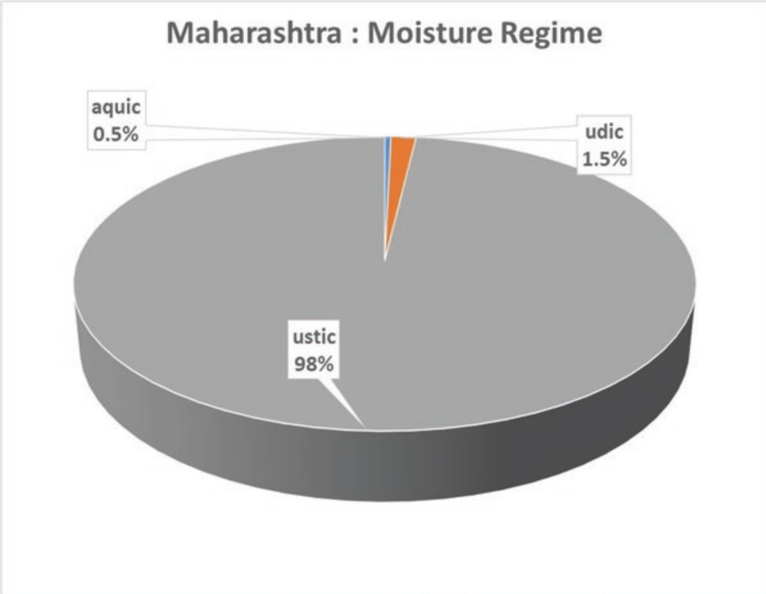


Fig. 2.28 Soil moisture regime in Maharashtra

2.4.3 Length of Growing Period (LGP) in Target Areas and Identification of Major Food Systems

2.4.3.1 Concept of Length of Growing Period (LGP)

The growing period is the period when the moisture in soils is adequate enough to support plant growth. The LGP was earlier estimated following the FAO model (Higgins and Kassam 1981) (Fig. 2.29). The growing period starts when precipitation (P) exceeds 0.5 PET and ends with the utilization of assumed quantum of stored soil moisture (100 mm) after P falls below PET. This is conditioned again by threshold temperature of 5 °C.

Concept of the length of growing period (LGP) (Sehgal et al. 1992) was mooted to address inadequacies in the above mentioned protocols for agro-ecological zones/regions. The LGP is an index of crop production because it takes care soil-water balance, which is a direct function of moisture availability in a landform rather than total rainfall. The 20 Agro-Ecological Regions (AERs) were delineated by the NBSS&LUP by superimposing bio-climate and LGP on soil-scape. The LGP classes were clubbed apparently related to cropping in an agro-environment (Mandal et al. 1999). While developing AER, only 5 LGP classes were considered showing due importance to crop durations, such as short (<90 days), medium (90–150 days), long (150–180 days), relay cropping (180–210 days) and double cropping (>210 days). Realising the importance of narrower LGP interval of 30 days for diverse crop suitability and also the need to further subdivide the bio-climate and

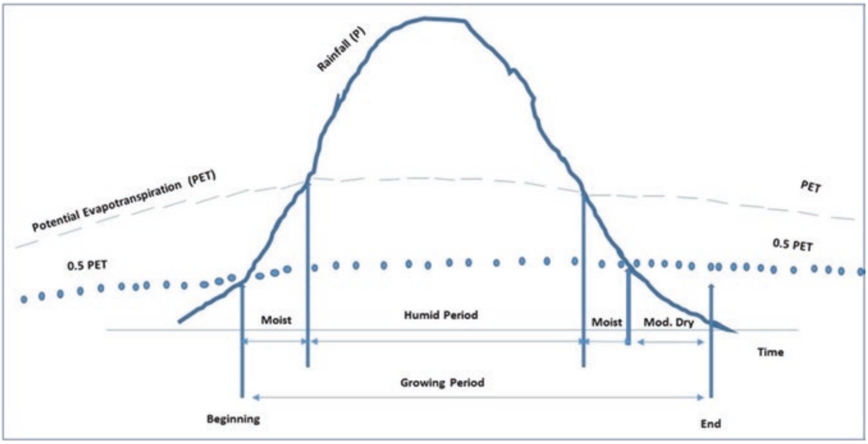


Fig. 2.29 Schematic diagram showing estimation of Length of growing period (LGP)

some important soil quality parameters like depth and available water capacity (AWC), NBSS&LUP divided 20 AERs into 60 Agro-ecological sub regions (AESRs) (Velayutham et al. 1999). Usefulness of 60 AESRs has been demonstrated in estimating soil carbon and available potassium stocks of the IGP and black soil regions and also in prioritizing areas for carbon sequestration (Bhattacharyya et al. 2007, 2008) and potassium management in different crop and cropping systems. In spite of this, refinement of AESR boundaries to match the new soil information of states (SRM at 1:2,50,000 scale) and moisture availability after cessation of rainfall, a function of the amount of rainwater that enters in the soil profile and their quantum of availability depending on nature of soil minerals and exchangeable Na^{+}, Mg^{2+} ions together in sub-soils. This has been a concern for raising *rabi* crops in SAT environment. However, to address this issue there is a need to gather antecedent soil moisture after the cessation of rains when rainfall (P) falls short of 0.5 potential evapotranspiration (PE). In the absence of such essential data the present AESR boundaries vis-a-vis crop performance exhibits scenarios a little away from reality under adverse soil condition. The information on different soil modifiers (gypsum, zeolite, palygorskite, lubenite; Bhattacharyya 2021b) must also be included in fine tuning the LGP computation. The 20 agro-ecological map of India published in 1992 by NBSS and LUP, was the outcome of superimposition of broad physiography, soils and bio-climate.

Later these 60 AESRs were revisited keeping in mind the shortfall of FAO's assumed quantum of stored soil moisture (100 mm) after P falls below PET (Mandal et al. 2014) to 84 AESRs, a few of which fall in the target states (Fig. 2.30). The AESR maps of the target states (Fig. 2.31) and details of LGP, crops, and their water requirements are shown in Tables 2.7, 2.8, and 2.9.

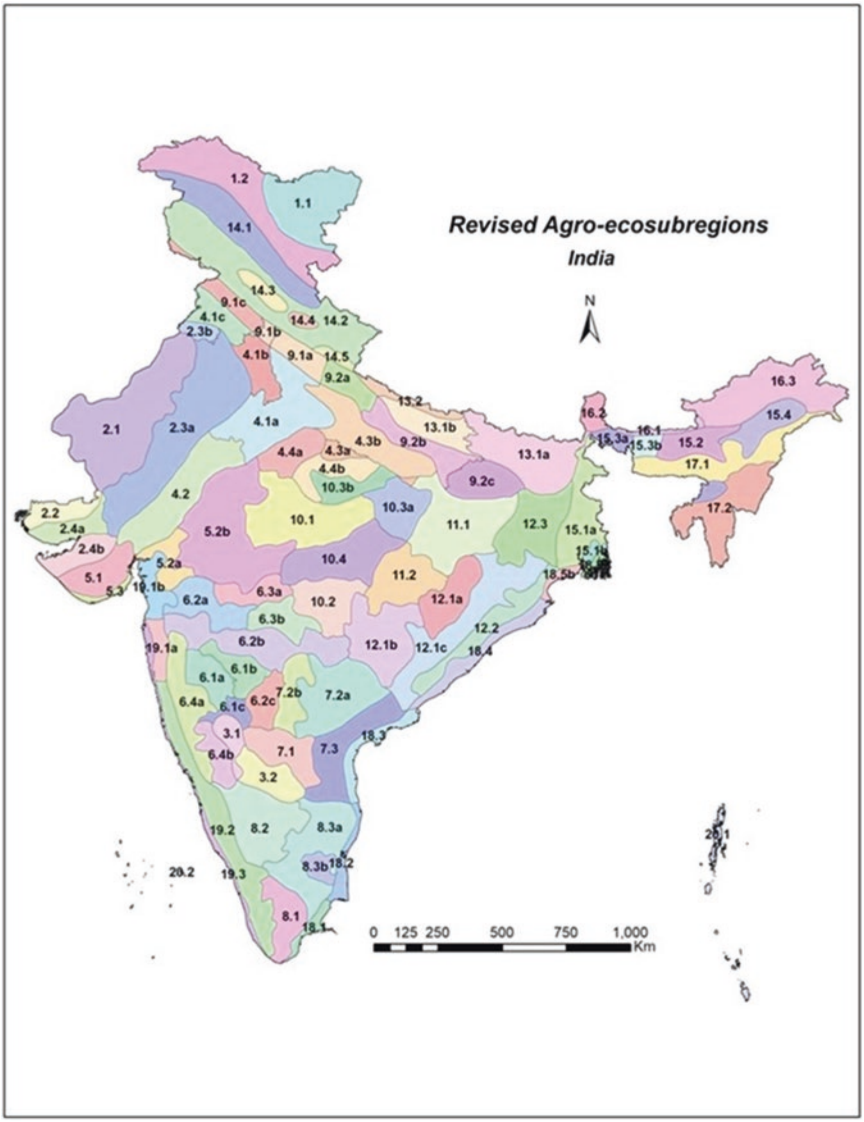


Fig. 2.30 Revised agro-eco sub-region (AESR) map of India

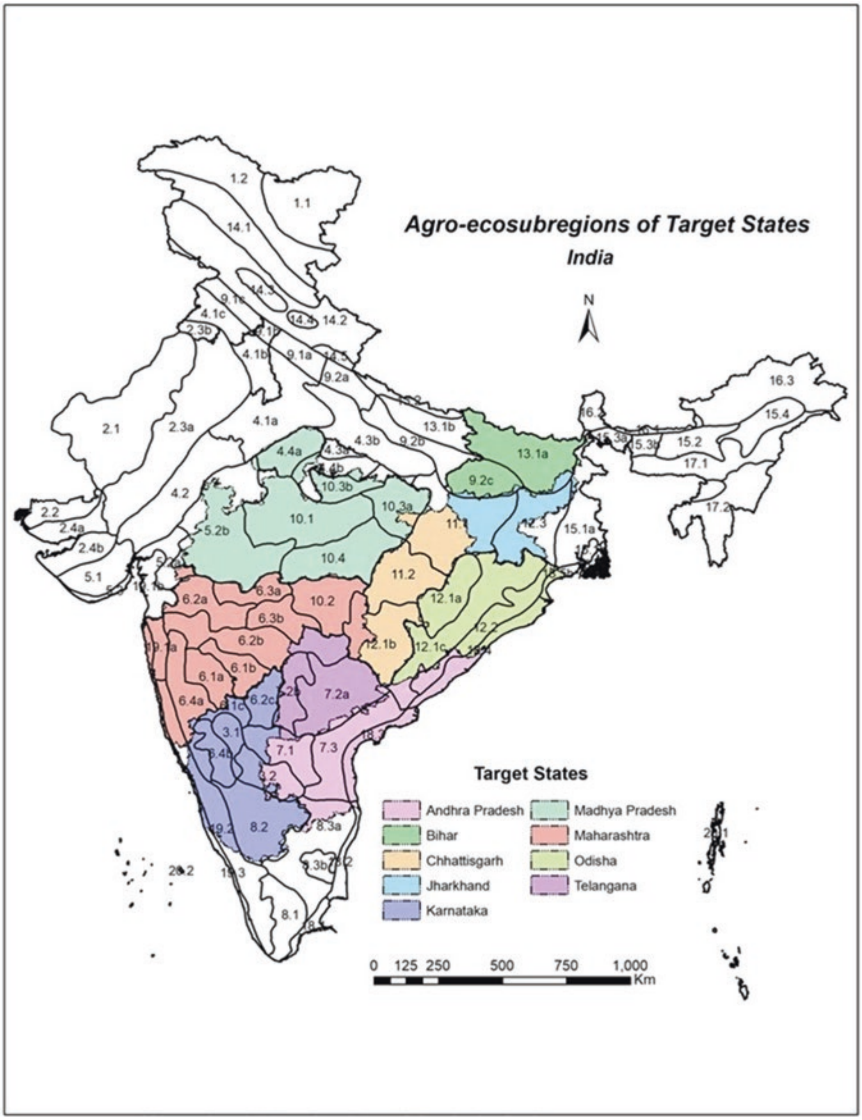


Fig. 2.31 Revised agro-eco sub-region (AESR) of the nine target states

Table 2.7 AESRs, LGP, crops and crop water requirements in target states: Arid and semi-arid ecosystem

AESRs							
Nos	Details	LGP days	States	Districts	Crops	Crop water requirement (m^3/ha)	Area mha
3.1	Deccan Plateau Hot Arid Ecoregion with well drained dominantly black soils	90–120	Karnataka	Bijapur (Part), Dharwad (Part), Raichur (Part), Bellary, Chitradurg (Part), Tumkur	Sorghum	3646	1.56
3.2	Deccan Plateau Hot Arid Ecoregion with well drained, red loamy soils	< 90	Andhra Pradesh	Anantapur	Sorghum, groundnut	3646,4570	3.08
4.3a	Northern Plain and Central Highlands Ecoregion – Ganga-Yamuna Doab, Rohilkhand and Avadh plain, hot, moist semi-arid eco-sub region with dominantly black soils, well drained	120–150	Madhya Pradesh	Gwalior, Morena, Shivpuri, Datia, Bhind	Rice, wheat	8922, 8275	0.02
5.2b	Northern Plain and Central Highlands Ecoregion – Madhya Bharat plateau Western Malwa plateau, Eastern Gujarat plain, Vindhyan and Satpura range and Narmada valley hot, moist semi-arid eco-sub region with black soils, well drained	150–180	Madhya Pradesh	Jhabua, Ratlam, Mandsaur, Ujjain, Indore, Dewas, East Nimar, East Dhar, Rajgarh (Part), Shajapur (Part)	Soybean, wheat	4686, 8275	14.72
6.1a	Deccan Plateau, hot semi-arid Eco-Region – South Western Maharashtra and North Karnataka plateau, hot dry semi-arid eco-sub region with black Soils (Shallow) loamy Skeletal, well drained	150–180	Maharashtra	Ahmadnagar (Part) , Bid, Latur (Western Part), Osmanabad, Solapur, Sangli (Part), Satara (Part), Pune (Part)	Sorghum	3565	2.77
			Karnataka	Bijapur (Part), Raichur			
6.1b	Deccan Plateau, hot semi-arid Eco-Region – South Western Maharashtra and North Karnataka plateau, hot dry semi-arid eco-sub region with black soils (Shallow), well drained	120–150	Maharashtra	Ahmadnagar (Part) , Bid, Latur (Western Part), Osmanabad, Solapur, Sangli (Part), Satara (Part), Pune (Part)	Sorghum	3565	2.38
			Karnataka	Bijapur (Part), Raichur			

6.1c	Deccan Plateau, hot semi-arid Eco-Region – South Western Maharashtra and North Karnataka plateau, hot dry semi-arid eco-sub region with black soils, well drained	150–180	Maharashtra	Ahmadnagar (Part) , Bid, Latur (Western Part), Osmanabad, Solapur, Sangli (Part), Satara (Part), Pune (Part)	Sorghum	3565	0.97
			Karnataka	Bijapur (Part), Raichur			
6.2a	Deccan Plateau, hot semi-arid Eco-Region – Central and western Maharashtra plateau and North Karnataka plateau and North Western Telangana plateau, hot moist semi-arid eco-sub region with Mixed Red and Black Soils	180–210	Maharashtra	Nashik, Dhule, Aurangabad, Jalna, Nanded, Parbhani, Latur, Ahmadnagar (Hilly part), Jalgaon (Part)	Sorghum	3565	3.75
			Karnataka	Bidar, Gulbarga			
			Telangana	Nizamabad, Adilabad			
6.2b	Deccan Plateau, hot semi-arid Eco-Region – Central and western Maharashtra plateau and North Karnataka plateau and North Western Telangana plateau, hot moist semi-arid eco-sub region with Dominantly Black Soils	150–180	Maharashtra	Nashik, Dhule, Aurangabad, Jalna, Nanded, Parbhani, Latur, Ahmadnagar (Hilly part), Jalgaon (Part)	Sorghum	3565	9.56
			Karnataka	Bidar, Gulbarga			
			Telangana	Nizamabad, Adilabad			
6.2c	Deccan Plateau, hot semi-arid Eco-Region – Central and western Maharashtra plateau and North Karnataka plateau and North Western Telangana plateau, hot moist semi-arid eco-sub region with Dominantly Black Soils	180–190	Maharashtra	Nashik, Dhule, Aurangabad, Jalna, Nanded, Parbhani, Latur, Ahmadnagar (Hilly part), Jalgaon (Part)	Sorghum	3565	2.11
			Karnataka	Bidar, Gulbarga			
			Telangana	Nizamabad, Adilabad			
6.3a	Deccan Plateau, hot semi-arid Eco-Region – Eastern Maharashtra plateau, hot moist semi-arid eco-sub region with Dominantly Black Soils, mod well drained	180–210	Maharashtra	Buldhana, Akola, Amravati, Yavatmal, Jalgaon (Part)	Cotton	6888	2.34
6.3b	Deccan Plateau, hot semi-arid Eco-Region – Eastern Maharashtra plateau, hot moist semi-arid eco-sub region with Dominantly Black Soils	180–210	Maharashtra	Buldhana, Akola, Amravati, Yavatmal, Jalgaon (Part)	Cotton	6888	2.73

(continued)

Table 2.7 (continued)

AESRs							
Nos	Details	LGP days	States	Districts	Crops	Crop water requirement (m^3/ha)	Area mha
6.4a	Deccan Plateau, hot semi-arid Eco-Region – North Sahyadris and Western Karnataka plateau, hot dry sub-humid eco-sub region with Red loamy soils well drained	180–210	Maharashtra	Kolhapur (Part), Satara (Part), Sangli, Pune	Sorghum, rice	3565, 8768	4.67
			Karnataka	Belgaum, Dharwad (Part)			
6.4b	Deccan Plateau, hot semi-arid Eco-Region – North Sahyadris and Western Karnataka plateau, hot dry sub-humid eco-sub region with Black Soils (calcareous), imperfectly drained	150–180	Maharashtra	Kolhapur (Part), Satara (Part), Sangli, Pune	Sorghum, rice	3565, 8768	2.08
			Karnataka	Belgaum, Dharwad (Part)			
7.2a	Deccan (Telangana) Plateau and Eastern Ghats, hot arid ecoregion – North Telangana plateau, hot moist, semi-arid eco-sub region with Dominantly Red soils	180–210	Telangana	Karimnagar, Warangal, Ranga Reddy, Mahbubnagar, Nalgonda, Khammam, Sangareddy and Hyderabad	Sorghum	3565	7.19
7.2b	Deccan (Telangana) Plateau and Eastern Ghats, hot arid ecoregion – North Telangana plateau, hot moist, semi-arid eco-sub region Dominantly black soils	180–190	Telangana	Karimnagar, Warangal, Ranga Reddy, Mahbubnagar, Nalgonda, Khammam, Sangareddy and Hyderabad	Sorghum	3565	2.77
7.3	Deccan (Telangana) Plateau and Eastern Ghats, hot arid ecoregion – Eastern Ghat (South) hot, moist, semi-arid, dry sub-humid eco-sub region with Deep well drained calcareous clay soils with occasional flooding, at places Deep well drained clayey soils.	150–180	Andhra Pradesh	West Godavari (part), Krishna (Machhlipatnam), Guntur (Part), Prakasam and Nellore	Rice, sorghum, groundnut	8985, 3672, 4626	3.4
8.2	Eastern Ghats, TN Uplands and Deccan (Karnataka) Plateau, hot, semi-arid Ecoregion – Central Karnataka plateau, hot, moist, semi-arid eco-sub region with Deep well drained clayey soils with mod. to severe erosion, at places imperfectly drained calcareous soils.	150–180	Karnataka	Hassan, Tumkur, Bangalore, Mysore, Mandya, Kolar, Chickmangalur, Shimoga (Part), Chitradurga (Part)	Sorghum, groundnut	3565, 4677	6.5

8.3a	Eastern Ghats, TN Uplands and Deccan (Karnataka) Plateau, hot, semi-arid Ecoregion – Tamil Nadu uplands and plains, hot moist semiarid eco-sub region with Black Soils of Cauvery Delta	180–210	Andhra Pradesh	Chittor	Rice	8985	7.38
8.3b	Eastern Ghats, TN Uplands and Deccan (Karnataka) Plateau, hot, semi-arid Ecoregion – Tamil Nadu uplands and plains, hot moist semiarid eco-sub region with Red loamy Soils	150–180	Andhra Pradesh	Chittor	Rice	8985	1.15

Source: Mandal et al. (2014), Kumari et al. (2017)

Table 2.8 AESRs, LGP, crops and crop water requirements in target states: Sub humid ecosystem

AESRs							
Nos	Details	LGP	States	Districts	Crops	Crop water requirement (m^3/ha)	Area m ha
9.2	Northern, plain hot sub-humid (dry) Ecoregion – Rohilkhand, Avadh and South Bihar plains, hot dry, sub-humid eco-sub region		Bihar	Bhojpur, Rohtas, Jahanabad, Patna, Bihar Sharif, Aurangabad, Gaya, Narwada,	Rice, Wheat	8985, 8136	8.3
10.1	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/moist) eco-region – Malwa plateau, Vindhyan scarpland and Narmada valley, hot dry, sub-humid eco-sub region with Dominantly black soils, well drained	180–210	Madhya Pradesh	Guna, , Raisen, Sagar, Bhopal, Sehore, Shajapur, Hoshangabad, Jabapur, Narsimhapur, Vidisha, Damoh	Soybean, wheat	3646, 8275	9.24
		180–210	Chhattisgarh	Rajgarh	Soybean, wheat	3646, 8275	
10.2	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/moist) eco-region – Satpura and Eastern Maharashtra plateau, hot dry, sub-humid eco-sub region with Dominantly black soils	180–210	Madhya Pradesh	Betul	Cotton, soybean	6888, 5106	4.44
			Maharashtra	Wardha, Nagpur, Chndarpur (Part0	Cotton, soybean	6888, 5106	
10.3a	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/moist) eco-region – Vindhyan scarpland and Baghelkhand plateau, hot dry, sub-humid eco-sub region with Black soils, well drained	180–210	Madhya Pradesh	Tikamgarh, Chhatrpur, Panna, Satna, Rewa, Sidhi, Shahdol	Rice, wheat	8922, 8275	3.83
10.3b	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/moist) eco-region – Vindhyan scarpland and Baghelkhand plateau, hot dry, sub-humid eco-sub region with Red loamy soils	150–180	Madhya Pradesh	Tikamgarh, Chhatrpur, Panna, Satna, Rewa, Sidhi, Shahdol	Rice, wheat	8922, 8275	2.41

10.4	Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range), hot, sub-humid (dry/moist) eco-region –Satpura range and Wainganaga valley, hot moist sub-humid eco-sub region with Deep to very deep, well drained to mod. Well drained clay soils with mod. to slight erosion, at places calcareous and cracking clay soils.	180	Madhya Pradesh	Chhindwara, Seoni, Mandla, Balaghat, Jabalpur (Part)	Rice, wheat	8922, 8275	
			Maharashtra	Bhandara	Rice, wheat	8922, 8275	
11.1	Chhattisgarh/Mahanadi Basin Agro eco-region – Chhattisgarh/Mahanadi basin, hot sub-humid, eco-sub region with Black, Red and yellow Sandy Loam	>210	Jharkhand	Hazaribag, Ranchi (Part), Lohardaga, Gumla, Palmu	Rice, wheat	8985, 8136	9.07
			Chhattisgarh	Bilaspur, Ambikapur, Raigarh, Durg, Rajnandgaon, Raipur, Jagdalpur (Part)	Rice, wheat	8985, 8136	
11.2	Chhattisgarh/Mahanadi Basin Agro eco-region – Chhattisgarh/Mahanadi basin, hot sub-humid, eco-sub region with Black Soils, at places imperfectly to poorly drained	180–210	Jharkhand	Hazaribag, Ranchi (Part), Lohardaga, Gumla, Palmu	Rice, wheat	8985, 8136	5.12
			Chhattisgarh	Bilaspur, Ambikapur, Raigarh, Durg, Rajnandgaon, Raipur, Jagdalpur (Part)	Rice, wheat	8985, 8136	
12.1a	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Garjat hills, Dandakaranya and Eastern Ghats, hot, moist sub-humid eco-sub region with Dominantly black soils of Mahanadi basin, poorly to imperfectly drained	180–210	Odisha	Koraput, Balangir, Sambalpur, Sundargarh, Dhenkanal, Kalahandi, Mayaurbhanj, Phulbani, Kendujhargarh	Rice, groundnut	8985, 4626	3.91
			Maharashtra	Chandrapur, Gadchiroli	Rice, groundnut	8985, 4626	
12.1b	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Garjat hills, Dandakaranya and Eastern Ghats, hot, moist sub-humid eco-sub region with Mixed red loamy and black soils	150–180	Odisha	Koraput, Balangir, Sambalpur, Sundargarh, Dhenkanal, Kalahandi, Mayaurbhanj, Phulbani, Kendujhargarh	Rice, groundnut	8985, 4626	6.70
			Maharashtra	Chandrapur, Gadchiroli			

(continued)

Table 2.8 (continued)

AESRs							
Nos	Details	LGP	States	Districts	Crops	Crop water requirement (m^3/ha)	Area m ha
12.1c	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Garjat hills, Dandakaranya and Eastern Ghats, hot, moist sub-humid eco-sub region with Red, sandy loam soils	>210	Odisha	Koraput, Balangir, Sambalpur, Sundargarh, Dhenkanal, Kalahandi, Mayaurbhanj, Phulbani, Kendujhargarh	Rice, groundnut	8985, 4626	8.71
			Maharashtra	Chandrapur, Gadchiroli			
12.2	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Eastern Ghats, hot moist sub-humid eco-sub region with Deep, poorly to imperfectly drained loamy to clay soils with occasional to severe flooding. At places mod. deep, well drained loamy soils.	>180	Andhra Pradesh	Vishapatnam (Hilly Parts), Vizianagaram, Srikakulam	Rice, rice	8985, 10791	
			Odisha	Ganjam, Puri, Cuttack, Baleshwar			
12.3	Eastern (Chhotanagpur) Plateau and Eastern Ghats, hot sub-humid ecoregion – Chhotanagpur plateau and Garjat hills, hot dry and moist sub-humid transitional eco-sub region	180–210	Jharkhand	Ranchi, Dhanbad, Giridih, Devghar, Santhal Pargana, Singbhum Sahibganj (Part)	Rice, maize	8985, 4328	5.6
			Odisha	Kendujhargarh (North)			
13.1	Eastern Plain, hot sub-humid (moist) ecoregion – North Bihar and Avadh plains, hot dry moist sub-humid eco subregion	180–210	Bihar	Gopalgang, Bhagalpur, Siwan, Saran, Muzaffarpur, Madhubani, Darbhanga, Begusarai, Samastipur, Saharsa, West Champaran, Purba Champaran, Munger, Katihar, Khagaria, Sitamarhi, Purnia, Munger, Katihar, Vaishali, Patna (Part)	Pulses, Wheat	3809, 8136	9.9
			Jharkhand	Sahebganj	Pulses, Wheat	3809, 8136	9.9

Source: Mandal et al. (2014), Kumari et al. (2017)

Table 2.9 AESRs, LGP, crops and crop water requirements in target states: Coastal ecosystem

AESRs							
Nos	Details	LGP	States	Districts	Crops	Crop water requirement (m^3/ha)	Area mha
18.3	Eastern Coastal Plain, hot sub-humid to semi-arid ecoregion – Andhra Coastal, hot dry sub-humid eco-sub region	150–180	Jharkhand	Sahebganj	Cotton, groundnut, rice	7092, 4626, 10791	2.0
			Andhra Pradesh	Nellore, Prakasam, Guntur, Krishna, West Godavari	Cotton, groundnut, rice	7092, 4626, 10791	
18.4	Eastern Coastal Plain, hot sub-humid to semi-arid ecoregion – Utkal Plain and East Godavari Delta, hot dry sub-humid eco-sub region	180–210	Andhra Pradesh	East Godavari, Vishakhapatnam, Vizianagaram, Srikakulam	Rice, rice	8985, 10791	3.2
			Odisha	Ganjam, Puri (Part), Cuttack	Rice, rice	8985, 10791	
18.5	Eastern Coastal Plain, hot sub-humid to semi-arid ecoregion – Gangetic Delta, hot moist, sub-humid eco-sub region	240–270	Odisha	Baleshwar (Part)	Rice, rice	8985, 10791	1.2
19.1a	Western Ghats and Coastal Plain, hot, humid-perhumid ecoregion – North Sahyadris and Konkan Coast, hot, humid eco-sub region with Red loamy soils, well drained, severe erosion and moderate salinity	180–210	Maharashtra	Raigarh, Thane, Pune (Part)	Rice	8985	1.3
19.1b	Western Ghats and Coastal Plain, hot, humid-perhumid ecoregion – North Sahyadris and Konkan Coast, hot, humid eco-sub region with Calcareous, well drained black soils, slight to moderate salinity	180–210	Maharashtra	Raigarh, Thane, Pune (Part)	Rice	8985	1.87
19.2	Western Ghats and Coastal Plain, hot, humid-perhumid ecoregion – Central and South Sahyadris, hot moist, sub-humid to humid eco-region	210–270	Maharashtra	Ratnagiri, Sindhudurg, Kolhapur (Part)	Rice	8985	6.9
			Karnataka	Uttar Kannad, mangalore, Chikmagalur (Part), Kodagu, Hassan, Shimoga	Rice	8985	
19.3	Western Ghats and Coastal Plain, hot, humid-perhumid ecoregion – Konkan, Karnataka and Kerala Coastal Plain, hot humid to perhumid eco-sub region	240–270	Karnataka	Mangalore, Karwar	Rice	8985	2.0

Source: Mandal et al. (2014), Kumari et al. (2017)

2.4.3.2 Consumptive Water Use Requirements in the Target Areas

The results of Crop Wat model give consumptive water use; however, it does not include water losses during water supply from source to crop field i.e. evaporation, percolation, seepage loses from conveyance channel (Kumari et al. 2017). Water requirements for crop productions are influenced by the various factors viz. area share of different crops, climatic factors (temperature, wind velocity, relative humidity, sunshine and rainfall), crop variety, crop duration and soil structure. Besides these, agronomic practices and plant physiology also affect the water consumption by the crops. Thus, these factors lead to difference in the consumptive water use for the same crop in different regions. Most of the crops growing during the *kharif* season are using more green water (rainfall mediated soil moisture) and supplemented by blue water (artificial irrigation), whereas crops grown in *rabi* (post-rainy) season were catering water requirement from irrigation water and somewhat fulfilled by off season rainfall for their crop cycle (Tables 2.10, 2.11, 2.12). The major crops grown during *kharif* season were rice, maize, *jowar* (sorghum), small millets and wheat, barley in *rabi* season (Kumari et al. 2017).

Table 2.10 AESRs, crops and consumptive water use in target states: Arid and semi-arid ecosystem

		Consumptive water use (m³/ha)					
		Blue water	Green water	Total water	Blue water	Green water	Total water
AESR Nos.	Crops	*Kharif*			Rabi		
3.1	Sorghum	1125	2521	3646			
3.2	Groundnut	1856	2713	4570			
4.3a	Wheat				7256	1018	8275
5.2b	Wheat				7256	1018	8275
	Cotton	2230	5225	7455			
6.1a	Groundnut	1585	3092	4677			
6.1b, 6.1c	Sorghum	1164	2400	3565			
6.2a, 6.2b, 6.2c	Sorghum	1125	2521	3646			
	Sunflower	5489	1538	7027			
6.3a	Cotton	2230	5225	7455			
6.3b	Sorghum	1125	2521	3646			
6.4a, 6.4b	Rice	3906	4862	8768			
	Sorghum	1164	2400	3565			
7.2a, 7.2b	Rice	3389	5595	8985			
	Sorghum	722	2949	3672			
7.3	Rice	3389	5595	8985			
	Sorghum	722	2949	3672			
	Groundnut	1430	3196	4626			
8.2	Groundnut	1430	3196	4626			
8.3a, 8.3b	Rice	3389	5595	8985			

Source: Mandal et al. (2014), Kumari et al. (2017); blue water (artificial irrigation), green water (rainfall)

Table 2.11 AESRs, Crops and consumptive water use in target states: Sub humid Ecosystem

AESRs Nos	Crops	Consumptive water use (m^3/ha)					
		Blue water	Green water	Total water	Blue water	Green water	Total water
		Kharif			Rabi		
9.2	Rice	3389	5595	8985			
	Wheat				6959	1176	8136
10.1	Soybean	1750	2936	4686			
	Wheat				7256	1018	8275
10.2	Cotton	2230	5225	7455			
	Soybean	1750	2936	4686			
10.3a, 10.3b, 10.4, 11.1, 11.2	Rice	3715	5207	8922			
	Wheat				7256	1018	8275
12.1a, 12.1b, 12.1c, 12.2	Rice	3389	5595	8985			

Source: Mandal et al. (2014), Kumari et al. (2017); blue water (artificial irrigation), green water (rainfall)

Table 2.12 AESRs, LGP, crops and crop water requirements in target states: Coastal ecosystem

AESR Nos	Crops	Consumptive water use (m^3/ha)					
		Blue water	Green water	Total water	Blue water	Green water	Total water
		Kharif			Rabi		
18.3, 18.4, 18.5	Rice	3389	5595	8985			
	Gram				1754	502	2256
19.1a, 19.1b, 19.2, 19.3	Rice	3906	4862	8768			

Source: Mandal et al. (2014), Kumari et al. (2017); blue water (artificial irrigation), green water (rainfall)

2.5 Use of New Science Tools for AESR-Based Agriculture

Land use planning is a systematic and iterative process carried out to create an enabling environment for sustainable development of land resources. It assesses the physical, socio-economic, institutional and legal potentials and the constraints with respect to an optimal and sustainable use of land resources, in addition, it also empowers people to make informed decisions about how to allocate those resources for reaping maximum benefit. Originating from an internationally accepted framework for land evaluation, the Agro-ecological zones/sub-regions methodology enables rational land management options to be formulated on the basis of an inventory of land resources and in the assessment of biophysical limitations and potentials.

Five basic elements which form the AESR framework are,

(i) *land utilization types (LUTs): specific agricultural production systems with defined input and management relationships and crop-specific environmental requirements and adaptability characteristics,*
(ii) *land resource database: georeferenced climate, soil and terrain data combined into a database,*
(iii) *crop yields and LUT requirements matching: procedures for calculating potential yields and for matching environmental requirements of the crop/LUT with the respective environmental characteristics contained in the land resource database, by land unit and grid-cell, and*
(iv) *assessments of crop suitability and production potential of land (models), and applications for agricultural developmental planning.*

Earlier, a generalized LGP value (based on overhead climatic data) of dominant soils of the region was considered, while developing an AESR map in 1994 with 60 delineations. Recent research indicates that the shrink-swell soils do not remain saturated with moisture at field capacity due to poor hydraulic properties caused by sub-soil sodicity characterized by high pH, exchangeable sodium percent and poor to very poor drainage as evidenced by low saturated hydraulic conductivity. To estimate LGP, 100 mm m^{-1} of stored soil moisture was used as standard for the deep soils assuming this amount to be the measure of available water after cessation of rains. Since this measure could be an over estimation the LGP values were modified (Mandal et al. 2014) using new science tools of database management, remote sensing, GIS, soil information system (Bhattacharyya 2021b).

LGP values were revised in the target states with soil data (Please see Tables 2.2 and 2.3). LGP values depend on water retention, bulk density (BD) and saturated hydraulic conductivity (sHC). In many cases pedotransfer functions (PTFs) were used to estimate these soil parameters (Tiwary et al. 2014).

(MC 33, MC 100, MC 1800 = moisture content (%) at −33 k Pa, −100 k Pa, −1800 k Pa; Clay= Clay % in soils; ECP= exchangeable Ca percent; Silt= silt % in soils; OC- organic carbon in soils (%); ESP= exchangeable Na percent; pH = soil reaction values; Ex Ca/Ex Mg = ratio of exchangeable Ca and Mg)

$$MC33 = 22.388 + 0.443 * Clay - 0.149 * ECP$$

$$MC100 = 9.006 + 0.429 * Clay - 0.071 * ECP + 0.102 * silt$$

$$MC1800 = 5.449 + 0.364 * Clay - 0.083 * ECP$$

$$BD = 1.634 - 0.002 * clay - 0.180 - OC + 0.005 * ESP$$

$$sHC = 120.637 - 13.094 * pH - 0.102 * clay + 1.151 * \left(\frac{ExCa}{ExMg} \right)$$

The estimated available water content, saturated hydraulic conductivity, and use of pedo-transfer functions (Tiwary et al. 2014) in assessing the drainage conditions and soil quality helped in computing precise LGP to generate agro-ecological sub regions (AESR) (Fig. 2.32). Since AESR is considered as a tool for agro-technology

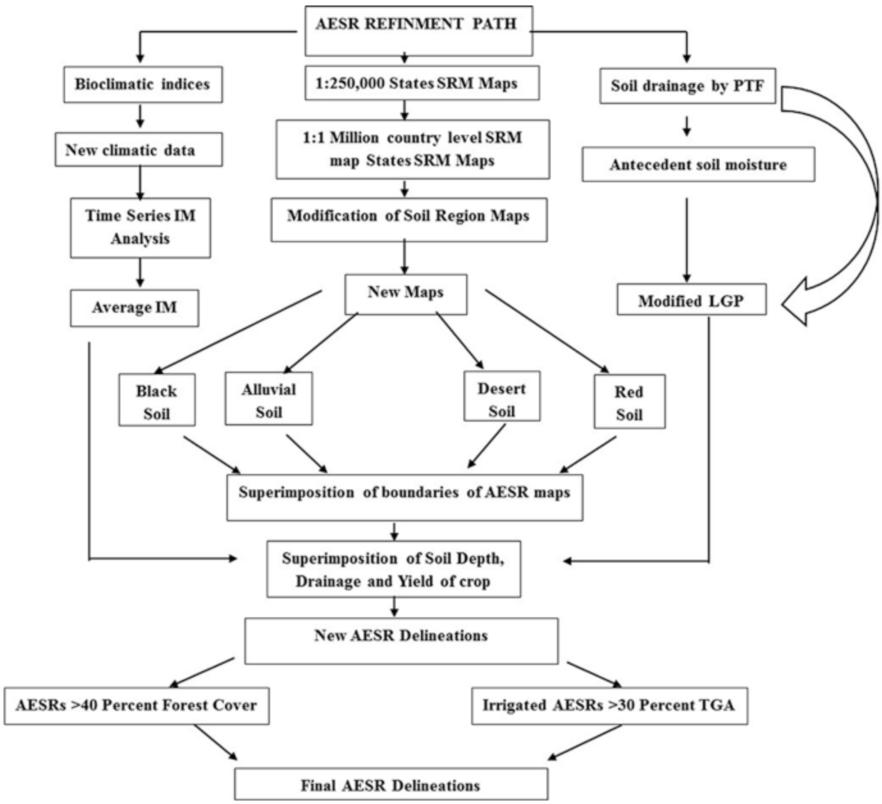


Fig. 2.32 Flowchart to generate agro-ecological sub-regions (AESR) map. (Source: Bhattacharyya et al. 2015)

transfer by scaling up research findings at the farmers' level, an example is shown here for two important crops in the target states.

2.5.1 Usefulness of GeoSIS to Develop Integrated Food Systems Strategy

Modern tools have made the natural resource management lot easier in terms of data access and retrieval. Many such information are detailed elsewhere (Bhattacharyya et al. this volume, this book). A few are discussed here.

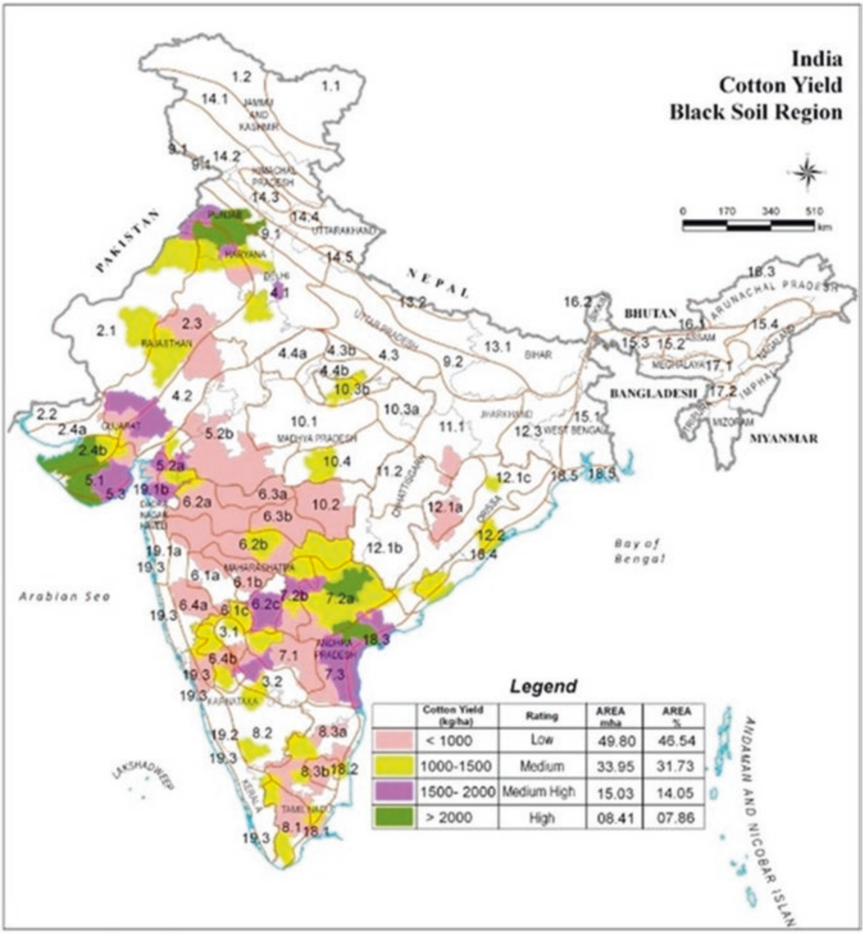


Fig. 2.33 AESR-based cotton crop planning in target states for livelihoods systems in target states. (Source: Bhattacharyya et al. 2015)

2.5.1.1 Cotton-Based Cropping for Livelihoods Systems in Target States

Based on productivity, the cotton growing areas in different AESRs of the BSR are mapped as a part of crop planning. The entire BSR is divided into four different regions such as low, medium, medium high and high indicating <1000, 1000–1500, 1500–2000 and >2000 kg seed cotton ha^{-1} (Fig. 2.33). It is interesting to note that merely 15% area under cotton produce >1500 kg ha^{-1} which is the national average. The distribution of cotton yield in different AESRs in the target states with a few exceptions shows that there is a scope to elevate low to medium cotton yield areas to medium high or high yield categories in 86% area through appropriate site specific management interventions including cultivar selection (Table 2.13; Fig. 2.34). Alternatively, area under cotton from the low productivity areas can be diverted to

Table 2.13 Cotton yield and acreage in different agro-ecological sub regions in the target states

AESR		Cotton area				
Nos.	Area (mha)	Area (mha)	%		Yield level	
	a	b	(b/a)*100	Districts	kg ha^{-1}	States
3.1	1.56	0.37	24	Koppal, Gadag	Low	Karnataka
	1.56	0.39	25	Bijapur, Belgaum	Medium	Karnataka
	0.39	0.06	15	Bellary	Medium High	Karnataka
3.2	3.08	0.27	9	Koppal	Low	Karnataka
	3.08	0.31	10	Chitradurga	Medium	Karnataka
5.2b	12.71	6	47	Banswara,Ratlam,Dhar, Jhabua, Barwani, Khargo, Khandwa, Dewas, Bhilwara	Low	Rajastahan, MP
	12.71	0.03	0.03	Nandurbar	Medium	Maharashtra
6.1a	2.77	0.99	36	Ahmadnagar, Satara, Sangli	Low	Maharashtra
	2.77	0.03	1	Bijapur	Medium	Karnataka
6.1b	2.38	2.02	85	Latur, Ahmadnagar, Bid Osmanabad	Low	Maharashtra
	2.38	0.01	0	Gulbarga	Medium High	Karnataka
6.1c	0.97	0.9	93	Bijapur, Kolhapur	Medium	Karnataka, Maharsahtra
	0.97	0.05	5	Gulbarga	Medium High	Karnataka
6.2a	3.75	3.38	90	Dhule, Nashik, Aurangabad, Jalna, Buldhana, Jalgaon	Low	Maharashtra
	3.75	0.3	8	Nandurbar	Medium	Maharashtra
	3.75	0.04	1	Surat	Medium High	Gujarat
6.2b	7.34	4.07	55	Dhule, Nashik, Aurangabad, Jalna, Buldhana, Jalgaon , Ahmadnagar, Bid, Nanded	Low	Maharashtra
	7.34	3.22	44	Parbhani, Hingoli, Adilabad, Karimnagar	Medium	Maharashtra, Telangana
6.2c	2.22	0.15	7	Bijapur, Raichur	Medium	Karnataka
	2.22	1.5	68	Gulbarga, Medak	Medium High	Karnataka
6.3a	2.34	2.33	100	Akola, Jalgaon, Buldhana, Amravati	Low	Maharashtra
	2.73	2.57	94	Washim, Akola, Yavatmal, Buldhana	Low	Maharashtra
	2.73	0.16	6	Parbhani, Hingoli	Medium	Maharashtra
6.4a	4.67	2.44	52	Satara, Sangli, Ahmadnagar, Uttarkahhad	Low	Maharashtra
	4.67	0.42	9	Belgaum	Medium	Karnataka

(continued)

Table 2.13 (continued)

AESR		Cotton area				
Nos.	Area (mha)	Area (mha)	%		Yield level	
	a	b	(b/a)*100	Districts	kg ha^{-1}	States
6.4b	2.08	0.61	29	Dharwad, Gadag	Low	Karnataka
	2.08	1.2	58	Belgaum, Haveri	Medium	Karnataka
	2.08	0.03	1	Bellary	Medium High	Karnataka
7.2a	7.19	0.86	12	Mahbubnagar	Low	Telangana
	7.19	4.13	57	Karimnagar, Khammam, Nalgonda, Hyderabad	Medium	Telangana
	7.19	0.56	8	Medak, Krishna	Medium High	Telangana, AP
	7.19	1.61	22	Warangal, Nalgonda	High	Telangana
7.2b	2.77	0.88	32	Mahbubnagar, Nizamabad	Low	Telangana
	2.77	1.18	43	Nizamabad, Hyderabad	Medium	Telangana
	2.77	0.7	25	Medak, Gulbarga	Medium High	Telangana, Karnataka
7.3	5.58	1.12	20	Kurnool, Kadapa	Low	AP
	5.58	0.16	3	Khammam	Medium	Telangana
	5.58	2.65	47	Ongole, Nellore, Krishna	Medium High	AP
	5.58	0.69	12	Guntur	High	AP
8.2	6.8	0.18	3	Erode	Low	TN
	6.8	1.33	20	Chitrdurga, Mysore, Dharmapuri	Medium	Karnataka, TN
8.3a	7.38	2.29	31	Vellore, Viluppuram, Erode , Salem, Tiruchirappalli	Low	AP, TN
	7.38	1.62	22	Dharmapuri, Namakkal, Coimbatore, Sivaganga	Medium	TN,
8.3b	1.15	0.82	71	Tiruchirappalli, Salem,Perambalu	Low	TN
	1.15	0.14	12	Cuddalore, Dharmapuri	Medium	TN
10.1	9.24	0.13	1	Dewas	Low	MP
	9.24	0.02	0	Chhatarpur	Medium	MP
10.2	4.41	3.57	81	Wardha, Nagpur, Chandrapur, Yavatmal, Amravati	Low	Maharashtra
10.3b	2.41	0.74	31	Chhatarpur	Medium	MP
10.4	6.56	0.08	1	Nagpur, Betul	Low	Maharashtra, MP
	6.56	1.26	19	Chhindwara	Medium	MP
11.1	9.07	0.58	6	Raigarh	Low	Chhattisgarh
	5.12	0.14	3	Raigarh	Low	Chhattisgarh
12.1a	3.91	1.3	33	Balangir, Bhawanipatna, Bargarh	Low	Odisha

(continued)

Table 2.13 (continued)

AESR		Cotton area				
Nos.	Area (mha)	Area (mha)	%		Yield level	
	a	b	(b/a)*100	Districts	kg ha^{-1}	States
12.1c	8.71	0.25	3	Bhawanipatna	Low	Odisha
	8.71	0.56	6	Deogarh, Chhatrapur	Medium	MP, Odisha
12.2	4.19	1.26	30	Chhatrapur, Vishakhapatnam	Medium	AP, Odisha
18.3	1.97	1.32	67	Ongole, Nellore, Krishna	Medium High	AP
	1.97	0.22	11	Gunntur	High	AP
18.4	2.9	0.72	25	Vishakhapatnam	Medium	AP
19.1a	1.38	0.02	1	Nashik	Low	Maharashtra
19.1b	2.02	0.44	22	Bharuch	Low	Gujarat
	2.02	0.01	0	Godhra	Medium	Gujarat
19.2	7.63	0.54	7	Uttar Kannad	Low	Karnataka
	7.63	0.21	3	Coimbatore	Medium	TN
19.3	1.87	0.12	6	Uttar Kannad	Low	Karnataka

Source: Bhattacharyya et al. (2015); MP: Madhya Pradesh; AP: Andhra Pradesh; TN: Tamil Nadu

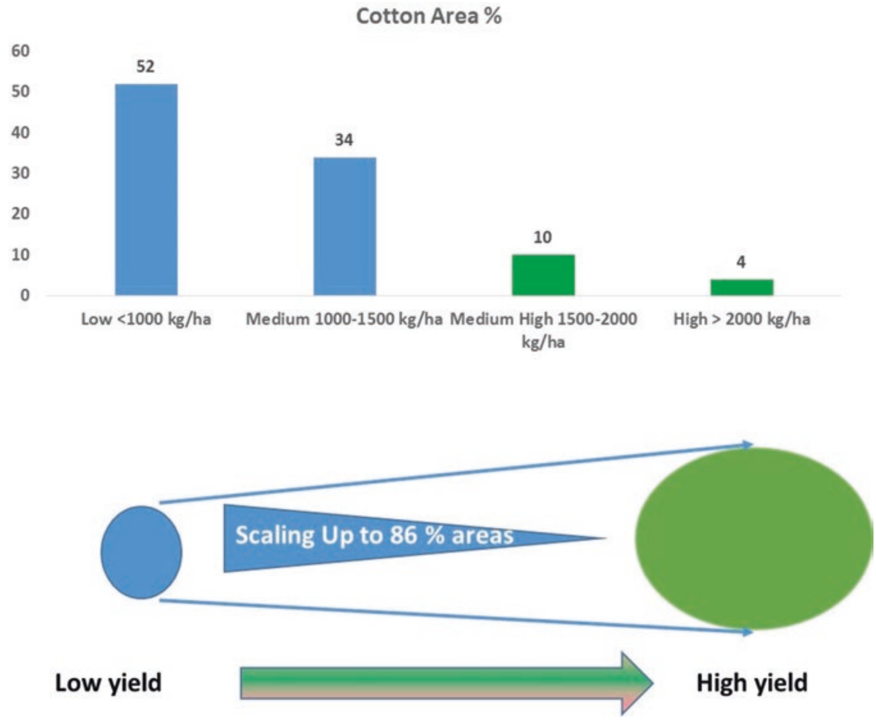


Fig. 2.34 Scaling up potential of cotton yield in target states. (Source: Modified from Bhattacharyya et al. 2015; also see Table 2.13)

more productive crops to ensure food security. Keeping crop variety and other management factors similar, the recently built geo-referenced soil information system (GeoSIS) (Bhattacharyya et al. 2014b) was used to find out exact soil-related constraints (mainly physical properties, such as saturated hydraulic conductivity, sHC), which can be ameliorated to improve the soil quality to plan cotton production in low and medium cotton yield areas for posterity (Bhattacharyya et al. 2015) in the target states.

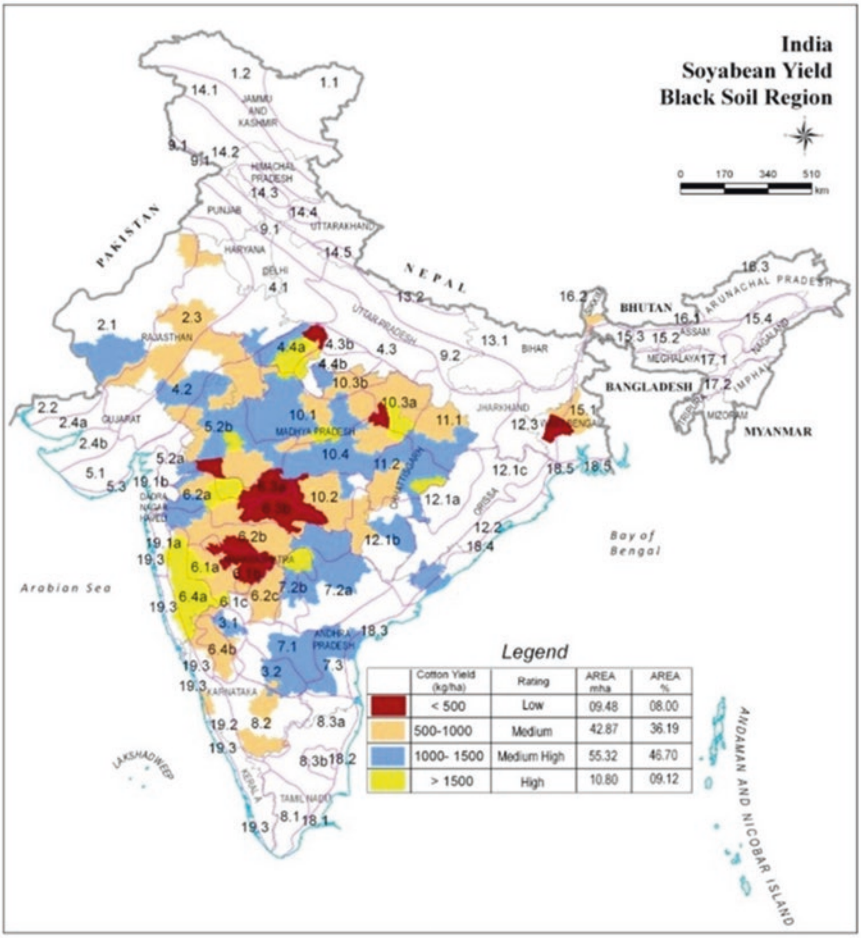


Fig. 2.35 AESR-based soybean crop planning in target states for livelihoods systems in target states. (Source: Bhattacharyya et al. 2015)

Table 2.14 Soybean yield and acreage in different agro-ecological sub regions in the target states (* in this Table is used to calculate % cotton area)

AESR		Cotton area				
Nos.	Area	Area m ha	%			
	a	b	b/a*100	Districts	Yield level kg ha^{-1}	States
3.1	1.6	0.24	15	Belgaum, Gadag	Medium	Karnataka
3.1	1.6	0.62	40	Bagalkot	Medium High	Karnataka
3.2	3.1	0.15	5	Tumkur	Medium	Karnataka
3.2	3.1	1.65	54	Anantpur	Medium High	Andhra Pradesh
4.3	6	0.01	0.2	Rewa	Medium	Madhya Pradesh
4.3b	1.1	0.02	2	Bind	Medium	Madhya Pradesh
4.4a	3	0.63	21	Bind, Datia, Baran	Medium	Madhya Pradesh, Rajasthan
5.2b	4.7	0.6	13	Barwani	Low	Madhya Pradesh
5.2b	13	6.16	48	Jhabua, Banswara, Khargon, Khandw, Hoshngabad, Mandsaur, Jhalawar, Kota , Bundi, Baran, Dhule	Medium	Rajasthan, Madhya Pradesh, Maharashtra
5.2b	13	5	39	Nimachi, Ratlam, Dhar, Ujjain, Shajapur, Harda, Dewas	Medium High	Madhya Pradesh
6.1a	5.2	0.14	3	Bid, Osmanbad	Low	Maharsahtra
6.1a	2.8	1.68	61	Solapur, Ahmadnagar	Medium	Maharsahtra
6.1b	72	1.73	2	Bid, Osmanabad, Latur	Low	Maharsahtra
6.1b	2.4	0.66	28	Solapur, Ahmadnagar, Bidar	Medium	Maharsahtra, Karnataka
6.1c	1	0.25	26	Belgaum, Gulbarga	Medium	Karnataka
6.1c	1	0.01	1	Bagalkot	Medium High	Karnataka
6.2a	9.7	0.36	4	Buldhana	Low	Maharsahtra
6.2a	3.8	1.84	49	Dhule, Aurangabad, Jalna	Medium	Maharsahtra
6.2a	3.8	1.02	27	Nashik	Medium High	Maharsahtra
6.2b	11	0.79	7	Bid, Latur, Yavatmal	Low	Maharsahtra
6.2b	7.3	3.59	49	Ahmadnagr, Aurangabad, Jalna, Perbhani, Hingoli,Nanded	Medium	Maharsahtra
6.2b	7.3	2.87	39	Adilabad	Medium High	Telangana
6.2c	1.2	0.03	3	Osmanbad, Latur	Low	Maharsahtra
6.2c	2.2	2.02	91	Bidar, Gulbarga	Medium	Karnataka
6.2c	2.2	0.03	1	Hydrabad	Medium High	Telangana

(continued)

Table 2.14 (continued)

AESR		Cotton area				
Nos.	Area	Area m ha	%		Yield level	
	a	b	b/a*100	Districts	kg ha^{-1}	States
6.3a	2.3	0.05	2	Khargon, Khandwa	Medium	Madhya Pradesh
6.3a	2.3	0.02	1	Betul, Chhindwada, Seoni, Balaghat	Medium High	Madhya Pradesh
6.3b	85	2.32	3	Amravati, Akola ,Buldhana, Washim, Yavatmal	Low	Maharsahtra
6.3b	2.7	0.39	14	Hingoli, Nanded, Parbhani, Chandrpur	Medium	Maharsahtra
6.3b	2.7	0.02	1	Adilabad	Medium High	Telangana
6.4a	4.7	0.03	1	Nashik	Medium High	Maharsahtra
6.4b	2.1	1.81	87	Belgaum, Dharwad, Haveri	Medium	Karnataka
6.4b	2.1	0.02	1	Bagalkot	Medium High	Karnataka
7.2a	7.2	3.09	43	Karimnagar, Warangal, Sangereddi	Medium High	Telangana
7.2b	2.8	0.16	6	Gulbarga, Nanded	Medium	Karnataka, Maharashtra
7.2b	2.8	0.97	35	Warangal, Sangareddi, Hydrabad	Medium High	Telangana
7.3	5.6	2.5	45	Ongole, Cuddapah	Medium High	Andhra Pradesh
8.2	6.8	1.59	23	Mysore, Tumkur	Medium	Karnataka
8.2	6.8	0.61	9	Chamrajnagar, Anantpur	Medium High	Karnataka, Telangana
8.3a	7.4	0.05	1	Chamrajnagar, Anantpur	Medium High	Karnataka, Telangana
10.1	0.2	0.01	7	Umaria	Low	Madhya Pradesh
10.1	9.2	2.53	27	Baran, Sagar , Hoshangabad, Panna, Katni	Medium	Madhya Pradesh
10.2	16	0.69	4	Amravati, Yavatmal	Low	Maharashtra
10.2	4.4	2.9	66	Wardha, Nagpur, Chandrapur	Medium	Maharashtra
10.3a	7.5	0.29	4	Umaria	Low	Madhya Pradesh
10.3a	3.8	2.26	59	Satna, Rewa , Sidhi	Medium	Madhya Pradesh
10.3b	2.4	1.41	59	Chhatrapur, Panna, Satna, Rewa	Medium	Madhya Pradesh
10.4	3.5	0.23	7	Umaria	Low	Madhya Pradesh
10.4	6.6	1.71	26	Hoshangabad, Mandla, Dindori, Nagpur	Medium	Madhya Pradesh, Maharashtra
11.1	9.1	1.84	20	Ambikapur	Medium	Chhattisgarh
11.2	5.1	1.55	30	Rajnadgaon, Durg	Medium	Chhattisgarh

(continued)

Table 2.14 (continued)

AESR		Cotton area				
Nos.	Area	Area m ha	%			
	a	b	b/a*100	Districts	Yield level kg ha^{-1}	States
12.1b	6.7	1.7	25	Gadchiroli, Durg	Medium	Maharashtra, Chhattisgarh
19.2	7.6	0.3	4	Udupi, Belgaum	Medium	Karnataka
19.3	1.9	0.11	6	Udupi	Medium	Karnataka
10.1	9.2	6.02	65	Guna, Vidisha, Rajgarh, Bhopal, Sahajanpur, Sehore, Raisen, Dewas, Damoh, Jabalpur	Medium High	Madhya Pradesh
10.2	4.4	0.43	10	Bhandara	Medium High	Maharashtra
10.3a	3.8	0.38	10	Bainkuthpur, Bilaspur	Medium High	Chhattisgarh
10.3b	2.4	0.56	23	Tikamgarh, Damoh	Medium High	Madhya Pradesh
10.4	6.6	4.33	66	Betul, Chhindwada, Seony, Balaghat	Medium High	Madhya Pradesh
11.1	9.1	2.38	26	Baikunthpur, Korba, Raigarh, Jashpurnagar	Medium High	Chhattisgarh
11.2	5.1	2.88	56	Kawaradha, Bilaspur, Jangir, Raipur	Medium High	Chhattisgarh
12.1b	6.7	1.84	27	Jagdalpur, Raipur	Medium High	Chhattisgarh
12.1c	8.7	0.17	2	Vishakhapantam	Medium High	Andhra Pradesh
12.2	4.2	0.7	17	Vishakhapantam	Medium High	Andhra Pradesh
18.3	2	0.46	23	Ongole	Medium High	Andhra Pradesh
18.4	2.9	0.4	14	Vishakhapantam	Medium High	Andhra Pradesh
19.1a	1.4	0.02	1	Nashik	Medium High	Maharashtra
4.4a	3	1.2	40	Shivpuri, Gwalior	High	Madhya Pradesh
4.4b	2.8	0.37	13	Shivpuri, Gwalior	High	Madhya Pradesh
5.2b	13	0.44	3	Indore, Jalgaon	High	Madhya Pradesh, Maharashtra
6.1a	2.8	0.92	33	Pune, Satara, Sangli	High	Maharashtra
6.2a	3.8	0.45	12	Jalgaon	High	Maharashtra
6.3a	2.3	0.77	33	Jalgaon	High	Maharashtra
6.4a	4.7	3.28	70	Sangli, Kolhapur	High	Maharashtra
7.2a	7.2	0.06	1	Nizaamabad	High	Telangana
7.2b	2.8	0.76	27	Nizaamabad	High	Telangana
10.1	10	0.63	6	Shivpuri	High	Madhya Pradesh

(continued)

Table 2.14 (continued)

AESR		Cotton area				
Nos.	Area	Area m ha	%			
	a	b	b/a*100	Districts	Yield level kg ha^{-1}	States
10.3a	3.8	0.85	22	Shadol	High	Madhya Pradesh
10.4	6.6	0.26	4	Shadol, Narsimhpur	High	Madhya Pradesh
11.2	5.1	0.49	10	Mahasamund	High	Chhattisgarh
12.1a	3.9	0.03	1	Mahasamund	High	Chhattisgarh
12.1b	6.7	1.91	28	Dantewara	High	Chhattisgarh
19.1a	8.7	0.01	0.1	Pune	High	Maharashtra
19.2	1.4	0.11	8	Kolhapur	High	Maharashtra

Source: Bhattacharyya et al. (2015)

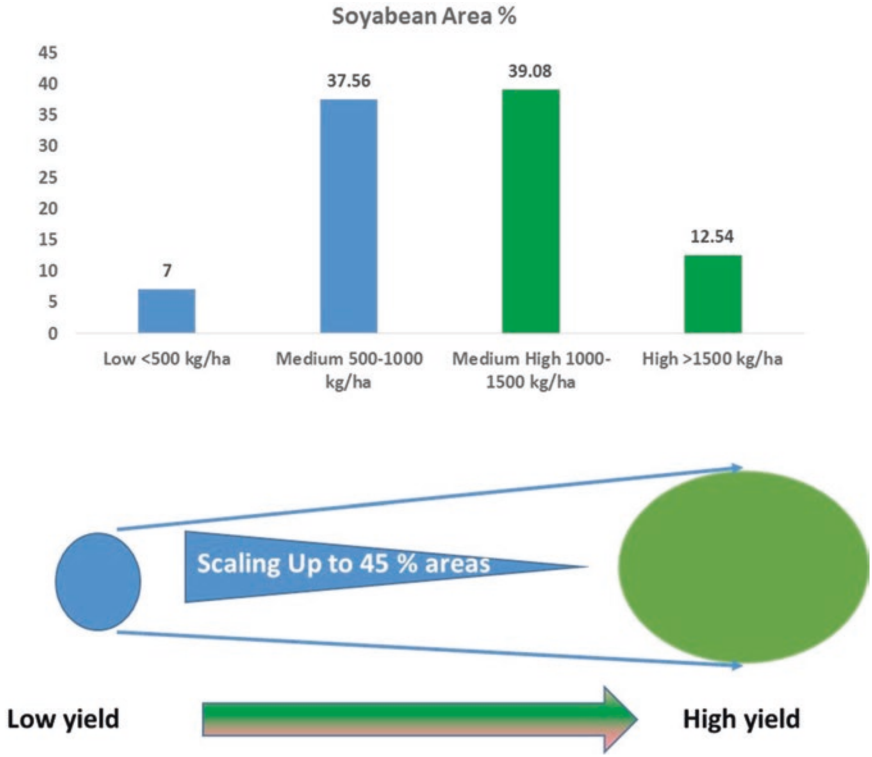


Fig. 2.36 Scaling up potential of soybean yield in target states. (Source: Modified from Bhattacharyya et al. 2015; also see Table 2.13)

2.5.1.2 Soybean- Based Cropping for Livelihoods Systems in Target States

Figure 2.35 shows soybean growing areas in the black soil region. District level soybean yield data were used to divide the BSR into four regions such as low, medium, medium high and high representing areas yielding < 500, 500–1000, 1000–1500 and >1500 kg ha^{-1} soybean. It may be noted that only 7% area is falling under low category, and ~ 52% areas fall under medium high to high yield category (Fig. 2.35). AESRs in the target states with a few exceptions shows that there is a scope to elevate low to medium soybean yield areas to medium high or high yield categories in 45% area through appropriate site specific management interventions including cultivar selection (Table 2.14; Fig. 2.36). The GeoSIS provides soil parameters in terms of their physical, chemical and biological properties to develop a theme map on soybean and its distribution cutting across different AESRs. Exact AESR and the locations of the districts are shown in Table 2.14 to identify areas under low and medium soybean yield.

2.6 Impacts of Climate Change

2.6.1 Impacts of Climate Change in Soils of the Target Regions

There has been a great interest in mitigating climate change due to global warming by sequestering and storing carbon in soil and through its influence on soil quality and agricultural productivity (Bhattacharyya et al. 2014a). Soils provide important ecosystem services at both local and global levels and are the mainstay for crop production. Soils act both as sources and sinks for carbon (Bhattacharyya et al. 2008). Among others, the most important impact of warming on soils is on soil carbon and its influence on different soil parameters as discussed in this section. Soils represent the largest terrestrial stock of C. The first 30 cm of soil holds 1500 Pg C in the world (Batjes 1996)) and 11.4 Pg C in India (Bhattacharyya et al. 2017b).

Table 2.15 Changes in carbon stock over years in soils (0–150 cm depth) of the target states

Soils	SOC stock (Tg/lakh ha)		SOC change over 1980 (%)	SIC stock (Tg/lakh ha)		SIC change over 1980 (%)
	1980	2005		1980	2005	
Asra	6.3	13.6	116	2	2	0
Semla	15.8	13.3	−16	74	46	−37
Vijaypura	7..7	7.7	0	0	0	0
Kaukantla	4.7	10.2	118	0	12.5	100
Kheri	5.6	10.5	87	8.3	9.7	17
Linga	9.7	12.9	34	15.4	21.7	40

Source: Bhattacharyya et al. (2007) (1 Tg= 10^{12} g)

Changes in terrestrial C stocks can be of both regional and global significance and may contribute significant amounts of CO_2 emissions and therefore be linked to climate change. Decline in soil organic carbon (SOC) has major implications for the maintenance of soil health. Carbon stock in the soil depends largely on the areal extent besides other factors such as carbon content, depth and bulk density (BD) of the soil. Even with a relatively small amount of SOC (0.2–0.3%), the arid and semi-arid tracts showed high SOC stock (Bhattacharyya et al. 2000) due to large areal extent of these two bioclimatic systems. To avoid such illusion, here the carbon stock changes have been expressed per unit area (Table 2.15) to interpret the influence of soil and/or a management parameters for sequestration of both organic and inorganic carbon in the soil (Bhattacharyya et al. 2000, 2006). The SOC tend to attain quasi-equilibrium (QE) values with varying duration of 500–1000 years in a forest system 30–50 years in agricultural systems after forest cutting, 5–15 years in agricultural systems after forest cutting in red soils of Odisha, India, and 20–50 years under different agricultural systems with cotton for 20 years, with cotton and pigeon pea for 50 years and horticultural system (citrus) for 30 years (Naitam and Bhattacharyya 2004). Our observations in two time periods (viz. 1980 and 2005) capture the changes in carbon stock over the last 25 years. Judging by the time required to reach the QE stage for the agricultural system, it may be presumed that the soils under study had reached the QE stage after 25 years.

Soil information system (Bhattacharyya 2021b; Bhattacharyya et al. 2021, this volume) helped estimating 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. Two-time series datasets for 1980 and 2005 developed earlier were used to assess changes in the levels of carbon in soils of the target states (Bhattacharyya et al. 2007) (Table 2.16). 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 (Bhattacharyya et al. 2006). To avoid such illusion, we express the changes in carbon stock per unit area (Table 2.16), to interpret the influence of soil and/or management parameter for sequestration of both SOC and SIC in the soil (Bhattacharyya et al. 2007). In the target states, a marginal decrease in arid and 80% increase in semi-arid bioclimatic system is reported (Bhattacharyya et al. 2014c). 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 (Naitam and Bhattacharyya 2004). Table 2.15 shows changes in BD and sHC in soils of the target states. Compared to 2005, BD shows a lower value in most of the soils. Changes of BD and sHC affect soil drainage (Table 2.16). Decrease in sHC values indicates that these soils are gradually becoming less porous and require immediate attention.

Table 2.16 Changes (%) in soil parameters over time in soils of the target states

MAR mm	Soils	SOC stock			SOC change*	SIC stock			SIC change	BD (Mg m^{-3})			BD change**	sHC (cm h^{-1})			sHC change**
		1980	2005	2010		1980	2005	2010		1980	2005	2010		1980	2005	2010	
<550	Sokhda	11.2	9.2	9.2	−17	23.6	61.0	53.1	125	1.4	1.8	1.5	−13	0.001	2.58	2.39	−7
1000	Teligi	7.4	15.2	13.1	80	21.0	29.6	28.5	35	1.4	1.4	1.7	22	0.001	0.55	0.07	−87

*Over 1980; ** at 2010 over 2005; ***Very high ESP values produce (–ve) values of sHC when PTFs are used; so we presented a value of 0.001; Teligi soils (Sodic Haplusterts) are found in semi-arid dry bioclimate (632 mm mean annual rainfall, MAR); Sokhda soils (Leptic Haplusterts) are found in arid bioclimate (533 mm MAR)

Source: Bhattacharyya et al. (2014b)

2.6.2 Climate Change and Land Degradation Neutrality in the Target Region

The United Nations Convention to Combat Desertification (UNCCD) is spearheading the issues of land/soil degradation to arrest the precious natural resources becoming unfertile at the global level (Cowie et al. 2018; IPBES 2018). Such steps will render land resources to be protected and restored for promoting sustainable use of terrestrial ecosystems including forests. The main objective is to help reversing land/soil degradation and to combat climate change. Since major soil (and landscape) forming factor is climate, the issues of climate change always involve soils/lands so far its effect on terrestrial ecosystem is concerned. Since landmass is finite, there is an ever-increasing competition to control land resources in terms of their services for the living organisms bringing tremendous pressure on the carrying capacity of land. There are many reasons for land area being dwindled of which degradation of both natural and anthropogenic are important. It seems, therefore, logical to save our motherland and focus on land degradation neutrality (LDN). LDN will help to provide necessary ecosystem functions and services of the land resources and enhance food security. It will also assist to keep the land resources stable and may also improve its quality within specified temporal and spatial scales and ecosystems. Since land and/or soil degradation has the potential to cause social problems leading to poverty and malnutrition, the implementation of LDN requires involvement of multi-stakeholders with adequate support of the national and regional governments (Bhattacharyya 2020). LDN could be achieved by balancing degradation for which major requirement is the information on soil and land for better horticulture, quality of irrigation water (Bhattacharyya et al. 2016b, 2017a; Bhattacharyya 2020).

Black soils (Vertisols and their intergrades) occupy 84.8 million hectares in India (Bhattacharyya et al. 2020). The soils in the target states are mostly found in arid and semi-arid conditions. An example is the soils in ICRISAT Farm, Telangana. It is established that due to aridity in the atmosphere, soil pedo environment dries up to begin the formation of pedogenic carbonates (PC) which triggers subsoil sodicity resulting in chemical degradation of soil (Bhattacharyya et al. 2016b). These soils manifest poor physical properties such as high bulk density (~1.8 kg m^{-3}), and poor drainage (sHC<1 cm hr^{-1}). In many cases such situation renders land as barren. The crops/trees grown on these landscapes have low available water, poor aeration, poor root proliferation and produce low yield (Bhattacharyya et al. 2016a). Interestingly in spite of hostile pedo environment, these soils in the semi-arid tropics, are showing resilience (Bhattacharyya et al. 2016b) otherwise, such soils could have been infertile and perhaps irreparable. The national agricultural research system (NARS) has been doing an excellent job for last many years (Bhattacharyya et al. 2016a). This was shown with SAT soils to understand the fate of soils and landscape with and without management interventions.

Changes in the level of soil carbonate mineral since 1975 till 2030, is predicted. In case present land use options are continued (BAU), the carbonates would increase

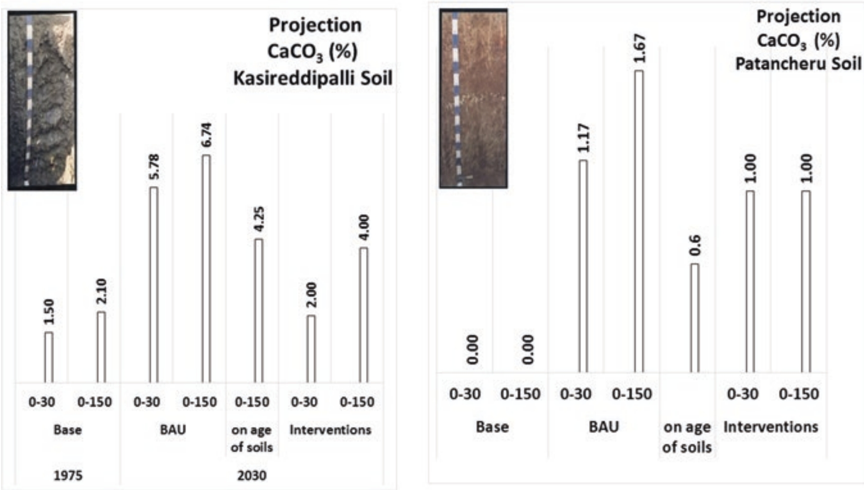


Fig. 2.37 Temporal changes of carbonate mineral in two different soils under BAU (business as usual) and with management interventions. (Source: Bhattacharyya 2020)

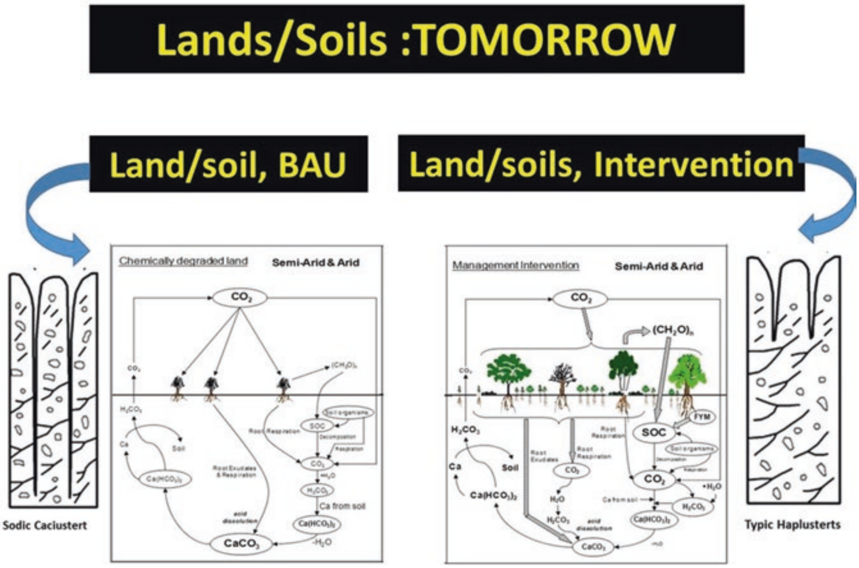


Fig. 2.38 Present and future look of soils and landscape with changes of time and land use changes in business as usual (BAU) and management intervention. (Source: Bhattacharyya 2020)

from 2 to 7% in black soils, and, for (non-calcareous) red soils, to 2%. However, if interventions are adopted, the content of carbonate minerals would reduce appreciably (Fig. 2.37) (Bhattacharyya 2020; Bhattacharyya et al. 2016a). Usually, carbonate minerals, start forming pedogenically, in the sub surface. If these are allowed to form, at the existing rates, with the present land use options these minerals will engulf the entire soil profile from the surface beyond the root zone depth. With poor drainage, very high bulk density, these SAT soils, may look like hard rock in future. The land dominated by such soils will look barren, without much vegetations left on it, as shown on the left side of Fig. 2.38 (Bhattacharyya et al. 2016a). Fortunately, these soils have tremendous resilience, and, therefore, if management interventions are adopted, the same soils will be mellowed, and the land surface will have lush green vegetation as shown on the right side of Fig. 2.38 (Bhattacharyya et al. 2016b).

2.7 Lessons Learnt and Way Forward

India is a large country with nearly 160 million ha area waiting for immediate attention in terms of better food production, resource management and scaling up research achievements to the farm level. It is a challenge. Things have been done which took shape in the target states, yet more is required. Through up-scaling techniques using partnership approach with line departments, government organizations and NGOs, such areas can be brought back to sustainable agriculture. Resilience of soils of SAT suggests that initially degraded soils could be made the vibrant crop production areas to feed the population for another couple of centuries. The

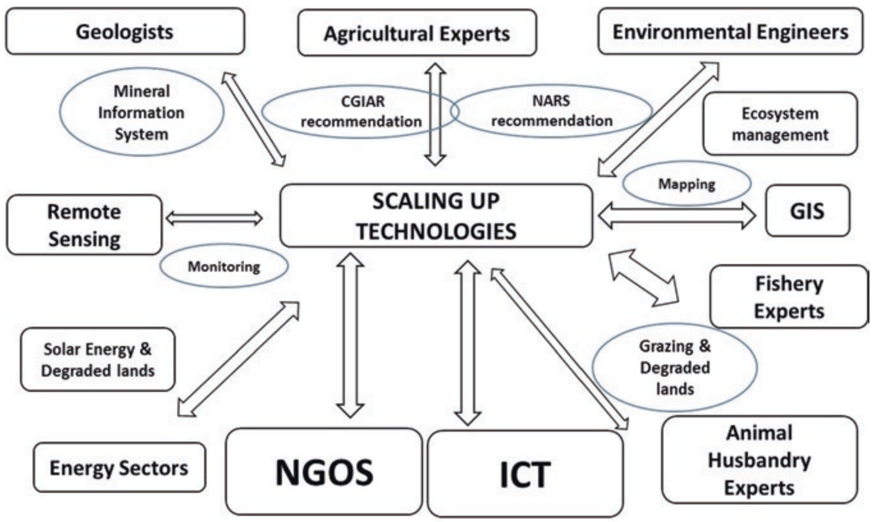


Fig. 2.39 Schematic diagram showing a tentative policy to achieve scaling up technologies

degradation in dry arid areas with desert and coastal sand dunes has been amply demonstrated.

Many soil scientists and natural resource managers are hesitant to talk on LDN, even if their research is devoted to land degradation neutrality. Future research should focus involving multi-disciplinary experts to fulfil the target of scaling up various technologies gathered by SAUs, ICAR, CGIAR and many other organizations directly or indirectly working in these sectors with active participation of non-governmental organizations (NGOs) with an acceptable policy (Fig. 2.39). The contribution of various experts is paramount not only from ecological point of view but also bringing some areas under agriculture and other allied activities. This will result in not only vertical but also horizontal expansion of areas under agriculture, animal husbandry, fisheries and other non-agricultural sectors. Bringing waste land to harness non-conventional source of energy can be doubly beneficial. Firstly, it will help using alternate source of energy to reduce carbon footprints, and secondly, shall enable farmers to utilise the generated energy for operating various agricultural implements.

As mentioned, the nine (9) target states cover nearly 151.9 million ha out of the total 84 revised AESRs (Fig. 2.30) in India. The Figs. 2.40 and 2.41 show the relative proportion of these AESRs occupying the state areas. Forty-eight (48) AESRs in the target states have 11 different categories of LGP starting from < 90 to 240–270 days (Figs. 2.40 and 2.41). Out of these eleven categories (Table 2.17), the LGP showing < 120 days (4 months), 120–150 days (4–5 months), and 150–180 days

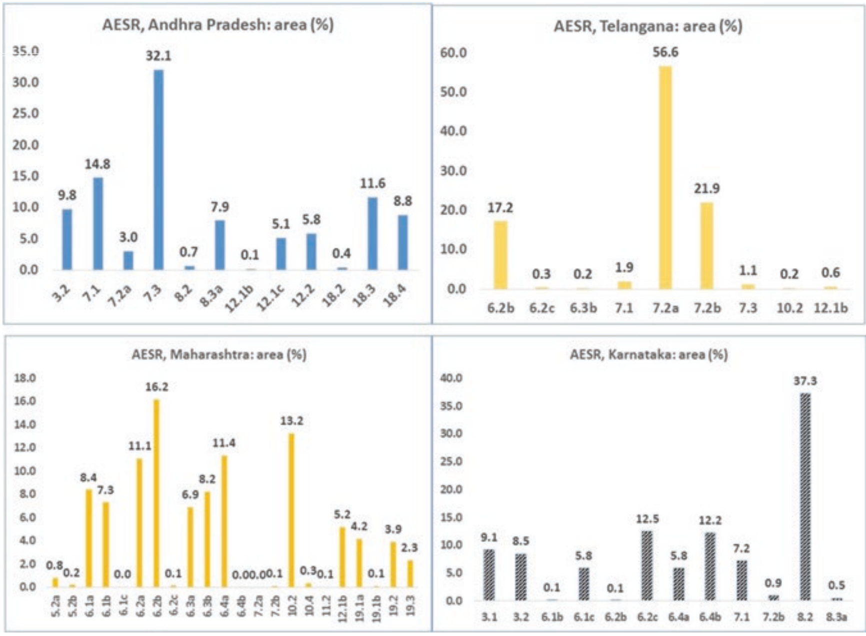


Fig. 2.40 Agro-eco sub-regions (AESRs) in four target states and their relative proportions

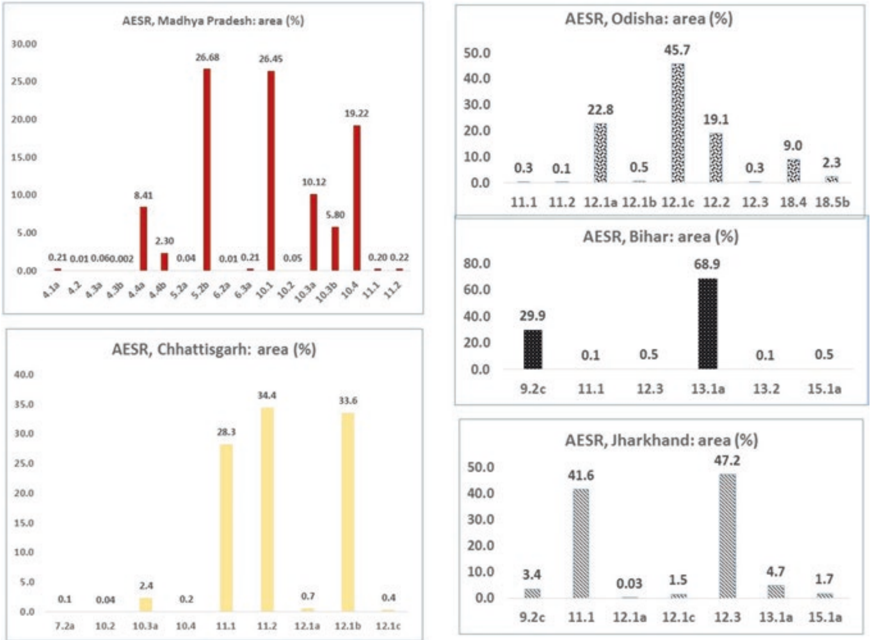


Fig. 2.41 Agro-eco sub-regions (AESRs) in five target states and their relative proportions

Table 2.17 Areas showing length of growing periods (LGP) of different AESRs in the target states (values in million hectare) (areas with bold digits need attention)

	Length of growing periods (LGP) days										
States	<90	90–120	120–150	150–180	180	180+	180–190	180–210	210+	210–270	240–270
	Priority 1		**Priority 2**	**Priority 3**							
Andhra Pradesh	1.59			9.69		0.94		4.05	0.02		
Telangana				2.26			2.49	6.37	0.06		
Maharashtra			2.50	7.61	0.11		0.07	16.96	1.59	1.21	0.71
Madhya Pradesh		0.07	2.62	10.01	5.92			12.13	0.06		
Chhattisgarh					0.02			5.14	8.37		
Karnataka	1.38	1.49		8.24			2.20	3.03			
Bihar				2.81				6.54	0.01	0.05	
Jharkhand				0.27				4.26	3.32	0.13	
Odisha				3.55		2.97		8.59	0.13		0.35
Total	**2.97**	**1.56**	**5.12**	**44.46**	**6.05**						

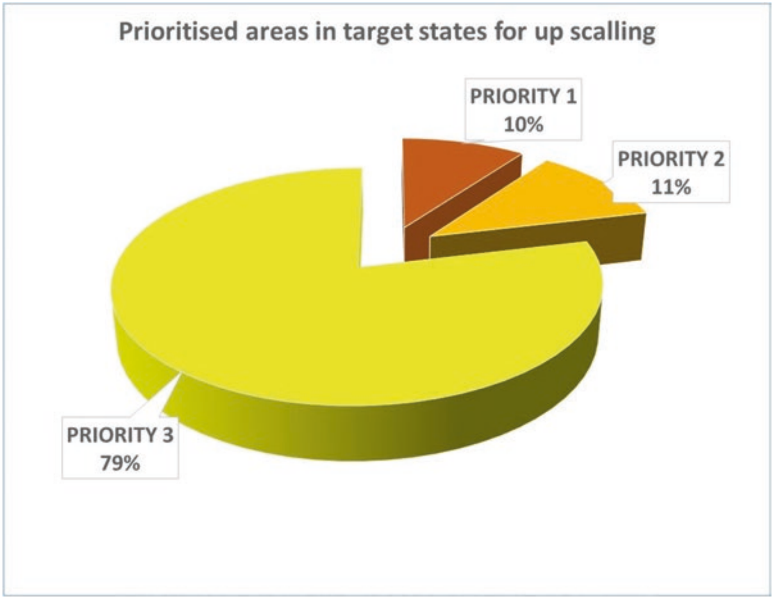


Fig. 2.42 The prioritised areas of the target states for up scaling (Also see Table 2.17)

(5–6 months) are grouped as Priority 1, 2 and 3 in terms of receiving attention from the administrators. Earlier 158.9 million ha areas were prioritised in India mostly from drier AESRs for organic C sequestration (Bhattacharyya et al. 2008) and Conservation Agriculture (Bhattacharyya et al. 2014c). The present study suggests the way forward for the planners in 10%, 11% and 79% of the AESRs providing 4 months to 6 months growing period as the top priority in the nine target states to better the livelihood of the farming community (Fig. 2.42).

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