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Extent of land degradation and status of wastelands in Rajasthan (NW India) with a focus on the Bhilwara District

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Abstract: Geographically, the Rajasthan is the largest state of India. The mapping of degraded and wasteland, its distribution and district base statistics are very important for land resource assessment and management. This paper deals with the status of land degradation affecting different kind of soils and under different management options. The study further illustrates the regional example of the Bhilwara district. The pressure on land resources has increased manifold with the increasing human and animal population. Western part of Rajasthan is severely affected by wind erosion (56%) and south-eastern part is affected by water erosion (42%) and salinity and sodicity (2%) affected area is scattered throughout the state. The area is characterised by a marked temperature range with strong diurnal variations, a typical phenomenon of the warm-dry continental climate. Desertification ranks among the greatest environmental challenge for the ecosystems in this region, and twelve districts of Rajasthan are already affected by severe desertification. Wind erosion is the major cause of soil degradation in western Rajasthan, whereas water erosion affects mostly south and eastern Rajasthan.

Keywords: degraded lands, erosion, management

Introduction

What is the most important natural resource in the world? You might think of diamonds, platinum or gold, or perhaps valuable fuels such as oil and natural gas. However, there is only one resource which needs greatest care in context of food security for increasing population: land and soil resource. Land resources are degrading at faster rate due to human interventions. Bhaskar (2015) conducted a study in cotton growing area of Yavatmal district of Maharatra and concluded that land evaluation exercise for cotton productivity programme in the region must be coupled

with conservation techniques to stop further land degradation in western India. The pressure on land resources has increased manifold with the increasing human and animal population. Catering to the needs of a rapidly increasing population is a factor leading to encroachment on fallows and wastelands (Sharma *et al.,* 2015). The nature and causes of land degradation, and the degree and extent of damaged lands need to be determined, so that developmental agencies in participation with local stakeholders can proactively adopt measures to reclaim degraded lands for distancing food insecurity (ICAR, 2010). Several agencies (National Commission on Agriculture 1976; Ministry of Agriculture 1978, 1985, 1994; National Bureau of Soil Survey and Land Use Planning -NBSS&LUP, 1994, 2004 and National Wasteland Development Board, 1985) had estimated the area under degraded and wastelands at National level, but no one agreed to any estimates due to differences in the definitions of degraded lands and in the methodologies used. Therefore, NBSS&LUP has developed a harmonized methodology which is agreed upon by all working agencies for estimating the degraded and wastelands status in India including Rajasthan state. The extent and distribution of degraded and wasteland in different states of India is estimated in a GIS environment (ICAR, 2010). Geographically, the Rajasthan is the largest state in India. The mapping of degraded and wastelands, its distribution and district base statistics is very important for the state. The datasets on the kinds of land degradations, their spatial distribution are tabulated and mapped. The land resource inventory of Rajasthan is georeferenced and therefore can be used for precise land use planning as well as for strategic development of unutilized degraded and wastelands for some better purposes such as rehabilitation, village or community forestry development or special economic zones (SEZs) delineation.

Location

Rajasthan state is located between 69°30' to 78°17' E longitudes and 23°30' to 30°12' N latitudes, covering about 34.22 M ha (342,239 km^2); which accounts for 10.4% of the total area of the country (Fig.1) The state is bounded in the west by Pakistan, in the north by Haryana and Punjab, in the east by Uttar Pradesh and Madhya Pradesh, and in the south by Gujarat. The main geographic features of Rajasthan are the Thar Desert in the northwest and the Aravalli Range, which runs through the state from southwest to northeast, almost from one end to the other, for more than 850 kilometres.

Physiography

The state has been demarcated into four physiographic zones: i) the Western Plains, ii) the Central Highlands, iii) the arid sandy plain and pediplain, and iv) the semiarid

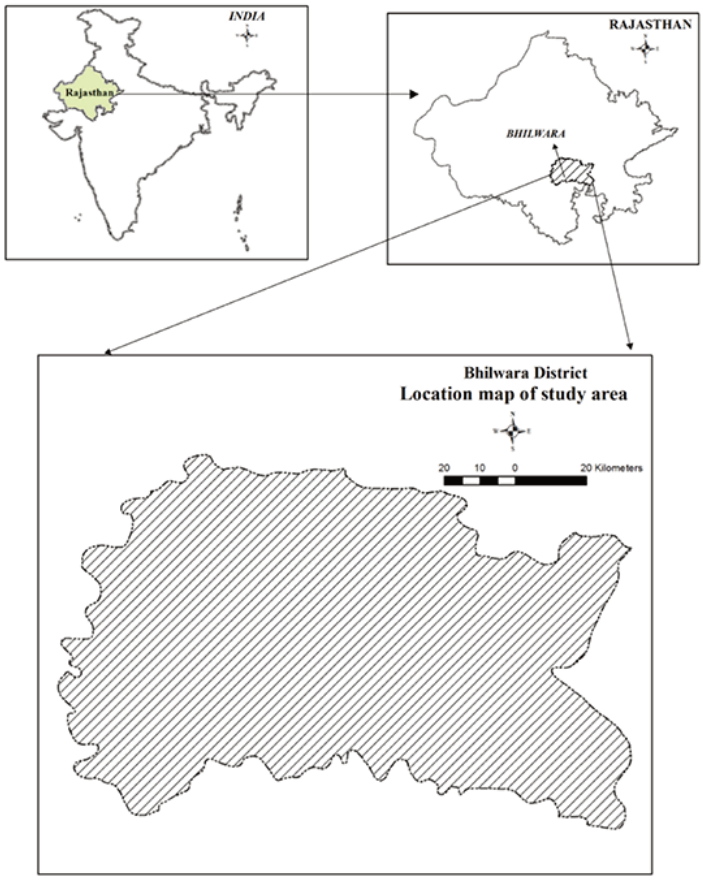

Figure 1 - Location map of study area.

transitional plain. The Western plains include two sub physiographic zones namely, the sandy arid plain and the semi-arid transitional plain. The Central highlands have four sub-zones, the Aravalli landscape, the Eastern Rajasthan upland, the Pathar and Bundelkhand uplands, and the Malwa plateau. The Central highlands constitute mainly discontinuous hilly tracts of Aravallis, extending diagonally from north-east to south-west of the state. The eastern Rajasthan upland includes eastern and north-eastern side areas of the Aravalli range, and is formed by the alluvium of the Banas and Mahi river system. The Pathar and Bundelkhand uplands are primarily the hilly regions of the Vindhyan system. The Malwa plateau consists of Deccan trap and abounds in basaltic formations. The sandy arid plain and the arid pediplain constitute a part of the Thar Desert in the western Rajasthan. The sandy arid plain is dotted by both stabilized and shifting sand-dunes. The semi-arid transitional plain lies roughly between eastern margins of the western desert and western foothills of Aravallis.

Geology

The state can be broadly divided into three geological regions: the Aeolian sands, the Alluvial deposits and the Aravallis. The Aeolian deposits belong to Pleistocene and recent times. The dune free areas of Barmer, Bikaner and Jaisalmer contain exposed marine deposits of Jurassic and Eocene periods, showing an anomaly in the nature of rock deposits of the region. Besides, the Vindhyan system crops out around Jodhpur, where there are small patches of Malani volcanic and granite rocks formations. The alluvial deposits, covering a part of the eastern plain, south-eastern plain and flood plain, belongs to the recent and sub-recent periods. The ravines flanking the river Chambal and its tributaries are of recent origin. The entire rock system of the state belongs to Palaeozoic, Proterozoic and Archean era. The Aravalli system is largely composed of argillaceous deposits, metamorphosed to mica schists, which crop out around Alwar, Udaipur, Ajmer and their surroundings. The Deccan trap covers the south-eastern part of the state forming the Malwa plateau.

Climate

There is a distinct temperature range (from freezing point in winter to 49°C maximum in summer season) with diurnal variations in state, revealing the most typical phenomenon of the warm-dry continental climate. The summer begins in the month of March. Mean winter temperature drops to 13°C during December to January. Due to the cold western winds, the whole of Rajasthan sometimes comes under the spell of the cold wave for 2 to 5 days during winters. Therefore, climate of the state ranges from semi-arid to arid on the west of Aravallis and semi-arid to sub-humid on the east of Aravallis.

The annual rainfall in the state differs significantly. The average annual rainfall ranges from less than 100 mm in north-west part of Jaisalmer region (lowest in the state), to 200 to 300 mm in the regions of Ganganagar, Bikaner and Barmer, 300 to 400 mm in the regions of Nagaur, Jodhpur, Churu and Jalor and more than 400 mm in the regions of Sikar, Jhunjhunun, Pali and the western fringes of the Aravalli range. The eastern side of the Aravallis receives 550 mm rainfall in Ajmer to 1020 mm rainfall in Jhalawar. Mount Abu in the Sirohi district in the southwest region receives the highest rainfall in the state (1638 mm). The southwest monsoon begins in the last week of June in the eastern parts and may last till mid-September. There are occasionally pre-monsoon showers in mid-June while post-monsoon rains may occur in October. Winters may also receive a little rainfall with the passing of western disturbances over the region. However, Rajasthan receives most of its monthly rainfall during July and August.

Natural Vegetation

The most prolific vegetation species is Kejri (*Prosopis cineraria*). This is found in major parts of Thar Desert. In this region, the sparse vegetation cover of xerophytic, thorny and spiny plants is present. Along with *Prosopis cineraria* the dominant species are Babul (*Acacia nilotica*), *Acacia senegal* and *Prosopis juliflora*. In depressions (generally saline), halophytes are observed. Tropical thorn forests are found in arid and semi-arid regions of western Rajasthan.

The eastern region has vegetation ranging from mixed deciduous forests to subtropical evergreen forests, but it has been adversely affected by reckless cutting and grazing. Forest in the eastern sector comprised of Amla (*Phyllanthus emblica*), Tendu (*Diospyros melanoxylon*), Khair (*Capparis decidua)*, Neem (*Azadirachta indica*), Mahuva (*Madhuca longifolia*), Jamun (*Syzygium cumini*), Babul (*Acacia nilotica*) and Teak (*Tectona grandis*). Grass species also abound, these are dominated by ratarda, *Cenchrus ciliaris*, *Sehima nervosum*, *Chloris barbata*, *Iseilema laxum*, *Dichanthium annulatum*, *Chrysopogon montanus* and *Cynodon dactylon*. Tropical dry deciduous forests are spread in Alwar, Bharatpur and Dholpur districts. Sporadic growth of certain species of dry deciduous forests is also found along the dry river beds of Jalore, Nagaur, Ganaganagar and Bikaner districts. The vegetation of Mt. Abu consists of many plants which are similar to the sub-tropical region of Himalayas. Mixed Miscellaneous Forests are found in southeastern and eastern part of Rajasthan comprising Chittaurgarh, Kota, Udaipur, Sirohi, Banswara, Dungarpur, Baran and Jhalawar districts.

Soils

Soils of Rajasthan have been classified (Soil Survey Staff 2003) into 5 orders, 8 suborders, 16 great groups, 32 subgroups, 86 families and 117 series. Entisols are observed to cover around 36% area, followed by Inceptisols, Aridisols, Vertisols and Alfisols with 23%, 20%, 2% and < 1% of total geographical area (TGA) (Shyampura and Sehgal, 1995). The soil mapping units, along with rock outcrops and active dunes cover together 99.7% of TGA, and salt flats, water-bodies and urban areas constitute only 0.3%.

Degraded and Wastelands status

Degraded soils are affected by erosion. Soil erosion is the process involving detachment and transport of soil particles by rain drop impact and wind. Detachment is the process of removal of finer particles from aggregates by the kinetic energy of rain drops. In India, the term, 'wasteland' is loosely used to define degraded lands

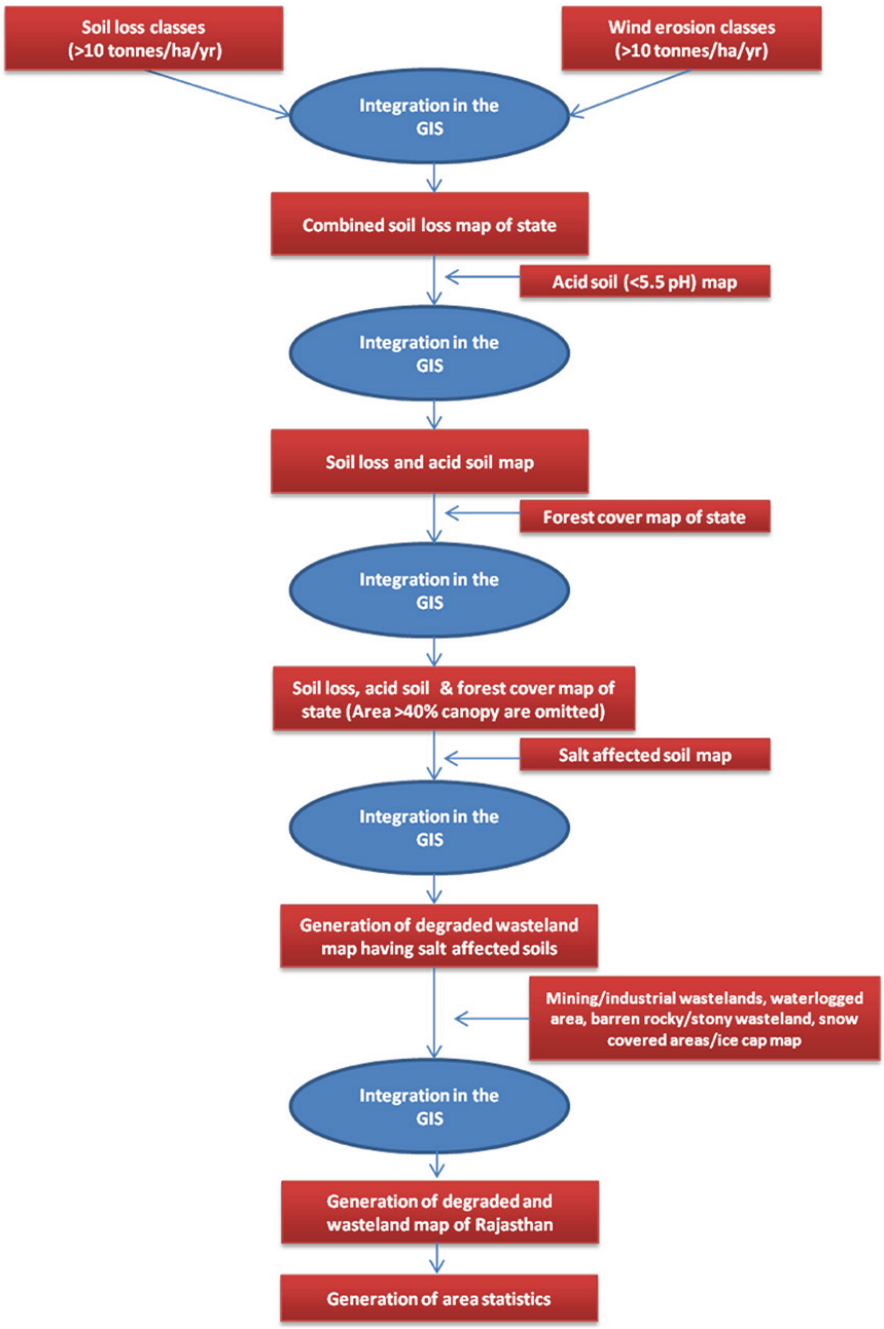

Figure 2 - Methodology for depicting degraded and wasteland status of Rajasthan.

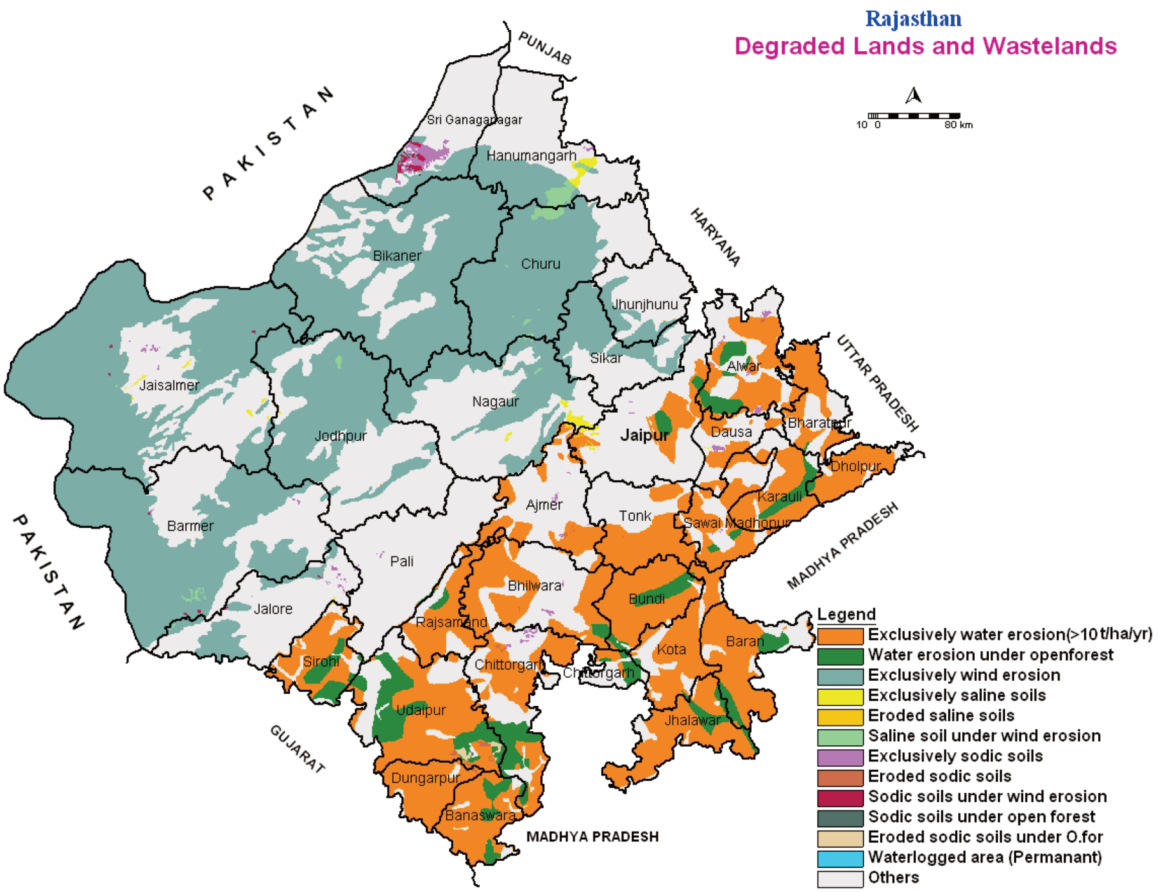

Figure 3 - Extent and distribution of degraded and wasteland in Rajasthan.

(Maji, 2007). The soil degradation occurs due to the interactive effects of anthropogenic and biophysical factors on soil properties and leads to adverse alteration in soil properties, environmental quality, agricultural productivity and sustainability (Lal, 1994). United Nations Environment Programme (UNEP 1992) defined land degradation is the reduction or loss, in arid, semi-arid and dry sub-humid areas of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and, (iii) long-term loss of natural vegetation. Land degradation, therefore, includes processes which lead to surface salt accumulation and water logging associated with salt-affected areas.

Wind erosion is the major cause of soil degradation in Rajasthan. About 11,419,000 ha area is affected with wind erosion followed by water erosion (8,632,000 ha). Chemical degradation is estimated to affect 373,000 ha; out of this 192,000 ha are affected by salinity and 181,000 ha by sodicity. Total area under different kind of degraded land in the state is accounted about 20,424,000 hectares (60% of TGA). Out of total degraded lands 56% area is affected by wind erosion, 42% by water erosion and rest 2% by salinity or sodicity.

National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur mapped the distribution of degraded and waste land in Rajasthan (Fig. 3). Bundi (97% of TGA) is the most affected and Pali (2% of TGA) is the least affected district. The total area statistics show that Jaisalmer district has the highest share of degraded lands (2,772,000 ha). Out of 33 districts, 21 districts of Rajasthan are affected by water erosion, 11 districts by wind erosion. Pali district is not affected by any kind of land degradation. In the western part of Rajasthan, the typical Thar Desert is mostly affected by wind erosion. Highly affected districts with wind erosion are also Jaisalmer (2,753,000 ha), Bikaner (2,119,000 ha), Barmer (1,908,000 ha), Churu (1,346,000 ha) and Jodhpur (1,235,000 ha). Water erosion is the major problem in Udaipur (986,000 ha), Chittorgarh including Pratapgarh (633,000 ha), Bhilwara (571,000 ha), Baran (564,000 ha) and Bundi (539,000 ha). Saline soils are mostly found in Hanumangarh, Churu, Nagaur, Jaipur and Jaisalmer districts. The area affected by sodicity is more confined in Sri Ganganagar, Udaipur, Alwar, Chittaurgarh and Ajmer districts.

A Regional case study: the district of Bhilwara

The Bhilwara district of Rajasthan is situated between 25°10' and 25°58'N latitude and 74°10' and 75°28'E longitude. It is bounded in the north by Ajmer district; in the north-west, west and south-west by Rajsamand district; in the south and south-east by Chittaurgarh district and in the east and north-east by Bundi and Tonk district. The total geographical area of the district is 10455 sq km (District Statistical Abstract, 2002), The total length of the district from west to east is 144 km. while the breadth from north to south is 104 km approximately. It ranks eleventh in terms of area (Fig.1) and seventh in terms of total population.

The area receives 700 mm annual rainfall with a potential evapo-transpiration (PET) of 1380 mm. On the basis of physiographic characteristics, the Bhilwara district has been divided in three units viz. Eastern plain (76.2%), Aravalli (11.36%) and Vindhyan landscape (9.01%). Forty soil series has been identified and mapped as associations of soil series on 1:50,000 scale. Out of that 22 occurred in Eastern plain, 10 in Vindhyan and 8 in Aravalli landscape. Soil series of eastern plain are moderately shallow to moderately deep, loamy in texture with high pH (8.42). Soils of Aravalli landscape are mostly shallow (Kolpura, Khumanpura) to moderately shallow (Jaitpura, Kirimar), relatively coarser in

Table 1 - Degraded and wastelands statistics for the Districts of Rajasthan.

	Water erosion[1]		Wind erosion[2]		Saline[3]		Sodic[4]		Total degraded land		Others[5]	Total
Districts	10^3 ha	%	10^3ha	%	10^3 ha	%	10^3 ha	%	10^3 ha	%		10^3 ha
Ajmer	275	96	1	0	3	1.0	7	2.4	286	34	559	845
Alwar	460	96	0	0	1	0.2	17	3.6	478	57	356	834
Banswara	465	100	0	0	0	0.0	0	0.0	465	93	37	502
Baran	564	100	0	0	0	0.0	0	0.0	564	81	133	697
Barmer	0	0	1908	99	10	0.5	4	0.2	1922	67	930	2852
Bharatpur	300	100	0	0	0	0.0	1	0.3	301	59	205	506
Bhilwara	571	99	0	0	0	0.0	6	1.0	577	55	466	1043
Bikaner	1	0	2119	100	0	0.0	0	0.0	2120	77	626	2746
Bundi	539	100	0	0	0	0.0	0	0.0	539	97	15	554
Chittaurgarh	633	98	0	0	0	0.0	12	1.9	645	60	435	1080
Churu	0	0	1346	97	35	2.5	0	0.0	1381	81	314	1695
Dausa	137	96	0	0	1	0.7	5	3.5	143	42	199	342
Dholpur	263	100	0	0	0	0.0	0	0.0	263	87	41	304
Dungarpur	357	99	0	0	0	0.0	2	0.6	359	95	19	378
Hanumangarh	0	0	320	80	78	19.5	2	0.5	400	32	860	1260
Jaipur	256	95	0	0	13	4.8	1	0.4	270	24	836	1106
Jaisalmer	0	0	2753	99	11	0.4	8	0.3	2772	72	1091	3863
Jalore	4	2	244	95	2	0.8	8	3.1	258	24	801	1059
Jhalawar	571	100	0	0	0	0.0	0	0.0	571	92	50	621
Jhunjhunu	0	0	149	100	0	0.0	0	0.0	149	25	442	591
Jodhpur	0	0	1235	100	6	0.5	0	0.0	1241	54	1042	2283
Karauli	431	100	0	0	0	0.0	0	0.0	431	78	120	551
Kota	426	100	0	0	0	0.0	0	0.0	426	78	119	545
Nagaur	7	1	735	95	31	4.0	0	0.0	773	44	995	1768
Pali	24	89	1	4	0	0.0	2	7.4	27	2	1202	1229
Rajsamand	288	100	0	0	0	0.0	0	0.0	288	75	98	386
Sawai Madhopur	275	100	0	0	0	0.0	1	0.4	276	61	173	449
Sikar	0	0	414	100	0	0.0	0	0.0	414	53	361	775
Sirohi	408	100	0	0	1	0.2	0	0.0	409	80	102	511
Sri Ganganagar	1	0	194	71	0	0.0	77	28.3	272	34	529	801
Tonk	390	100	0	0	0	0.0	0	0.0	390	54	327	717
Udaipur	986	97	0	0	0	0.0	28	2.8	1014	76	317	1331
Total	8632	42	11419	56	192	0.9	181	0.9	20424	60	13800	34224

[1] Exclusively water erosion (>10 tonnes/ha/yr) + Water erosion under open forest.
[2] Exclusively wind erosion
[3] Exclusively saline soils + Eroded saline soils + Saline soils under wind erosion
[4] Exclusively sodic soils + Eroded sodic soils + Sodic soils under wind erosion + Sodic soils under open forest + Eroded sodic soils under open forest
[5] Others: Normal agricultural lands + water-bodies + rivers, lakes and habitats etc. (based on the limited reconnaissance survey)
Source: NBSS&LUP

texture with high pH (8.25). Soils of Vindhyan landscape are shallow, relatively finer in texture with average pH of 7.86. The mineralogy of this study area revealed that none of the clay minerals was found to be dominating in either silt or clay fractions. Both the fractions showed the presence of mixture of minerals, namely mica, smectite, kaolinite and vermiculite (Sharma *et al.*, 2010).

Soil Resources and Mapping

Semi-detailed soil survey of Bhilwara district of Rajasthan was conducted during period of 2000-01 using the Survey of India (SOI) topographic sheet (1:50,000 scale) as base map following the 3-tier approach (Sehgal *et al,* 1989). Indian Remote Sensing satellites (IRS 1B) imageries on 1:50,000 scale were visually interpreted for variations in surface features along with SOI toposheets. Based on this interpretation, the entire area in the district was delineated into landform units and transferred to the topographic base prepared from the Survey of India topographic sheets. These topographic base maps were used during field surveys. To build rational landform-soil relationship, soils of the area were studied in detailed for different physiographic units. Soil profiles in representative areas were excavated down to a depth of 150 cm or to the layer of lithic contact or any non-soil layer like concretionary lime, *murrum,* etc. Once excavated, detailed morphological study was carried out and observations recorded in the profile description cards. From each representative profile, soil samples of diagnostic layers were collected for laboratory analysis. On an average 33 observations were taken to establish a soil series. A total of 1,322 observations were recorded to finalize the soil map of Bhilwara district. Random observations were taken in the same physiographic units occurring elsewhere to confirm and check the landform-soil relationship. At every 2 km interval, random observations were taken to record the variations in soil site characteristics and to supplement the information through 50 cm mini pit and auger down to 150 cm or compact layer.

Physiography, Relief and Drainage

The district has thirteen geomorphic regions according to the physiographic, geologic, drainage, slope and relief characteristics. These were delineated based on the interpretation of satellite mosaic images followed by ground truth validation. Generally, the district is roughly rectangular in shape except for its western portion which is comparatively broader than the eastern one. The north and southwestern part of the district is almost an open plain with a few hillocks rising intermittently, whereas south and northeastern part of the district is undulated with hills and plains. The district generally consists of an elevated plateau having cluster of hills in its eastern portion. There is a distinct hill range in the north east corner which extends up to the town of Jahazpur. Aravalli ranges intersect the district at several places. These hills are prominent in the south eastern part in Mandalgarh tehsil. Bijoliya-Mandalgarh region of the district is termed as Uparmal due to its situation on a plateau. The north plain of the district is situated at 380 m a.m.s.l. The elevation gradually increased towards the western part of the district about 500 m a.m.s.l. The area has a general north-west aspect.

Table 2 - Rainfall and water balance data of Bhilwara district.

Month	Bhilwara		Shahpura		Jahazpur		Gangapur		District	
	RF*	RD**	RF	RD	RF	RD	RF	RD	RF	RD
Jan	5.6	0.6	5.1	0.6	5.3	0.4	4.6	0.4	5.1	0.5
Feb	1.3	0.2	3.1	0.4	2	0.2	2.3	0.3	2.2	0.3
Mar	2.8	0.4	4.6	0.4	3.6	0.4	3.3	0.3	3.6	0.4
Apr	0	0	3.3	0.4	4.1	0.6	3.8	0.4	2.8	0.3
May	0.5	0.1	11.2	1	3.6	0.4	11.9	0.8	6.8	0.6
Jun	52.8	2.4	63.7	3.9	59.4	2.7	61.5	3.7	59.3	3.2
Jul	261.6	11.8	236	10.1	348.2	12.8	181.1	9.4	256.7	11
Aug	296.9	11.6	225.8	10.1	299.2	11.1	190	8.6	253	10.3
Sept	120.4	4.4	85.1	4.3	98.5	4	78.5	4	95.6	4.2
Oct	1	0.2	10.7	0.6	1	0.1	12.2	0.6	6.2	0.4
Nov	0	0	3.6	0.3	1.3	0.1	2.8	0.2	1.9	0.1
Dec	5.6	0.3	4.8	0.4	9.1	0.2	3.6	0.2	5.8	0.3
Annual	748.5	32	657	32.5	835.3	33	555.6	28.9	699	31.6
Humidity Index	16.08		8.68		23.58		2.11		12.61	
Aridity Index	61.84		61.08		63.05		61.85		62.00	
Moisture Index	-45.76		-52.39		-39.47		-59.74		-49.34	
Water surplus (mm)	221.94		119.84		325.41		29.14		174.1	
July	21.64		0.04		128.21		0.04		37.5	
August	194.9		119.8		197.2		29.1		135.3	
Deficit (mm)	853.4		842.8		870.1		853.5		855	
LGP (days)	105-120		105-120		120-135		90-105		90-135	

*RF= rainfall (mm), **RD= rainy days

The important river which flows in the district is Banas and its tributaries, Berach, Kothari and Khari. The Banas river originates in the Aravalli hills in the north part of Rajsamand district and enters Bhilwara district near village Duiya (Bhilwara Tehsil). This river flows towards north and then north east direction along the western side of the Jahazpur tehsil and enters Tonk district.

Geology

The area of the district is almost entirely underlined by Pre-Cambrian rocks which consist of Bundelkhand gneiss, Banded gneissic complex, Aravalli System, composite gneisses, Delhi System and Vindhyans. The Bundelkhand gneiss spreads over in extensive area of the district which comprised of granites and schists. Granite is prominent in the rocky area adjoining to Chittaurgarh district. The Banded gneissic complex also cover extensive area in the south eastern region while Aravalli system covering a wide area in the district is seen in the form of belts and comprises quartzites, conglomerates, shales, slates, phyllites and composite gneisses. The

members of the composite gneisses are classified into arenaceous and calcareous rocks. The Delhi system comprising conglomerates occur in the midst of the Aravalli schists and gneisses. The rocks of Vindhyans comprise by red, brown hard and flaggy sand stone, shale and lime stone. The district is rich in mineral resources. The important minerals found in the district are mica, soapstone, garnet, asbestos, lead, zinc, copper, iron ore and building materials.

Climate

The district experiences semi-arid subtropical climate with dry hot summer and intense winter. The average rainfall in the district is 699 mm. It ranges from 556-940 mm (Table 2). On an average, the number of rainy days in a year is 32. Out of the total rainfall about 90-95 percent received during June to September. The maximum rainfall is received in the month of July. There is a large variation in the annual rainfall. Variability of 457 to 1012 mm has been observed in between 1985 to 2001.

The mean annual air temperature (MAAT) varies between 25.6 °C and 27.1 °C (Table 3). The MAAT is higher in the eastern part, adjoining Bundi District. The winter season starts in December and continues up to February. The hot season commences from March and ends with the middle of June. The monsoon season spread over mid June to mid September. January is the coldest month with mean daily maximum temperature of 25.2 °C and mean daily minimum of 7.8 °C. Sometimes the minimum temperature reaches to the freezing point and occasionally causes frost. The diurnal variation of temperature is large particularly in the winter and summer months. May is the hottest month with mean daily maximum temperature of 41.5 °C.

Table 3 - Meteorological data of Bhilwara district.

Month	Average Temperature °C		PET	Relative Humidity		Mean wind speed
	Max.	Min.	mm	Max.	Min.	km/hr
Jan	25.2	7.8	59	66	40	3.6
Feb	28.9	10.2	79	55	29	5.0
Mar	34.0	16.4	125	43	24	6.0
Apr	38.5	22.1	159	34	23	6.8
May	41.5	26.8	204	38	25	9.7
Jun	39.5	27.4	179	63	48	12.2
Jul	33.4	24.8	120	78	70	11.2
Aug	31.1	29.2	102	81	75	8.4
Sept	32.1	23.0	115	76	65	7.2
Oct	33.1	17.9	112	62	42	4.1
Nov	30.2	11.9	71	57	39	3.7
Dec	26.7	8.3	55	63	40	3.6
Annual	32.7	18.4	1380	60	43	6.8

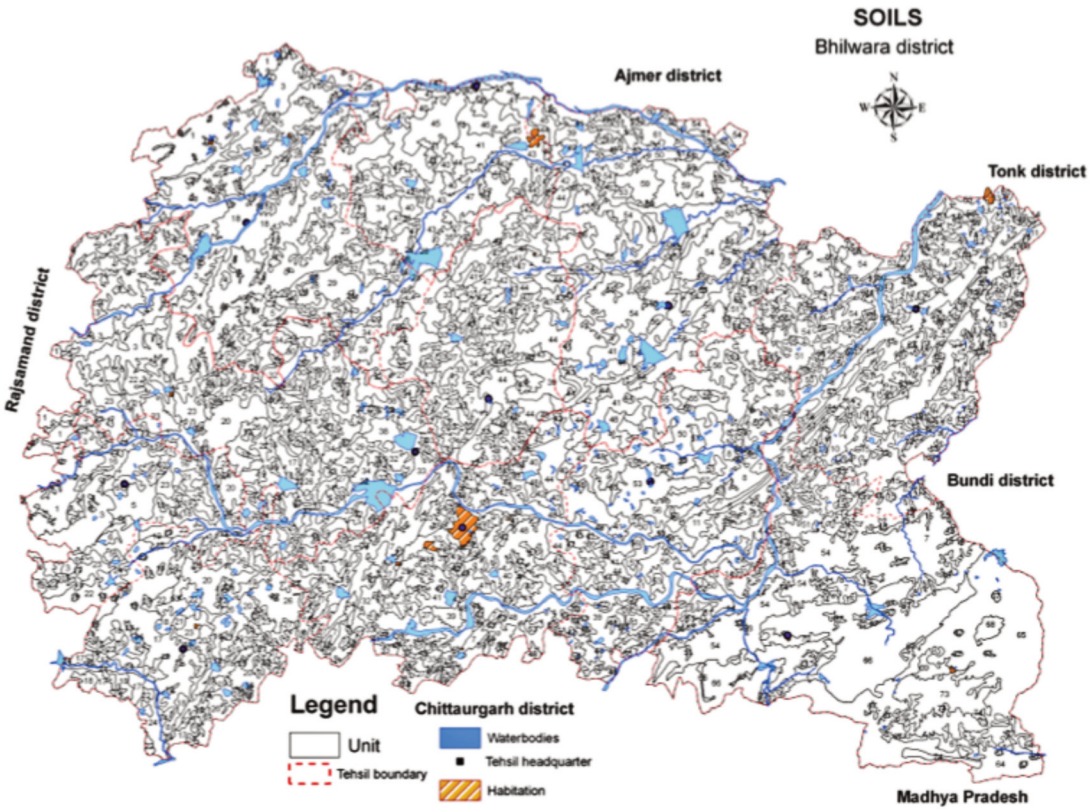

Figure 4 - Soils of Bhilwara district.

The moisture index ranges between -59.7 and -39.5, indicating semiarid dry to moist condition. The relative humidity varies between 40-80 percent. Average PET is 1380 mm. Water balance of Shahpura, Gangapur, Jahazpur and Bhilwara (sub divisions of district) indicates small to large seasonal water surplus varying from 29.1 to 325.4 mm annually. The precipitation is found greater than 0.5 PET for 90-105 days. Length of growing period ranges from 90-135 days in a year. The soil moisture and temperature regimes are Ustic and Hyperthermic, respectively.

Soils and site characteristics

Soils of the study area vary greatly in their nature and degree of evolution depending on the geographical setting in which they have evolved. Knowledge of the kind of soils and their extent is crucial for sound land use planning. Based on the image interpretation and physiographic delineations, soil survey was conducted and boundaries of the soil series have been demarcated and mapped. The soil map is

Table 4 - Soil site characteristics of series in Bhilwara district.

SERIES	DEPTH CLASS[1]	SURFACE TEXTURE (USDA)	PARTICLE SIZE CLASS	SLOPE (%)	EROSION[2]	STONINESS (%)
ARAVALLI LANDSCAPE						
Barach	Shallow	sl	L	1-3	Moderate	
Bhana	Shallow	sl	L	1-3	Severe	40-75
Hathisar	Mod.deep	sl	Fl	1-3	Slight	
Jaitpura	Mod.shallow	sl	Fl	1-3	Slight/Mod	
Khumanpura	Shallow	sl	L	3-8	Severe	40-75
Kirimar	Mod.shallow	sl	Fl	1-3	Moderate	
Kolpura	V.shallow	sl	Lsk	15-30	V.severe	>75
Patan	Deep	sl	Fl	<1/1-3	Slight	
EASTERN PLAIN						
Atoli	Deep	c	F	<1	Slight	
Baland	Mod.deep	sl/scl	Fl	<1/1-3/3-8	Slight/Mod	
Bantal	Shallow	sl/scl	L	1-3/3-8	Mod/Sev/V.Severe	Nil/15-40
Bawari	Shallow	sl/scl	L	1-3	Slight/Mod/Sev	
Bhilakhera	Deep	ls/sl	Cl	<1/1-3	Slight	
Dabla	Mod.shallow	sl/scl	Fl	<1/1-3/3-8	Slight/Mod/Sev	
Dhamania	Mod.shallow	cl/c	F	1-3	Slight/Moderate	
Dhanop	Deep	scl	Fl	1-3	Slight	
Gandher	Mod.shallow	cl/c	F	1-3	Slight/Moderate	
Ganeshpura	Mod.deep	cl	F	<1	Slight	
Ganglas	Mod.shallow	sl/scl	Fl	<1/1-3/3-8	Slight/Moderate	
Hurda	Mod.shallow	cl/c	F	1-3	Slight/Moderate	
Inaini	Shallow	sl/scl	L	1-3	Severe/V. Sev	
Jahazpur	V.shallow	sl	Lsk	15-30	V.Severe	>75
Kajlodiya	Deep	sl/scl	Fl	1-3	Slight	
Kaliyas	Mod.shallow	sl/scl	Fl	1-3	Slight/Moderate	
Lachhmi	Shallow	sl/scl	L	1-3	Mod/Severe	
Motipura	Deep	sl/scl	Fl	<1/1-3	Slight	
Rajyas	Mod.deep	sl/scl	Fl	<1/1-3	Slight/Mod/Sev	
Rakshi	Mod.shallow	cl/c	F	1-3	Moderate	
Santokpura	Deep	ls	S	1-3	Moderate	
Tikar	Shallow	sl	L	1-3/3-8	Mod/Sev/V.Severe	Nil/15-40
VINDHYAN LANDSCAPE						
Genoli	Shallow	l	L	1-3/3-8	Moderate/Sev	Nil/15-40
Hem Niwas	Mod.shallow	cl	F	1-3	Moderate	
Japarpura	Deep	cl	Fl	<1	Slight	
Kotwal ka	Mod.shallow	sl	Fl	1-3	Slight	
Ladpura	Shallow	sl/scl	Lsk	3-8	Severe	>75
Mandalgarh	Mod.deep	l	F	1-3	Slight	
Nayagaon	Deep	c	F	1-3	Slight	
Ritya Khera	Mod.shallow	cl	F	1-3	Slight	
Tharod	Mod.deep	c	F	1-3	Slight	
Tilasva	Shallow	l	L	1-3	Moderate	

[1] Deep (>100cm), Moderately deep (75-100cm), Moderately shallow (50-75cm), Shallow (25-50cm) and Very shallow (<25cm)
[2]Soil erosion was assessed by methods described in USDA Soil survey manual

Table 5 - Physico chemical properties in relation to landforms in Bhilwara district.

LANDFORM	SAND	SILT	CLAY	pH	EC dSm-1	OC	$CaCO_3$	CEC	ESP
	----------%----------			1:2.5 (soil:H_2O)		%	%	cmol (p+) kg-1	
CaH	55.4	27.7	16.9	7.57	0.25	0.66	0	12.13	3.09
CaV	60.5	22.1	17.4	8.07	0.13	0.45	1.71	11.53	5.67
CaP1	57.8	23.5	18.7	7.69	0.12	0.38	0	13.20	3.62
CaP2	67.4	13.9	18.7	8.80	0.30	0.27	4.72	14.14	8.85
CaB1	55.0	23.6	21.4	7.64	0.10	0.37	0.25	14.20	3.33
CaB2	53.8	24.2	22.0	7.52	0.25	0.39	0	12.83	3.16
Aravalli	**64.4**	**17.2**	**18.4**	**8.25**	**0.24**	**0.37**	**2.52**	**12.76**	**6.00**
CeH	59.2	19.8	21.0	7.88	0.15	0.82	0.11	17.53	3.27
CeP	46.7	29.8	23.5	7.96	0.12	0.41	2.14	20.61	8.77
CeV	28.8	42.5	28.9	8.33	0.15	0.45	5.22	23.52	10.78
CeB1	59.2	19.6	21.2	8.14	0.29	0.47	1.96	17.24	5.31
CeB2	59.4	15.7	24.9	8.37	0.43	0.40	4.10	22.56	7.47
CeB3	52.2	18.6	29.2	8.46	0.59	0.42	6.34	24.94	7.60
CeB4	45.6	23.7	30.7	8.70	0.89	0.47	9.96	28.87	8.76
Eastern plain	**52.9**	**20.1**	**27.0**	**8.42**	**0.53**	**0.43**	**5.94**	**23.45**	**8.20**
CpH	35.4	36.5	28.1	6.98	0.10	0.71	0.54	16.71	2.05
CpV	23.6	38.5	38.0	7.98	0.10	0.63	4.12	31.89	4.25
Vindhyan	**25.0**	**38.0**	**37.0**	**7.86**	**0.10**	**0.64**	**3.68**	**30.00**	**3.98**

prepared as association of dominant and subdominant soil series with inclusions. In Bhilwara district, 40 soil series have been identified and characterized. These have been mapped as 74 soil series associations. Out of 40 series, 22 occur in eastern plain, 10 in Vindhyan and 8 in Aravalli landscape, respectively. The soil map of Bhilwara is given in figure 4. The legends of mapping units are reported in appendix-I, and soil site characteristics is given in table 4. A summary of physico-chemical properties for different landforms of the study area has been given in table 5. Rock outcrops occupy 13.73% area, occurring in Vindhyan (47%), Aravalli landscape (37%) and eastern plain (7%). Soil series occurring in pediments and hilly terrains are, in general, shallow, loamy to loamy skeletal and Lithic Ustorthents and Haplustepts in association with rock outcrops with moderate to severe erosion and stoniness. Soil series in valley and plains are moderately shallow to deep, fine loamy, Typic Haplustepts. Significant areas in eastern plain and Vindhyan landscape region are occupied by the soil series having fine (clayey) textured, Typic or Vertic Haplustepts (Dhamania, Ganeshpura, Gandher, Rakshi series) and Typic or Sodic Haplusterts (Nayagaon, Ritya Khera, Tharod, Atoli series). Majority of soil series in eastern plain are moderately shallow (Dabla Chanda, Ganglas, Kaliyas) to moderately deep (Baland, Rajyas), fine loamy, Typic Haplustepts. In the Aravalli landscape soils are mostly (Kolpura, Khumanpura) to moderately shallow (Jaitpura, Kirimar), loamy to fine loamy, Lithic Ustorthents or Typic Haplustepts. Shallow, loamy skeletal (Ladpura) Lithic Ustorthents are found in the Vindhyan landscape.

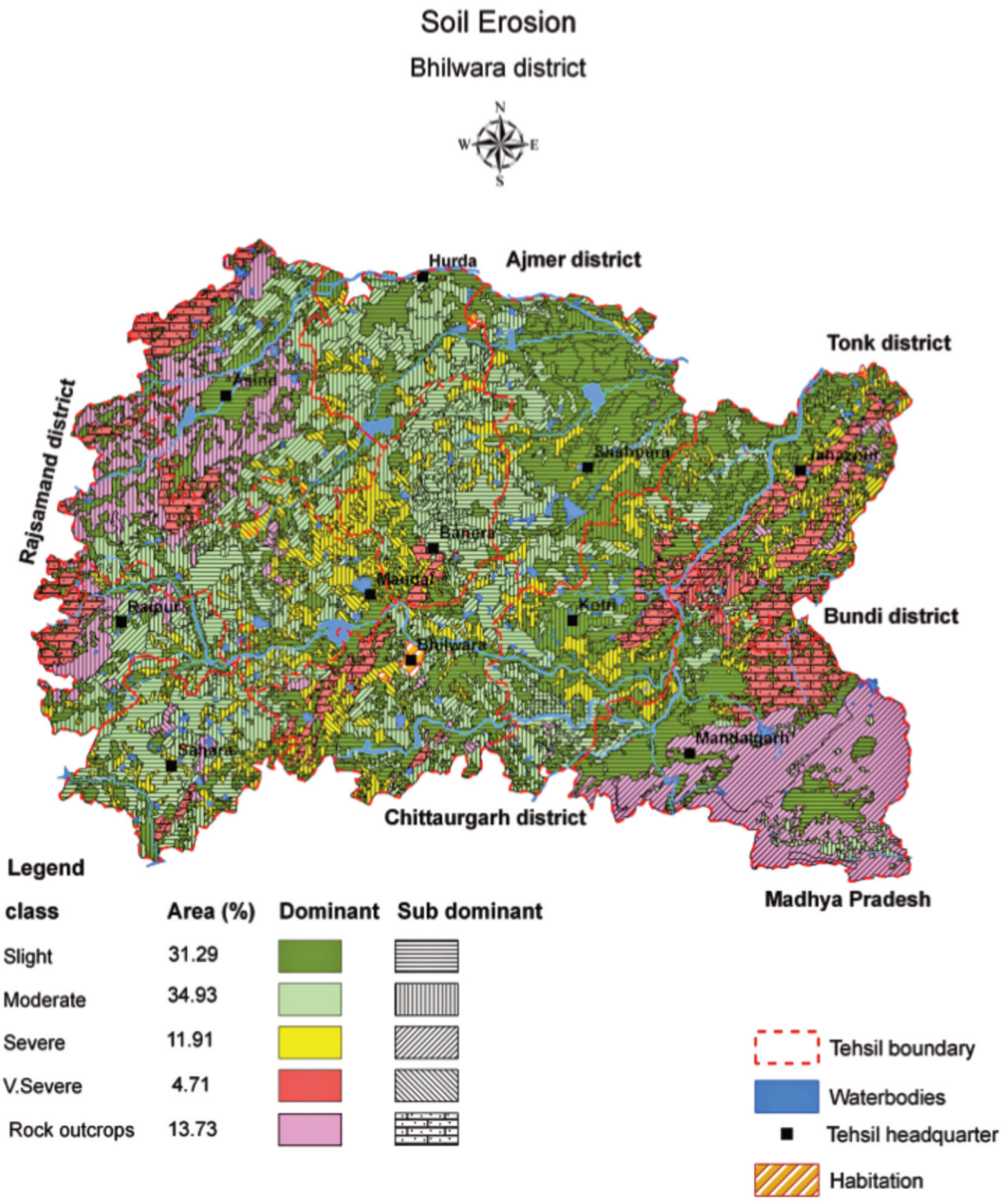

Figure 5 - Soil erosion status of Bhilwara district.

Table 6 - Soil erosion status of Bhilwara district.

LANDFORMS	SLIGHT	MODERATE	SEVERE	VERY SEVERE
	----------PERCENT----------			
Aravalli	16.9	24.3	13.5	8.5
Eastern plain	37.0	40.7	10.4	4.9
Vindhyan	12.9	12.6	27.2	0.0
Tehsil				
Asind	20.0	36.9	12.4	5.5
Banera	21.2	55.8	14.9	4.7
Bhilwara	28.7	43.0	9.8	5.3
Hurda	24.8	58.1	11.1	0.9
Jahazpur	44.6	10.1	11.4	11.3
Kotri	44.1	34.2	9.3	4.7
Mandal	18.6	43.5	14.3	5.7
Mandalgarh	27.4	13.3	17.7	4.9
Raipur	17.0	44.5	9.7	4.5
Sahara	21.3	62.4	7.8	1.4
Shahpura	62.1	25.8	7.3	0.2
District	31.3	34.9	11.9	4.7

Soil erosion

Out of 1,045,000 hectare area of Bhilwara district 4.7% is affected by very severe erosion, 11.9% by severe erosion, 34.9% by moderate erosion and 31.3% by slight erosion (Table 6 and Fig.5). Severe to very severely eroded lands requires immediate protection measures. Severity of erosion is more prominent in Vindhyan landscape followed by Aravalli and eastern plain. About 17-22% area is severely to very severely eroded in Asind and Mandalgarh tehsil (an administrative unit within a district) comprising mainly Kolpura and Ladpura series. Severity of erosion is relatively less in Kotri and Shahpura tehsil. Severity of erosion is generally higher in north east region and North West region of the district. Soils associated with rock outcrops in south east part of the district in Mandalgarh tehsil are severely eroded. South west and central part of the district is slight to moderately eroded with pockets of severe erosion in dominant soils and moderately eroded subdominant soils.

Management of degraded lands

Grazing of small ruminants (goat and sheep) removes the natural surface cover of soils. Once their surface is exposed, single grained and coarse textured soils of western Rajasthan are more prone to wind erosion due to high wind velocity from west

direction in summer season. The sand dune shifting is reported as great problem in Thar Desert. Sand encroachment is a very common phenomenon in agricultural fields which inhibits the crop growth and development. To reduce the wind speed the locally available brushwood, such as *Leptadenia pyrotechnica, Zizyphus nummularis, Calligonum polygonoides* etc. can be planted in parallel lines at a distance of 2-3 m. Checker-board system of 2-3 m^2 is also very effective in arresting the sand movement. Mechanical mulching with plant residues or polythene on the sand surface is also a very effective barrier to wind erosion (Sehgal 1996).

Erosion by water is the single most serious degradation problem in eastern and southern part of Rajasthan. The monsoon type of climate coupled with intensive cultivation practices and large scale deforestation are largely responsible for water erosion. Construction of roads, big dams, mining, and cultivation of crops in fragile areas are the other soil degradation related issues. Sheet erosion, rill erosion, gully erosion, stream bank erosion are the major kind of water erosion in Rajasthan. It has been estimated by Sehgal (1996) that a total 5,334 m tonnes of top soil (16.4 t/ha) is being eroded every year. Such alarming rate of soil erosion can be protected with certain principles of soil conservation. Mulching, contour farming, contour bunding, contour trenching and bench terracing are the common soil and water conservation measures being operated in India. Mulching is a practice to cut the loss of water through capillary rise by hoeing or spreading loose material on the soil surface which is effective in moisture conservation during drought period. Contour farming forms a first line of defense, with mini-barriers across the slope to reduce runoff and soil loss, thereby increase crop production. Contour bunds, graded bunds and conservation ditches serve as a second line of defense on moderately slopping lands. Contour bundings are very effective on slopes between 3-6% with moderate infiltration and permeability in area receives rainfall below 500 mm. Ridge and furrow or broad bed and furrow method of cultivation, corrugation, compartmental bunds, organic trenching, vegetative barriers, etc. are very effective measures for uniform distribution of water and controlling rill and sheet erosion. Contour trenching and bench terracing is more effective in areas having slope from 6 to 33% depending on effective soil depth and other socio-economic factors.

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