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Technical Bulletin

Soil Erosion in Rajasthan

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ICAR

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In Co-operation with
Department of Watershed and Soil Conservation, Govt. Rajasthan, Jaipur

About the NBSS&LUP

The National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur, a premier Institute of the Indian Council of Agricultural Research (ICAR), was set up in the year 1976 with the objective to prepare soil resource maps at state and district level and to provide research inputs in soil resource mapping, and its applications, land evaluation, land use planning, land resource management, and database management using GIS for optimising land use on different kinds of soils in the country. The Bureau has been engaged in carrying out agro-ecological and soil degradation mapping at the country, state and district level for qualitative assessment and monitoring the soil health towards viable land use planning. The research activities have resulted in identifying the soil potentials and problems, and the various applications of the soil surveys with the ultimate objective of sustainable agricultural development. The Institute is also imparting in service training to staff of the soil survey agencies and SAU's in the area of soil survey and land evaluation, soil survey interpretations for land use planning, remote sensing applications to soils and agriculture, and GIS for land resource management. The Bureau in collaboration with Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola and Maharana Pratap University of Agriculture and Technology is running post-graduate, teaching and research programme in land resource management, leading to M.Sc. and Ph.D. Degrees.

The publication on "Soil Erosion in Rajasthan" is prepared from soil resource information generated during Soil Resource Mapping will help in understanding erosion status in each district of the state for undertaking soil and water conservation work on priority and to have proper resource allocation in the state.

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Foreword

Information on soil resource and its management is an important endeavour to all the sections of people, Everyone's livelihood, well-being and future prosperity depend directly and indirectly on natural resources. The economy of all the sectors is also based on the soil resource available in the region specified. However, in recent years, the country experiences the rapid deterioration of soil resources. The estimation of it becomes possible through modern tools of remote sensing coupled with field traversing. It become clear that even though we inherited a cleaner and greener earth from our forefathers, we are eroding its value by stealing from future generations what is rightfully their inheritance. It is a matter of great concern to all of us that above 57 per cent of the total geographical area of the country is suffering from various *forms of degradation – water erosion, wind erosion, chemical and physical deterioration. Over 5.3 billion* tons of top soil alone is lost every year through erosion resulting in a loss of around 8 M tons of plant nutrients. In addition, about 9.4 M ha land is suffering from water logging and soil salinity in varying degrees. Soil resource base is also shrinking at an alarming rate of 0.25 M ha/annum due to rapid industrialization and urbanization.

Water is another critical resource whose availability is continuously diminishing for agricultural use due to enhanced demand from other competitive sectors. Declining water tables in high potential – high productivity regions have raised the concerns like hydrological sustainability in intensively irrigated cropping systems areas – a backbone of India's food grain production. Quality of water resources is being deteriorated due to enhanced disposal of pollutants, sewage and effluents. The soil resource forms the basic sink for these elements. The surface, ground and rain water resources need to be efficiently managed in order to preserve and protect productivity of soil base to enhance and to achieve the sustainable crop productivity.

The pros and cons of all the above issues lie in proper quantification of soil loss categorizing systematically the land mass into defined soil units indicating their inter-relationship, and capability to respond to ameliorative measures and allied management practices.

Under such a challenging scenario, it gives me a great pleasure to note that the Regional Centre, Udaipur of NBSS & LUP, CSWCR & TI, Dehradun and CAZRI, Jodhpur have brought out a joint publication on "Soil Erosion in Rajasthan" quantifying the extent of problems, and needed ameliorative measures. The publication also presents a state of the art, knowledge and future strategies for adopting proper soil conservation measures. I congratulate Dr. R.L. Shyampura, Sub-Project Coordinator and the team of Scientists at Regional Centre, Udaipur, State Department of Agriculture, Govt. of Rajasthan, Central Arid Zone Research Institute and Dr. R.K. Singh, Regional Research station, Kota of CSWCR & TI for their excellent job.

The publication is extremely valuable to researchers, planners and policy makers of the state of Rajasthan. I hope that this volume will help in better understanding the effect caused due to soil erosion in the state to formulate developmental and extension programmes and to implement them for achieving the policies of soil and water conservation.

(J.S. Samra)
Dy. Director General (NRM)
ICAR

Preface

In this millennium the population of India has crossed over the mark of one billion. This has tremendously increased the need for food, fodder and fiber in the country. In order to meet these demands, the people are constrained to use the marginal land resources. This leads to various kinds of second generation problems of soil degradation. Such degradation problems are high in Rajasthan (33.2). Among the degradational problems, the soil erosion is the most serious affecting greatly the quality and productivity of the land in many aspects. Soil erosion is wearing away of the earth's surface by the forces caused by wind, water and ice resulting the damaged of vast areas which cannot be used for productive purposes. Much of the good land is degraded due to over and improper use under the increasing productivity the intensity/severity of erosion and its spatial extent is to be known to take up soil and water conservation practices in an area.

Soil and water conservation aims at preventing soil erosion and heal its scars where it has not advanced too far to respond to curative methods. This involves, in many instances, changing the uses to which land is put. It has been found, in fact, as stated previously, that the first requisite to conservation of land is to fit the crop – (crops, trees, or grazing plants) to the capabilities of the soils and the water available. Use of engineering and agronomic practices will control and conserve water and counteract the erosive action of both water and wind on the soil. These conservation measures can be used singly or in combination within the economic limitations and acceptance of farmers. These will support one another and thereby provide sustainability to the land.

This bulletin provides the details of the Rajasthan state, the different factors of universal soil loss equation and wind erosion/deposition. The bulletin also attempts the consequences of soil erosion, depletion and suggests the major soil and water conservation measures which, when applied to the land in correct combinations, will greatly reduce or prevent soil erosion, improve fertility, and increase yields for which every one of us are responsible.

Towards this endeavour Scientists of National Bureau of Soil Survey and Land use Planning, Nagpur, Central Soil and Water Conservation Research & Training Institute, Dehradun and Central Arid Zone Research Institute, Jodhpur under the able supervision of the Directors of the institutes in cooperation with Department of Agriculture, Govt. of Rajasthan, combinedly made an effort to bring out a bulletin and map of "Soil Erosion of Rajasthan". This bulletin is prepared for the use of planners, technicians and agriculturists working for controlling water erosion and making better use of rainfall available and irrigation water in the state. The suggestions are based largely on the experience and existing situation in the state.

I hereby appreciate the effort of the scientists of both ICAR institutes and officials of State Govt. Rajasthan in accomplishing this task.

(K.S. Gajbhiye)
Director, NBSS & LUP

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Executive Summary

Soil erosion is a process that leads to a huge amount of soil loss, thus lowering the capacity of the soil to support human life. For the protection of the land from soil erosion, it is imperative to locate and measure the type, degree and severity of soil erosion for proper planning to conserve or to opt for alternative uses. Government organizations require information on soil erosion for implementing various soil conservation projects and deciding the priority areas for undertaking control measures. Quantitative estimates of soil loss from different parcels of land are required to delineate the priority areas where work on afforestation, bunding and terracing can be taken up. Sediment yield predictions are required for designing reservoirs and erosion control structures, and soil erosion data can thus be very important for this purpose.

The National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) and the Central Soil and Water Conservation Research and Training Institute (CSWCR & TI) have jointly initiated the preparation of soil erosion maps of the different states using the components of Universal Soil Loss Equation (USLE) utilizing the field data of soil resource maps (on 1 : 250,000 scale) of NBSS & LUP. The preparation of the individual state soil erosion map forms the first step in this endeavour.

The state of Rajasthan has an area of 3,42,479 sq. km. and is divided physiographically into two regions: Western Plains and the Central Highlands. The rainfall ranges from 100 mm in extreme western part of Jaisalmer district to 900 mm in eastern part of Jhalawar and Banswara district. About 85% of total rainfall is received during south-west monsoon period extending from June to September. In each of these months, there are 2-7 rainy days. The forest covers an area of 7.53 per cent. The shallow and moderately shallow soils covers an area of 36.85 and 21.86 per cent, respectively. The soils are classified into five soil orders: Entisols (36.85%), Inceptisols (21.86%), Aridisols (19.55%), Vertisols (2.83%) and Alfisols (0.73%). The land degradation in the state is mostly due to wind and water erosion resulting into the loss of top soil. The loss of soil due to erosion vary from different land uses in addition to quality of soil and intensity of climatic parameters especially rainfall and wind. Since soil erosion is the major reason for soil loss and consequent decline in soil productivity, it becomes imperative for the land use managers and land use planners to adopt appropriate soil conservation measures to check it. The conservation measures depends on type of soil and the degree of soil erosion thus it becomes more important to know the amount of soil loss due to soil erosion.

The spatial distribution and the data on soil loss indicates that about 43.35 per cent area in the state can be managed with slight management practices like field bunding or with proper land cover through crop planning. About 33.82 per cent area can be conserved through contour bunding and vegetative barriers. Rest of the area (22.83%) is mostly affected by severe, very severe and extremely severe erosion and is very fragile. It needs utmost care for the management. If these areas are encroached by the growing population, it may lead to deforestation and denudation of forest vegetation thus exposing the soil surface to the intensity of rain. Due to this, these areas get severely eroded exposing the substrata. In order to protect these areas, the awareness campaign among the local people is of paramount importance. With the participative approach by the people these areas could be either brought under natural vegetation/

crop cover. The proper contour trenching and bench terracing techniques could be followed to prevent the soil loss by erosion. The government enactment of introducing a legislative policy to prevent the deforestation and to undertake afforestation in such areas is an appropriate step. The social organizations and extension agencies should propagate the essence of the slogan **"Each one plant one"**. These practices can only green the areas and bring in the resilience in these areas thus sustaining the ecosystem.

❑

1

Introduction

RAJASTHAN state is located between 69°30' to 78°17'E longitude and 23 °30' to 30 °12' N latitude covering an area of about 342479 sq. kms, which accounts for 11 percent of the total area of the country (Fig.1). It 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 state has 32 administrative districts with Jaipur as its capital.

1.1 Physiography Regions: Based on the general elevation, slope and landscape configuration in the terrain, Rajasthan state has been demarcated into following subunits of two major physiographic units (Fig.2).

The Western Plain

(i) The sandy Arid Plain
(ii) The Semi-arid Transitional Plain

The Central Highlands

(i) The Aravalli Landscape
(ii) The Eastern Rajasthan Upland
(iii) The Pathar and Bundelkhand Upland
(iv) The Malwa Plateau

The sandy arid plain and arid pediplain constitute the part of the Thar desert in western Rajasthan. Vast stretches of aeolian sand deposits in this area have drifted from the coastal areas and deposited over the rock outcrops of the Jurassic, Eocene and sedimentary origins. The sandy arid plain is dotted by both stabilized and continuously shifting sand dunes of varying size and shapes.

The semi-arid transitional plain lies between eastern margins of western desert and western foothills of Aravallis. It is formed of alluvium deposits laid by Luni, Ghaggar, Saraswati, Chouthan and Sutlej river systems. In the western arid regions the slope generally runs from northeast to southwest. The north-eastern part of the region has a general elevation of about 300 m above m.s.l. but towards the south the elevation is about 150 m. Except in Jalore-Siwana upland which lies above 300 m. In eastern semi-arid plains, the topography is varied, as a result, the region presents a queer and confused amalgam of low land and upland topography.

The Aravalli landscape constitutes mainly discontinuous hilly tracts extending diagonally from north-east to south-west of the state. It is discontinuous in north-east of Ajmer leaving a number of wind gaps at Sambhar, east of Sikar and between Ajmer and Beawar where ripples of sand dunes extends several kilometers over the eastern plain.

The eastern Rajasthan upland includes the area on the eastern and north-eastern side of the Aravalli range. The area is formed by the older and recent alluvium laid by the Banas and the Mahi river system originating from the Aravalli range. The general gradient of the upland is towards east to south-east.

The Pathar and Bundelkhand upland consists primarily of the hilly region which belongs mainly to the Vindhyan system. The plains within this region are mostly formed by the alluvium laid by the river Chambal and its tributaries viz. the Parvan, the Parbati and the Kalisindh rivers.

The Malwa plateau primarily consists of deccan trap and abounds in the basaltic formations. The plains within this region are formed by the alluvium laid by the river Chambal and its tributaries viz. the Parvan, the Parbati and the Kalisindh.

1.2 Drainage: The Aravalli ranges which run across the state from the south west to north east direction largely influence the drainage system of the state. The major portion of western Rajasthan has an inland drainage system, the southern, the south-eastern and eastern part have a well developed drainage system (Fig.3). The river system of the state can be put into two major groups first draining its runoff ultimately to the Bay of Bengal, and second flowing to reach the Arabian sea. All the rivers (Chambal, Banas, Banganga and Gambhiri) flowing on the eastern side of the Aravalli range fall in the first group. Rivers flowing in the southern (Mahi and Sabarmati) and the western (Luni and its tributaries) part of the state belong to the second group.

1.3 Rainfall: The mean annual rainfall in Rajasthan varies from less than 100 mm in the extreme western parts of Jaisalmer district to more than 900 mm in the eastern parts of Jhalawar and Banswara (Fig. 4). The arid parts of western Rajasthan receive less than 500 mm. The isohyets run from SSW to NNE over Rajasthan with an increasing gradient towards the eastern Rajasthan. These steep gradients in isohyets in the eastern parts of the State are due to the influence of rainfall towards the west of Aravallis. About 85% of the total rainfall is received during the southwest monsoon period extending from June to September. Remaining portion of rainfall is received in the cold weather period (January and February) in association with local connective activity. Though, the total rainfall received in arid areas is low, high intensity showers are common.

The southwest monsoon sets in over the eastern parts of the state by about the last week of June and extends over the entire state by the first week of July. July and August are the rainiest months, each accounting individually to about 30% of the annual rainfall. In each of these months there are 2-7 rainy days (with daily rainfall of at least 2.5 mm) in west Rajasthan and 7-14 rainy days in east Rajasthan. The withdrawal of the southwest monsoon begins from the northwestern part of the state around Ist September and by 15th September monsoon withdraws from the entire state.

1.4 Forest and natural vegetation: The floral wealth of Rajasthan is rich and varied. It has 2.6 M ha (7.53 per cent) of forest area. (Statistical Abstract, Directorate of Economics and Statistics, Government of Rajasthan 2000).

The western half is desert terrain and most of the area under forests is restricted to eastern and southern parts of the state. The forests are unevenly distributed in the various districts. Most of the forests are over the hilly areas i.e. in Udaipur, Rajsamand, Kota, Baran, Sawai Madhopur, Chittaurgarh, Sirohi, Bundi, Alwar, Jhalawar and Banswara districts, which make up for about 50 per cent of the forests of the state. Dense natural forests are in protected patches, mostly confined to various national parks and wild life sanctuaries. Most of the remaining forests of the state are in various stages of plant growth.

There are three broad types of forests; (1) Tropical Thorn Forests, (2) Tropical Dry Deciduous Forests, and (3) Central Indian Subtropical hill forests. They can broadly be categorized into two distinct groups (i) comprising the arid vegetation, falling into western part of the state and (ii) semi arid to sub humid one of eastern and southern Rajasthan.

Vegetation of Western Zone: *Calligonum-Haloxylon-Leptadenia, Salvadora oleoides-Euphorbia caducifolia, Zizyphus nummularia-Capparis decidua, Suaeda fruticosa-Salsola*

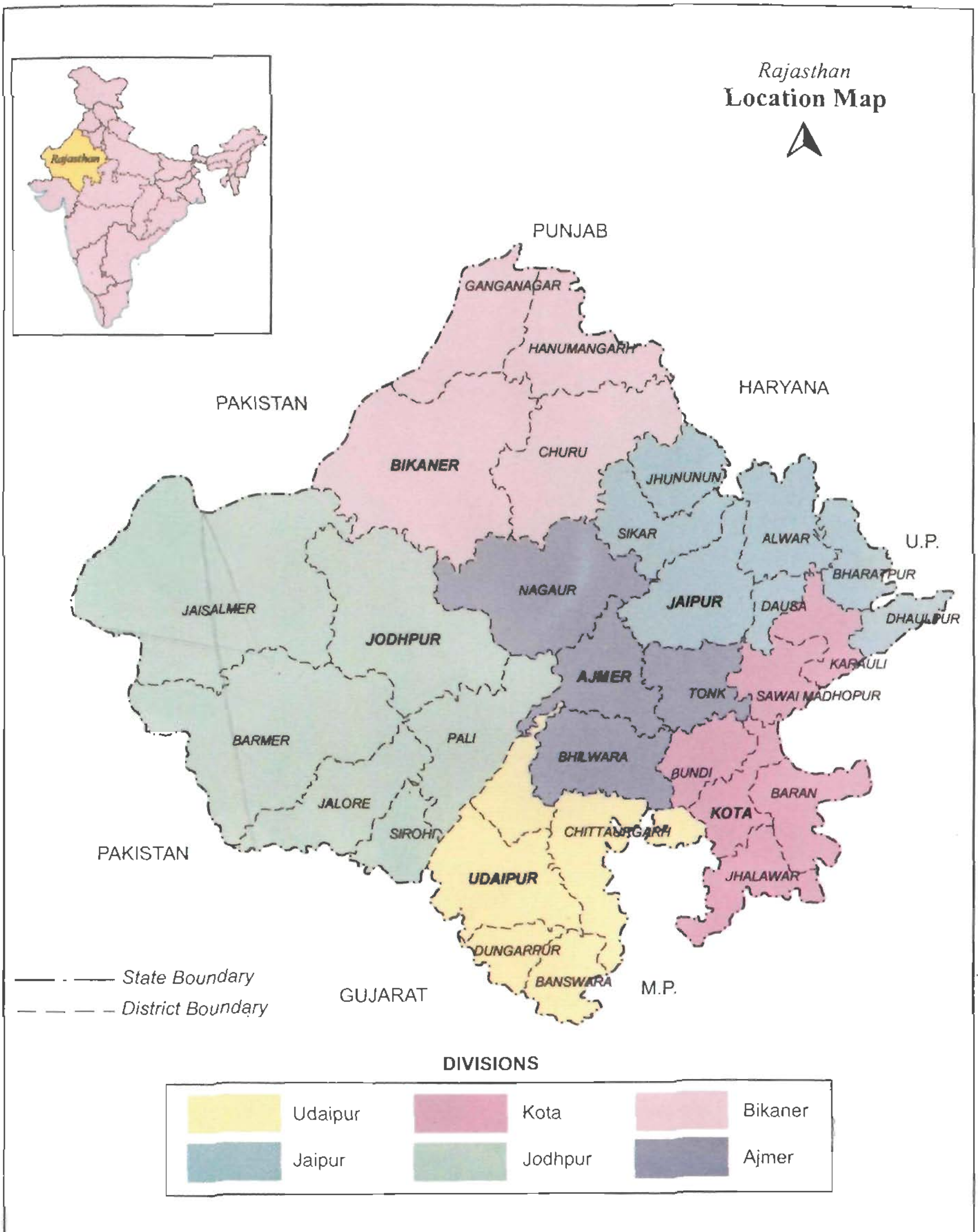
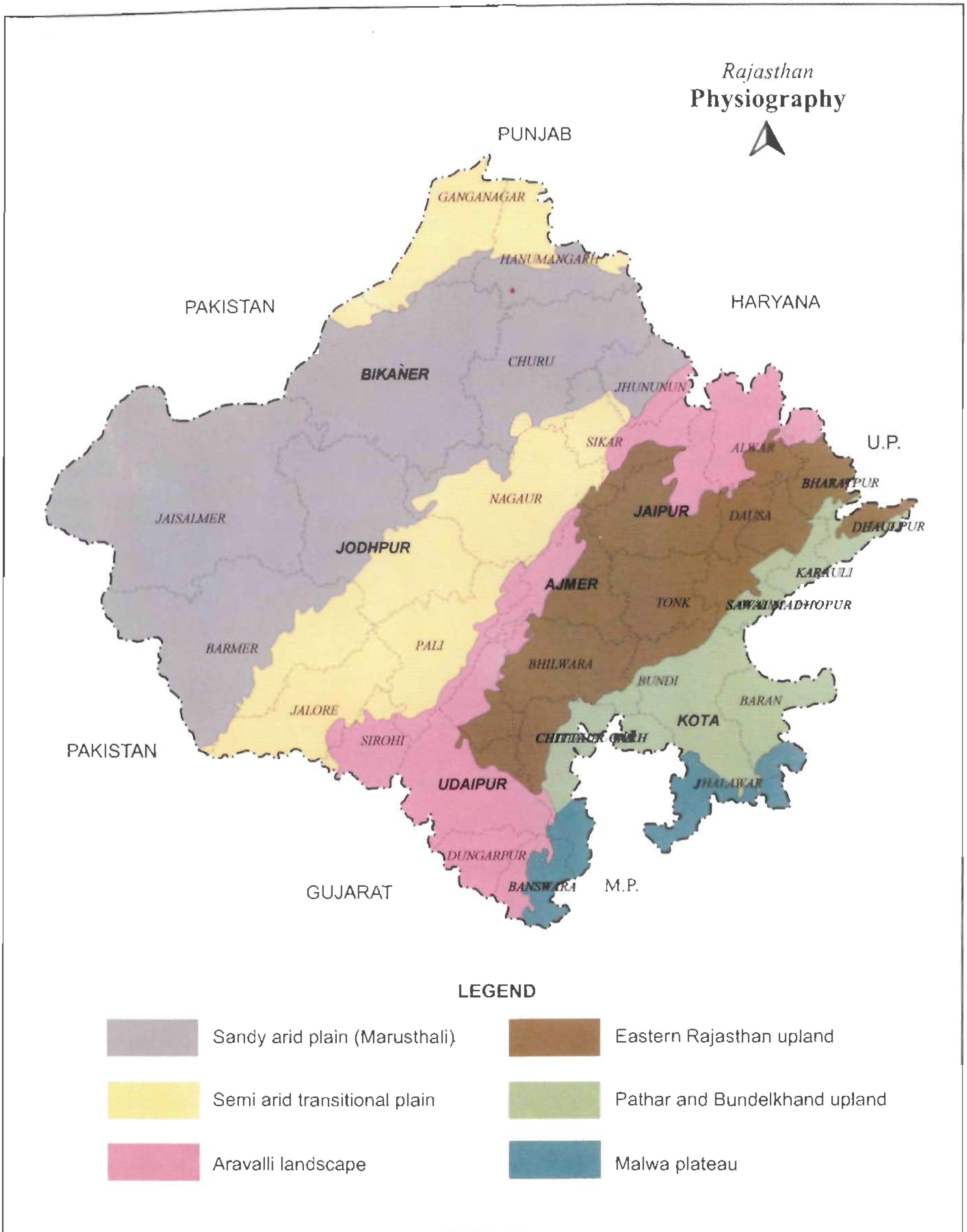

Rajasthan
Location Map
Rajasthan
PUNJAB
GANGANAGAR
HANUMANGARH
HARYANA
PAKISTAN
BIKANER
CHURU
JHUNUNUN
SIKAR
ALWAR
U.P.
BHARATPUR
NAGAUR
JAIPUR
DAUSA
DHAULPUR
JAISALMER
JODHPUR
KARAULI
AJMER
TONK
SAWAI MADHOPUR
BARMER
PALI
BHILWARA
BUNDI
BARAN
KOTA
JALORE
SIROHI
CHITTAURGARH
PAKISTAN
UDAIPUR
JHALAWAR
DUNGARPUR
BANSWARA
M.P.
GUJARAT
State Boundary
District Boundary
DIVISIONS
Udaipur
Kota
Bikaner
Jaipur
Jodhpur
Ajmer

Fig. 1


Rajasthan
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BARMER
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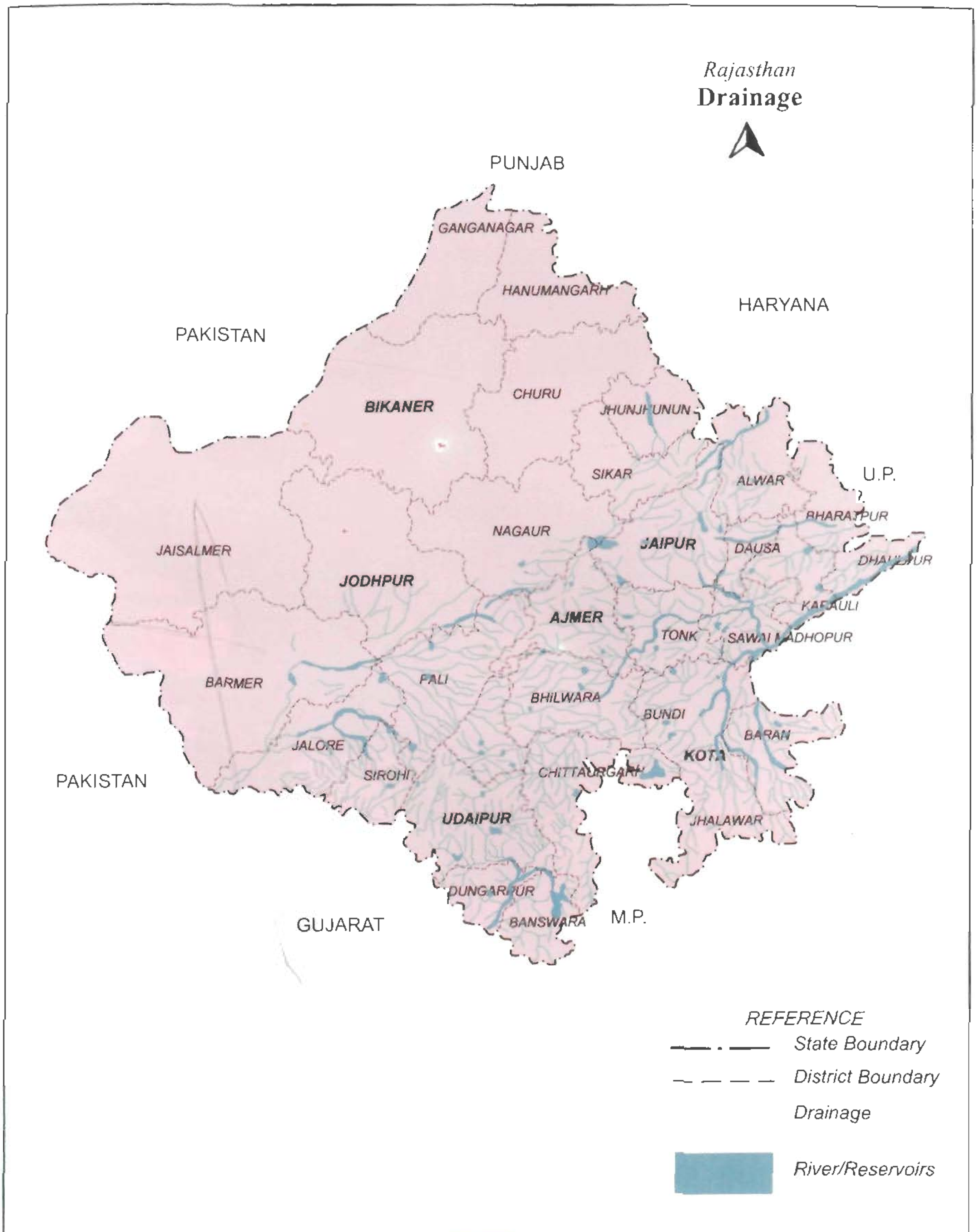
BUNDI
BARAN
JALORE
KOTA
SIROHI
CHITTAURGARH
UDAIPUR
JHALAWAR
DUNGARPUR
BANSWARA
LEGEND
Sandy arid plain (Marusthali)
Eastern Rajasthan upland
Semi arid transitional plain
Pathar and Bundelkhand upland
Aravalli landscape
Malwa plateau

Fig. 2


Rajasthan
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JALORE
SIROHI
KOTA
UDAIPUR
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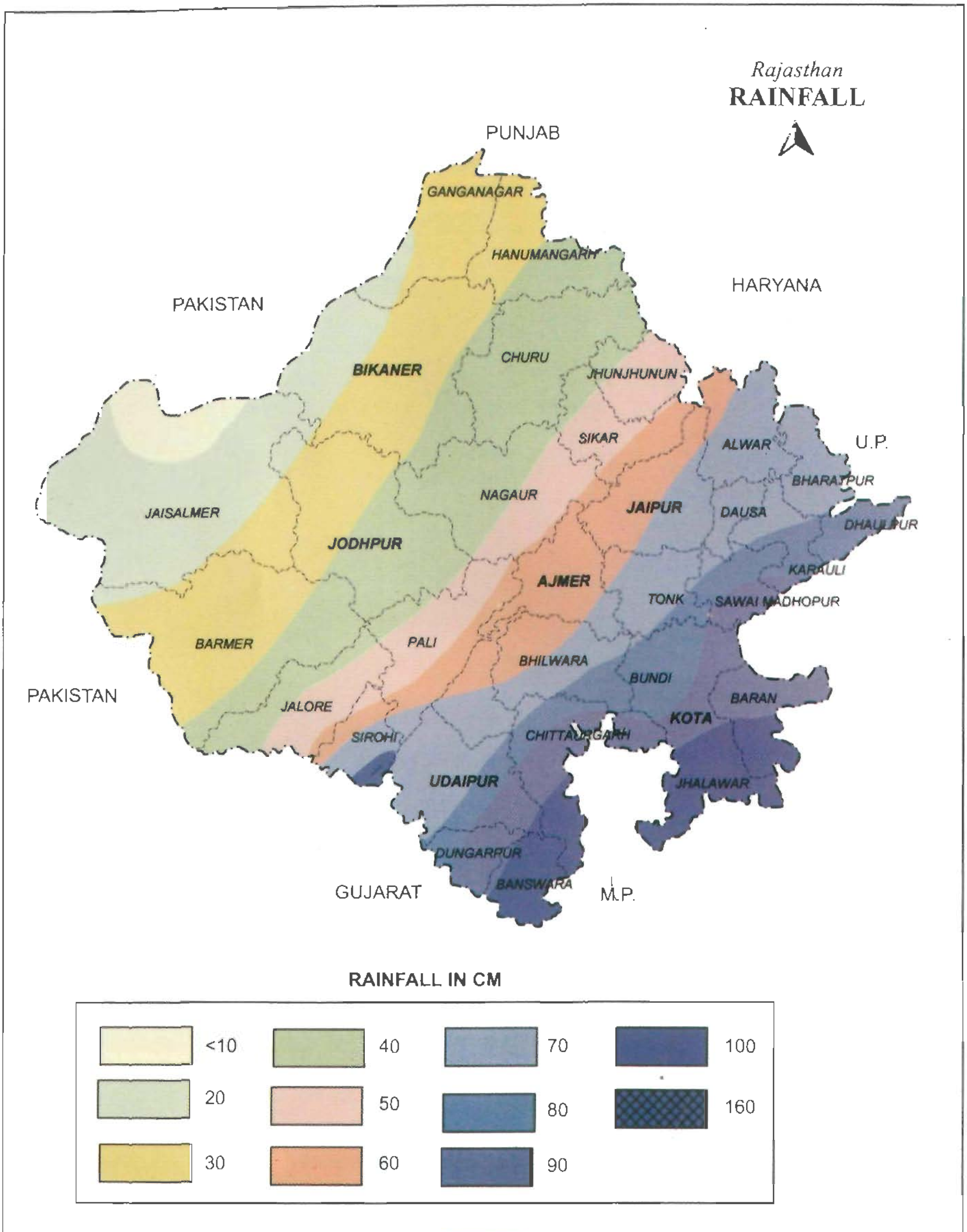
DUNGARPUR
BANSWARA
REFERENCE
State Boundary
District Boundary
Drainage
River/Reservoirs

Fig. 3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RAINFALL IN CM
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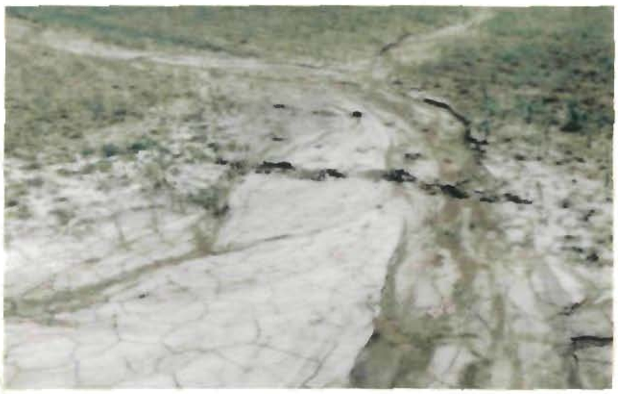
160

Fig. 4

Soil Erosion - Problems

Severe wind erosion

Road encroachment by sand



Sheet erosion

Rill and gully erosion

Extension gully erosion

Fig. 5

Order	Area (%)	General features of Soils
Entisols	36.85	Shallow to deep, loamy to sandy, excessively to well drained on dunes, pediments and hills.
Inceptisols	21.86	Moderately Shallow, moderately deep to deep, clayey to loamy, moderately well to well drained on undulating lands, rolling lands and plains.
Aridisols	19.55	Moderately Deep to deep, sandy to loamy well drained on dunes and interdunal plains.
Vertisols	2.83	Moderately deep, deep to very deep clayey, moderately well drained on plains of Malwa plateau, Pathar and Bundelkhand and eastern Rajasthan upland.
Alfisols	0.73	Moderately shallow to moderately deep, loamy, well drained soils undulating land and hills of Aravallis.

baryosma, Prosopis-Capparis, Zizyphus – Prosopis-Tecomella, Prosopis cineraria-Acacia nilotica, Salvadora oleoides-Prosopis cineraria-Capparis decidua and *Acacia senegal-Euphorbia caducifolia* are major type of vegetation.

Vegetation of Eastern Zone: *Acacia leucophloea-Prosopis cineraria-Acacia nilotica, Acacia nilotica-Capparis decidua, Butea monosperma-Madhuca indica*-Zizyphus mauritiana, *Anogeissus pendula-Boswellia serrata, Tectona grandis, Mangifera indica-Syzygium cumini* type of vegetation

1.5 Soils and land degradation: The soils occurring on each landform are characterized. There are five soil orders namely Entisols, Inceptisols, Aridisols, Alfisols and Vertisols were identified and described below. They are further categorized into eight sub-orders, sixteen great groups, thirty two subgroups, one hundred seventeen soil series.

Based on these soil information thematic maps such as soil depth, slope, texture and AWC, etc. has been generated by using GIS under SPANS environment (Shyampura and Sehgal, 1995).

Declining productivity indicates land degradation. Erosion due to water and wind is the main cause of land degradation. The process of erosion takes place when rain and wind strike the soil aggregates and detach the soil particles. These detached particles are then transported through the action of wind and runoff water. The runoff water also carries away dissolved nutrients. Deep soils with favourable substrata (weathered parent material) have resilience and can be renewed through, fertilizers, organic matter and other management practices though they are affected by soil erosion while shallow soils with unfavourable substrata (hard rock) can not be renewed by the above means and so they degrade due to erosion resulting into loss in productivity. Similarly, Wind erosion gradually removes silt, clay and organic matter from the surface soil leaving the coarse material behind. In extreme conditions, the sand begins to drift and form unstable dunes that encroach on productive surrounding (Fig.5) land and thus decreases the productivity of land at both the sites. Wind erosion also causes serious problems for infrastructural facilities especially roads, railway tracts, canal and settlements which get buried during sand storms (Fig.5).

Database on soil loss due to wind and water erosion is important for advocating the conservation measures properly (Shyampura and Sehgal 1995). The individual farmer may be interested in planning for his own field based on soil loss. Government organizations need *information on soil erosion for implementing* various soil conservation projects and deciding the priority areas for undertaking control measures. Quantitative estimates of soil loss from different sections of catchments under the river valley projects (RVP) are required to delineate the priority areas for undertaking afforestation, bunding and terracing. Sediment yield predictions are required for designing of reservoirs and erosion control structures etc.

Rainfall erosivity, soil erodibility, topography, vegetative cover, management, and conservation practices are the major factors affecting the soil erosion. The erosion takes place in the form of *sheet, rill and gullies. Sheet erosion takes place on* slopes due to overland flow (Fig.5). Rills form in the areas where overland flow concentrates. Excess concentration of flow results in gully erosion (Fig.5). On decreasing slopes of overland flow area eroded materials get deposited. Total erosion in the form of sheet, rill and gullies are termed as gross erosion. *Sheet and rill erosion from a unit area of a* field at a specified slope is defined as soil loss. The sediment flowing out of watershed outlet is called sediment yield and its deposition subtracted from gross erosion. The process of soil transport and deposition is quite complex. The soil loss and sediment yield are estimated by using several models, which are based on large number of parameter and input variables.

Universal Soil Loss Equation (USLE) is used in the eastern Rajasthan. It is simple and empirical model that estimates average annual soil loss from a field whereas qualitative assessment of erosion in the western Rajasthan on 1:1m scale carried out by Pratap Narain *et al.* (2000) using field criteria and satellite characteristics has been presented to view the scenario of erosion in the state. ❑

Erosion Prediction Equations

2

2.1 Universal soil loss equation: The USLE is an erosion model for prediction of long-term average annual soil loss from a specified field area in specified cover and management conditions. The equation predicts the soil loss due to sheet and rill erosion. It computes soil loss for a site as a product of six factors. The equation of soil loss is described as:

A = R K L S C P, where

A = *Soil loss per unit area (computed), expressed in tons/ha/year.*

R = *Rainfall erosivity factor. It is the number of rainfall erosion index units for a particular location.*

K = *Soil erodibility factor. It is the soil loss rate per erosion index unit measured on a unit plot of 22.13 m (72.6 ft.) length supposed to have uniform 9 per cent slope continuously in clear-tilled fallow.*

L = *Slope length factor. It is the ratio of soil loss from the field slope length to that from a 22.13 m (72.6 ft.) length under identical conditions.*

S = *Slope-steepness factor. It is the ratio of soil loss from the field slope gradient to that of a 9 per cent slope under otherwise identical conditions.*

C = *Cover and management factor. It is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.*

P = *Conservation practice factor. It is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight-row farming up and down the slope.*

By using USLE model, the assessment of soil erosion in West Bengal was estimated by Narain *et al.* (1993), in Gujarat by Kurothe *et al.* (1997) and in Maharashtra Challa *et al* (2001). The maps depicting soil loss have also been generated.

The parameters of USLE were estimated at a particular grid area (10,000 ha) using the average conditions. Limitations arising due to averaging of the parameters are in built in the empirical formula itself. The soil erosion map thus generated indicates the first approximation of soil loss (t/ha) from the fields of farmers or other areas in the grid and will serve as a guide for the planning purpose in a better way than the existing qualitative distribution of soil erosion (Shyampura and Sehgal 1995) available till date.

2.2 Wind erosion prediction equation: Several types of wind erosion equations have been developed from time to time to predict the amount of soil loss. The most comprehensive soil loss equation has been developed for predicting wind erosion by Woodruff and Siddoway (1965) and Skidmore and Williams (1991) taking into account the soil erodibility, wind energy, surface roughness, length of open wind and vegetative cover. The wind erosion equation is a set of complex relationships among those parameters that influence wind erosion. The equation is designed to serve as a tool for determining the potential amount of wind erosion on any field under existing local climatic conditions and as a guide for determining the conditions of surface roughness, soil cloudiness, vegetative cover and sheltering to reduce potential wind erosion to the desirable extent.

The mean annual soil loss can be estimated from the wind erosion equation:

$WE = f(I\ C\ K\ L\ V)$

Where WE = Mean annual wind erosion (t/ha/year).

I = Soil erodibility index (t/ha / year).

C = Climate factor.

K = Ridge roughness factor.

L = Unsheltered length of eroding field (m), and

V = Vegetative cover factor

The elements involved in the calculation of the above factors are numerous and somewhat complex. Moreover, it is not easy to gather the required information from many sites in the difficult desert terrain. Consequently, the method is difficult to apply for regional mapping of the phenomena.

Some studies have been carried out by the CAZRI to find out sediment loss due to wind erosion, as well as to understand the processes of erosion. The qualitative assessment of erosion through the measurement of known parameters of climate and terrain properties in conjunction with satellite data was found to be a quick and reliable technique for identification of mappable areas of wind erosion/deposition in the western Rajasthan. ❑

3

Database

THE database compiled from various sources for different factors of USLE are described factor wise as under.

3.1 Erosivity factor (R): It is the annual total value of the erosion index (EI_{30}) for a particular location. Computation of EI_{30} from recording type rain gauge chart is described by Singh *et al.* (1981). An iso-erodent map indicated the spatial distribution of R factor in a region. An iso-erodent map of India was revised by Raghunath *et al.* (1982) by inclusion of additional rainfall data from new stations. The iso-erodent map of Rajasthan was prepared. This map was used to obtain the R factor values at various grid points.

3.2 Erodibility factor (K): It is a measure of potential erodibility of a particular soil under a set of conditions. It depends on the inherent properties of the soils. Some of the intrinsic soil properties that influence the erodibility are soil texture, stability of soil structure, soil permeability, infiltration, organic matter and soil mineralogy. The best way to get K factor for a particular soil is through field measurements on a unit plot. Central Soil and Water Conservation Research and Training Institute, Dehradun and its Centres have measured K value for some of the soils in India. Wischmeir and Smith (1978) used soil properties to estimate K values and presented a nomograph for this purpose.

For soils containing less than 70 per cent silt and very fine sand, the soil erodibility factor K can be calculated from the equation.

$$K = 1.2917\,[2.1\times10^{-4}\,M^{1.14}\,(12-a)+3.25\,(b-2)+2.5(c-3)]/100$$

Where,

M = Per cent silt × (100-Per cent clay)

a = per cent organic matter,

b = the soil structure code used in soil classification

c = the profile permeability code.

For computing K factor at various grid points the data base generated by Shyampura and Sehgal (1995) during soil resource mapping of Rajasthan were used.

3.3 Topographic factor (LS): It is the Length (L) and degree (gradient) of the slope that affect the soil erosion by water in a landscape. In general, the erosion increases with increase in slope length as well as gradient of slope. For field application the L and S factors are combined as a single topographic factor (LS) and is computed by:

$$LS\,(\lambda\;22.13)\;m\;(0.065 + 0.045s + 0.0065s2)$$

Where,

λ = slope length (m),

s = slope gradient (%) and

m = an exponent

Current recommendation (Wischmeir and Smith, 1978) for the exponent 'm' are:

m = 0.2 if slope <1 per cent

m = 0.3 if slope <3 per cent and >1 per cent

m = 0.4 if slope <5 per cent and >3 per cent

m = 0.5 if slope > 5 per cent

The values of λ and s for each grid point were compiled from the profile data sheets obtained during soil resource mapping of Rajasthan.

3.4 Cover and Management factor (C): The cover and management factor is the expected ratio of soil loss from land cropped under specified conditions to soil loss from clean tilled fallow on identical soil and slope and under the similar rainfall. This factor reflects the effect of crop cover, crop sequence, productivity level, length of growing season, tillage practices. The data for estimating cover and management factor for various crops grown in Rajasthan state have been complied from the grid data. Central Soil and Water Conservation Research and Training Institute and its Research Centers have evaluated C factors for various crops (Kurothe, 1991-92; Nema, *et al.* 1978; Verma, *et al.* 1982; CSWCRTI AR 1983-84 & 1984-85; Singh *et al* 1981 and USDA 1978). The cover and management factors for some of the crops were taken from Singh *et al.* (1981).

S.No.	Cover and Management (C)	C - factor values
1	Forest and grass lands	0.01–0.38
2	Bushy forest/waste land	0.14
3	Crop lands	0.2–0.43
4	Degraded (waste) lands	0.50
5	Fallow lands	1.00

A combined 'C' factor of 0.01 was used for forest and grassland areas. The C factors for orchards, vegetable crops and minor millets were estimated by professional judgment. The 'C' factor for each grid point was selected on the basis of

Field indicators for assessing wind erosion/deposition in western Rajasthan

Terrain	Rainfall	Major indicators for assessment	Severity
Flat sandy plains with dominantly loamy sand to sandy loam soil	100-550 mm	Fresh sand sheet upto 30 cm thick; few scattered new fence line hummocks and nebkhas upto 100 cm high.	Slight
Moderately sandy undulating plains and sand dunes with loamy sand soils; thickly sand sheeted plains.	Above 300 mm	Presence of reactivated fresh sand of 50 to 150 cm thickness on stable dunes, sandy plains and fence line hummocks; many recently formed nebkhas.	Moderate
Moderately sandy undulating plains and sand dunes with sand to loamy sand soils.	Below 300 mm	Reactivated and fresh sandy hummocks (nebkhas) and sand ridges of 90-300 cm height; sand sheets of 60-150 cm thickness between undulations; reactivated stable dunes with fresh sand deposits of 70 to 200 cm thickness; exposed plant roots to a depth of 40 to 100 cm in the sandy plains indicate erosion.	Moderate
Moderate to strongly undulating sandy plains with closely spaced hummocks and high sand dunes with sand to loamy sand soils.	100-550 mm	Closely spaced sandy hummocks and sand ridges of 1 to 4 m height with fresh sand cover; sand deposits of 100-300 cm thickness usually present between undulations; highly reactivated sand dunes are covered by fresh sand and superimposed by crescentic bedforms of 2 to 4 m height.	Severe
Barchan dunes and very thick sandy plains with loose sand throughout the profile.	100-550 mm	Areas to drift sand, especially as fields of barchans of 2 to 5 m height, which encroach upon roads, settlements and agricultural fields; also areas with very closely spaced nebkhas of 2-5 m height.	Very severe

Satellite FCC image characteristics of wind erosion/deposition features

Wind erosion/deposition feature	Signature on satellite FCC
Sand sheets and fence line hummocks	Uniform whitish or light pale brown colour
Fresh sand deposits on stable sand dunes	Reactivated sand in bright white colour; stable dune surface in light yellow.
Fresh sand deposits on closely spaced sandy undulations as sand ridges	Medium white tone, because of cultivation practices.
Barchans	Bright white tone.

main crop grown in that grid square.

3.5 Conservation Practice Factor (P): In order to restrict the influence of erosion intensive rain, the crop management practices are to be supported by different conservation practices through land management and shaping. Although conservation practices such as contour cultivation, contour/graded bunding, terracing and field bunding are adopted on smaller scale and it was not possible to generalize a single practice for 10 km grid observation. Therefore P factor values and not taken into account in soil loss estimation.

3.6 Indicators of Wind erosion: Integration of information on geomorphic features in the field and their spectral signatures on remote sensing data, known climatic norms, air flow pattern and sand flow pattern under the different geomorphic situations provides evidence of wind erosion/ depositions. Exposed plant roots, calcretes in sandy plains, bowl shape of the cultivated fields and high bounding fence-line sand ridges are the some of markers of the net erosion, while reactivation and extension of the stabilized sand dunes, formation of barchans, nebkhas and other smaller sand bodies like sand streaks provide the evidence of net deposition.

3.7 Field indicators: It has been possible to identify some field indicators of wind erosion and deposition in the different rainfall zones of the desert (modified after Singh *et al*., 1992)

3.8 Satellite image characters: Visual interpretation of the false colour composites (FCCs) of satellite imagery, especially the IRS LISS II images (36.5 m spatial resolution) of dry summer months (May-June), and varification of the interpreted units in field have led to identification of some typical image characteristics of wind erosion and deposition. Although these patterns were recognized in Jalore area (Raina *et al*., 1991), chances of their application potentials in other similar environments are high.

The visual interpretation is, however, subjective. No two interpreters will, perhaps, agree to the severity of a degradation class, since value-based judgement is involved. Therefore, efforts have also been made to understand the digital image characteristics of wind erosion/deposition features. This was tried for the reactivated aeolian sand categories in the north-eastern fringe of the desert.

❑

4

Generation of Soil Erosion Map

- The grid information (10 × 10 km) at 1472 locations of Rajasthan generated during Soil Resource Mapping by NBSS & LUP (Shyampura and Sehgal, 1995) was compiled for computations of K, LS, C and P factors.
- The location number, latitude, longitude, soil textural class and other parameters were used for computing soil erodibility (K-factor); land use (C-factor); conservation practice (P-factor); length of slope, degree of slope (LS-factor); and erosivity (R factor) values on a spread sheet for each grid point (Appendix I).
- Iso-erodent map of Rajasthan was used to obtain the R-factor values at each grid point.
- The values of R-factor, K factor, LS factor, C-factor and P-factor are used for generating the maps of each factor through GIS (SPANS Software).
- The product of all the parameters of USLE gave the annual average soil loss in t/ha for each grid point.
- The latitudes, longitudes and soil loss values were then used in a GIS (SPANS) software for generating the erosion map of the State.
- The erosion classes as given in Tables 6 and 7 were used considering the range of soil loss values and soil tolerance limits. Area for each class was computed.

In addition to the soil erosion map of the state, the following maps thus generated were also categorized and the area under each class was computed.

- R-factor (Erosivity)
- K-factor (Soil erodibility)
- LS-factor (Topographic factor)
- C factor (Cover and management practice)

- Wind erosion/deposition map prepared using field criteria and satellite data by Pratap Narain *et al.* (2000) was digitized for generating wind erosion map of the state in a GIS (SPANS) software.

❑

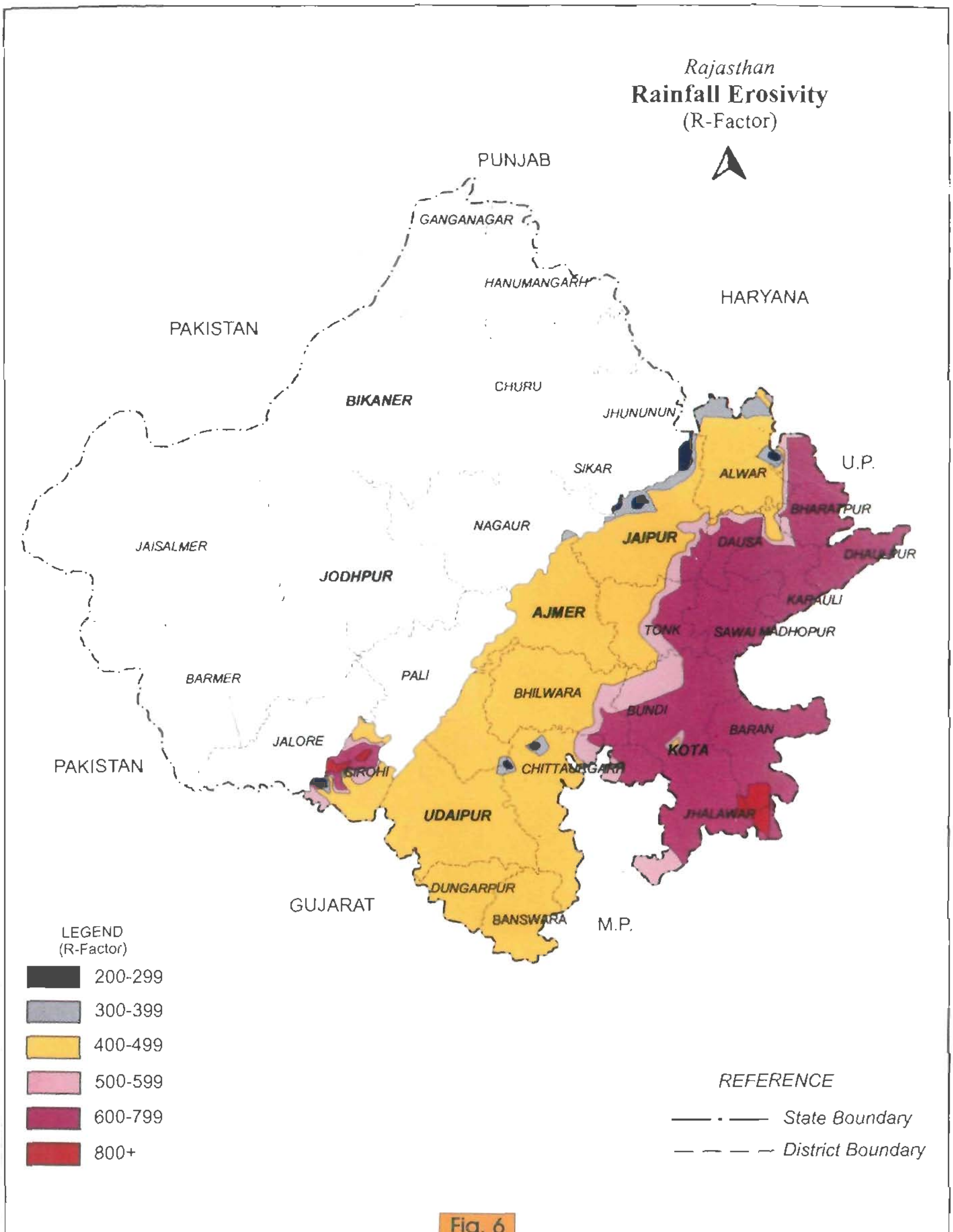

Rajasthan
Rainfall Erosivity
(R-Factor)
PUNJAB
GANGANAGAR
HANUMANGARH
HARYANA
PAKISTAN
BIKANER
CHURU
JHUNUNUN
SIKAR
ALWAR
U.P.
BHARATPUR
NAGAUR
JAIPUR
DAUSA
DHAULPUR
JAISALMER
JODHPUR
AJMER
KARAULI
TONK
SAWAI MADHOPUR
BARMER
PALI
BHILWARA
BUNDI
BARAN
JALORE
KOTA
PAKISTAN
SIROHI
CHITTAURGARH
UDAIPUR
JHALAWAR
DUNGARPUR
GUJARAT
BANSWARA
M.P.
LEGEND
(R-Factor)
200-299
300-399
400-499
500-599
600-799
800+
REFERENCE
State Boundary
District Boundary

Fig. 6

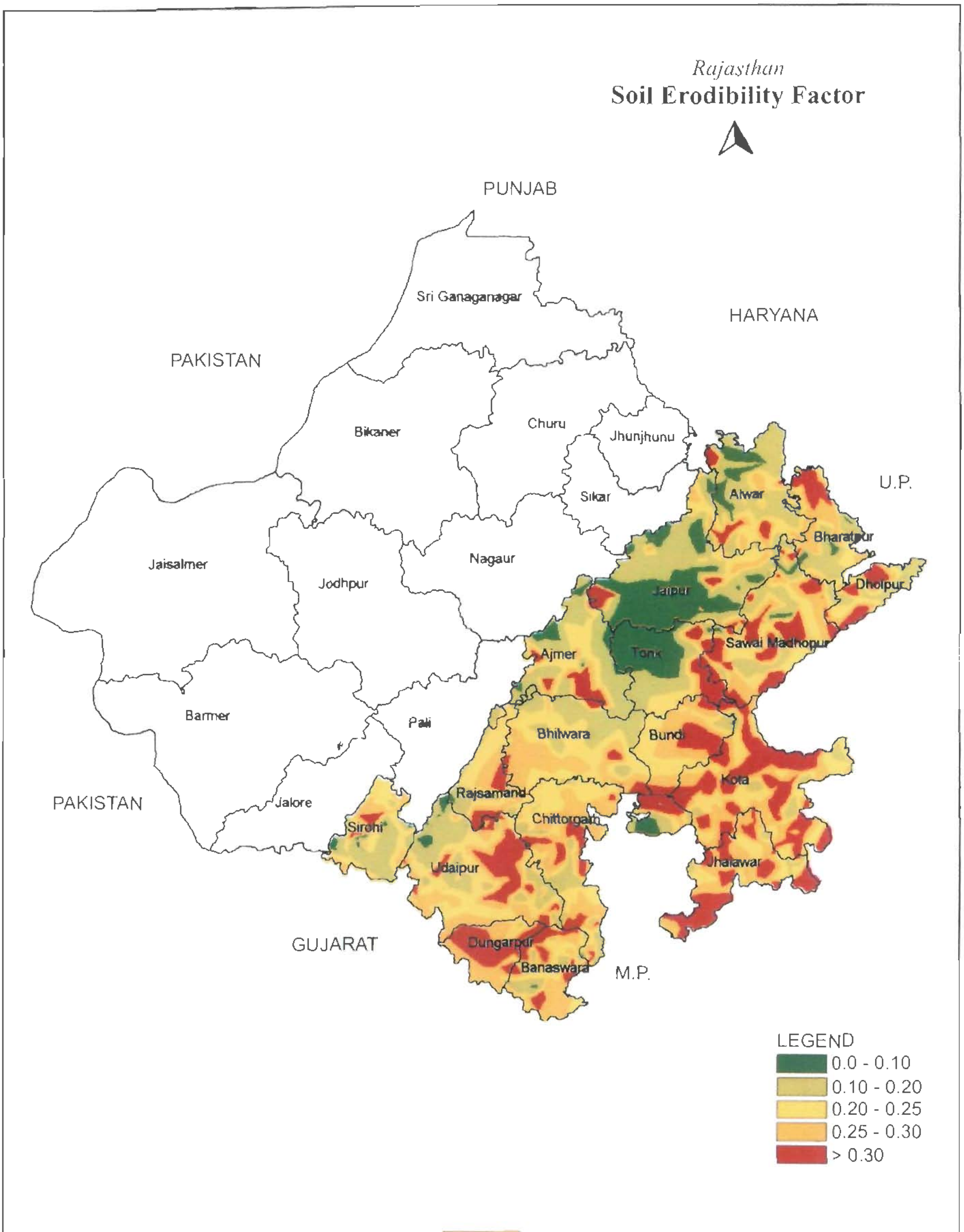
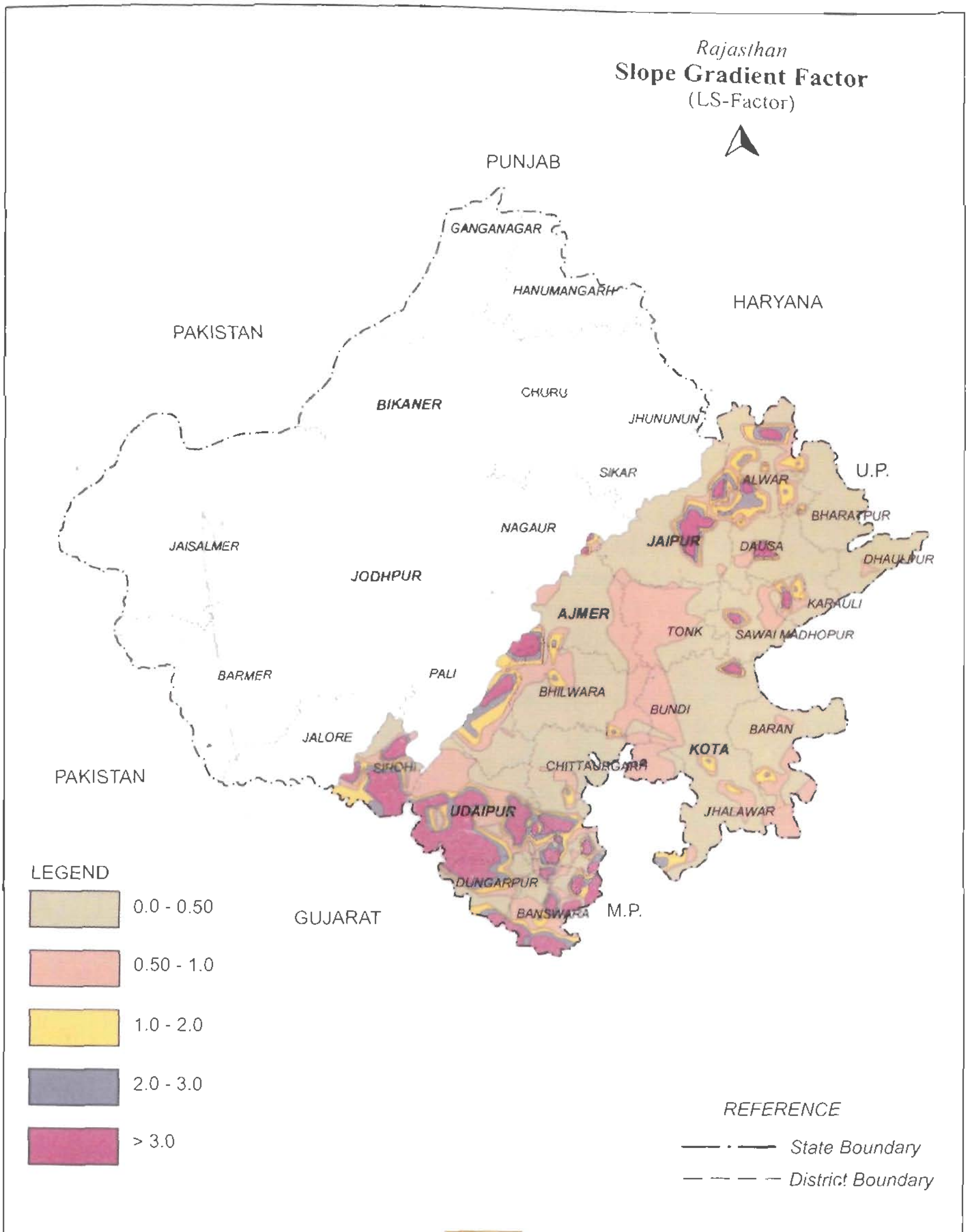

Rajasthan
Soil Erodibility Factor
PUNJAB
HARYANA
PAKISTAN
U.P.
Sri Ganaganagar
Bikaner
Churu
Jhunjhunu
Sikar
Alwar
Bharatpur
Dholpur
Jaisalmer
Jodhpur
Nagaur
Jaipur
Ajmer
Tonk
Sawai Madhopur
Barmer
Pali
Bhilwara
Bundi
Kota
PAKISTAN
Jalore
Sirohi
Rajsamand
Chittorgarh
Udaipur
Jhalawar
GUJARAT
Dungarpur
Banaswara
M.P.
LEGEND
0.0 - 0.10
0.10 - 0.20
0.20 - 0.25
0.25 - 0.30
> 0.30

Fig. 7



Rajasthan
Slope Gradient Factor
(LS-Factor)
PUNJAB
HARYANA
PAKISTAN
U.P.
M.P.
GUJARAT
PAKISTAN
GANGANAGAR
HANUMANGARH
BIKANER
CHURU
JHUNUNUN
SIKAR
ALWAR
BHARATPUR
JAIPUR
DAUSA
DHAULPUR
NAGAUR
JAISALMER
JODHPUR
AJMER
TONK
KARAULI
SAWAI MADHOPUR
BARMER
PALI
BHILWARA
BUNDI
BARAN
JALORE
SIROHI
CHITTAURGARH
KOTA
UDAIPUR
JHALAWAR
DUNGARPUR
BANSWARA
LEGEND
0.0 - 0.50
0.50 - 1.0
1.0 - 2.0
2.0 - 3.0
> 3.0
REFERENCE
State Boundary
District Boundary

Fig. 8

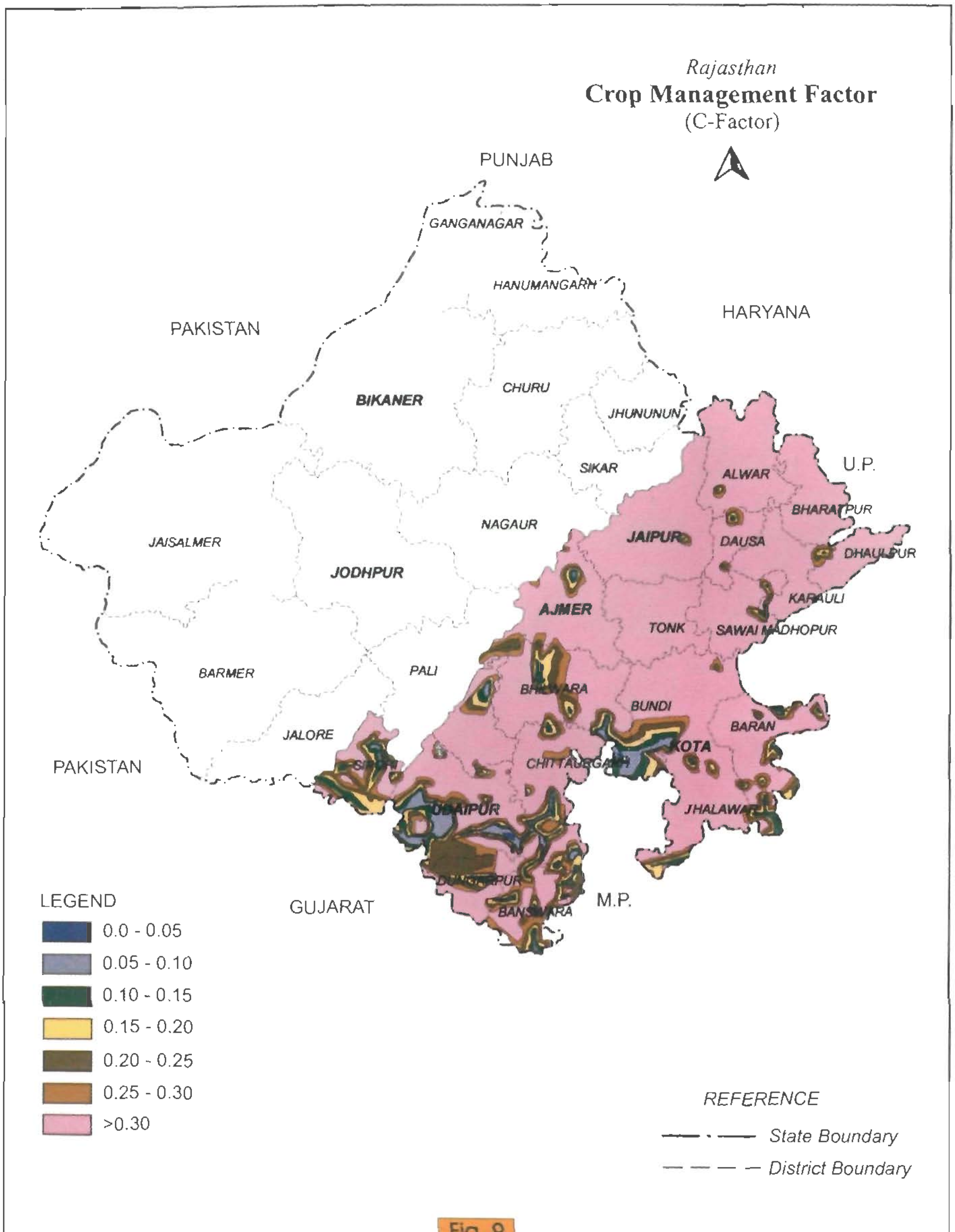

Rajasthan
Crop Management Factor
(C-Factor)
PUNJAB
HARYANA
PAKISTAN
U.P.
PAKISTAN
GUJARAT
M.P.
GANGANAGAR
HANUMANGARH
BIKANER
CHURU
JHUNUNUN
SIKAR
ALWAR
BHARATPUR
DHAULPUR
JAISALMER
JODHPUR
NAGAUR
JAIPUR
DAUSA
KARAULI
AJMER
TONK
SAWAI MADHOPUR
BARMER
PALI
BHILWARA
BUNDI
BARAN
KOTA
JALORE
CHITTAURGARH
JHALAWAR
UDAIPUR
DUNGARPUR
BANSWARA
LEGEND
0.0 - 0.05
0.05 - 0.10
0.10 - 0.15
0.15 - 0.20
0.20 - 0.25
0.25 - 0.30
>0.30
REFERENCE
State Boundary
District Boundary

Fig. 9

5

Interpretation

THE average annual soil loss estimated using USLE equation (Fig. 10, Tables 5). Different parameters used for estimating the soil loss are interpreted in the following sections.

5.1 Erosivity factor (R): The spatial distribution of erosivity factor (R) ranges from 200 to 800 (Fig. 6). It is high in eastern part of Kota and Bharatpur division (600 to 799). Part of Kota, Jhalawar and Sirohi district have highest R-value (>800). The high erosivity in this region could be attributed to the orographic high intensity rains received during the south-west monsoon. The annual rainfall in these areas ranges from 650-950 mm and mostly received during June to September. While the rain shadow region comprising central part of Rajasthan receives 450 to 600 mm rainfall and has medium R values.

The rainfall gradually increases from west of the Aravalli towards eastern parts of the state, ranging from 450 to 950 mm. The R-factor in this region ranged from 200 to 800 (Table 1). The district wise rainfall, erosivity values (R) showed higher erosivity (>600) in Kota, Jhalawar, Sawai Madhopur, Dholpur, Bharatpur and part of Chittorgarh, Bhilwara, Bundi, Tonk and Jaipur (Appendix II) covering an area of 4.65 M ha (13.45%). It is attributed to the higher intensity of rainfall through southwest monsoon. In the central parts of Rajasthan, the erosivity ranged from 400 to 600. The low erosivity in this area explain the low rainfall under rain shadow conditions. About 8.4 M ha (24.6%) area falls under this class (Table 1). In the west of Jaipur, Alwar and Sirohi districts, the R values ranged from 200 – 399. The data indicate that the erosivity class has 0.4 M ha (1.18%) area of the region.

Table 1. Erosivity (R-factor) classes in Rajasthan

Class	Range of 'R' values	Area (%)	Area ('000 ha)
1	200-299	0.29	99.4
2	300-399	0.89	305.8
3	400-499	21.83	7476.5
4	500-599	2.77	948.4
5	600-799	13.02	4460.4
6	800+	0.43	146.7

5.2 Erodibility factor (K): The erodibility factor is the intrinsic property of the soil. It is deduced from the soil parameters such as per cent sand, silt, clay, organic matter, soil structure and soil permeability. The 10x10 km grid point (1472) observations were considered for calculation of erodibility factor. The location specific soil information of grid points (Shyampura and Sehgal, 1995) was compiled and this information was used for calculating K values (Wischmeir and Smith, 1978). These K-values at each grid point are used as input file to generate erodibility map through GIS under SPANS environment (Fig. 7). The data on erodibility (Table 2 and Appendix III) indicates

Table 2. Erodibility classes (K factor) in Rajasthan

Class	K-values	Area (%)	Area ('000 ha)
1	<0.1	3.40	1164.4
2	0.1-0.2	9.89	3371.0
3	0.2-0.25	10.10	3459.7
4	0.25-0.30	9.30	3182.8
5	>0.30	6.60	2259.3

that the K values in the range of greater than 0.3 that shows high erodibility have an area of 2.26 M ha (6.60%). While the K values in the range of 0.1 to 0.3 that show low erodibility have major area of 9.88 M ha (29.29%). About 1.16 M ha (3.40%) area has very low erodibility (<0.1).

5.3 Topographic factor (LS): The topographic factor is a single parameter computed through gradient and length of slope at each location of the grid observation. The LS values are obtained through an equation suggested by Wischmeir and Smith (1978). The LS values are used as input file for the generation of topographic factor map under GIS-SPANS environment. The spatial distribution of LS values in the state are presented in map (Fig. 8) and the data are given in Table 3 and Appendix IV.

Table 3. Topographic factor (LS) classes in Rajasthan

Class	LS values	Area (%)	Area ('000 ha)
1	<0.5	22.60	7739.8
2	0.5-1.0	8.16	2794.0
3	1.0-2.0	2.98	1018.6
4	2.0-3.0	1.94	667.8
5	>3.0	3.55	1217.0

The data indicate that the LS factor values ranged from 0.5 to >3.0 in the state. The LS factor values of >1.0 have an area distribution of 1.9 M ha (8.47%) in the state. The LS factor values ranging from 0.5 to 0.1 have a spatial distribution of 10.49 M ha (30.76%) in the state.

Table 4. Cover and management factor (C) classes in Rajasthan

Class	C values	Area (%)	Area ('000 ha)
1	<0.05	0.04	13.5
2	0.05-0.10	0.81	276.5
3	0.10-0.15	1.45	495.5
4	0.15-0.20	1.82	624.6
5	0.20-0.25	2.70	925.9
6	0.25-0.30	2.59	887.0
7	>0.30	29.83	10214.2

5.4 Cover and management factor (C): The C factor in the state indicates not only the land cover by the natural vegetation but also the land use under the crops. It also indicates the status of the land in an area. For each land use/land cover C-factors were attributed (Appendix-I) and the spatial distribution of cover and management factor in the state is depicted in the Fig. 9. The data for the state under each class of this factor are given in Table 4 while the district wise data on cover and management factor (C) are presented in Appendix-V.

The data indicate that among land cover classes forest and bushy forest/waste land (<0.05 to 0.15) cover an area of 0.78 M ha (2.3%) in the state. It has a spatial distribution in Sirohi, Udaipur, Chittorgarh, Rajsamand, Bhilwara, Kota, Jhalawar and Bundi districts. The crop cover (>0.2) has the spatial distribution in majority of the area especially in central and eastern parts of Rajasthan State. The data indicate (Table 4) that it has an area of 12.0 M ha (35.12%) in the state.

❑

Soil Erosion Status

6

Soil erosion refers to a process causing wearing away of the earth surface by the different forces like wind, water and ice. The erosion process can be both constructive and destructive. Erosion is primarily responsible for the variations in topography as it erodes the elevated surface and simultaneously builds alluvial plains. It is aggravated due to human intervention (indiscriminate felling of trees, mining, cultivation of marginal lands and over grazing).

Qualitatively four soil erosion classes namely slight, moderate, severe and very severe were identified in the state (Shyampura and Sehgal, 1995) based on the field studies. As per these estimates, major area is under moderate (40.2%) erosion class followed by slight erosion class (33.6%). The area under severe class is 16.8 per cent while the area under very severe class is 4.2 per cent.

6.1 Soil Loss through water erosion: The soil loss through water erosion in the state was estimated by relevant information on factors like erosivity (R), soil erodibility (K), topographic factor (LS), cover and management factor (C) and conservation practice factor (P).

For estimating the soil loss (t/ha/yr) in the state, the data on the above factors were used in the universal soil loss equation (USLE). The spatial distribution of the soil loss in the state is given in a soil erosion map (Fig. 10) generated under GIS-SPANS environment. Accordingly the state is classified into seven classes of soil loss:

- Very slight (<5 t/ha/yr),
- Slight (5-10 t/ha/yr),
- Moderate (10-15 t/ha/yr),
- Moderately severe (15-20 t/ha/yr),
- Severe (20-40 t/ha/yr)
- Very Severe (40-80 t/ha/yr) and
- Extremely severe (>80 t/ha/yr)

The soil loss under these classes is presented in Table 5&7. It indicates that about 4.4 M ha area (13.06%) is under the very slight to slight erosion class which is mainly covering the central parts of the state. Moderate, moderately severe and severe classes cover 7.0 M ha (20.34%) area which is restricted in eastern and southern parts of the state. Very severe and extremely severe soil loss classes are in the hills of Aravallis, eastern Rajasthan uplands and Malwa plateau region of the state. The area under these two classes is 2.0 M ha (5.84%). The major contributing factor is soil loss in this region in slope length and slope gradient.

The qualitative classes from the field data and the estimation of erosion values through USLE formula indicate that the quantitative estimations are providing better assessment of erosion under similar conditions.

Table 5. Soil Erosion (soil loss) classes in eastern Rajasthan

Class	Range of soil loss (t/ha/yr)	Area (%)	Area ('000 ha)
Very slight	<5.0	3.92	1341.5
Slight	5.0-10	9.14	3128.7
Moderate	10.0-15.0	7.59	2600.0
Moderately severe	15.0-20.0	4.61	1578.4
Severe	20.0-40.0	8.14	2786.9
Very Severe	40.0-80.0	3.86	1323.0
Extremely severe	>80.0	1.98	678.6

6.2 Soil Loss through Wind erosion: Using the field criteria and the satellite image characteristics, Pratap Narain *et al.* (2000) prepared wind erosion/deposition map of western Rajasthan on 1 : 1 million scale (fig. 11). The classes mapped are: very severe, severe, moderate, slight and negligible. Table 6&8 provide the area statistics for the different classes. According to it 32.23 per cent area of the region is under moderate to very severe categories, while the rest 28.54 per cent is almost free of such hazard.

Table 6. Wind erosion/deposition classes in western Rajasthan

Erosion/deposition class	Area (%)	Area ('000 ha)
Very severe	1.73	592.3
Severe	8.81	3016.8
Moderate	21.69	7430.0
Slight	15.31	5242.0
Negligible	13.23	2529.6

Broadly, the extreme western part of Jaisalmer district, bordering Pakistan, is under very severe class, where large, elliptical fields of high megabarchanoids occur amidst linear dune fields, and where the wind erosivity index is greater than 480. Human settlement is almost absent in this zone, so that the activity can be related to natural processes only. This zone is flanked to the east by several southwest to northeast running belts of severe and moderate erosion/deposition classes that can be traced roughly up to Sanchor-Balotra-Jodhpur-Osian-Nagaur-Sikar-Jhunjhunu-Nohar-Suratgarh line in the east and north. The pattern almost replicates the erosivity pattern in the southern part, where the erosivity index is of moderate to severe categories. Large variation occurs in the northeast, especially in Ratangarh-Churu-Sikar area where the erosivity index is low, but high cultivation and grazing pressures on the highly erodible dune-interdune landscape has resulted in moderate to severe problems of wind erosion/deposition. In between the above zones the shallow sandy and rocky tracts of Barmer-Jaisalmer-Ramgarh-Pokaran are dominated by slight erosion/deposition, because of the paucity of sediments and hardness of the surface. Roughly to the east of Bhinmal-Jalor-Pali-Bilara-Merta-Nagaur the terrain consists mainly of sandy alluvial plains, with scattered hillocks and rocky pediments. These areas are without appreciable sand sheet cover, have lesser wind erosivity and erodibility indices, and hence, have negligible problem of wind erosion. The deep alluvial plains in the north, especially along the Ghaggar valley and around Ganganagar, as well as the hilly areas of the Aravallis in the north-east, especially around Khetri, Nim ka Thana, Palsana and Nawa, are also under negligible wind erosion class.

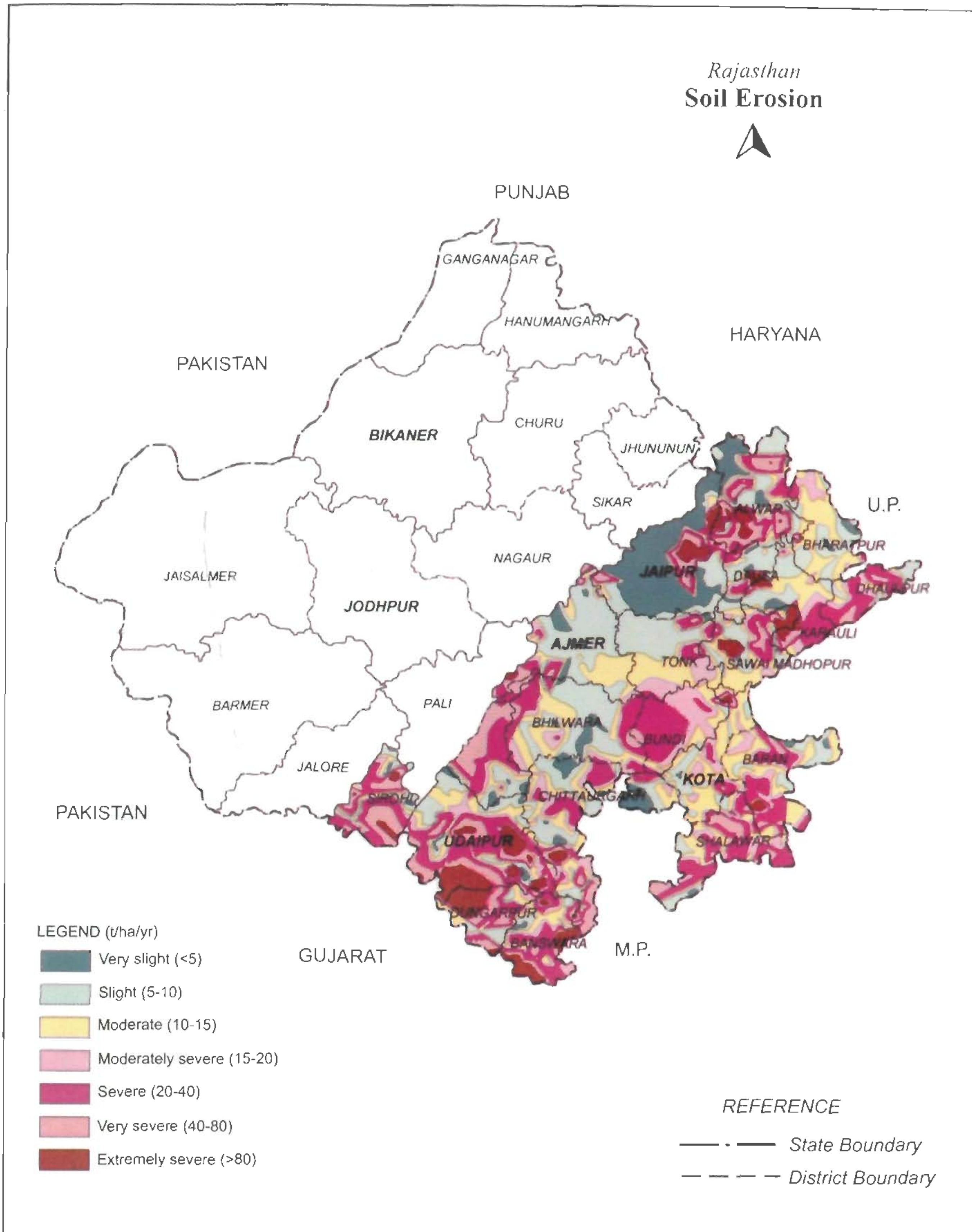
6.3 Working example: To determine the average soil loss per year from a particular area, the values for various components of USLE namely erosivity factor (R), soil erodibility factor (K), topographic factor (LS), cover and management factor (C) and conservation practice factor (P) are assigned.

From Appendix 1, the values of the above parameters are estimated under the existing conditions. From these values the annual soil loss 'A' is estimated based on this equation:

A = R K L S C P

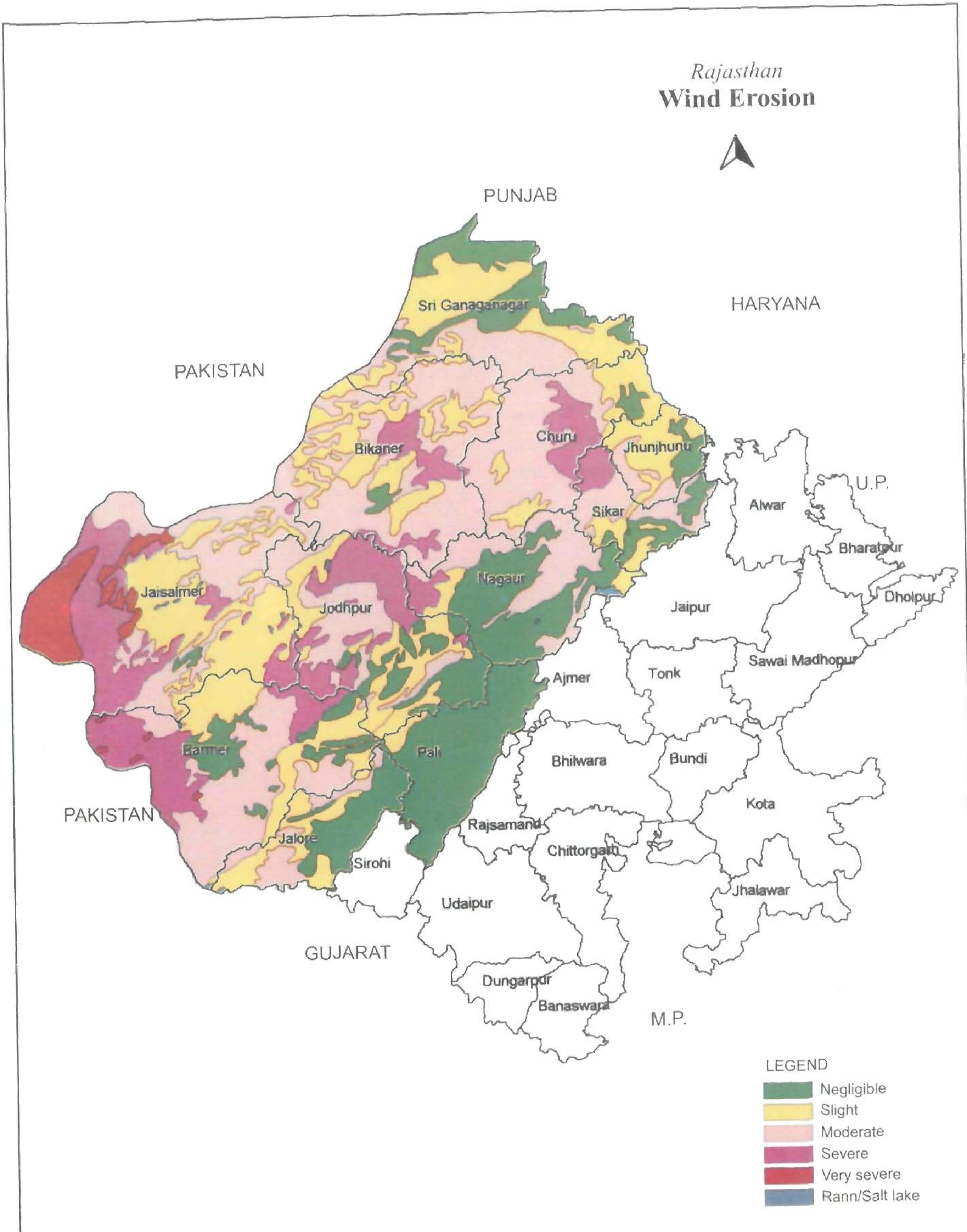
e.g.: As an example for a grid from the Udaipur area (45H, Grid no. 22) the values of different components of the above equations are:

Erosivity factor (R)	=	400
Topographic factor (LS)	=	0.50
Conservation practice factor (P)	=	0.3



Rajasthan
Soil Erosion
PUNJAB
HARYANA
PAKISTAN
U.P.
GANGANAGAR
HANUMANGARH
BIKANER
CHURU
JHUNUNUN
SIKAR
NAGAUR
JAISALMER
JODHPUR
JAIPUR
ALWAR
BHARATPUR
DAUSA
DHAULPUR
KARAULI
AJMER
TONK
SAWAI MADHOPUR
BARMER
PALI
BHILWARA
BUNDI
BARAN
KOTA
JALORE
SIROHI
CHITTAURGARH
JHALAWAR
PAKISTAN
UDAIPUR
DUNGARPUR
BANSWARA
GUJARAT
M.P.
LEGEND (t/ha/yr)
Very slight (<5)
Slight (5-10)
Moderate (10-15)
Moderately severe (15-20)
Severe (20-40)
Very severe (40-80)
Extremely severe (>80)
REFERENCE
State Boundary
District Boundary

Fig. 10



Rajasthan
Wind Erosion
PUNJAB
HARYANA
PAKISTAN
U.P.
PAKISTAN
GUJARAT
M.P.
Sri Ganaganagar
Bikaner
Churu
Jhunjhunu
Sikar
Alwar
Bharatpur
Dholpur
Jaisalmer
Jodhpur
Nagaur
Jaipur
Ajmer
Tonk
Sawai Madhopur
Barmer
Pali
Bhilwara
Bundi
Kota
Jalore
Sirohi
Rajsamand
Chittorgarh
Jhalawar
Udaipur
Dungarpur
Banaswara
LEGEND
Negligible
Slight
Moderate
Severe
Very severe
Rann/Salt lake

Fig. 11

Table 7. District-wise soil loss in eastern Rajasthan

District	Classes							
	Very slight	Slight	Moderate	Moderately *severe*	Severe	Very severe	Ext. *severe*	Total
	<5.0	5.0-10	10.0-15.0	15.0-20.0	20.0-40.0	40.0-80.0	>80.0	
	Area sq. km and percent							
Ajmer	1038 0.30	4303 1.26	1800 0.53	320 0.09	553 0.16	379 0.11	28 0.01	8421 2.46
Alwar	1002 0.29	1949 0.57	778 0.23	550 0.16	1599 0.47	1430 0.42	519 0.15	7827 2.29
Banswara	68 0.02	547 0.16	885 0.26	769 0.22	1749 0.51	529 0.15	522 0.15	5069 1.48
Bharatpur	325 0.09	1703 0.50	2341 0.68	530 0.15	146 0.04	22 0.01	2 0.00	5069 1.48
Bhilwara	615 0.18	4007 1.17	2271 0.66	1144 0.33	1904 0.56	531 0.16	0 0.00	10472 3.06
Bundi	*2* 0.00	*109* 0.03	*802* 0.23	*1927* 0.56	*2773* 0.81	186 0.05	*18* 0.01	*5817* 1.70
Chittaurgarh	1150 0.34	2988 0.87	2180 0.64	1560 0.46	1772 0.52	499 0.15	205 0.06	10354 3.02
Dholpur	1 0.00	441 0.13	345 0.10	533 0.16	1441 0.42	247 0.07	0 0.00	3008 0.88
Dungarpur	0 0.00	428 0.12	427 0.12	210 0.06	671 0.20	963 0.28	1156 0.34	3855 1.13
Jaipur & Dausa	7503 2.19	2922 0.85	802 0.23	408 0.12	1007 0.29	1054 0.31	760 0.22	14456 4.22
Jhalawar	*64* 0.02	*536* 0.16	*936* 0.27	*1087* 0.32	*2825* 0.83	865 0.25	*6* 0.00	*6320* 1.85
Kota & Baran	150 0.04	2286 0.67	4982 1.45	1992 0.58	2394 0.70	243 0.07	157 0.05	12204 3.56
Rajsamand	63 0.02	387 0.11	268 0.08	390 0.11	1575 0.46	1765 0.52	2 0.00	4450 1.30
Sawai Madhopur and Karauli	584 0.17	2381 0.70	2522 0.74	1058 0.31	1846 0.54	688 0.20	964 0.28	10043 2.93
Sirohi	196 0.06	613 0.18	637 0.19	527 0.15	1636 0.48	1348 0.39	220 0.06	5177 1.51
Tonk	125 0.04	3200 0.93	1946 0.57	1213 0.35	632 0.18	62 0.02	0 0.00	7178 2.10
Udaipur	525 0.15	2479 0.72	2071 0.60	1562 0.46	3338 0.97	2416 0.71	2226 0.65	14617 4.27
Total	13414.763 3.92	31287 9.14	25999.98 7.59	15784.152 4.61	27869.16 8.14	13230.157 3.86	6786.33118 1.98	134372 39.24

Table 8. District-wise soil erosion in western Rajasthan

Districts	Classes					Total
	Negligible	Slight	Moderate	Severe	Very severe	
	Area sq. km. and per cent					
Barmer	3881 1.13	5774 1.69	11403 3.33	6835 2.00	272 0.08	28165 8.22
Bikaner	459 0.13	7651 2.23	16252 4.75	2912 0.85	0 0.00	27274 7.96
Churu	544 0.16	3446 1.01	10177 2.97	2691 0.79	0 0.00	16858 4.92
Jaisalmer	278 0.08	11850 3.46	10984 3.21	9620 2.81	5649 1.65	38381 11.21
Jalore	4471 1.31	3486 1.02	2606 0.76	0 0.00	0 0.00	10563 3.08
Jhunjhun	1191 0.35	3246 0.95	1461 0.43	17 0.00	0 0.00	5915 1.73
Jodhpur	4480 1.31	5815 1.70	6362 1.86	5900 1.72	0 0.00	22557 6.59
Nagaur	8997 2.63	1142 0.33	6459 1.89	1041 0.30	0 0.00	17639 5.15
Pali	11806 3.45	509 0.15	12 0.00	0 0.00	0 0.00	12327 3.60
Sikar	2209 0.65	1375 0.40	3013 0.88	1143 0.33	0 0.00	7740 2.26
Sri Ganganagar	6967 2.03	8111 2.37	5549 1.62	0 0.00	0 0.00	20627 6.02
Total	45296 13.23	52420 15.31	74300 21.69	30168 8.81	5923 1.73	208107 60.77

Soil erodibility (K) = 0.23

Cover and management factor (C) = 0.38

Based on the above data, the soil loss (A) is estimated through the equation

$$A = R \times K \times L \times S \times C \times P$$
$$= 400 \times 0.23 \times 0.50 \times 0.38 \times 0.3$$
$$= 17.27 \text{ tonnes/ha/year}$$

6.4 Soil loss Tolerance: This is a limit which denotes the maximum level of soil erosion that will permit crop productivity to be sustained economically and indefinitely. Considerable work has been done on this aspect and the tolerance limits were ranging from 4.5 to 11.2 tonnes/ha/year. Soil loss in excess of 11.2 tonnes/ha/year affect the effectiveness of water conservation structures. At this stage, the gully formation starts which in turn obstructs the cultural operations (Gurmel Singh *et al.*, 1981).

In Rajasthan as per the soil erosion classes (Table 5); it is evident that moderate, moderately severe, severe, very severe and extremely severe classes covering an area of 6.4 M ha (18.46%) have exceeded this tolerance limit of 11.2 tones/ha/year. This leads to a huge amount of nutrient loss in a year. In terms of fertilizer loss this accounts to a staggering loss of nutrients in a year. Looking to the above data it is evident that there is a need to have conservation planning in the state. Off-site impact of soil erosion/loss takes place through sedimentation of reservoirs during subsequent years threatening the existence of these irrigation projects. Sedimentation in reservoirs at a rate faster than expected is an indicator of soil loss in their catchments. Prioritizations of watersheds for treatments are to be demarcated according to the problem of sedimentation.

❑

7

Soil and Water Conservation

THE severity of erosion is varied in the different regions in the state (Fig.12, tables.5&6). Accordingly the measures for soil and water conservation planning are suggested in order to maintain eco-balance in the region.

7.1 Sandy Arid Plain Region: The region is located between 25°07' to 29°26' N latitude and 69°29' to 75°59' E longitude. It covers 1,37,49,747 ha. land comprising 40.15% of the total geographical area of the state. The region has high and low dunes that occurs mainly in Barmer, Jaisalmer, Bikaner, western part of Jodhpur and Churu. The low dunes are observed in Jhunjhunu, Sikar and in remaining part of Churu. Longitudinal, transverse and compound parabolic dunes are the major high dunes, which are very old and have appreciable vegetation cover (Fig.13). The recent activation of these high dunes due to excessive use has led to the formation of low mobile dunes. Most notable among them is barchans, crescentic shape dunes at Sam. The other physiographic position is high level rocky structural plains between Pokharan, Jaisalmer and Ramgarh, the isolated hills of granites, rhyolites, sandstones, limestone and rocky pavements of Bap, Phalodi, Chandan and Sankara, sandy plains with shallow soils and saline depressions. Summer temperatures are always high. It is as high as 49°C during the day and falls to less than 20°C during the night. The day temperatures are higher but the night temperatures may be near freezing point during winters which are short, not exceeding more than two months mainly during December and January. The mean annual rainfall ranges between 200 to 300 mm. The rainfall received is at its peak during August and second fortnight of September. In general the monsoon circulation is shallow, limited to about a kilometer or so and is over run by dry air from north, circulating anti cyclonically, inhibiting proper cloud development over the region.

Annual potential evapotranspiration (PET) is highest (206.32 cm) at Jaisalmer and the lowest (166.22 cm) at Ganganagar. PET is lowest in December due to low temperature but shows a gradual rise from January. Generally it is higher than precipitation even during the rainy months, making this region arid to extremely arid in climate with perpetual water deficit in all the months. The length of growing period is small ranging between 45 to 60 days.

The soils are commonly occurring on gently to moderately sloping dunes or gently sloping interdunal plains (Fig.13) as either dominant or subdominant soils. These soils are classified as Typic Torripsamments (Fig.13). The other less extensive soils occupying relatively lower topographic position in the interdunal plains are classified under Typic Calciorthids, Typic Paleorthids and Typic Salorthids, owing to the presence of diagnostic subsurface characteristics. Physiographic units, soils their potentials and constraints are described below:

The moderately to steeply sloping dunes consist of moderately shallow to deep, excessively drained, slightly to strongly alkaline (pH 7.5 – 9.5) sandy, Typic Torripsamments with low available water capacity and severe erosion. Gently sloping rocky structural plains between Pokharan, Jaisalmer and Ramgarh support shallow, excessively drained, loamy/sandy skeletal, slightly

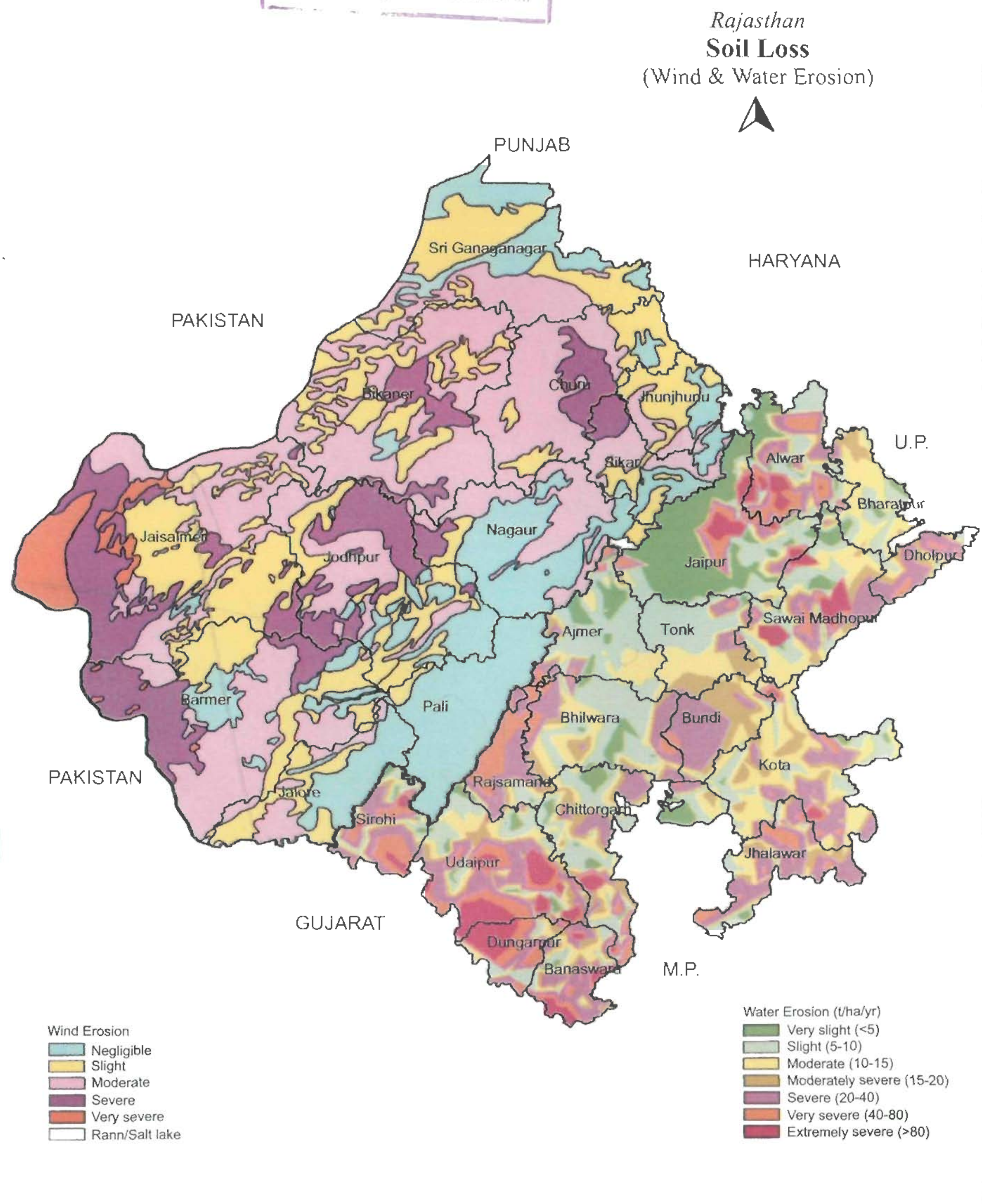
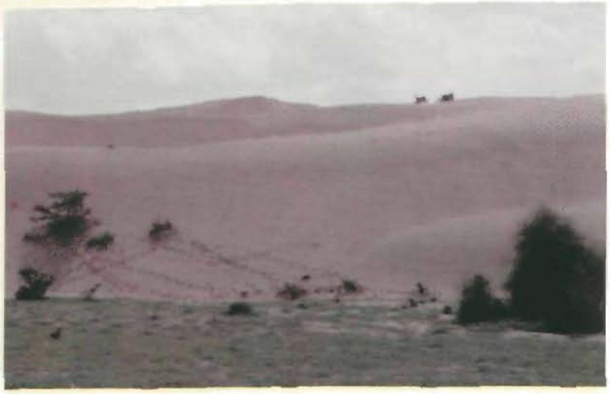

Rajasthan
Soil Loss
(Wind & Water Erosion)
PUNJAB
HARYANA
PAKISTAN
U.P.
PAKISTAN
GUJARAT
M.P.
Sri Ganaganagar
Bikaner
Churu
Jhunjhunu
Sikar
Alwar
Bharatpur
Dholpur
Jaisalmer
Jodhpur
Nagaur
Jaipur
Sawai Madhopur
Ajmer
Tonk
Barmer
Pali
Bhilwara
Bundi
Kota
Rajsamand
Chittorgarh
Jalore
Sirohi
Udaipur
Jhalawar
Dungarpur
Banaswara
Wind Erosion
Negligible
Slight
Moderate
Severe
Very severe
Rann/Salt lake
Water Erosion (t/ha/yr)
Very slight (<5)
Slight (5-10)
Moderate (10-15)
Moderately severe (15-20)
Severe (20-40)
Very severe (40-80)
Extremely severe (>80)

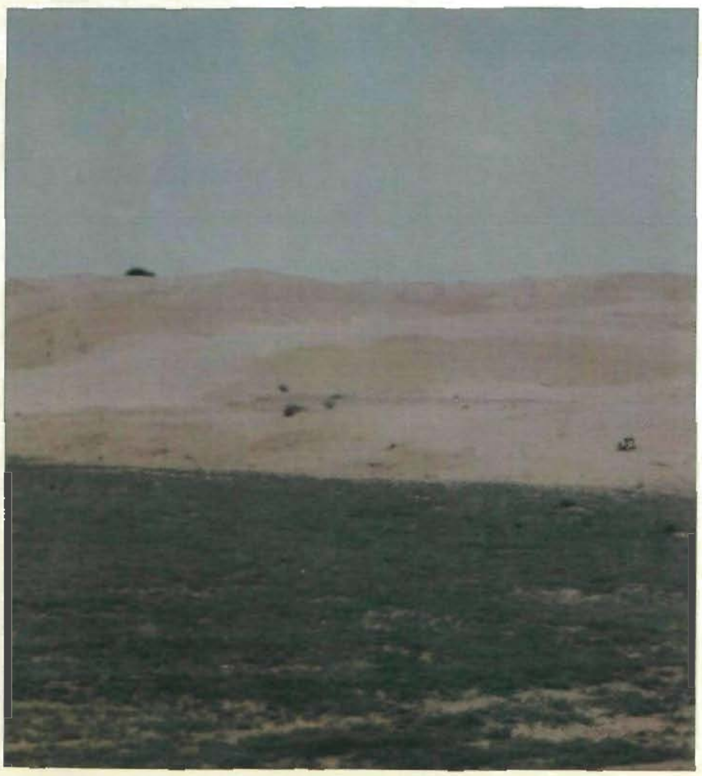
Fig. 12

Sandy Arid Plain

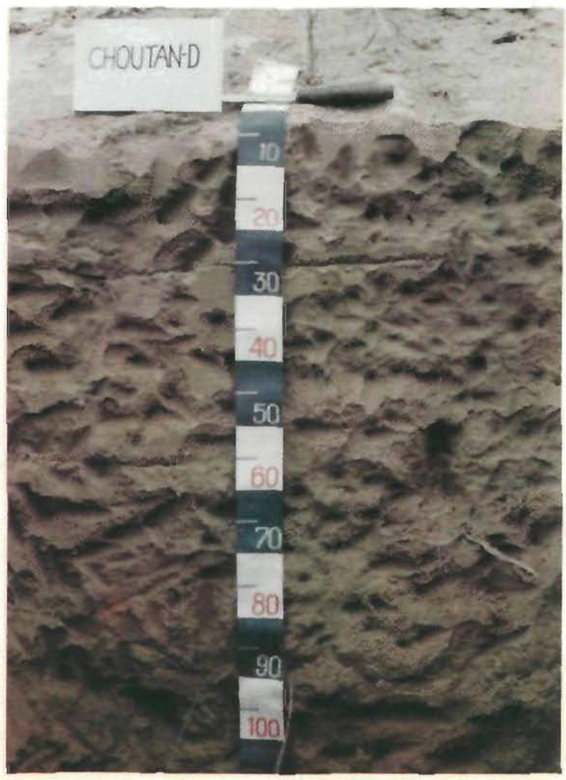


Parabolic dunes

Transverse dunes



Inter-dunal plain



Soil profile - Typic Torripsamments

Fig. 13

Soil and Water Conservation

Stabilization of sand dunes

Rain water harvesting

Fig. 14

Semi Arid Transitional Plain

Low sand dunes

Inter - dunal plains

Aridisol profile

Fig. 15

alkaline Lithic Torriorthents with very low AWC and severe to very severe erosion. Very gently to gently sloping interdunal plains consist of moderately deep to deep, well drained, coarse loamy to sandy, slightly to moderately alkaline (pH 7.5 – 8.5) Typic Paleorthids/Calciorthids/ Camborthids and Torripsamments with low medium AWC. Very gently sloping interdunal plains are prone to moderate erosion while gently sloping plain are subjected to moderate to severe erosion.

7.2 Semi-arid Transitional Plain: The region is located between 24°58' to 30°11' N latitude and 71°04' to 75°23' E longitude extending from the northern foothills of Aravalli to the sandy arid plain and is sub divided among three sub regions, namely Luni-Jawai plains, Sekhawati tracts of low dunes, sandy plains and the Ghaggar flood plains. Luni-Jawai plains occur in the districts of Jodhpur, Pali, Jalore and Sirohi and in the southern part of Nagaur. The number of ephemerals flowing the area are responsible for the formation of alluvial plains through which they flow. It spreads in 69,06,473 ha. land, comprising 20.16% of the total geographical area of the state. The dominant land forms are young alluvial plains along the major stream where the cultivation is more assured because of ground water, the older plains, the occasional isolated hills wi . fringing pediments and some dunes with interdunal plains (Fig.14). The ranns of Pachpadra, Sanwerla and Kaparda are the important saline depressions. The second important Sekhawati tract of the region occurs in Jhu...unu, Sikar, Churu and north part of Nagaur. The zone is infested by sand dunes of low to medium height (Fig.14), over much of its area, as well as deep sandy plains. The sand dunes in this zone support more vegetation than the west because of high rainfall. The third most important part of the region is Ghaggar flood plains occupied much of its area in Ganganagar district. The wide dry valley of Ghaggar is now known to be that of legendary Saraswati river which originated in Himalayas. The dry valley passes through Hanumangarh and Suratgarh before entering into Pakistan. Low sand dunes and hummocks are the scatteredly distributed on the deep sandy alluvial plains in this zone. Barchans have appeared in some parts of plain because of deep ploughing of soils without assured supply of canal irrigation.

The climatic conditions are almost the same as in the western arid region except that the rainfall which is slightly higher. The annual rainfall ranges between 300 to 400 mm in Nagaur, Jodhpur, Churu and Jalore region and more than 400 mm in Sikar, Jhunjhunu and Pali region and along the western fringes of Aravalli range.

Comparatively high rainfall and lower mean annual potential evapotranspiration (1,600 to 1,700 mm) bring about longer length of growing period, ranging between 60 to 90 days. Some times length of growing period exceeds to 90 days. The ground water level is high in the river basin and in the area falling in the vicinity of canal. All these factors together make the situation more conducive for agriculture as compared to its counterpart western plain (Marusthali).

The dominant soils are deep to very deep, either calcareous or non-calcareous, sandy in nature occupying gently sloping plains with dotted hummocks. The soils are classified as Typic Torripsamments. The sub-dominant soils are deep to very deep, well drained, either calcareous or non-calcareous on nearly level plains, coarse loamy/ fine loamy in nature. These are classified as fine loamy/coarse loamy, calcareous/non-calcareous, Typic Camborthids (Fig.14). Some of these soils are classified under Ustochreptic Camborthids and

Ustic Torripsamments subgroups which have aridic soil moisture regime that borders to ustic soil moisture regime. Other inclusions are placed under Typic Calciorthids, Typic Paleorthids, Typic Salorthids, depending upon the dominant subsurface diagnostic horizons. Sub-physiographic units, soils their potentials and constraints are given below.

Very gently to gently sloping Ghaggar plain endowed with low dunes and scattered hummocks have deep to very deep, well to excessively drained coarse loamy to fine loamy, moderately to strongly alkaline (pH 8.5 – 9.5), Ustochreptic Camborthids, Typic Camborthids and Typic Calciorthids with moderate to severe erosion. Nearly level flood plain consists of very deep, well drained, coarse/fine loamy and fine at places slightly to moderately alkaline Typic Camborthids, Ustochreptic Camborthids and Typic Torrifluvents with slight to moderate erosion. Gently sloping Luni basin support moderately deep to deep, well drained to excessively drained, coarse loamy to sandy, neutral to strongly alkaline (pH 7.5 – 9.5), Typic Camborthids, Typic Torripsamments with medium to low AWC and severe erosion. Soils are shallow, skeletal, Lithic Torriorthents and Lithic Calciorthids at the foot hills of the Aravalli with severe erosion and moderate to strong stoniness. Very gently sloping Luni plains consist of deep, well drained, coarse loamy to sandy, slightly alkaline to moderately alkaline, Typic Camborthids/Calciorthids and Typic Torripsamments with moderate erosion. At places soils are fine loamy to fine, deep with slight erosion. Gently sloping plains of interior drainage (Shekhawati tract) is endowed with very shallow to moderately shallow, skeletal, moderately to strongly alkaline (pH 8.5 – 9.5) Lithic Torriorthents with severe to very severe erosion. Very gently sloping dunal plains of Shekhawati region have moderately shallow to moderately deep, well drained coarse loamy to fine loamy, neutral to slightly alkaline Typic Paleorthids/Camborthids and Calciorthids with medium AWC and moderate erosion.

7.2.1 Soil and water conservation in Western Plain: Terrain characteristics, rainfall and wind velocity are the major causes of wind erosion in the Western Rajasthan. The terrain is dominated by sandy landforms consisting of sandy plain, sandy undulating plain, sand dunes and interdunal plains. Wind erosion in the Western Rajasthan is severe in summer months when south westerly winds blow at high speed. Soil and water conservation measures that can be followed are described below.

- *Stubble mulch farming:* Crop residue like stubbles, of 30–45 cm height, should be left over in agricultural land for checking the movement of sand and nutrients associated with it. Long small grain stubbles have been found more effective than equal quantities of short stubbles.
- *Strip cropping:* Alternate plantation of erosion susceptible and erosion resistant crops against the prevailing wind direction should be followed to reduce the impact of wind velocity. Perennial grasses such as *Lasiurus sindicus, Ricinus communis, Cenchrus biflorus* and *Panicum turgidom* should be planted as protective barriers.
- Rocky/stony and other degraded pasturelands could be rehabilitated by following an integrated approach of raising pastures and silvi-pasture systems. This is possible through *in-situ* or *ex-situ* water harvesting, profile modifications and re-seeding technology. *Acacia tortilis,*

Prosopis juliflora, Acacia Senegal, Grewia tenax, Anogeisus rotundifolia etc. have been successfully established through water harvesting techniques.

- The technology for sand dune stabilization (Fig.15) has been perfected. This includes protection of areas by fencing, erection of micro-wind breaks, tree planting and seeding of grasses or planting of grass strips. Most suitable tree and grass species identified for this purpose are: *Calligonum polygonoides, Colophospermum mopane, Acacia tortlis, Acacia nubica* and *Prosopis juliflora* and grasses namely *Lasiurus sindicus, Cenchrus ciliaris* and creeper *Citrullus colosynthis.*
- Wind break and shelterbelt plantation reduces wind velocity by 20 to 46 per cent on the leeward side of shelterbelt at 2 H and 10 H (H: height of shelter belt) distance. A number of trees including *Azardichata indica* and *Eucalyptus spp* have been identified for this purpose.
- Design of improved tanks (underground cistern) that stores harvested rain water (Fig.15) to meet drinking water demand in less than 200 mm rainfall zone has been developed. For rational use of scarce water resources, techniques of drip and sprinkler systems of irrigation have been standardized.

7.3 Aravalli Landscape: The region is located between 23°37' to 28°24' N latitude and 72°20' to 77°19' E longitude. It extends in 47,06,772 hectare area, comprising 13.74% area of the state. Aravalli hills are the most important feature, extending from Sirohi, Udaipur and Dungarpur districts in the south west to Jaipur and Alwar in the north east. These range form a labyrinth of low hills in Udaipur, Dungarpur and Banswara and stretch north eastward in the form of undulating hills through parts of Ajmer, Tonk, Sawai Madhopur, Jaipur and Alwar. Quartzite is being a very resistant rock forms most of the hills in northern and central parts. Granite forms the high hills in south near Abu.

Annual rainfall varies from 500 to 600 mm with an increasing trend towards the east. Summer and winter temperatures are not as extreme as in the arid west but the temperature may reach around 45°C during summer and minimum temperature is recorded 8°C during winter. The water table varies from 15 to 25 meters but the annual fluctuation is high, especially in the year of monsoon failure when replenishments are low. Surface water sources are scarce. High rainfall and comparatively low evapotraspiration (1,500 to 1,600 mm) result in longer length of growing period, ranging between 90 to 120 days.

The landscape is mainly comprised of the following physiographic units viz pediments, hills, intervening basins, plains (Fig.16). A significant portion of the physiography is occupied by rock outcrops while the pediment and plains are having very deep to deep, with intermittent, moderately shallow to moderately deep, either calcareous or noncalcareous, fine loamy/coarse loamy soils occurring in association as dominant and subdominant soil families. Generalized soil scape characteristics their potentials and constraints are described below.

Moderately to steeply sloping hilly terrain (Fig.16) predominantly occupied by rock outcrops associated with very shallow to shallow, excessively drained loamy-skeletal/loamy, slightly acidic (pH 5.5 – 6.5) to neutral (pH 6.5 – 7.5) Lithic Ustorthents and Lithic Ustochrepts with low AWC, moderate to strong stoniness and severe erosion

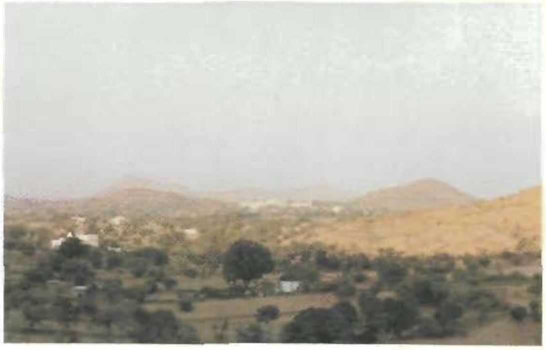
(Fig.16). Very gently to gently sloping intervening valley/basins (Fig.16) are covered with moderately shallow to deep, moderately well to well drained, moderately coarse loamy to fine loamy, neutral (pH 6.5 – 7.5) to slightly alkaline (pH 7.5 – 8.5) Typic Ustochrepts/ Ustorthents/ Ustipsamments.They are prone to secondary salinization and restricted drainage condition. Very gently to gently sloping pediment (Fig.16) consists of moderately shallow to moderately deep, well drained fine loamy to coarse loamy, neutral (pH 6.5 – 7.5) to slightly to moderately alkaline (pH 7.5 – 8.5), Typic Ustochrepts/ Haplustalfs (Fig.16), Ustorthents and Aridic Ustochrepts with medium AWC, moderate to severe erosion and slight to moderate stoniness. Gently sloping Aravalli plain with hillocks have moderately shallow to moderately deep, well drained, coarse loamy to fine loamy slightly alkaline Typic Ustorthents, Typic Ustochrepts and Typic Haplustalfs with medium AWC and moderate erosion whereas very gently to gently sloping Aravalli plain have moderately deep to deep, well drained fine loamy soils. They are prone to slight to moderate erosion, medium to high AWC and secondary salinization.

7.3.1 Soil and Water conservation Planning: This landscape is mainly comprised of hills, pediments, intervening basin/vallies and plains. Nearly 40% area of this physiography is occupied by hilly terrain which are mostly rocky, barren and sparsely vegetated followed by pediments covering about 16 per cent area plains and intervening valley/basins. Erosion is moderate to severe in hills and pediments whereas plains and basins are slight to moderately eroded. The soil and water conservation measures that are to be considered in this region are as under:

- The plantation surfaces can be covered with horticultural crops or agro forestry and silvi pastoral systems.
- The steeply sloping hills with narrow valleys could be rejuvenated with forest vegetation through aerial broad casting of seeds of resistant forest species.
- Stone bunding on moderately sloping shallow soils area.
- In situ water conservation in plateau through small ponds.
- Initiating watershed approach to conserve runoff water in small tanks at the lower reaches.
- Bench-terracing in the areas, with suitable waste weirs to conserve soil and water.
- Plugging of stream courses with rock, gabion structures or concrete masonry weirs.
- Restricting the deforestation in these areas and also human-induced degradation.
- Protection of already existing lakes.
- Development of roads only to serve villages and restriction to motor vehicular traffic in the rest of the area.
- Restriction of the urban encroachment.
- Developing the summer resort for tourism thus restricting the encroachments by rich people.
- Preventing of transfer of land from agricultural to non-agricultural purposes through promulgation of policies.

7.4 Eastern Rajasthan upland: The region is located between 24°45' to 27°50' N latitude and 73°38' to 78°17' E longitude. It extends in 52,42,314 ha area comprising 15.31% area of the state. Eastern Rajasthan upland covers most part of Alwar, Bharatpur, Jaipur, Dholpur, Tonk, Sawai Madhopur, Bundi and Kota districts. The entire plain has been divided into two sub region (a) flood prone eastern plains (b) sub humid southern plains

Aravalli Landscape

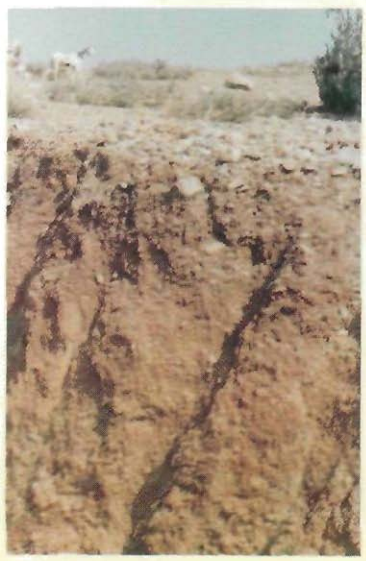


Hilly terrain with narrow valley

Severely eroded burried pediment

Aravalli plains

Inceptisols profile (Typic Ustochrepots)



Entisols profile(Lithic Ustorthents)

Fig. 16

Eastern Rajasthan Upland

Gently to moderately sloping plain
with monadnocks

Gently sloping plain

Very gently sloping plain

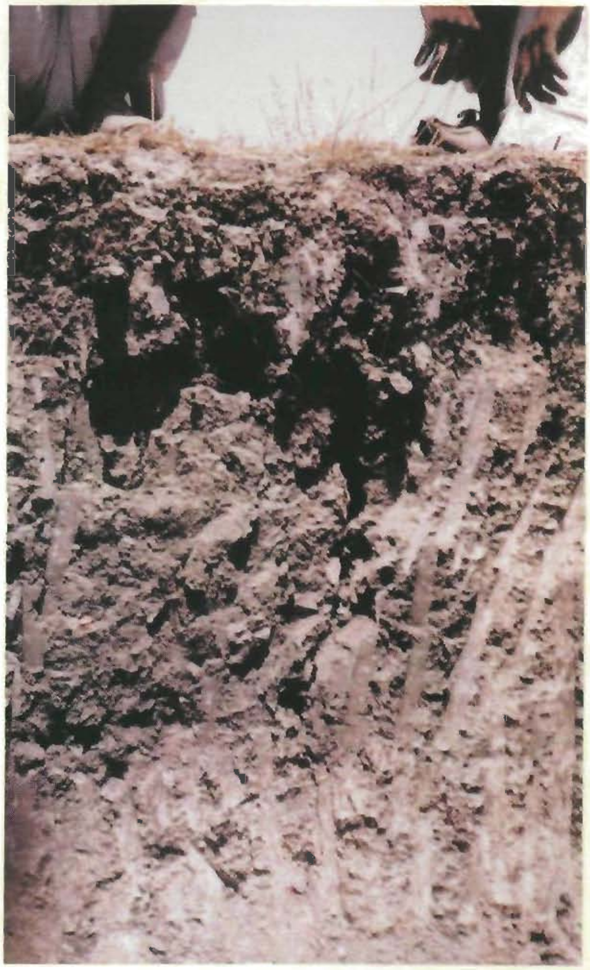
Flood plain

Severely eroded land

Fig. 17

Eastern Rajasthan - Dominant soils

Moderately deep Inceptsols
(Typic Ustochrepts)



Inceptsols (Vertic Ustochrepts)

Fig. 18

Pathar and Bundelkhand Upland

Vindhyan scarpland

Rocky plateau

Alluvial plain

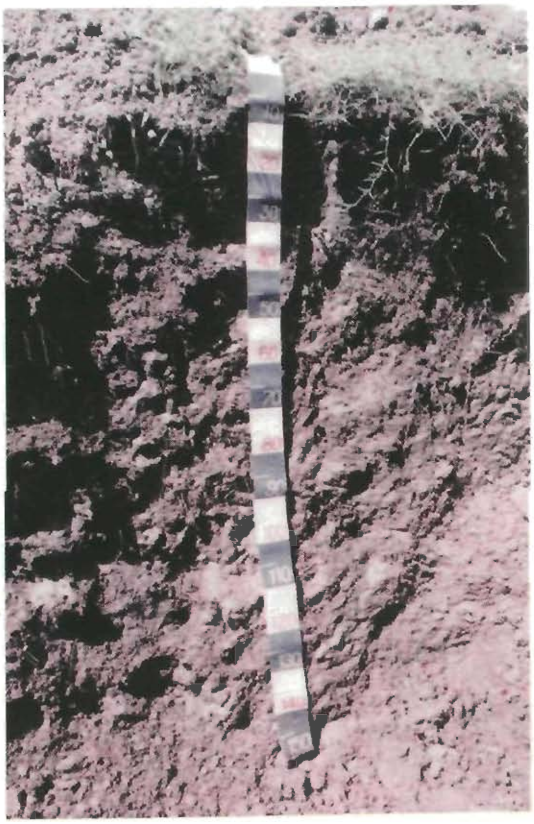
Inceptisols (Typic Ustochrepts)

Vertisols (Typic Chromusterts)

Fig. 19

Malwa Plateau

Gently sloping plain



Vertisol profile (Typic Chromusterts)

Fig. 20

Eastern Rajasthan - Soil and Water Conservation


Bunding


Gully plugging with rocks/stone


Gully plugging with rocks/stone


In-situ water conservation


Bio-Engineering


Engineering measures

Fig. 21

and the Aravalli hills.

(a) Flood prone eastern plains: The region comprises of the districts of Alwar, Bharatpur, Dholpur and the northern part of Sawai Madhopur. The entire region is flood plain of Banganga and the river Ghambiri. The region has rich alluvial soils, the fertility of which is replenished every year. In the periods of heavy rainfall the rivers outflow their banks and inundate the surrounding village. The major land forms are young and old alluvial plains (Fig.17).

(b) Sub humid southern plains and Aravalli hills: Bhilwara and Udaipur districts mainly constitute the region. The region is of low aravalli hills with the inter mountain plateau, deeply dissected plains. There are number of surface water streams like Ghambiri, Sabarmati, Banas and its tributaries but they are all ephemeral. The surface rocks are granitic and highly metamorphosed. The pediments, gently sloping plains and hills are the major landforms (Fig.17).

Climatically the area is similar to the plains of Aravalli but the rainfall is relatively higher in the east, the annual rainfall ranges between 700 to 800 mm. The mean annual water surplus is 50 to 100 mm in the eastern margin while the western margin experiences moisture deficit round the year.

Agro-climatic situation is comparatively better than Aravalli region owing to higher rainfall and better surface and ground water potential. A network of canals drawn from the upper Yamuna canals and the Panchana dam irrigate the area, classified as flood prone eastern plain. The ground water acquifer vary from 5 to 15 meters and therefore well water is also in practice for irrigation.

Length of growing period varies from 120 to 150 days. The growing period starts in the second fortnight of June when rainfall exceeds from 0.5 PET and terminates during second fortnight of October. Generalised soil scape characteristics their potentials and constraints are given below:

Very gently to gently sloping land with monadnocks have moderately deep to deep well drained, fine loamy to fine, neutral (pH 6.5 – 7.5) to slightly alkaline (pH 7.5 – 8.5) with medium to high AWC, slight to moderate erosion and moderate to severe alkalinity and salinity. These are classified as Typic Ustochrepts (Fig.18), Vertic Ustochrepts (Fig.18), Aridic Ustochretps and Typic Chromusterts. Moderately shallow coarse loamy soils with moderate erosion are also found in pockets.Gently sloping river valley covers deep to very deep, moderately well to well drained coarse loamy to fine loamy, moderately to strongly alkaline (pH 8.5 – 9.5) Typic Ustochrepts, Fluventic Ustochrepts with medium AWC, moderate to severe erosion. These are prone to occasional flooding and moderate to severe salinity. Moderately to steeply sloping dissected hills and ridges consist significant area under rock outcrops in association with extremely shallow to shallow, loamy skeletal Lithic Ustorthents with severe erosion and strong stoniness. Gently sloping footslopes are endowed with moderately shallow to moderately deep, well drained coarse/fine loamy Typic Ustochrepts and Typic Haplustalfs with moderate erosion and stoniness. Nearly level lake margins comprises deep to very deep, poorly to imperfectly drained, coarse loamy and sandy Typic Salorthids with severe salinity and sodicity. Gently sloping aeofluvial plain consists of very deep excessively drained sandy Ustic Torripsamments, Typic Ustifluvents and Typic Ustipsamments with low AWC and moderate erosion. Soils on very gently sloping plains are deep to very deep, well drained coarse loamy to fine loamy with slight to moderate erosion and moderate alkalinity and salinity. Gently to moderately sloping pediments is covered with very shallow to shallow, excessively drained, loamy-skeletal Lithic Ustorthents with severe erosion, low AWC and moderate stoniness (Fig.17). Very gently to gently sloping pediments comprises moderately shallow to deep, well drained, coarse/fine loamy, Typic Ustochrepts, Typic Ustorthents with medium AWC and moderate to severe erosion.

7.4.1 Soil and Water conservation Planning: The rainfall increases from western to eastern parts of the region. The physiographic units in this region consist of dissected hills and ridges isolated hillocks and pediments, gently to moderately sloping land with hillocks, river valley, aeofluvial plain and margins of salt lake. Cultivation of marginal areas and faulty management practices induce the soil erosion and surface runoff of rain water. In order to restrict the soil erosion and surface runoff in these areas the following soil and water conservation measures are suggested.

- Contour trenching and planting forest species in the inter trench areas of non-arable lands of spurs, isolated hill tops and pediments.
- Drought tolerant horticultural crops like ber, custard apple and amla could also be planted.
- Construction of masonry/concrete or gabion structures to check gully erosion in waste lands.
- To check surface runoff and sheet erosion contour bunding/graded bunding, with land smoothing (harrowing) in the inter bund area, bund stabilization by grasses (Fig.21).
- Construction of farm ponds to have supplemental irrigation.
- Watershed based approach to conserve soil and water resources in the area.
- Deep ploughing before the onset of monsoon to restrict the runoff during initial rains.

7.5 Pathar and Bundelkhand Upland: The region is located between 24°29' to 27°13' N latituce and 74°29' to 78°13' E longitude. It is extended in 24,64,485 ha comprising 7.19% of the total geographical area of the state. The region is popularly known as Hadauti plateau, this includes the districts Kota, Baran, Bundi and Jhalawar and two tehsil of Sawai Madhopur. It has low hills of Gwaliar series, interspersed with broad plateaux of vindhyan rock. Large number of rivers drain the area. Chambal is the main river along with main tributaries like Parvati, Kalisindh, Parwan and Banas. Physically the region is divided into two defined units, namely Vindhyan scarpland and Bundelkhand alluvial plains.

The region has warm summers but mild winters. Summer temperatures sometimes touches 45°C. The relative humidity is generally high in this zone. The annual rainfall varies from 700 to 900 mm.

Mean annual water surplus is 100 to 200 mm and potential evapotranspiration ranges between 1500 to 1600 mm. The length of growing period varies from 120 to 160 days in Bundelkhand alluvial plains while it is shorten by few days in Vindyan scarpland due to low AWC. Generalized soil scape characteristics are described below:

A significant area of this physiography is characterized by steeply sloping escarpments, residual hillocks and gently sloping rocky plateau (Fig.19), which are rocky and barren in combination with very shallow to shallow, somewhat excessively drained, loamy skeletal, neutral to slightly alkaline Lithic Ustorthents with very severe erosion and strong stoniness. However, shallow to moderately shallow, loamy skeletal to fine loamy either calcareous or non calcareous are the dominant soils on gently sloping hills and very gently sloping plateau (Fig.19). These soils are classified as Typic Ustorthents and Typic Ustochrepts.Gently sloping undulating plateau consists of moderately shallow, well drained, fine loamy to fine, neutral to slightly alkaline Typic Ustochrepts and Typic Chromusterts with medium AWC and moderate erosion. Very gently sloping plateau is represented by deep, moderately well to well drained, coarse loamy to fine loamy Typic Ustochrepts with medium to high AWC and slight to moderate erosion. Very gently to gently sloping intervening basin is covered by moderately shallow to deep, moderately well drained to well drained, fine loamy to fine slightly alkaline Typic Ustochrepts and Vertic Ustochrepts with slight to moderate erosion medium to high AWC and slight stoniness. Gently sloping pediment surface is represented by very shallow to shallow, somewhat excessively drained, loamy and loamy skeletal neutral to slightly alkaline Lithic Ustorthent and Lithic Ustochrepts with severe to very severe erosion and moderate stoniness. Very gently sloping pediments are dominated by moderately shallow to deep, well drained, coarse loamy to fine loamy, slightly alkaline Typic Ustochrepts with slight to moderate erosion. Gently to moderately sloping ravinous plains are endowed with deep to very deep, well drained, highly calcareous, coarse loamy to fine loamy, slightly to moderately alkaline Typic Ustochrepts and Fluventic Ustochrepts with medium AWC, severe erosion and severe dissection due to deep gullies. Very deep to deep, dark grayish brown to very dark grayish brown, well drained, calcareous, fine soils with weakly expressed slickenslides on nearly level plains constitute the dominant soilscape and are classified as Typic Chromusterts and Vertic Ustochrepts (Fig.19). These soils occur in association with deep to very deep, calcareous fine loamy soils which are placed under Typic Ustochrepts.

7.5.1 Soil and Water Conservation Planning: Broadly this physiographic unit can be divided into moderately to steeply sloping scarpland, residual hillocks, rocky plateau, pediments, intervening basins, Bundelkhand alluvial plains with or without ravines. The management and mechanical soil and water conservation practices envisaged (Fig.21) for this region are:

- ***Graded bund:*** For in situ conservation of rainfall and to minimize erosion hazards on gently sloping (3–5%) arable lands, graded bunds of 1 sq. m cross section with 0.5 to 1 m vertical interval having grade 0.2 to 0.3% have been found suitable for the region.
- ***Gully control structure:*** Gully control structures are provided to reduce the erosive velocity of runoff, to facilitate establishment of vegetation or to provide protection at points that can not be adequately protected by other ways. If the amount of runoff is not excessive temporary structures are useful and cost effective. Loose boulder and brush wood check dams perform satisfactorily in subsidiary gullies which do not carry much runoff. Loose boulder check dams are suitable for main gullies as it help in silt deposition which facilitate stabilization of gully beds. Permanent gully control structures are constructed to control the over fall at the head of large gully, to drop the discharge from a grassed waterway and to take up the fall at various points in the gully bed.

- ***Conservation bench terrace:*** For in-situ utilization of rainfall, conservation bench terrace (CBT) systems with 1 : 2 ratios of contributing to receiving catchments was recommended for the region to minimize erosion hazards and maximize production on rainfed arable lands.
- ***Across the slope tillage operations and seeding*:** Tillage operations and planting should be performed on contour or across the general slope of the field to provide series of mini barriers for surface flow.
- Use of vegetative barriers of *Vetiveria zezanioides*, *Sacchrum munja*, *Cenchrus ciliaris* and *Dichanthium annulatum* at horizontal spacing of 11 m on gently sloping land.
- Contour furrows (0.02 sq. m) should be opened at 5–7 m horizontal spacing just after seeding of rainfed crops to reduce runoff and soil loss.
- Deep tillage (15–20 cm) has shown greater absorption of rain water in the profile and higher yield of rainfed crops.
- ***Cropping system:*** Single cropping during *kharif* or *rabi* is a prevalent practice in the region. On the basis of annual rainfall and its distribution and moisture holding capacity of the soil the region, however, is best suited for intercropping systems. Sorghum + pigeonpea (1 : 1), Pigeonpea + blackgram (1 : 2), Castor + greengram (1 : 2), Soybean + pigeonpea (4 : 1) and Chickpea + linseed (2 : 1) are some of the promising intercropping systems.
- *Shallow ravine reclamation:* Shallow ravines should be reclaimed by putting earthen embankment/check dams and leveling of irregular side slopes into bench terraces for agriculture. Check dams and terrace risers may be stabilized with grasses.
- *Medium and deep ravines reclamation:*
  - Closure of ravinous area against biotic interferences.
  - For regulated entry of runoff into ravine lands, marginal bund of 2.7 sq. m cross section (bottom width, 5m; top width, 1m; height, 0.9 m and side slope 1 : 2) with 0.1 to 0.2% grade should be constructed at the periphery of agriculture land to demarcate the agricultural table land and the ravines. The bund should be constructed at a distance of twice the depth of active gully heads.
  - ***Provision of spillway:*** Runoff so diverted should be safely disposed off into the ravines through masonry spillways construction on active gully heads carrying large volume of runoff.
  - ***Stabilization of steep ravine heads/ side slopes:*** For stabilizing gully heads and side slopes 1 : 1 slope-easing treatment is sufficient to establish a good cover. *Dichanthium annulatum* was found very suitable for sodding the eased slopes. This type of work is expensive, and is recommended where protection of costly construction like roads, buildings etc. is required. The stabilization of gully heads can also be achieved slowly if the area is protected against grazing. In that case the heads develop a natural angle of repose in due course of time.
  - ***Stabilization of gully beds:*** Check dams flatten out the gully bed slopes,

which would help to minimize the scour and erosion during peak flow. Loose boulder check dams at vertical interval of 0.9 m has been found cost effective and satisfactory in gully beds carrying comparatively larger volume of runoff. Live hedge check dams of *Ipomoea carnea, Agave Americana, Arundo lonax* and *Vitex negundo* have been found successful in subsidiary gully beds carrying less runoff.

- ***Plantations:*** Vegetative treatment not only stops ravine ingress into tablelands but also stabilize the ravines for productive use like fuel and fodder production. Following tree and grass species are suitable for ravine control. *Prosopis juliflora, Balanites aegyptiaca, and Acacia tortilis* (Hump and side slope of ravines); *Acacia nilotica* (side slope); *Dendrocalamus strictus* (ravine beds); *Eucalyptus tereticornis* (ravine beds near river); *Prosopis juliflora* and *Tamrix dioica* (saline ravine beds); *Dichanthium annulatum* and *Cenchrus ciliaris* (ravine hump, side slope and bed) and *Brachiaria mutica* (for saline and waterlogged beds).

- Watershed based approach to harvest available water through percolation tanks. This will increase water table in the surrounding areas.
- In the non-arable lands of escarpments, pediments and hill side slopes the silvi-pastoral and agro horticultural crops will restrict the soil erosion.

7.6 Malwa Plateau: The Malwa having intrusions of black volcanic rocks into the vindhyans extends to a great part in Jhalawar. Baran and Kota. It also extends into the southern parts of Chittaurgarh and Banswara districts. The plateau has an altitude of 500 m above MSL and is dotted with isolated low range of hills at places. The plateau in Rajasthan occurs in the upper catchment of Chambal river to south east of Mewar plains. The greater part of the area is drained by river Chambal and its right bank tributaries like Kalisindh, Parwan and Parvati. The region is located between 23°32' to 25°06' N latitude and 74°18' to 77°07' E longitude. It extends in 10,57,000 ha area comprising 3.08% area of the state.

The region receives maximum rainfall of the state, 1,020 mm in Jhalawar and 920 mm in Banswara plain. In most of the places the highest normally monthly rainfall is during July to August. Normally the rainy days range between 40 to 45 days in full season.

Potential evapotranspiration is comparatively lower in comparison to other parts of Rajasthan. Length of growing period is slightly longer and almost comparable to bundelkhand alluvial plains. Mean annual water surplus is around 200 mm or more, comparatively higher than the other region of Rajasthan.

The soil scape comprising moderately deep to deep, dark grayish brown, moderately well drained, calcareous, fine soils with prominent expression of slickenslides are classified as Fine, Typic Chromusterts, occurring on nearly level plains (Fig.20). The subdominant soils are of the similar nature except differing in the expression of slickenslides and wedge shaped aggregates consequently placed under fine, Vertic Ustochrepts soil family. These soils are slightly eroded and prone to secondary salinization. A significant area is occupied by hills with escarpments and plateau, usually rocky with interspersed veneer of loamy skeletal soils which are shallow to very shallow, well drained Lithic Ustorthents with severe erosion and moderate to strong stoniness. However, gently sloping plateau is covered with moderately shallow, well drained, fine loamy to fine Typic Ustorthents, Typic/Vertic Ustochrepts and Typic Chromusterts with medium AWC and moderate erosional hazards.

7.6.1 Soil and Water Conservation Planning: Physiographically this region can be divided into hilly terrain, isolated hillocks with pediments, plateau, mesa & butes and plains. The deforestation and encroachment of marginal areas for cultivation are the major soil erosion problems in the hilly non-arable areas of this region. In the arable lands soil conservation and drainage are the two problems in this region. The soil and water conservation practices that could be followed in this region are as under.

- The hilly terrain, butes, mesa could be covered with forest vegetation or drought resistant horticultural crops.
- Contour trenching and staggered trenching to conserve soil and water in these non-arable areas.
- Nala bunding and gully control in these areas.
- Restricting the cultivation of marginal areas in the region.
- In the cultivated areas graded bunding with grassed waterways to drain the excess water.
- Land smoothing between the bunded areas.
- Farm ponds at convenient places.
- Vegetative bunds.
- Gully stabilization structures like check dams and gabion structures.
- Management practices like Broad bed furrow and raised and sunken beds.
- Agro-horticultural systems to cover the area.
- Watershed based approach to conserve both soil and water resources.

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Appendices

APPENDIX -I

Sample of data used for estimation of soil loss in Rajasthan

Topo no.	Grid no.	Latitude	Longitude	Texture	Sand (%)	Silt+Vfs.* (%)	Organic M (%)	Structure code	Permeability code	K factor
45L	G40	24:43:00	74:53:00	c	7.80	41.60	1.03	4	6	27.771
45L	G42	24:38:00	74:05:00	cl	9.90	61.70	0.96	3	5	41.408
45L	G43	24:40:00	74:14:00	cl	9.70	60.90	0.50	3	5	41.751
45L	G44	24:37:00	74:18:00	sl	35.20	45.20	1.15	2	3	26.086
45L	G45	24:40:00	74:22:00	cl	13.60	54.70	1.96	3	5	33.165
45L	G46	24:38:00	74:30:00	scl	29.00	50.20	0.72	2	3	30.046
45L	G47	24:38:00	74:38:00	gscl	70.10	18.50	1.93	2	3	9.774
45L	G48	24:38:00	74:44:00	cl	25.60	45.60	1.15	3	5	31.190
45L	G5	24:00:00	74:22:00	c	22.50	37.20	1.53	4	6	28.360
45L	G51	24:26:00	74:01:00	scl	13.00	65.00	0.76	2	3	39.520
45L	G52	24:32:00	74:05:00	scl	7.00	70.10	0.33	2	3	44.134
45L	G53	24:32:00	74:14:00	scl	31.10	42.10	0.93	2	3	22.062
45L	G54	24:33:00	74:22:00	c	22.70	32.10	1.98	4	6	24.539
45L	G55	24:33:00	74:24:00	cl	26.40	39.50	2.72	3	5	23.509
45L	G56	24:33:00	74:30:00	c	23.20	33.60	0.74	4	6	26.994
45L	G57	24:33:00	74:38:00	gscl	33.70	37.90	0.95	2	3	19.054
45L	G58	24:33:00	74:44:00	cl	21.80	46.00	0.69	3	5	31.101
45L	G61	24:28:00	74:01:00	sl	24.50	57.90	0.36	2	3	38.171
45L	G62	24:28:00	74:05:00	gcl	5.60	60.00	2.58	3	4	30.560
45L	G63	24:28:00	74:12:00	scl	34.30	37.90	0.52	2	3	19.985
45L	G64	24:28:00	74:22:00	cl	18.90	41.30	1.36	3	5	24.851
45L	G66	24:39:00	74:35:00	cl	17.10	45.00	1.60	3	5	26.788

*Vfs = Very fine sand

APPENDIX -II

District-wise Erosivity (R-Factor) in Rajasthan

Districts	Classes						Total
	200-299	300-399	400-499	500-599	600-799	>800	
	Area sq.km and percent						
Ajmer	0	112	8309	0	0	0	8421
	0	0.03	2.43	0	0	0	2.46
Alwar	59	1068	6248	332	120	0	7827
	0.02	0.31	1.82	0.10	0.04	0	2.29
Banswara	0	0	5069	0	0	0	5069
	0	0	1.48	0	0	0	1.48
Bharatpur	37	48	146	434	4404	0	5069
	0.01	0.01	0.04	0.13	1.29	0.00	1.48
Bhilwara	0	0	8957	752	763	0	10472
	0	0	2.62	0.22	0.22	0	3.06
Bundi	0	0	284	2322	3211	0	5817
	0	0	0.08	0.68	0.94	0	1.70
Chittaurgarh	121	389	7518	776	1550	0	10354
	0.04	0.11	2.20	0.23	0.45	0	3.02
Dholpur	0	0	0	0	3008	0	3008
	0	0	0	0	0.88	0	0.88
Dungarpur	0	0	3855	0	0	0	3855
	0.00	0.00	1.13	0.00	0.00	0.00	1.13
Jaipur & Dausa	659	1296	8381	1254	2866	0	14456
	0.19	0.38	2.45	0.37	0.84	0.00	4.22
Jhalawar	0	0	0	872	4846	602	6320
	0.00	0.00	0.00	0.25	1.41	0.18	1.85
Kota & Baran	0	0	63	187	11439	515	12204
	0.00	0.00	0.02	0.05	3.34	0.15	3.56
Rajsamand	0	0	4450	0	0	0	4450
	0.00	0.00	1.33	0.00	0.00	0.00	1.33
Sawai Madhopur	0	0	515	383	9145	0	10043
& Karauli	0.00	0.00	0.15	0.11	2.67	0.00	2.93
Sirohi	118	144	2443	1030	1092	350	5177
	0.03	0.04	0.71	0.30	0.32	0.10	1.51
Tonk	0	0	3892	1139	2147	0	7178
	0.00	0.00	1.14	0.33	0.63	0.00	2.10
Udaipur	0	0	14617	0	0	0	14617
	0.00	0.00	4.27	0.00	0.00	0.00	4.27
Total	994	3058	74765	9484	44604	1467	134372
	0.29	0.89	21.83	2.77	13.02	0.43	39.24

APPENDIX -III

District-wise Erodibility (K-Factor) in Rajasthan

Districts	Classes					Total
	<0.10	0.10-0.20	0.20-0.25	0.25-0.30	>0.30	
	Area sq.km and percent					
Ajmer	697 0.20	4146 1.21	2101 0.61	763 0.22	714 0.21	8421 2.46
Alwar	920 0.27	3726 1.09	1704 0.50	965 0.28	512 0.15	7827 2.29
Banswara	22 0.01	796 0.23	1499 0.44	1843 0.54	909 0.27	5069 1.48
Bharatpur	153 0.04	1701 0.50	1206 0.35	1331 0.39	678 0.20	5069 1.48
Bhilwara	0 0.00	3002 0.88	3922 1.15	3093 0.90	455 0.13	10472 3.06
Bundi	9 0.00	246 0.07	1929 0.56	2322 0.68	1311 0.38	5817 1.70
Chittaurgarh	313 0.09	1572 0.46	3400 0.99	3557 1.04	1512 0.44	10354 3.02
Dholpur	0 0.00	993 0.29	700 0.20	569 0.17	746 0.22	3008 0.88
Dungarpur	0 0.00	28 0.01	346 0.10	1615 0.47	1866 0.54	3855 1.13
Jaipur & Dausa	5931 1.73	5557 1.62	1723 0.50	766 0.22	479 0.14	14456 4.22
Jhalawar	0 0.00	277 0.08	1123 0.33	2483 0.73	2437 0.71	6320 1.85
Kota & Baran	6 0.00	735 0.21	2961 0.86	3932 1.15	4570 1.33	12204 3.56
Rajsamand	46 0.01	1019 0.30	1808 0.53	1047 0.33	530 0.15	4450 1.33
Sawai Madhopur & Karauli	194 0.06	2252 0.66	2843 0.83	2296 0.67	2458 0.72	10043 2.93
Sirohi	132 0.04	2151 0.63	1700 0.50	1020 0.30	174 0.05	5177 1.51
Tonk	2943 0.86	1860 0.54	1003 0.29	394 0.12	978 0.29	7178 2.10
Udaipur	275 0.08	3640 1.06	4620 1.35	3824 1.12	2258 0.66	14617 4.27
Total	11644.3 3.40	33709.8 9.84	34596.8 10.10	31828.2 9.30	22592.94 6.60	134372 39.24

APPENDIX -IV

District-wise topographic (LS-Factor) in Rajasthan

Districts	Classes					Total
	0<0.5	0.50-1.00	1.00-2.00	2.00-3.00	>3.00	
	Area sq.km and percent					
Ajmer	5656 1.65	1844 0.54	385 0.11	237 0.07	299 0.09	8421 2.46
Alwar	3586 1.05	1233 0.36	1754 0.51	895 0.26	359 0.10	7827 2.29
Banswara	1344 0.39	1535 0.45	786 0.23	488 0.14	916 0.27	5069 1.48
Bharatpur	4879 1.42	66 0.02	109 0.03	15 0.00	0 0.00	5069 1.48
Bhilwara	6564 1.92	2860 0.84	689 0.20	201 0.06	158 0.05	10472 3.06
Bundi	3548 1.04	2178 0.64	25 0.01	21 0.01	45 0.01	5817 1.70
Chittaurgarh	6429 1.88	2199 0.64	636 0.19	356 0.10	734 0.21	10354 3.02
Dholpur	2853 0.83	155 0.05	0 0.00	0 0.00	0 0.00	3008 0.88
Dungarpur	1001 0.29	436 0.13	589 0.17	573 0.17	1256 0.37	3855 1.13
Jaipur & Dausa	11118 3.25	1074 0.31	749 0.22	526 0.15	989 0.29	14456 4.22
Jhalawar	3945 1.15	1875 0.55	375 0.11	125 0.04	0 0.00	6320 1.85
Kota & Baran	9983 2.91	1695 0.49	359 0.10	74 0.02	93 0.03	12204 3.56
Rajsamand	1353 0.40	581 0.17	1059 0.34	859 0.25	598 0.17	4450 1.33
Sawai Madhopur & Karauli	7857 2.29	1210 0.35	452 0.13	208 0.06	316 0.09	10043 2.93
Sirohi	1544 0.45	574 0.17	776 0.23	595 0.17	1688 0.49	5177 1.51
Tonk	2669 0.78	4509 1.32	0 0.00	0 0.00	0 0.00	7178 2.10
Udaipur	3047 0.89	3909 1.14	1440 0.42	1504 0.44	4717 1.38	14617 4.27
Total	77397.7 22.60	27940 8.16	10185.6 2.98	6678.51 1.95	12170.18 3.55	134372 39.24

APPENDIX -V

District-wise cover and management (C-factor) in Rajasthan

Districts	*Classes*							*Total*
	<0.05	0.05-0.10	0.10-0.15	0.15-0.20	0.20-0.25	0.25-0.30	>0.30	
	Area sq. km and percent							
Ajmer	0 0.00	26 0.01	69 0.02	108 0.03	329 0.10	611 0.18	7278 2.13	8421 2.46
Alwar	0 0.00	0 0.00	3 0.00	27 0.01	53 0.02	83 0.02	7661 2.24	7827 2.29
Banswara	0 0.00	89 0.03	320 0.09	491 0.14	754 0.22	895 0.26	2519 0.73	5069 1.48
Bharatpur	0 0.00	0 0.00	7 0.00	26 0.01	23 0.01	22 0.01	4991 1.46	5069 1.48
Bhilwara	0 0.00	64 0.02	287 0.08	645 0.19	961 0.28	1262 0.37	7253 2.12	10472 3.06
Bundi	0 0.00	0 0.00	35 0.01	141 0.04	211 0.06	259 0.08	5171 1.51	5817 1.70
Chittaurgarh	32 0.01	700 0.20	990 0.29	1000 0.29	882 0.26	930 0.27	5820 1.70	10354 3.02
Dholpur	0 0.00	0 0.00	3 0.00	22 0.01	30 0.01	48 0.01	2905 0.85	3008 0.88
Dungarpur	0 0.00	20 0.01	122 0.04	241 0.07	1244 0.36	365 0.11	1863 0.54	3855 1.13
Jaipur & Dausa	0 0.00	3 0.00	38 0.01	89 0.03	133 0.04	156 0.05	14037 4.10	14456 4.22
Jhalawar	0 0.00	0 0.00	669 0.20	562 0.16	365 0.11	378 0.11	4346 1.27	6320 1.85
Kota & Baran	6 0.00	187 0.05	446 0.13	558 0.16	977 0.29	1083 0.32	8947 2.61	12204 3.56
Rajsamand	0 0.00	67 0.02	140 0.04	169 0.05	297 0.09	353 0.10	3424 1.03	4450 1.33
Sawai Madhopur & Karauli	0 0.00	8 0.00	45 0.01	105 0.03	194 0.06	268 0.08	9423 2.75	10043 2.93
Sirohi	0 0.00	97 0.03	643 0.19	913 0.27	764 0.22	675 0.20	2085 0.61	5177 1.51
Tonk	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	0 0.00	7178 2.10	7178 2.10
Udaipur	97 0.03	1504 0.44	1137 0.33	1148 0.34	2040 0.60	1480 0.43	7211 2.11	14617 4.27
Total	135.01 0.04	2765.37 0.81	4955.11 1.45	6246.49 1.82	9259.11 2.70	8870.16 2.59	102140.73 29.83	134372 39.24

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