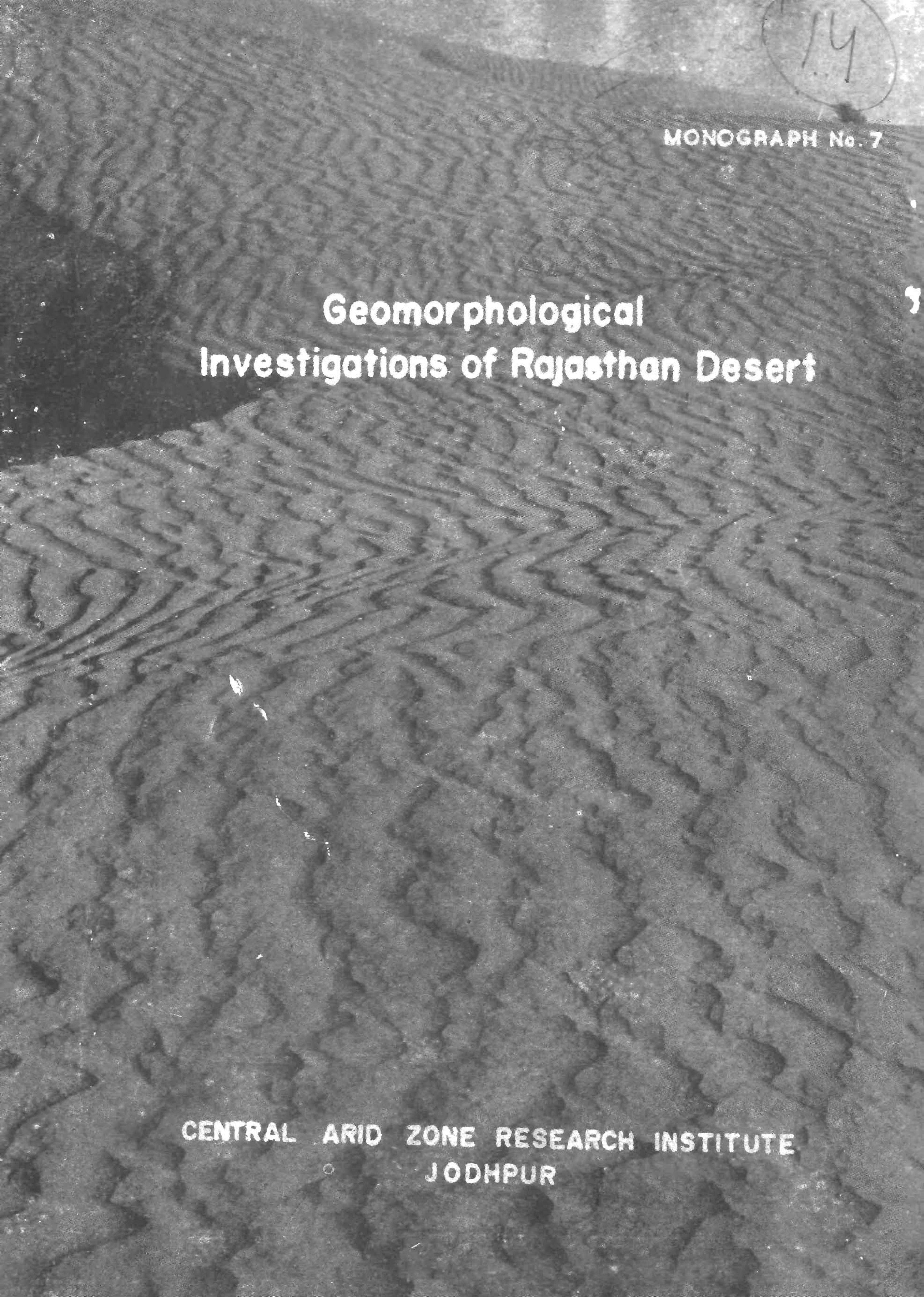

MONOGRAPH No. 7

Geomorphological Investigations of Rajasthan Desert

CENTRAL ARID ZONE RESEARCH INSTITUTE
JODHPUR

Monograph No. 7

14

Geomorphological Investigation of the Rajasthan Desert

Compiled and Edited

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Printed December, 1977

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Printed at Rathi Printers, Pungalpara, Jodhpur-342001

FOREWORD

Besides aridity, the major environmental problems which limit the agricultural productivity and overall development of the Rajasthan desert are the erosional, depositional and salinity hazards, shifting of the sand dunes and river courses, and dearth of water. Applied geomorphological researches on the Rajasthan desert have been underway at the Central Arid Zone Research Institute since 1960 and techniques have been standardised to identify and locate such problems and to provide suitable solutions.

Survey and mapping techniques which are essential pre-requisites for the rational assessment and management of the physical potentials and hazards of the different landforms and for the overall development of arid lands, have been satisfactorily worked out. Methodology for study of the dynamics of sand dunes and the river system has been developed. Techniques for locating and exploiting the subsurface water potentials and commercial salts and evaporites in different landforms, especially along the buried courses of the prior drainage channels, have also been evolved. Attention has also been focussed on small agricultural drainage basins for harvesting their surface water potential at suitable sites.

Basic questions on the palaeoclimate and spread of the Thar desert have also been accorded due recognition in the research programme.

The findings of the basic and applied geomorphological researches, conducted in Rajasthan desert over the past sixteen years, have been synthesized in the present monograph. It is earnestly hoped that the material presented here will be useful to scientists, administrators, extension workers and others interested in the development of the arid zones.

H. S. MANN

DIRECTOR

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We are thankful to the Regional Botanist, Botanical Survey of India, Arid Zone Circle, D–7, Shastri Nagar, Jodhpur for providing the front cover page photograph of this monograph.

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INTRODUCTION

With the establishment of the Geomorphology Section at the Central Arid Zone Research Institute, Jodhpur, studies on the evolution, classification and analysis of landforms in the Rajasthan Desert and mapping of their geomorphological characteristics, have been underway with a view to evaluate the physical potentials of the land for agricultural and hydrological development. These studies, carried out in conjunction with other disciplines like pedology, plant ecology, geohydrology and land use, have enabled the recognition of Major Land Resources Units in western Rajasthan which have similar resource potential and similar management needs and thus provide useful base line for administrators and planners for development of natural resources of a region.

In addition to the geomorphological surveys, the investigations on the origin and distribution of the important environmental problems, such as erosional, depositional and salinity hazards, dynamics of sand dunes and river systems, dearth of water resources and process of desertification, which limit the agricultural productivity and overall development of the desert regions, have been carried out in difierent parts of the Rajasthan desert. All the investigations were conducted through the interpretation of large scale aerial photographs and topographical sheets, detailed fieled checks for all the geomorphological features and analysis of their morphological and morphometric characteristics in the laboratory. The research findings of the above geomorphological investigations, conducted during the period from January 1960 to December 1976, have been discussed briefly in this monograph. The detailed examples of the geomorphological research findings have been cited, however, from the central Luni basin, since it is a large contiguous area, representing all the landforms and associated problems encountered in the investigated areas and hence it is also very convenient to depict and correlate these through maps and charts.

2. GEOMORPHOGENY AND GEOMORPHOLOGY

The evolution, classification and mapping of the landforms and analysis of their geomorphological characteristics help in evaluating the physical potentials of the land for agricultural and hydrological development of a region. The geomorphological investigations carried out on the above aspects in different parts of Rajasthan desert, with special reference to the central Luni basin, have been discussed in this chapter.

2.1 Geomorphological Evolution of Landforms

Geomorphological investigations on the evolution of the landforms in different parts of Rajasthat desert revealed that they have been sculptured to the present forms by the orogenic, erosional and depositional processes. The geomorphogeny of the area is quite old and the landforms from Archaean to Quaternary eras occur in this region. The argillaceous Aravallis of Archaean era were laid down in a syncline existing at that time among the gneissic Archaean. The sediments were derived from the Archaean basement (banded gneissic complex and Bundelkhand granite gneiss) which were constituting the highlands during that age. After the depositional phase, the Aravallis were uplifted and put to prolonged subaerial denudation during the Algonkian era. The igneous activities, which took place during this era, were *pari passu* with the upliftment and they produced the Erinpura suite of granite along the isoclinal foldings of the Aravallis of this region. The Aravallis were eroded to such an extent that the Erinpura granite, pegmatites and quartz veins of Algonkian age were exposed to subaerial denudation. The weathering and erosion of the Aravallis continued for a long period during which the sediments of Raialo series, mainly limestone, were laid down in the denudation valleys of the softer and weathered Aravallis or basement granities (Heron, 1917) and subsequent deposits of Delhi system. Consequent upon the uplift of the Aravalli range, second cycle of erosion started and the low lying areas of the eroded surface of the Aravallis and the exposed Erinpura granite suite were deeply weathered but the uplands remained unaffected. This weathered zone was later on eroded away in part and exposed the underlying rocks. The exposed rocks, constituting the Algonkian surface, started being worn down by the subaerial denudation. During the Lower Vindhyan period, another igneous activity took place. The intrusives formed the Jalor and the Siwana granites and the extrusives, the Malani rhyolite. During the second crustal movement, Upper Vindhyan formations came into being.

After Tertiary period, this region was subjected to different climatic fluctuations, sub-aerial denudation and deposition. The existing major landforms of this region were formed during the Quaternary period by the fluvial and aeolian processes operating on various lithological formations and under different climatic phases. The Aravalli drainage system, comprising of the Luni river and its tributaries, and the drainage system of Himalayan origin, constituting the Ghaggar river and its tributaries, were well integrated in the past humid period and they were responsible for the formation of vast existing alluvial plains with varying thickness of alluvial sediments (Ghose, 1965, Singh and Ghose, 1976). The piedmont plains and pediments were also formed by slope retreat at the bases of the hills of different formations. This major humid phase, which was responsible for the creation of vast alluvial plains and pediments, was followed by a major arid phase, probably in pre-Holocene period. The major arid phase, which was responsible for the formation of three lakes of the Rajasthan desert, terminated around 10,000 years B. P. (Singh *et al*; 1974). During this arid phase, the high active sand dunes, sandy undulating aggraded older alluvial plains and interdunal plains were formed and the two major drainage systems were disintegrated and disorganised. The barriers created by the formation of sand dunes astride the major drainage channels segmented many valleys into sandy inland basins (Ghose *et al*., 1975). The desert extended to the east of its present limit and there was widespread desiccation.

The major arid phase, responsible for the formation of aeolian landforms, was replaced by a major humid phase, probably in early Holocene period. From 10,000 to 3800 years B. P., the climate again became humid but it was less humid from 9500 to 5000 years B. P. (Singh *et al*; 1974). The fluvial activities became intense and the high active dunes were stabilised and dissected. The sandy inland basins were filled with water and sediments, thus creating fresh water lakes at certain places. The younger alluvial plains were formed along the rivers and their major tributaries. This major humid phase was replaced by a second arid phase, probably in late Holocene period. The second arid phase set in around 3800 years B. P. (Singh *et al*., 1974). Due to renewed aeolian activities, the younger aeolian landforms viz., barchan dunes, shrub-coppice dunes and sand ripples were formed on the old fluvial and aeolian landforms. The fresh water lakes were dried up and turned into saline depressions. In Recent period, increasing biotic activities in asssociation with occasional severe droughts reactivated the crests of the stabilised sand dunes, deflated and deposited the sand on fluvial and aeolian landforms, turned the fertile lands into saline lands and intense fluvial activities dissected the old landforms

2.2 Geomorphology and Integrated Surveys

A reliable and comprehensive inventory of the natural resources is an essential pre-requisite for the reclamation and development of the arid regions. Geomorphology, which is a binding element in the integrated natural resources surveys, has significantly contributed in the preparation of the inventory of natural resources in different parts of Rajasthan desert and in the assessment and managment of their physical potentials. The details of the areas covered by geomorphological survey are given in Table 1.

Table 1. Areas covered by geomorphological surveys

Type of survey	Basin/district/ block/village	State	Extent in sq. km.
Reconnaissance geomorphological survey	Central Luni basin	Rajasthan	11,000.00
	Bikaner district	,,	27,336.00
		Total	38,336.00
Semi-detailed geomorphological survey*	Siwana block	Rajasthan	2,045.00
	Saila block	,,	1,455.00
	Ahor block	,,	1,590.00
	Jalor block		943.00
	Chohtan block	,,	3,164.00
	Luni block	,,	1,989.00
	Sumerpur block	,,	3,646.00
	Pali block	,,	1,400.00
	Jodhpur district	,,	22,860.00
		Total	39,092.00
Detailed geomorphological survey	Kitnod village	Rajasthan	10.00
	Nokha & Roda villages	,,	40.00
	Mahajan village	,,	10.00
	Rozu ,,	,,	0.80
	Parasurampura village	,,	43.41
		Total	104.21
		Grand Total	77,532.21

*Geomorphological survey of Nagaur district covering an area of 17,718 sq. km is in progress.

The above surveyed areas have been divided into different landform units which have also been mapped out by employing suitable geomorphological mapping techniques (Ghose and Singh, 1966) and the results of these surveys have been integrated in the form of reports. The central Luni basin, which represents all the surveyed areas, has been divided into fourteen landform units and they have been mapped in their correct positions and mutual relationships (Fig. 1). This will help to assess the physical potentials of the land for development.

The distribution and salient geomorphological characteristics of the landforms of the basin are described below.

Hills (Area 575.4 sq. km): The low and high hills, comprising of metamorphic, igneous and sedimentary rocks, occur mainly in the central, southern and southeastern parts of the region. The chief rocks of the Aravalli and Delhi systems (Archaean to Algonkian period) of Pre-Cambrian age are the metamorphic quartzite, slate, phyllite and mica-schist. These hills occurring mostly in Sumerpur and Pali blocks are of 307 to 579 metres height and have narrow ridges, conical shape and high relative relief. Khiwandi phyllite has been intruded by dolerite dykes. The hill slopes are generally rectilinear in form with 25° to 30° angles, and are covered in their lower parts with thick colluvial debris in the form of talus. All the hill slopes are highly dissected by numerous streams draining into the Luni, and its major tributaries.

The hills of 300 to 972 metres height and comprising of intrusive and extrusive igneous rocks of Lower Vindhyan period are scatterdly distributed over the southern, central and western parts of the region in the form of domes and inselbergs. The chief constituents of these hills are the Jalor and the Siwana granites of pink to red and grey colours or the rhyolites. All the granite hills are of domal shape with convex summit and concave basal slope. The convexities of the domes have, however, been interrupted by several concavities, due to weathering and erosion along the horizontal joint planes (Pandey, 1966). In many cases, the domes have also been 'splitted' along the vertical joints of granite. Spheroidal weathering along the granite hills has produced boulders of different shapes and sizes, and the hill slopes are covered with boulders. Cavernous weathering is also predominant, particularly in the porphyritic Jalor granite, and has produced semicircular tafonis of different sizes along the joints and on the individual boulders (Photo 1). The slope generally varies from 15° to 35°. The extrusive hard and massive rhyolite with vertical and horizontal joints is more resistant to weathering and are standing as rugged inselbergs and domed inselbergs. However, where the rock is more felsic than glassy, it is more susceptible to chemical weathering, producing angular and platy fragments which cover the foothills in the form of talus. The average slope varies from 15° to 35°.

The hills composed of horizontally bedded Vindhyan sandstone of early Paleozoic age, occur in extreme north western part of the region near Jhanwar village. The sandstones are of grey and red colour, ferruginous and of coarse to fine texture. The slope varies from 20° to 35°. The shape of the hills are like masas and buttes and height of these hills vary from 28 to 88 metres above ground level. In these hills, tafonies of different shape and size have been formed.

Piedmont plains (Area : 819.1 sq. km.) : In the central Luni basin, around Jalor, Siwana, Bujawar, etc., the hills are flanked at their bases by piedmont plains (Ghose *et al*, 1966), and are composed of thick colluvial debris derived from the adjoining hills. The total thickness of the sediments vary from 10 to 25 m in the upper part and 3 to 5 m in the lower part. In the upper part, large boulders and angular rock fragments of 2 to 3 m diameter are dominant and the slope varies from 5° to 10°. The lower part is covered with small pebbles, gravels and gritty sand of 2 to 3 mm size along with silt. The slope varies from 3° to 5°. At certain places, obstacle dunes and whalebacks are formed on the colluvial sediments of the piedmont plains. All these deposits have been dissected by gullies of 5 to 25 m depth and 15 to 100 m width. The drainage patterns in this unit vary from dendritic to subparallel.

Rocky/gravelly pediments (Area : 788.9 sq. km) : This unit along the base of the rhyolite, granite and quartzite hills occurs mainly around Thob, Nagarmewa, Bhadrajan, north east of Sumerpur, north and north east of Pali and are characterised by gentler slopes (Photo 2). These pediments are mostly developed at the base of the rhyolite hills and the slope varies from 3° to 8° in the upper part, 1° to 3° in the middle part and 0°8′ to 1° in the lower part. The micro variations in the rock characters have, however, definite impact on the production of debris and maintenance of a rocky pediment. It was observed that the ideal condition of a pediment is maintained when the rhyolite is more glassy than felsic and the joints are more widely spaced. In most cases, the pediments are covered with rock fragments of various sizes and shiny desert varnish are observed on their surfaces. In some parts, the granitic outcrops of 1 to 2 metres height are present in the shape of domes.

Photo 1. Semi-circular tafonis developed along the joints and on individual boulders.

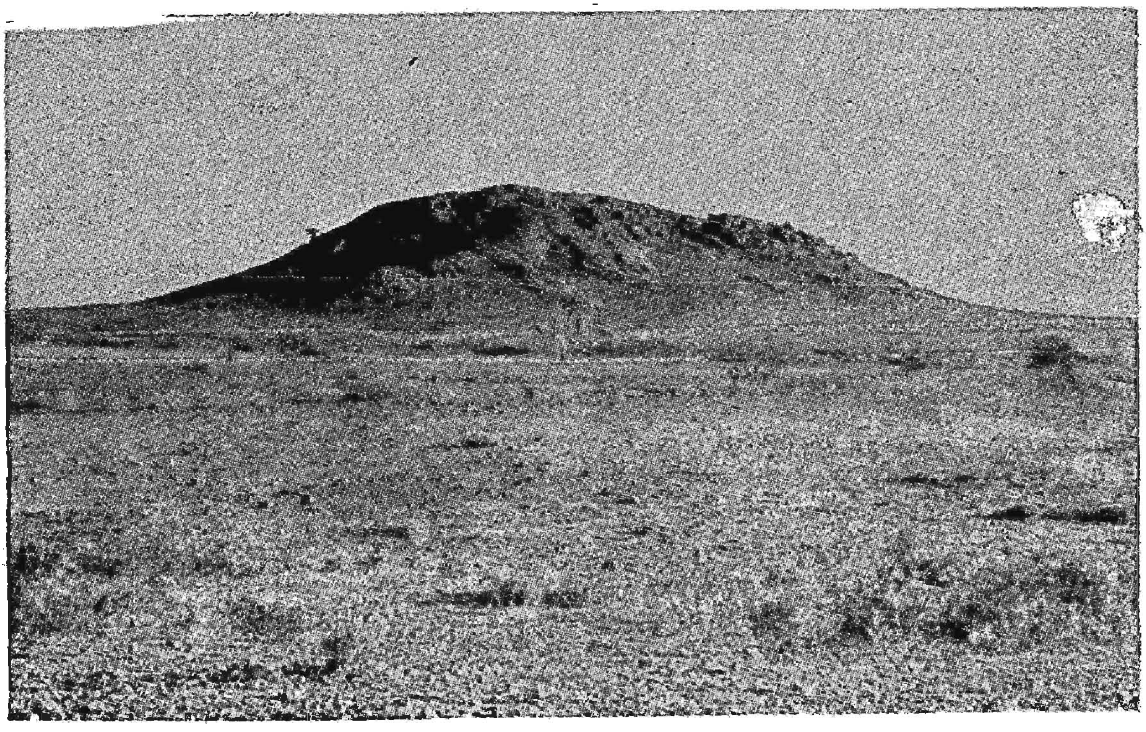


Photo 2. Rocky, gravelly pediments with gentle slope, veneer gravelly deposits and rhyolite hills in the background

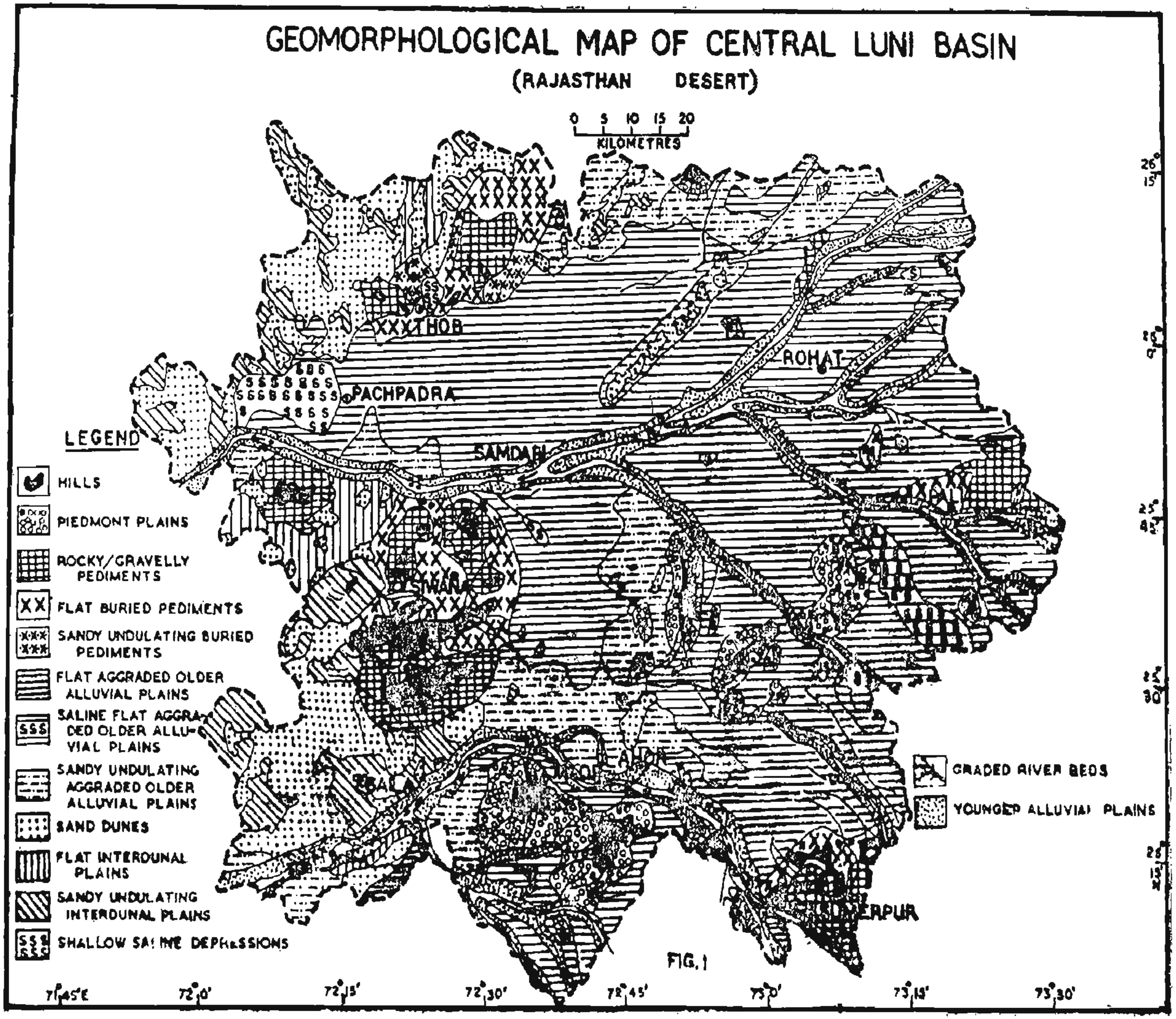

GEOMORPHOLOGICAL MAP OF CENTRAL LUNI BASIN
(RAJASTHAN DESERT)
0 5 10 15 20
KILOMETRES
THOB
PACHPADRA
SAMDARI
ROHAT
BALA
LEGEND
HILLS
PIEDMONT PLAINS
ROCKY/GRAVELLY PEDIMENTS
FLAT BURIED PEDIMENTS
SANDY UNDULATING BURIED PEDIMENTS
FLAT AGGRADED OLDER ALLUVIAL PLAINS
SALINE FLAT AGGRADED OLDER ALLUVIAL PLAINS
SANDY UNDULATING AGGRADED OLDER ALLUVIAL PLAINS
SAND DUNES
FLAT INTERDUNAL PLAINS
SANDY UNDULATING INTERDUNAL PLAINS
SHALLOW SALINE DEPRESSIONS
GRADED RIVER BEDS
YOUNGER ALLUVIAL PLAINS
71°45'E
72°0'
72°15'
72°30'
72°45'
73°0'
73°15'
73°30'
26° 15'
26° 0'
25° 45'
25° 30'
25° 15' N

FIG. 1

Flat buried pediments (Area : 867.3 sq. km) : This unit, flanking the rocky gravelly pediments, lies around Mokalsar, Ramania and Kundal and is covered with 1 to 3 m deep alluvial sediments which are mainly transported by stream channels from the adjoining hills and pedimented surfaces and are partly developed *in situ*. These alluvial sediments are underlain by hard rocky strata and *kankar* pan is absent. The diameter of the sediment particles varies from 0.06 to 0.85 mm. More than 50% of the sediment particles are, however, of 0.06 to 0.12 mm size. The slope in these plains is less than 1° and drainage channels are few. Many of the channels originating from the hills and the pediments have lost their courses in the buried pediments. However, the surface runoff that comes from the adjoining hills and rocky pediments sinks underground and accumulates along the courses of the prior drainage channels

Sandy undulating buried pediments (Area . 70.1 sq. km) . The mode of formation of this unit is similar to that of the flat buried pediments, but later on these have been affected by intense aeolian activities which created sand sheets of 50 to 200 cm thickness and sand dunes of 2 to 10 m hight, and at certain places even of 20 to 40 m height. Slope is irregular in this unit and it varies from 1° to 3°. These sandy deposits near Jalor and Kakhni have been dissected by rills and gullies of 1 to 10 m depth and 5 to 20 m width: These deposits are also underlain by rocky strata at a deeper depth.

Flat aggraded older alluvial plains (Area : 6326.6 sq. km) : This unit is most extensive and covers 38.3% area of the region. The alluvial sediments of these plains, composed of rounded to subrounded particles of quartz, hornblende, biotite and iron, have been deposited by well-integrated prior drainage channels which were active during the past humid phases (Ghose, 1965). At certain places, the sediments are developed *in situ* by weathering of bed rock. Within the alluvial deposits a thick illuviated layer of $CaCo_3$ has developed in the form of nodules, and is locally known as *kankar* pan. The coating of $CaCo_3$ is usually on the parent weathered materials occurring below the alluvial deposits. The depth of the *Kankar* pan varies from 7 cm to 180 cm. The nature of the surface sediments varies from loamy sand to sandy loam and also loam, but at certain places in pockets silty clay loam to clay loam are found. The size of the sediment particles varies from 0.06 to. 0.84 mm, but more than 60% of the sediment particles have diameter of 0.06 to 0.18 mm. Slope is less than 1° in this unit and surface drainage channels are almost absent, except in the eastern fringe. The quality of ground water along the courses of the prior drainage channels is good.

Saline flat aggraded older alluvial plains (Area : 171.89 sq. km) : This unit occurs between Rupawas and Gondoch, Peswas and Nimbla and Pachpadra and Patau. The flat aggraded older alluvial plains have become saline at certain places due to impeded drainage conditions: Construction of tanks and canals across the courses of these buried channels result in surface and subsurface waterlogging. Consequently the subsurface salts along the prior drainage channels come up to the surface through evaporation and capiliary action and turn the agricultural fields saline (Ghose *et al.*, 1975). Mostly such salinity occurs in the medium to heavy textured flat aggraded older alluvial plain. The slope is nearly level with less than 1^0. The *kankar* pan has been encountered at a depth of 200 to 300 cm. The diameter of the sediment particles of this unit varies from 0.06 to 0.25 mm.

Sandy undulating aggraded older alluvial plains (Area : 1649.7 sq. km) : The mode of evolution of this unit is the same as of the flat aggraded older alluvial plain, but later on this unit has been affected by intense aeolian activities which have created sand sheets of 20 to 300 cm thickness, longitudinal and transverse dunes of 90 cm to 5 m height and sandy hummocks and ridges of 30 cm to 1 m height over the flat alluvial plains. As a result, the slope in this unit is irregular and it varies from 1^0 to 3^0. Within the sandy deposits, a weakly developed layer of $CaCo_3$ has been observed in some parts of the desert. The hard layer of $CaCo_3$ within the alluvial deposits which are overlain by aeolian deposits, has been found at 400 cm depth. The size of the sediment particles varies from 0.06 to 0 59 mm and particles of more than 0.59 mm size are almost absent. Drainage channels are almost absent in this unit.

Sand dunes (Area : 1474.5 sq km) : The unit occurs mostly in the western and north western parts of the region. In this region six types of sand dunes viz., obstacle, parabolic and coalesced parabolic, longitudinal, transverse, barchan and shrub-coppice have been encountered.

The first four types of dunes are stabilized and fossilised and have well developed nodular or finger type lime concretions of 1 to 100 mm size. They are of 10 to 80 m hight. The windward slopes are gentler and the leeward slopes are steep. These dunes could be developed into good grasslands. The diameter of sand grains in these dunes vary from 0.06 to 0.25 mm.

Barchans and shrub-coppice dunes have been formed in recent period. They are active and constituted of noncalcareous sands. The barchan dunes are of 3 to 10 m height. The sand grains in the barchan dunes are of 0.06 to 0.25 mm size, but the sand grains of 0.18 mm size are dominant. The shrub-coppice dunes are generally of 0.5 to 3 m height and occur in the form of sand mounds, fence-line hummocks and low longitudinal and transverse ridges. The sand grains of these dunes are finer than in all other types of dunes and the average diameter of the sand grains is 0.11 mm.

Flat interdunal plains (Area : 258.5 sq. km) : This unit within the duny tracts, mostly occur between the stabilised coalesced parabolic, longitudinal and transverse dunes in the western part of the region. The slope is here less than 1°. Texture of the surface sediment varies from loamy sand to sandy loam in pockets. The size of the sediment particles varies from 0.06 to 1.19 mm; but 60 percent of the sediment particles are of 0.06 to 0.12 mm size. These sediments are underlain, at 30 to 180 cm depth, by a hard lime concretionary layer.

Sandy undulating interdunal plains (Area : 967.4 sq. km) : This unit is more widespread than the flat interdunal plains and occurs between the stabilised dunes around Bautra, Padru, Dakhan, Dudwa and Bhimarlai villages. Intense aeolian activities have created undulations on the alluvial surfaces of this unit in the form of sand sheets of 100 to 400 cm thickness, sandy hummocks of 1 to 3 m height and low longitudinal and transverse dunes of 3 to 5 m height. The size of the sand grains varies from 0.06 to 0.59 mm. Slope is irregular and varies from 1° to 3°.

Shallow saline depressions (Area 348.6 sq. km) . The saline depressions of different shapes and sizes are distributed within the region. They mostly occur at Thob, Pachpadra, Chanaud, Sanwarla, Samuja and Bhadrajan. Among these, the Pachpadra saline depression covers the largest area. These saline depressions are the gathering grounds of salts and evaporites (Ghose and Singh, 1968). The generalized stratigraphy of the saline depressions is characterised by a layer of silt and clay with sand admixture, overlain by a thin layer of blown sand and underlain by a layer of sand, followed by another layer of silt and clay with *kankar* nodules (Singh and Ghose, 1976). The surface of these depressions are nearly level with less than 1° slope. The size of the sediment particles varies from 0.06 to 1.19 mm, and the particles of 0.06 to 0.07 mm diameter are predominant.

Graded river beds (Area : 522.1 sq. km) : The Luni river and its major tributaries like the Khari, the Bandi, the Sukri, the Jawai, the Mitri and the Sagi have graded their courses in the long period of their evolutionary history. The longitudinal profiles of the Luni, the Sukri, the Jawai and the Khari have the gradients of 1 : 600, 1 : 600, 1 : 500 and 1 : 550 respectively (Singh *et al.* 1971). It has also been worked out that in the case of the Luni, the gradient is 1 : 500 in the upper reaches and 1 : 1000 in the lower reaches. All the above streams have wide, flat sandy beds with sand bars of different size. In the bed of the Luni, the sand bars are of 500 to 700 m length and 250 to 300 m width while in the beds of the Jawai and the Khari, the length and width of the sand bars are 600 to 700 m and 300 to 400 m respectively (Singh *et al.* 1971). The diameter of the sediment particles of the river beds varies from 0.06 to 1.19 mm and the particles of 0.59 to 1.19 mm size are dominant. The river banks are cut vertically during the heavy floods.

Younger alluvial plains (Area : 1618.0 sq. km) : These plains, in narrow strips, have been formed along the banks of the Luni river and its major tributaries due to the occasional flooding in the rivers and consequent overbank deposition of riverine materials. The plains occur in all the development blocks of the region. The width of the plains vary from 1000 to 6000 m; and it is widest along the lower and middle reaches of the Luni. The texture of the surface sediments vary from sand to loamy sand, sandy loam and also loam. The depth of the sediment vary from 10 to 20 m and *kankar* pan is absent. The size of the sediment particles varies from 0.06 to 1.19 mm., and the mean diameter of the sediment particles is 0.39 mm. In some parts of these plains, especially near the banks, sandy hummocks of 50 cm to 2 m height and longitudinal and transverse dunes of 3 to 6 m height have been formed due to the reworking of the riverine sands and their deposition along the banks by aeolian processes. Excepting the above parts, the plains are nearly level, with less than 1° slope. At certain places of these level plains, salinity has developed due to the construction of dams across the Luni, the Mitri, the Bandi and the Jawai rivers and the fertile agricultural lands have turned into saline lands.

3. GEOMORPHOLOGY AND ENVIRONMENTAL PROBLEMS

Erosional, depositional, and salinity hazards, sand dunes and lateral shifting of the rivers are the major environmental problems which are related to the interaction between man, land and water. Geomorphology is an important element of the complex environment and plays a significant role in identifying and providing suitable solution to these environmental problems. The origin and distribution of these problems are discussed under different subheads of this chapter.

3.1 Erosional, Depositional and Salinity Hazards

The erosional, depositional and salinity hazards created by the geomorphic processes and/or accelerated by the human activities, are the major factors which limit the agricultural productivity in the Rajasthan desert. Hence, the studies on the type, degree and extent of these hazards are of paramount importance for the reclamation and development of desert regions. So far, such studies have been conducted in the central Luni basin, Jodhpur and Bikaner districts and in parts of Nagaur district.

The studies have revealed that the hazards of different intensities, created by various processes, occur in different landforms of these regions. These hazards, according to their different intensities and processes, have been classified into slight, moderate, severe and very severe water, wind and salinity hazards. The areas of the different landforms within the central Luni basin, affected by the erosional, depositional and salinity hazards of different intensities, have been mapped (Fig. 2) and are presented in Table 2. The origin and distribution of these hazards have been discussed under different subheads.

3.1.1. Origin and distribution of water erosional hazards

The water erosional hazards in the form of sheet, rill and gully have been created by the running water in the different landforms of the central Luni basin. The sheet erosion is predominent in the flat aggraded older alluvial plains. At certain places, due to severe intensity of water erosional hazard, the top soil has been removed and the underlying *kankar* pan has been exposed to the surface. Rill and gully hazards are mainly concentrated in the hills, piedmont plains, rocky pediments and parts of the buried pediments because of the higher intensity of runoff, steeper slope and nature of sediments obtained in these units. In general, the depth of the rills vary from 0.5 to 2 m and that of the gullies from 2 to 10 m. The rills have less than 1 m width but the gullies are of 3 to 10 m or even 20 m width. Excepting these activities, the major streams affect certain parts of the younger alluvial plains through bank cutting during the floods. The slight to moderate sheet erosional hazard along with severe gully hazard in parts, is predominant in the flat aggraded older alluvial plains around Sandera, Rajpura, Sankwati, Keswana, etc. Moderate sheet to rill and gully hazard is dominant in the flat buried pediments, around Siwana, Nenri, Korna, etc. But, the isolated small hills are affected by moderate rill to gully hazard, while the hills with larger area and relief are affected by severe rill to gully hazard. The major parts of the piedmont plains, rocky pediments and flat buried pediments around Jalor, Bhagli, Narnawa, Mera, Bankli, Bujana, Mokalsar, Gura, Thapan, Baria, etc., are affected by moderate to severe rill and severe to very severe gully hazard. Moderate to severe stream bank erosion is present along the courses of the Guhia, the Bandi, the Sukri, the Jawai and the Khari rivers.

About 3858.0 sq. km area of this region has been affected by the water erosional hazards of different intensities.

3. 1.2 Origin and distribution of wind erosional and depositional hazards

The aeolian activities are mainly responsible for the creation of hazards in different landforms through the deflation of aeolian and fluvial sediments or through the deposition of aeolian sands. The process of sand deflation has been termed as the wind erosional hazard while the deposition of the sand has been termed as wind depositional hazard. During the summer months, the whirlwinds scoop out the fine sands and the top layer of alluvial sediments from the cultivated fields and expose the underlying *kankar* pan to surface, especially where the soil is shallow. In the central Luni basin, such wind erosional hazard is of slight magnitude in the flat interdunal plain to the north of Pantheri and of moderate to severe magnitude around Semarkhia, Ada and Tapra in the flat interdunal plains. The total area of the basin affected by wind erosional hazard is 253.1 sq. km.

In contrast, the wind depositional hazard in the form of sand sheets of 50 to 200 cm thickness, sandy hummocks of 1 to 5 m height, low longitudinal and transverse ridges 3 to 6 m height and fresh sand deposition along the dune slopes, has affected a greater area. Slight and slight to moderate wind depositional hazards have affected parts of the sandy undulating aggraded older alluvial plain around Harmu, Komtran, etc., and parts of sand dunes around Pantheri. Sufficient areas in the sandy undulating older alluvial and interdunal plains have been affected by moderate and moderate to severe wind depositional hazards around Hingola, Jhanwar, Fithkasni, Bhandla, Baori, Bokra, Khar, Reotha, Balau, Nawatala, Akarli, Sarana and Bautra. Severe and very severe wind depositional hazards have affected mainly the duny areas around Nawatala, Patodi, Baguri, Mithura, Pau, Dewara, etc., and parts of the sandy undulating interdunal plains around Chanderra and Bhimarlai. The total area affected by wind depositional hazard is 3453.8 sq. km.

3. 1.3 Origin and distribution of salinity hazards

The salinity of soil is another major hazard which affects the agricultural productivity of land. Formerly it was believed by Holland and Christie (1909) and Godbole (1952) that the soil salinity in the Rajasthan desert is linked with wind borne particles from Rann of Kutch and marine regression. The geomorphologists at the CAZRI, however, have contradicted these earlier concepts and have proved that the origin and distribution of the salt lakes are linked with the courses of the prior drainage channels. It has also been proved that

EROSIONAL, DEPOSITIONAL AND SALINITY HAZARDS IN CENTRAL LUNI BASIN (RAJASTHAN DESERT)

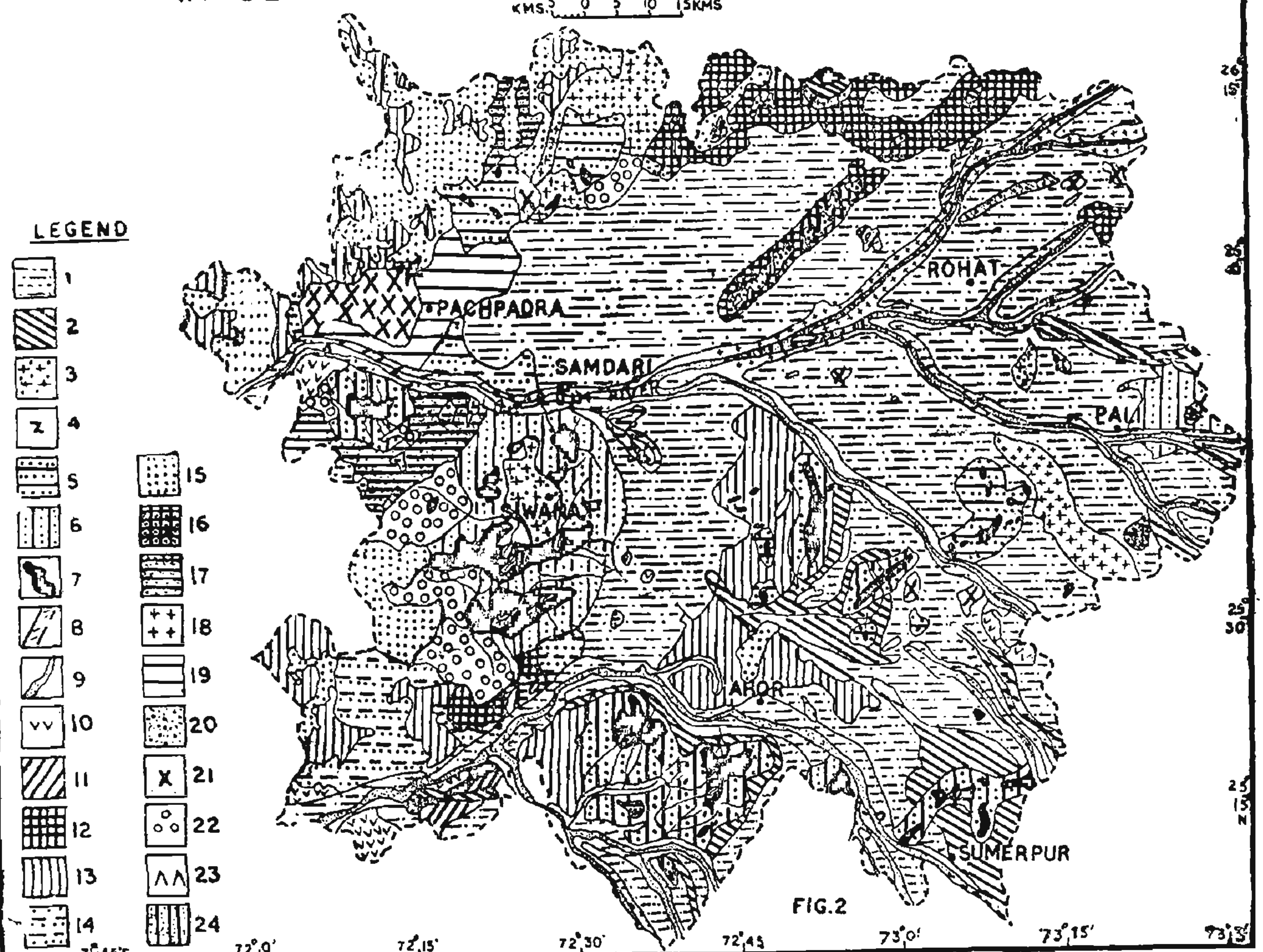


FIG.2

1. Free from hazards
2. Slight to moderate sheet and severe gully hazard
3. Moderate sheet to rill and gully hazard
4. Moderate rill to gully hazard
5. Moderate to severe rill and gully hazard
6. Moderate to severe rill and severe to very severe gully hazard
7. Severe rill to gully hazard
8. Severe to very severe sheet to gully hazard
9. Moderate to severe stream bank erosional hazard
10. Slight wind depositional hazard
11. Slight to moderate wind depositional hazard
12. Moderate wind depositional hazard
13. Moderate to severe wind depositional hazard
14. Severe wind depositional hazard
15. Very severe wind depositional hazard
16. Slight wind erosional hazard
17. Moderate to severe wind erosional hazard
18. Slight to moderate salinity hazard
19. Moderate salinity hazard
20. Severe salinity hazard
21. Severe to very severe salinity hazard
22. Moderate to severe gully and severe to very severe wind depositional hazards
23. Moderate to severe stream bank erosional and wind depositional hazards
24. Moderate stream bank erosional and slight to moderate salinity hazards

there are two types of salinity in the Indian desert–one is 'natural', comprising the 'ranns' and other saline depressions, and the other is 'man-induced', occuring in the medium to heavy textured alluvial plains. Both types of salinity hazards are linked with the courses of the prior drainage channels (Ghose *et al*, 1975).

(i) *Natural salinity :* It has now been established that the salt basins are nothing but the relics of the prior well-integrated drainage systems (Ghose, 1964; Ghose and Singh, 1968). Along with the sediments of different composition, mineral salts detached in soluble form from the parent material, were carried downstream along the channels and precipitated according to their solubility. For example, calcium and sodium chloride was deposited in the lower reaches and at confluences. In the central Luni basin, the saline depressions of Thob, Pachpadra, Sanwarla, Bhetnada, etc., are the relics of the prior well-integrated Luni-Jawai drainage system.

The generalized stratigraphy of these saline depressions is : silt and clay with sand admixture, overlain by a thin layer of blown sand and underlain by sand. Below the sand a thick layer of silt and clay with *kankar* nodules occurs above the basement rocks. These depressions are affected by severe to very severe salinity hazard, while severe salinity hazard is present along the prior course of the Agaria Nala from Mori Manana to Nimbla.

(ii) *Man-induced salinity hazard :* The man-induced salinity has resulted in recent times, because of the construction of tanks and canals along the courses of the prior drainage channels.

Such constructions along or across the prior drainage channels result in surface and subsurface waterlogging. Consequently the subsurface salts along the prior drainage channels come up to the surface through evaporation and capillary action and turn the agricultural lands saline. Such salinity is of slight to moderate intensity in the saline older alluvial plain around Gondoch, Madri and Rupawas and in the younger alluvial plains of the Luni upto Khantia. The salinity is of moderate intensity around Gopri, Nawai and Pachpadra in the flat aggraded older alluvial plain.

A total of 962.1 sq.km area of the basin has been affected by natural and man-induced salinity hazards.

Some parts of certain landforms of the central Luni basin have also been affected by the combined effectes of two hazards and it has been termed as 'complex hazard'. Moderate to severe gully and severe to very severe wind deposition hazards have affected significant parts of the rocky pediments around Kankhi, sand dunes around Simalia; Ada, etc. and sandy undulating interdunal plains around Indrana, Siner, Kuaber, Padru, etc. The Luni river bed from Golio to Khantia and the bed of the Mitri are affected by moderate salinity hazards. From Khantia downstream, the bed of the Luni is affected by moderate to severe stream bank erosional and wind depositional hazards. The total area affected by these combined activities is 701.1 sq.km.

From the above investigations, it has been concluded that out of the total **16528.0** sq km area of the central Luni basin, 9228.1 sq.km is affected by the various hazards of different intensities and the remaining 7299.9 sq.km is free from any hazard.

3.2 Dynamics of Sand Dunes

The sand dunes are the most spectacular features of the Rajasthan desert and about 58 per cent of this region is covered with the sand dunes of different form, magnitude and orientation. The intensity increases from east to west. Due to intense biotic activities, the stabilised dunes are reactivated and the sands are carried away by the strong southwest winds and are deposited on the agricultural lands in the form of active dunes and sand sheets which affect the production of food and fodder. The dunes are not only a menace to the farmers but also to the roads, railway tracts and permanent structures. They are, therefore, one of the major problems of the Rajasthan desert and hence, detailed investigations on the dynamics of sand dunes are of paramount importance. Geomorphological investigations on the types, origin, distribution and morphology of the sand dunes, source of dune sand and dune systems have been carried out in the central Luni basin, Bikaner district and Jodhpur district (Pandey *et al*, 1964; Vats *et al*, 1976; Singh, 1977). The results of these investigations reveal that the sand dunes of these areas are of six types viz., obstacle, parabolic and coalesced parabolic, longitudinal, transverse, barchan and shrub-coppice. The first four types of dunes are of old dune system and the remaining two types of dunes belong to the new dune system. The analysis of the sand samples collected along a traverse line running from Rann of Kutch to the north east extremity of the desert indicated that the dunes are formed of local sands and not of the Rann of Kutch. The results of the investigations carried out on the dynamics of sand dune development in the central Luni basin have been discussed below in detail.

3.2.1 Types, Distribution and Morophology of the Sand Dunes

The sand dunes in the central Luni basin are mostly concentrated in the western, northwestern and southwestern parts. In this basin, six types of sand dunes viz., obstacle, parabolic and coalesced parabolic, longitudinal, transverse, barchan and shrub-coppice have been identified and mapped (Fig. 3).

(i) *Obstacle dunes :* The dunes formed against the windward and/or leeward slopes of the existing major hills have been termed as windward and leeward obstacle dunes. The windward obstacle dunes, in the form of sand shields and longitudinal ridges, occur along the south western flanks of the hills near Jalor, Bhadrajan, Kankhni, Israna etc. These dunes are of 30 to 45 m height, well cemented and static. The size of the sand grains varies from 0.06 to 0.25 mm and the average diameter comes to 0.14 mm. The leeward obstacle dunes exist in the northeast side of Bhadrajan and Jalore hills and they gently move upslope. These dunes are of 18 to 20 m height and are not widely spread. The presence of the leeward obstacle dunes indicate that the northeasterly winds are sometime of sufficient force and frequency to affect the aeolian morphology of the area.

(ii) *Parabolic and coalesced parabolic dunes :* These dunes are approximately in the form of parabola and have gentler 1° to 3° windward slope. The slopes of the leeward side and flanks are 20°–22° and 1°–3° respectively. The coalesced parabolic dunes have been formed by fusing together a number of parabolic dunes. There are two broad zones of these dunes within the region–one is in the Nawatala-Gol-Sajialo sector to the north of the Luni and the other is in the Kaluri-Dakhan-Bhata-Sarana sector to the south of the Luni. Excepting these zones, the areas around Hingola, Chincharli, Kagnada and Salawas in the north and around Nosra in the central part also have parabolic and coalesced parabolic dunes. The height of these dunes vary from 30 to 45 m in the Nawatala-Gol-Sajialo sector, 65 to 135 m in the Kaluri-Sarana sector and 20 to 35 m in the other parts. The axial direction varies from N 45°E to N 50°E, i.e, approximately along the direction of the prevailing southwest wind. The average length and width of the coalesced parabolic dunes are 1 to 2 km and 200 to 300 m respectively. The average spacing between the dune chains is 1 to 5 km. In all the sectors, these dunes are well stabilized, but along the crests and flanks of some of these dunes fresh sand deposits have been encountered. The sand grains vary in size from 0.06 to 0.25 mm and the average diameter is 0.14 mm.

(iii) *Longitudinal dunes :* These dunes occur in the Bautra-Kura Jeran-Punawas sector of the region and are oriented N 45°E to N 50°E, i. e. along the direction of the prevailing southwest wind. These dunes are longest among all the dune types and are 1.5 to 8 km in length and 200 to 220 m in width. The slopes of the leeward side, flanks and windward side of these dunes vary from 20° to 24°, 11° to 15° and 2° to 3° respectively. All the dunes are well stabilised and are of 15 to 16 m height. The sand grains of these dunes vary in size from 0.06 to 0.18 mm, but the sand grains of 0.12 to 0.14 mm size are predominant.

(iv) *Transverse dunes :* These dunes of 12 to 15 m height are concentrated in Gura-Indrana-Sinar sector and in Changari-Sedria sector. The orientation of these dunes is N 35° W to N 40° W, i. e. almost across the path of the prevailing southwest wind. The length of the dunes vary from 1.5 to 2 km while the width is about 400 m. Slopes of these dunes vary from 16° to 20° along the leeward side, 8° to 11° along the flanks and 1° to 2° along the windward side. The sand grains vary in size from 0.06 to 0.18 mm, but the average diameter of sand grains is 0.12 mm.

(v) *Barchan dunes :* These dunes of crescent shape are very few within the region and occur in the interdunal plains to the north of Gopri in the north-west. In contrast to the above four types of dunes, these dunes are active and are formed in the prevailing southwest to northeast wind direction. The height of these dunes vary from 3 to 5 m and the slopes along the leeward side, flanks and windward side are 10°-15°, 3°-6° and 1°-2° respectively, The sands are non-calcareous. Size of the sand grains vary from 0.06 to 0.18 mm diameter, but the sand grains of 0.12 mm size are dominant.

(vi) *Shrub–coppice dunes :* These are formed against shrubs, bushes and fences and do not have any definite shape. Like the barchans, these dunes are also active and have 1 to 3 m height. Slope is highly irregular. These dunes are found mainly in the sandy undulating interdunal plains and sandy undulating aggraded older alluvial plains in the western part of the region. The size of the sand grains vary from 0.06 to 0.18 mm and the average diameter of the grains vary from 0.12 to 0.14 mm.

3. 2. 2 Source and Origin of Dune Sands

The source and origin of the dune sands has been a controversial subject. Wadia (1961) has reported that the dune sands of this region have been largely transported by southwest winds from Rann of Kutch and they are of marine origin. Contrary to it, the geomorphological investigations on the size and shape of the grains of the dune sands revealed that these sands have been locally derived from the existing landforms by the aeolian process under the prolonged arid climatic phases and are of aeolian origin.

(i) *Source of the dune sands :* The magnitude, shape, orientation and distribution of the sand dunes depend upon the size of the sand grains as the coarse grains drop at a shorter distance while the fine sand grains continue their flight downward to varying distances, depending upon the velocity of the prevailing winds and the violence of the eddies in the leeward side of the dunes. The statistical analysis to compare the mean diameter of the grains of the dune sand from two blocks viz., Chohtan block which is near to the Rann of Kutch and the Ahor block which lies far away from the Rann of Kutch, was done and the calculated values of the mean, standard deviation and the coefficient of variation are given in the Table 3.

Table 3. Analysis of the size of sand grains in sand dunes

S. No.	Block	Mean (mm)	Standard deviation (mm)	Coefficient of variation %	t
1.	Chohtan block	0.120	0.0025	4.16	2.57*
2.	Ahor block	0.156	0.0270	17.31	

*Significant at 5 per cent probability level.

From the above table, it may be inferred that there is significant difference between the mean diameter of the grains of the dune sands from two blocks. The lower values of the mean, standard deviation and coefficient of variation of the mean diameter of the sand grains indicate that the dune sands of the Chohtan block are finer than that of the Ahor block. The significance of the difference between the size of the sand grains in two blocks has been tested by using t-test, which shows that the difference between the sand grain size is statistically significant at 5% probability level. The significant difference between the size of the sand grains conclusively proves that dune sands have been locally derived by intense aeolian activities from the existing landforms of these blocks and have not been transported from Rann of Kutch as advocated by Wadia (1961). If it had been true that the source of dune sands is Rann of Kutch, then the sands of the Ahor block, which lies far away from the source region of dune sands, should have been finer. The study on the size distribution of sand grains at various depth along the different slopes of the dunes in Phalodi and Osian tehsils has also indicated that dune sands in Phalodi tehsil, which is nearer to Rann of Kutch, are finer than that of Osian tehsil. The results of this study also confirms that the dune sands have not been transported from Rann of Kutch but have originated from the local rocks and other landforms under the physico-chemical reaction of the weathering and erosion agencies.

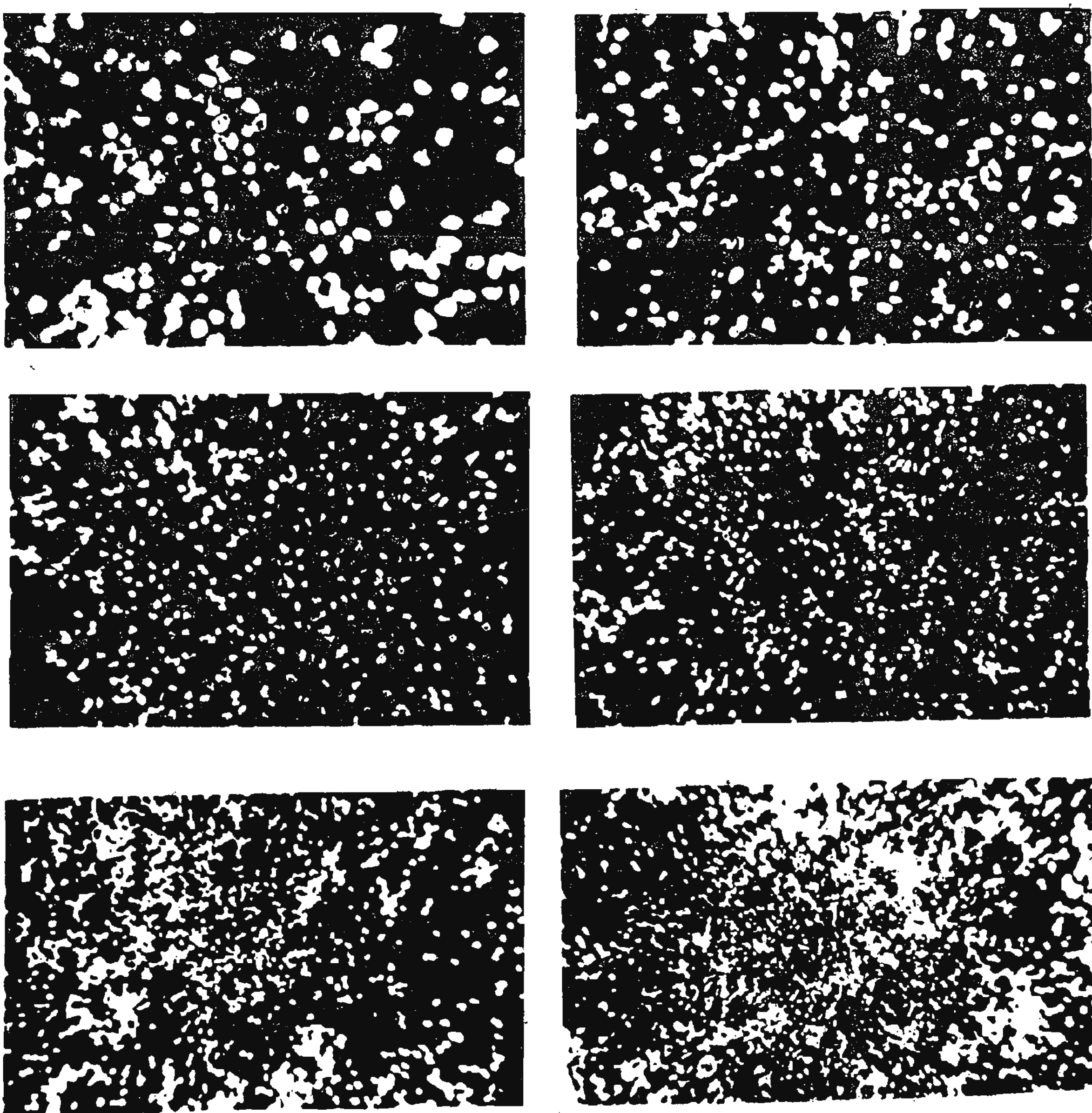
The mineral analysis of the dune sands has shown that the predominant minerals in the sands are quartz, hornblende, felspar and mica. The Aravallis metamorphic rocks and the igneous rocks of this region consist almost the similar minerals. This indicates that the sediments were reworked by aeolian activities and were transported by the prevailing winds through saltation and surface creep processes to form the sand dunes of the Rajasthan desert.

(ii) *Origin of dune sands :* The analysis of the size and shape of the sand grains from different parts of the Rajasthan desert has indicated that the dune sands are of aeolian origin and not of marine or fluvial origin. It is observed from Table 4 that 60 to 75 per cent sand grains in all the six types of dunes are of 0.06 to 0.12 mm size which reveals that the dune sands were originated under arid phases by aeolian process. The average size of the sand grains varies from 0.12 to 0.14 mm which is much below the average diameter of 0.3 mm for aeolian sands, reported by Bagnold (1941) for Libiyan desert. The microscopic examination and the microphotographs of the sand grains (Fig. 4) and their comparison with the five standard roundness classes of Faber (1960) have shown that more than 75 per cent of the sand grains are of subrounded to rounded and also well rounded shape. The roundness in the sand grains has been caused during wind transportation by abrasion such as bouncing off obstructions and wearing off their irregularities and not due to the capacity of winds to pick up the rounded particles reported by Pettijohn and Lundahl (1943). There is, however, very small percentage of subangular sand grains of more than 0.12 mm size. The micro-photographs of the sand grains also show that there is a difference in the roundness of various size of sand grains which increases with the decrease in the size.

The examination of the soil profiles in sand dunes also reveals that the sands are of aeolian origin. It is seen from the mechanical composition of the dune profile (Table 5) that the fine sands are predominant throughout the profile, which bears clear testimony to their aeolian origin.

3.2.3 Sand dune systems

The studies on the dynamics of sand dunes in different parts of the Rajasthan desert have revealed that there are two dune systems viz., old and new. The dunes of old system were formed by intensive dune building acti-



SIZE AND SHAPE OF SAND GRAINS IN SAND DUNES

(a) Size: 0·25 to 0·18 mm; Shape: angular to sub angular

(b) Size. 0·15 to 0·12 mm; Shape: sub angular to sub rounded

(c) Size: 0·07 to 0·06 mm; Shape: rounded to well rounded

FIG. 4

Table 4. Percentage grain size distribution of surface sands in different type of sand dunes

No.	Type and site of dune	Sand grain diameter in mm						Average
		0.25	0.18	0.15	0.12	0.07	0.06	
1.	Obstacle dune (Adhur Bhakari) Shergarh	1.03%	3.37%	20.84%	45.20%	28.26%	1.31%	0.14
2.	Parabolic dune (Dabari village)	2.09%	8.08%	22.73%	41.78%	21.45%	3.87%	0.14
3.	Longitudinal dune (Jethania village)	0.91%	13.66%	18.12%	23.56%	40.73%	3.02%	0.14
4.	Transverse dune (Near Chhatargarh)	—	31.46%	11.22%	28.46%	21.38%	7.48%	0.12
5.	Barchan dune (Shergarh, south of Kairliwala Dhora)	—	5.05%	23.78%	31.90%	37.55%	1.72%	0.12
6.	Shrub-coppice dune between Chordiya and Jethania	—	14.36%	23.45%	20.91%	39.36%	1.92%	0.12

Table 5. Soil profile in sand dunes

Depth in cm.	Mechanical composition			
	Coarse sand %	Fine sand %	Silt %	Clay %
0-5	4.0	91.0	1.0	4.0
5-25	5.2	90.0	1.1	3.7
25-50	7.1	88.6	0.9	3.4
50-100	5.6	90.7	0.7	3.0
100-200	3.7	91.0	1.6	3.7
200-300	3.1	92.8	1.7	2.4
300-400	10.7	86.1	1.0	2.2
400-500	6.0	90.0	1.0	3.0
500-600	8.4	87.5	1.0	3.0
600-700	3.4	91.3	1.7	3.6

vities during the earlier prolonged arid climatic phases. These dunes are of high relief, well stabilised, vegetated and cemented. The dunes to the east of 300 mm isohyet do not have fresh sand accumulation along their crests and flanks, but to the west of this isohyet the crests and flanks of these dunes have been reactivated by cultivation and grazing and are covered with thick sand deposits. The sand dunes of new system have been formed in the Recent arid climatic phase, due to the renewed aeolian activities and are still in evolutionary stage. In the central Luni basin, two dune systems have been recognised and mapped (Fig. 3) and the salient characteristics of these systems are discussed below.

(i) *Sand dunes of old system :* The obstacle, paraboilc and coalesced parabolic, longitudinal, and transverse dunes are of high relief and maturity and belong to the old system. These sand dunes occur in the western part of the region and occupy an area of 2604.5 sq. km. The dunes are fossilised and well cemented. The soil development in these dunes is in an advanced stage of progress and the soil profile is in semi-matured stage. The percentage of $CaCo_3$ varies from 3 to 5% and 5 to 10% which keeps the sand particles bound together. The dunes are deeply weathered and the finger type lime nodules of 8 to 10 cm length and 2 to 3 cm width are exposed along their flanks, leeward and windward sides. Fluvial action has created rills and gullies of different dimensions in these dunes and the irregularities developed at the time of their formation have been removed and smoothed by the slope wash and mass movement. A comparative annlysis of the toposheets of the year 1934 and the recent aerial photographs revealed that the height of some sand dunes have been reduced by 2 to 3 m and they are in eluvial phase and new dunes of this system are not being formed. However, the crests of certain stabilised sand dunes have been reactivated by biotic activities which may again be stabilised by natural regeneration of plants in due course of time. The presence of the tree vegetation viz., *Acacia senegal* (20–40/ha), *Prosopis cineraria* (8–20/ha), *Maytenus emarginata* (30–50/ha) and *Balanites aegyptiaca* (10–46/ha) on these dunes also suggest that they are highly stabilised. The advanced stage of soil development, the dissections, the layers of lime concretions along the dune slopes, reduction in heights of the dunes and the high density of tree vegetatian conclusively prove that the dunes of the old system are well stabilised and do not need any plantation to ensure their stability, if they are protected from biotic interference.

(ii) *Sand dunes of new system :* The sand dunes of this system are barchans, shrub–coppice, longitudinal and transverse ridges. These dunes are active, smaller in size and have different morphological characteristics than the dunes of old system. These dunes occupy an area of 1233.3 sq.km and occur in the sandy undulating aggraded older alluvial and interdunal plains. The sands are loose, non–calcareous, have only 1.2% $CaCo_3$ and the lime concretions are absent. The dunes of this system are the greatest menace to the agricultural fields, settlements, roads, railway lines and other permanent structures. These dunes, therefore, need immediate attention for their rehabilitation by suitable stabilisation techniques. If these dunes, which constitute only 7.5% of the total area, are stabilised the entire region will be protected from the menace of shifting sand. These sand dunes have more than 3% moisture after I0 to 25 cm depth and it increases with the increase in depth. Krishnan *et al*; (1966) have also reported that high moisture concentration (75 %) occurs below 1.5 m depth in unstabilised sand dunes throughout the year. These active sand dunes, due to the presence of sufficient moisture in them, provide favourable conditions for stabilisation by suitable plant species.

Saxena and Singh (1976) have suggested that locally adapted indigenous species like *Zizyphus nummularia, Capparis decidua, Calligonum polygonoides, Acacia senegal* and *Lasiurus sindicus* can be used for the stabilisation of the active dunes. These species will thrive well on these dunes and their regeneration will be quite effective while majority of exotics fail to survive under Indian conditions.

3. 3 Dynamics of River Systems

Rivers form an essential element in man's use of environment and they are dynamic systems. Geomorphological investigations on the dynamics of rivers and particulary the effects of lateral sapping of the river beds have large scope of practical application in the management of environment. During high floods, the damage caused by the rivers at the point of meandering are enormous. Since the courses of the rivers oscillate across the meandering belt, sometimes they cause havoc on right bank side and sometimes on the left and consequently any structure such as bridge, dam, road, pump house and settlement etc., are at a great risk, specially in arid lands where torrents of rain and floods are unpredictable. The power of such devastations caused by periodic floods in the rivers are the effect of the morphological characteristics such as amplitude, mean radius of curvature, length of meander belt and width of the meander belt of the meandering streams which determine the flood discharge capacity through that point of meander.

In view of the significance of knowledge on the behaviour of the river systems in the environmental management of Rajasthan desert, geomorphological investigations on the interrelationships between morphological characteristics of the Sukri–Jawai river system and also on the nature and size of their bed materials were conducted (Pandey *et al;* 1972) and the results are discussed below.

3. 3. 1 Relationships between different morphological characteristics of the meandering rivers

The range, mean and coefficient of variation of the different morphological characteristics of the meandering streams of the Sukri–Jawai system (Table 6) indicate that the length of the meander belt has the maximum range, whereas the width of the existing channel has the minimum range. The coefficient of variation is the highest for the width of the meander belt and the lowest is for the mean radius of curvature. It ranges from 20.60 to 44.86 for all the five characteristics.

Table 6. Values of range, mean and coefficient of variation for different characteristics of the meandering rivers in the Sukri-Jawai system

Characteristics	Range (in metres)	Mean (in metres)	Coefficient of variation
Length of meander belt	1931–4380	3071.0	27.49
Width of meander belt	515–1890	1192.8	44.86
Width of existing channel	96–265	191.9	32.04
Amplitude	261–990	587.6	37.68
Mean radius of curvature	257–450	358.1	20.60

Table 7 shows the total correlation coefficient between all possible pairs of the 5 characteristics. The data show that only length, width and amplitude of the meander belt are significantly correlated with width of the existing channel. The length and width of the meander belt are also mutually dependent upon each other. The rest of the correlations are non-significant.

The relevant simple regression equations are given in table 8 with the corresponding values of correlation and coefficient of determination. The equations can be utilised to predict the length, the width and the amplitude of meander belt by knowing the width of the existing channel within its range of 96–265 metres in the given environment. The length of the meander belt can also be predicted by its width.

From the result of this study, it has been inferred that the meandering course of the streams can swing in the meander belt from 515 to 1890 metres. The lands lying within this meander belt are unstable and these should not be used for constructing permanent structures. During 1967 flood the newly constructed bridge on the Mitri river was breached as the river eroded the land on both the sides of the bridge. It is, therefore, concluded that the width, length and amplitude of the rivers are to be taken into consideration before any structural work is undertaken for checking the bank and bed scours or constructing bridges over the rivers.

Table 7. Total correlation between different characteristics of meandering.

Characteristics	Mean radius of curvature	Width of the existing channel (WEC)	Width of the meander belt (WMB)	Length of the meander belt (LMB)
Amplitude (AM)	0.2182	0.7365*	0.6613	0.6334
Mean radius of curvature (MRC)	—	0.0834	0.0961	-0.0282
Width of the existing channel (WEC)	—	—	0.9293**	0.8594*
Width of the meander belt (WMB)	—	—	—	0.9192

*Significant at 5 per cent level
**Significant at 1 per cent level

Table 8. Regression equations and corresponding values of correlation coefficient and coefficient of determination.

Relationship	Correlation	Coefficient of determination (R^2 %)	Regression equation
(i) Length of the meander belt and width of the meanber belt.	0.9192	84.46	LMB = 1.45 WMB + 1341.44
(ii) Width of the meander belt and width of the existing channel	0.9293	86.30	WMB = 8.33 WEC—406.11
(iii) Length of the meander belt and width of the existing channel	0.8594	72.79	LMB = 11.79 WEC + 809.26
(iv) Amplitude and width of the existing channel.	0.7365	54.17	AM = 2.652 WEC + 78.68

3.3.2. Nature and size of river bed materials

The discharge of water in these rivers is mainly derived from the headwater mountainous area of the Aravalli Range. The run-off is caused by thunderstorms during monsoon period. The study of sediment deposited on the point bars and sand bars at Babagaon, Bhant, Guria and Chanaud was done in the field. The sediments deposited by the flows along the river banks are unconsolidated but differentiated columnwise. The beds of the rivers consist sediments of variable nature and size. The height of the point bars ranges from 30 to 180 cm. There is a gradual decrease in the height of this channel feature as one proceeds towards the lower reach of the stream. At Babagaon the height is 150 cm, at Bhant 60 cm and at Guria 30 cm. The height of the sand bar is generally 50 cm. At Chanaud the height is 180 cm and the deposit is slightly consolidated. The diameter size of the grains is given in Table 9.

From the table 9, it appears that the successive deposits belong to different sedimentation rate with varying intensities of flows. It can be observed that comparatively coarser grains have been deposited in the top layer and bottom layer of point bar at Babagaon i. e. above 30 cm and below 50 cm respectively. The diameter of more than 50 per cent grains in the layers of 10–30 cm and 50–150 cm at Babagaon, 50–60 cm at Bhant and 0–30 cm at Guria is more than 0.42 mm. In the rest of the layers at these places, the diameter of grains is less than 0.42 mm and the maximum size is 0.07 mm at Babagaon and Guria. The diameter size of 72 per cent grains of sand bar at Babagaon is more than 0.25 mm.

Due to varying discharges in the streams during different years, the characters of transported and deposited materials differ considerably. Pebbles are not found in the river courses.

3.3.3 Erosional characteristics of the rivers

The bank erosion is mostly located downstream from the axis of the bend. The bank caving and slumping of overhanging materials have been marked near Bhant. In some cases point bars have been formed on the same side of the concave bank. The materials of these sand bars are transported slightly away from the place of formation. It has been observed by Fridkin (1945) that sand eroded from a concave bank in the laboratory river did not travel across the channel to the convex bank but was deposited on a point bar downstream on the same side of the channel. During heavy floods these point bars are eroded as the maximum current passes away from the concave bank and gives impact on the deposit on crossover and so greater power of such

Table 9. Percentage size distribution of sediment particles

Sl No.	Site	Depth in cm	Size of sediment particles in mm									
			2 mm	0.84 mm	0.59 mm	0.42 mm	0.25 mm	0.18 mm	0.15 mm	0.12 mm	0.07 mm	0.06 mm
1.	Point bar at Babagaon.	0–10	5.18	14.18	8.49	11.99	16.06	9.04	4.46	4.10	13.00	13.53
2.	—do—	10–30	16.14	17.83	12.63	20.57	20.03	6.16	1.86	1.65	1.96	1.17
3.	—do—	30–50	—	0.90	1.01	2.01	7.20	14.83	11.65	12.13	35.12	15.15
4.	—do—	50–150	33.97	23.81	11.04	13.03	10.20	3.09	1.10	1.04	1.62	1.10
5.	Sand bar at Babagaon	—	3.56	18.26	17.11	25.01	26.76	6.01	1.00	0.64	0.90	0.75
6.	Point bar at Bhant	0–50	6.40	8.97	7.53	16.27	32.74	14.43	4.85	3.01	4.13	1.67
7.	—do—	50–60	33.33	22 19	8.22	10.01	13.11	6.54	2.24	1.45	1.93	0.98
8.	Point bar at Guria	0–30	3.16	16.63	13.47	18.16	21.73	11.02	3.58	3.16	6.85	2.24
9.	—do—	30–50	—	0.62	0.92	2.36	7.60	7.80	6.57	10.06	52.05	12.02

erosion migrates to the downstream side of the bends. This process helps in shifting of meanders downstream. During low flood level lateral erosion of concave banks takes place due to migration of maximum velocity towards them. Under these circumstances, geomorphic features of the stream channel are unstable in character. Vertical bank cuts of 3 to 4 metres have been observed along the rivers.

4. GEOMORPHOLOGY AND WATER RESOURCES

Water, which is of prime importance in every walk of human life, is a rare commodity in the Rajasthan desert. There is, therefore, an urgent need for locating and harnessing the water resources in this region by developing cheap and quick techniques because the location of the surface and subsurface water potential zones in the vast sandy and rocky tracts is a difficult and costly affair. The technique of quantitative geomorphological analysis of the drainge basins for locating the surface water potential zones in different landforms of the region has been developed at this Institute. The photogeomorphological techniques for reconstructing and mapping the buried cources of the prior drainage channels and also for mapping and evaluating the hydrogeomorphological characteristics of different landforms to locate and exploit the subsurface water potentials have been evolved. The importance of these geomorphological techniques in prospecting the water resources of the desert regions without wasting much money and time, has been discussed in this chapter.

4.1 Surface Water Resources

4.1.1 Quantitative geomorphological analysis of drainage basins for evaluating surface water potentials

Studies on the quantitative analysis of the geomorphological characteristics of the drainage basins of the Luni, the Jawai and the Banas catchments situated in different landforms of Rajasthan desert were carried out to evaluate the hydrological conditions of these basins (Ghose *et al*, 1967; 1969; Singh *et al*; 1969–71). Analysis of the quantitative geomorphological characteristics of the drainage basins presented in table 10, reveals that the basins of phyllite–schist and rhyolite pediments have the greater values of bifurcation ratio, stream length ratio, drainage density, number of streams, stream frequency and frequency of first order segment over total basin area. The greater values of the geomorphological variables indicate that the drainage basins of these landforms have circular shape, shorter stream lengths, steep stream gradients and closely spaced and integrated drainage network which will enable the large volume of runoff to proceed at faster rates with minimum infiltration through sediments. The drainage basins of granite pediment and sandy aggraded older alluvial plain due to widely spaced joints and fissures and permeable nature of sandy alluvial material have longer stream lengths, elongated shape, gentler stream gradients and widely spaced drainage channels. These geomorphological characteristics of the basins will, therefore, enable the large volume of rain water to percolate rapidly rather than to allow it to flow on the surface and they will have poor runoff and discharge potentials. From these findings, it may be concluded that the drainage basins of phyllite-schist and rhyolite pediments have better surface water potentials than that of granite pediment and sandy aggraded older alluvial plains.

4. 1. 2 Mathematical models for evaluating the hydrological characteristics of the drainage basins in different landforms.

It has been observed from the findings of the quantitative geomorphological analysis of drainage basins that the distribution of surface water in diffeient landforms is controlled by the combined effect of the quantitative geomorphological characteristics of the drainage basins. In order to compare the relative contribution of the quantitative geomorphological variables in evaluating the hydrological characteristics of the drainage basins in different landforms, the mathematical models by establishing pairwise and - multiple relationships among geomorphological variables were developed, (Singh and Ghose 1973; Singh *et al*; 1976).

(a) *Pairwise relationships between geomorphological varicbles of the drainage basins*

Pairwise relationships between geomorphological variables of the drainage basins in the Luni, the Jawai and the Banas catchments of the Rajasthan desert, to evaluate the hydrological characteristics of these drainage basins, are presented in Table 11.

It is seen from the table that the bifurcation ratio is strongly correlated to total stream length, total basin area and stream length ratio and the correlation is significant at 1 per cent probability level. But it is less strongly correlated to drainage density and constant of channel maintenance and their relationships are significant at 5 per cent probability level. The value of the coefficient of determination (88.74 per cent) is the highest for the comparisons between bifurcation ratio and total stream length. This highest value

Table 10. Average quantitative geomorphological characteristics of the drainage basins in different landforms

Quantitative geomorphological characteristics	Granite pediment	Rhyolite pediment	Phyllite-schist pediment	Aggraded older alluvial plain
Number of streams	22	24	21	8
Total stream length (km)	24.8	48.3	20.3	16.1
Bifurcation ratio	1.8	2.7	6.7	1.2
Stream length ratio	1.4	1.5	1.6	1.2
Drainage basin area (Sq.km)	18.6	15.6	14.6	12.7
Basin area ratio	2.2	2.1	2.4	2.0
Basin length (km)	19.0	10.0	6.0	7.0
Drainage density (km/km^2)	1.3	1.9	5.0	0.8
Constant of channel maintenance (km^2/km)	3.0	1.2	2.7	2.4
Relief ratio	0.7	0.9	0.5	0.03
Stream frequency (Nos./km^2)	0.8	2.5	6.0	1.7
Frequency of first order segment over total basin area	0.9	1.3	1.4	0.4

shows that the variance in the bifurcation ratio from one basin to another is better explained by total stream length than by other independent geomorphic variables. A unit increase in the total stream length produces an increase of

Table 11. Coefficients for linear regression equations between geomorphological variables of drainage basins in the Luni, the Jawai and the Banas catchments

Relationships between	Linear regression equations	Coefficient of determination R^2 (%)	Correlation coefficient
1. Bifurcation ratio (Rb) and total stream length (ΣL)	$Rb=4.75+0.03\ \Sigma L$	88.74	0.942**
2. Bifurcation ratio (Rb) and total basin area (ΣA)	$Rb-4.77+0.02\ \Sigma A$	83.72	0.915*
3. Bifurcation ratio (Rb) and stream length ratio (R_L)	$Rb=0.13+0.40\ R_L$	76.04	0.872**
4. Bifurcation ratio (Rb) and drainage density (D)	$Rb=3.25+1.95\ D$	32.12	0.572*
5. Bifurcation ratio (Rb) and constant of channel maintenance (C)	$Rb=1.51+1.42\ C$	31.92	0.565*
6. Stream frequency (F) and drainage density (D)	$F=0.25+1.20\ D$	76.21	0.873*
7. Stream frequency (F) and stream length ratio (R_L)	$F=0.28+0.18\ R_L$	36.24	0.602*
8. Stream frequency (F) and constant of channel maintenance (C)	$F=0.25+1.30\ C$	76.21	0.873**
9. Relief ratio (Rh) and total stream length (ΣL)	$Rh=0.12+0.02\ \Sigma L$	76.72	0.876**
10. Basin area ratio (Ra) and stream length ratio (R_L)	$Ra=0.49+3.24\ R_L$	30.47	0.552*

** Significant at 1 per cent probability level.
* Significant at 5 per cent probability level.

0.03 in bifurcation ratio. The stream frequency is positively correlated to stream length ratio and drainage density is negatively correlated to constant of channel maintenance.

The greater value of correlation coefficient indicates that stream frequency is strongly correlated to drainage density and the correlation is significant at 1 per cent probability level. The highest value of coefficient of determination (R^2) for the comparison of the stream frequency and drainage density shows that the variance in the stream frequency is well explained by drainage density than the other independent geomorphological variables. A unit increase in drainage density causes an increase of 1.20 streams/sq. km in stream frequency. The relief ratio is significantly correlated to total stream length and the correlation is highly significant at 1 per cent probability level. Relationship also exists between basin area ratio and stream length ratio and it is significant at 5 per cent probability level.

The results of the relationships revealed that bifurcation ratio and total stream length, bifuracation ratio and total basin area, bifurcation ratio and stream length ratio, stream frequency and drainage density and relief ratio and total stream length are strongly correlated to each other. The advantage of these relationships is that the above geomorphological variables could be used to evaluate the hydrological characteristics of the drainage basins in the Luni, the Jawai and the Banas catchments. The regression equations of these relationships can also be used to predict the morphohydrological characteristics of the new drainage basins, assuming that the new basins come from the similar environment and fall within the range of the values of the geomorphological variables from which the regression lines were calculated. These models will allow one to plan soil conservation measures in different drainage basins to increase water yield and to minimise sediment runoff in the streams.

(b) *Multiple relationships among geomorphological variables of the drainage basins*

In order to understand the relative importance of the contributions provided by each geomorphological variable to evaluate the hydrological characteristics of the drainage basins in a more rational and scientific way, the multiple relationships among the bifurcation ratio and some geomorphological variables were established by employing the criterion of the step (up) wise regression equations and coefficient of determination. The results of the analysis of multiple relationships revealed that the total stream length (ΣL) provides the largest contribution for explaining the variance in bifurcation ratio

(Rb) followed by the constant of channel maintenance (C), total basin area (ΣA) and the drainage density (D).

To quantify the relative importance of the contribution provided by each independent variable, the coefficient of determination (R^2), rate of increment in coefficient of determination and F value were computed and are given in table 12.

Table 12 Relative importance of the contribution of the geomorphological variables for explaining variances in bifurcation ratio of drainage basins

Sl. No.	Contribution of	Coefficient of determination (R^2)	Rate of increment in coefficient of determination (R^2)	F value computed
1.	Total stream length (ΣL)	0.898267	—	114.79*
2.	Drainage density (D) and total stream length (ΣL)	0.909648	0.011381	1.51
3.	Constant of channel maintenance (C), total stream length (ΣL) and drainage density (D)	0.927972	0.018324	2.80
4.	Total basin area (ΣA), constant of channel maintenance (C), total stream length (ΣL) and drainage density (D)	0.939836	0.011864	1.97

* *Significant at 1 per cent probability level*

The multiple relationships among the total basin area (ΣA) and the geomorphological variables of drainage network were also established. The results of these multiple relationships also revealed that length and number of first order streams (L_1 and N_1) and total number of streams (ΣN) are the most important geomorphological variables for explaining the variances in the total basin area (ΣA).

To quantify the relative importance of the contribution of the independent variables, rates of increment in coefficient of determination (R^2) and values of 'F' test were computed and are given in table 13.

Table 13. Relative importance of the contribution of the geomorphological variables of drainage network for explaining the variances in total basin area

Contribution of	Coefficient of determination (R^2)	Rate of increment in coefficient of determination (R^2)	F value computed
Length of the first order streams (L_1)	0.9362	—	190·66**
Length of the first order streams (L_1) and length of the second order streams (L_2)	0.9528	0.0166	4.21*
Length of the first order streams (L_1), length of the second order streams (L_2) and length of the third order streams (L_3)	0.9538	0.0011	0.25
Number of first order streams (N_1)	0.6743	—	26.92*
Number of first order streams (N_1) and number of third order streams (N_3)	0.8242	0.1499	10.23**
Number of first order streams (N_1), number of third order streams (N_3) and number of second order streams (N_2)	0.8482	0.0240	1.74

** Significant at 1 per cent probability level

* Significant at 5 per cent probability level

The higher values of incremental rate in coefficient of determination (R^2) and its consequent F test also confirms that the largest variances in total basin area (ΣA) are accounted for by length and number of first order streams (L_1 and N_1) and total stream length (ΣL).

From the results of the multiple relationships among different geomorphological variables, it is concluded that total stream length (ΣL), bifurcation ratio (Rb), total basin area (ΣA), length and number of first order streams (L_1 and N_1) and total number of streams (ΣN) are the most important geomorphological variables for evaluating the hydrological characteristics of the drainage basins in different landforms. These geomorphological variables could also be applied for evaluating the morphohydrological characteristics of the new drainage basins.

4. 1. 3 Correlations between landforms and surface water resources

Geomorphological characteristics of the different landforms and the quantitative geomorphological characteristics of the different drainage basins indicate that rocky/gravelly pediments, flat buried pediments with a veneer of deposits, the flat interdunal and aggraded older alluvial plains underlain by indurated *kankar* pan are the most suitable units for conserving the surface water resources.

It is seen from Fig. 5 that the tanks of 3 to 5 m and 3 to 10 m depth are largely concentrated in the flat interdunal and aggraded older alluvial plains. The presence of large number of tanks in these landform units is due to the occurrence of indurated *kankar* pan at shallow depth which does not allow the surface runoff to percolate. The distribution of surface water here is, therefore, controlled by the impervious layer of the lime concretions encountered at a shallow depth below the alluvial material. In these units, there is still scope for harvesting the surface runoff at suitable sites after detailed geomorphological studies, particularly of the micro-relief features. The quantitative analysis of the drainage basins revealed that phyllite-schist and rhyolite pediments are the most potential units for surface water conservation. Due to the fine textured topography and less percolation of water, well integrated drainage network has developed which substantially contributes towards the surface water potentials of the drainage basins of these two units. The existence of very few tanks in these units reveal that the surface water resources are not fully harnessed and most of the surface water goes as a waste. The surface water resources could be harvested at suitable sites after calculating water yield, construction cost and detailed contour survey. The harvested water can be utilised for drinking, irrigation and also for augmenting the recharge capacity of the adjoining dug wells.

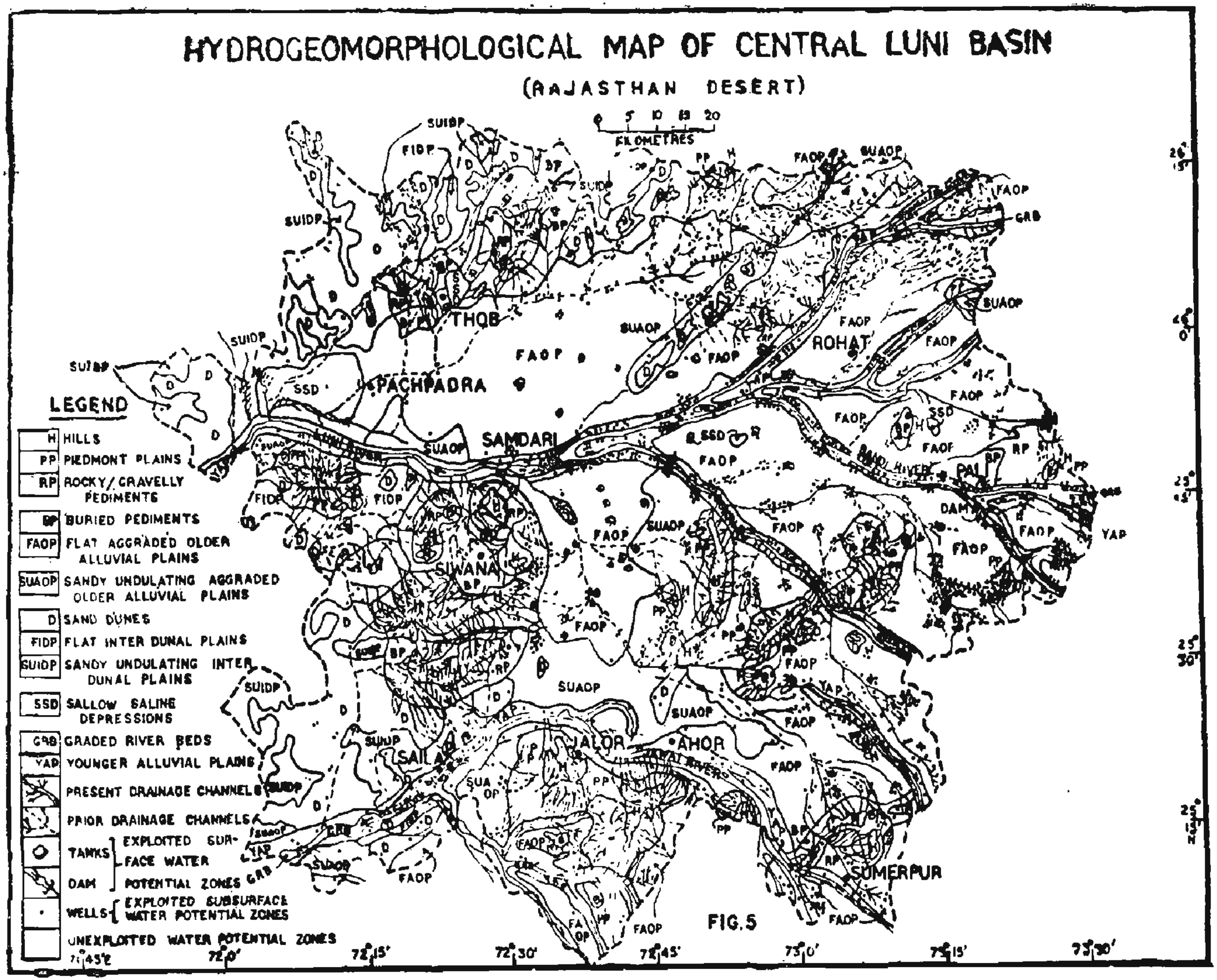

HYDROGEOMORPHOLOGICAL MAP OF CENTRAL LUNI BASIN
(RAJASTHAN DESERT)
0 5 10 15 20
KILOMETRES
LEGEND
H HILLS
PP PIEDMONT PLAINS
RP ROCKY/GRAVELLY PEDIMENTS
BP BURIED PEDIMENTS
FAOP FLAT AGGRADED OLDER ALLUVIAL PLAINS
SUAOP SANDY UNDULATING AGGRADED OLDER ALLUVIAL PLAINS
D SAND DUNES
FIDP FLAT INTER DUNAL PLAINS
SUIDP SANDY UNDULATING INTER DUNAL PLAINS
SSD SALLOW SALINE DEPRESSIONS
GRB GRADED RIVER BEDS
YAP YOUNGER ALLUVIAL PLAINS
PRESENT DRAINAGE CHANNELS
PRIOR DRAINAGE CHANNELS
TANKS
DAM
EXPLOITED SURFACE WATER POTENTIAL ZONES
WELLS
EXPLOITED SUBSURFACE WATER POTENTIAL ZONES
UNEXPLOITED WATER POTENTIAL ZONES
THOB
PACHPADRA
SAMDARI
ROHAT
PALI
SIWANA
SAILA
JALOR
AHOR
SUMERPUR
BANDI RIVER
FAOP
SUAOP
SUIDP
FIDP
SSD
GRB
YAP
71°45'E
72°0'
72°15'
72°30'
72°45'
73°0'
73°15'
73°30'
26°15'
26°0'
25°45'
25°30'
25°15'N

FIG.5

4.2 Subsurface Water Resources

4. 2. 1 Location and evaluation of subsurface water potential zones in different landforms

The reconstruction and mapping of the subsurface extensions of the buried courses of the prior drainage channels within different landform units of the Rajasthan desert has been done so far in the central Luni basin, Jodhpur district and in parts of Nagaur district. Geomorphological interpretation of these courses have revealed that the well integrated drainage systems in these regions were disorganised and buried under alluvial and aeolian sediments of varying depth. These sediments are good accumulator of subsurface water and regulate the flow of ground water. The water along the buried courses occurs at 5 to 25 m and its distribution is related with the distribution of the prior drainage channels. The other potential aquifers of these regions are younger alluvial plains, buried pediments and filled valleys. The depth of water in these landforms ranges from 8 to 50 m. The availability of ground water along the courses of the present and prior drainage channels in different landform units of the central Luni basin has been discussed below in detail.

In the central Luni basin, the identification and mapping of the present and prior drainage channels indicate that this basin was drained by several well integrated drainage channels, forming the dendritic drainage patterns in the past humid phases. At present the water flows on the surface only along the beds of the major streams like the Luni, the Mitri, the Guhia, the Bandi, the Sukri, the Jawai and the Khari. Numerous short drainage channels also originate from the existing hills which flow through the rocky and buried pediments and die out in the adjoining alluvial plains without draining the water in their master streams. The subsurface extensions of these short drainage channels, however, have been traced in the flat and sandy undulating alluvial and interdunal plains. The subsurface water potential zones in different landforms units have been located, demarcated and mapped (Fig. 5).

It has been observed that the shallow subsurface water is available in the allvuial material along the prior drainage channels. The alluvial meterial beneath the prior drainage channels acts as a aquifer. The depth of the water bearing riverine sands and gravelly sands varies from 10 to 20 m. The rain water sinks through these sediments and flows subterraneously along the buried courses and forms flows in them. The shallow subsurface water, available along the buried courses, could be economically exploited and properly utilised for the agricultural and domestic uses. The younger alluvial plains lying in narrow strips along the major streams are the potential subsurface water zones. The water bearing material here is alluvium which is of pervious nature. Due to the absence of *kankar* pan, the water percolates through the coarse alluvial sediments and is accumulated in the aquifer zone at 8 to 25 m depth. The buried pediments, piedmont plains and filled valleys have also good subsurface water reserves. The water which infiltrates rapidly through the joints, fissures and bedding planes and also the alluvial, colluvial and aeolian sediments is accumelated at verying depths within the rocky strata. The potential aquifer in these landforms are the rocks of the different formations on which the pediments have developed.

4. 2. 2 Correlations between landforms and subsurface water resources

Correlations have also been established between the distribution of landforms and the dug wells in the central Luni basin. It is seen from Fig. 5 that the distribution of the existing wells is directly correlated with the geomorphological locations of the landforms. In the younger alluvial plains, the subsurface water along the major streams is available at a depth of 8 to 25 m. The wells are generally dug along the younger alluvial plains flanking the streams. The water is sweet to brackish and the discharge is good and hence, numerous wells have been dug along the courses of these streams.

In the buried pediments, piedmont plains and filled valleys, several wells have been dug along the short channel courses because here the subsurface water potential zones along the existing courses of the channels are easily located. The water in these landforms is available at 15 to 30 m depth, especially around Meli, Siwana, Mokalsar, Nimbla, Jalor and Bhadrajan. At certain places, the subsurface water has also been exploited along the buried courses and the water is found at 5 to 15 m depth.

The shallow subsurface water in this basin is largely available along the prior buried drainage channels mainly in the flat aggraded older alluvial plains and also in the sandy undulating aggraded older alluvial plains and the flat and sandy undulating interdunal plains. In the flat aggraded older alluvial plains subsurface water is available at a depth of 10 to 20 m around Mandawas, Chenda, Bharwani, Bhandla, Bhetnada, Rohat, etc. Around Depura, Kalanpur, etc., to the north of the Luni, however, the depth to water table is 30 to 35 m. Along the occasional present courses of the drainage channels within this unit subsurface water is available at a depth of 10 to 20 m around Sagdara, Sankwali, Kurla, Nimbara, etc. In these landforms, several wells are also existing along the major unobliterated drainage channels around Sankwali, Bargaonra and Marla.

In the sandy undulating aggraded older alluvial plains and the flat and sandy undulating interdunal plains, the depth to water table varies from 18 to 40 m. This is because the alluvial materials are overlain here by a thick deposit of aeolian sand. Around Pantheri, Debhawas, Balwara, Baori, Jhanwar, Dharna, Taliana, and Surana, the depth is 18 to 20 m, while around Nawatala, Dudwara, Bhimarlai, etc, the depth is 30 to 40 m.

These evidences indicate that the buried courses of the prior drainage channels, younger alluvial plains, buried pediments and filled valleys are good host of subsurface water. The circulation of the subsurface water is, therefore, directly correlated with the geomorphological setting of the landforms. The results of this study also reveal that the subsurface water resources in the different landforms of the basin are fully exploited and there is sufficient scope for digging the wells at new site. It may be concluded that if similar photogeomorphological studies are carried out over the vast desertic regions, suitable sites for dug wells and dug well cum bored wells could be easily located.

5. GEOMORPHOLOGY, PALAEOCLIMATE AND DESERTIFICATION

5.1 Spread of Thar Desert - A Geomorphological Analysis

Analysis of information gathered on the different geomorphological aspects of a region provides enough clue about the past and present climatic set up of that region. This is especially true for the desert where the evidence of alternate fluvial and aeolian processes indicate the changes in climatic condition and associated desertification and de-desertification.

In the Rajasthan desert, the geomorphological investigations carried out for the last 16 years on different geomorphological aspects, like the prior well integrated drainage systems, evolution of vast alluvial plains, pediments and saline depressions, origin and distribution of stabilised and active sand dunes and recent morphological changes in the old fluvial and aeolian landforms, have been analysed and integrated. The results of the integrated geomorphological analysis reveal that there is no evidence of recent spread of Thar desert, although this desert had experienced two major humid phases with intervening arid phases during the late Quaternary period (Ghose *et al*, 1975; 1976). But contrary to it, the presence of stabilised dunes in the east of the present desert belt indicate that formerly this desert was more widespread and it subsequently shrank upto the present desert boundary. Within the desert belt, there are also two distinct zones of aeolian and fluvial activities. To the west of 300 mm isohyet, the aeolian activities are intensive which have reactivated and degraded the stabilised dunes and created new active dunes. But to the east of 300 mm isohyet, the fluvial activities are more vigorous which have dissected the old existing landforms through rills and gullies. In this part, sheet wash has been accelerated, new channels are being created and the former braided streams are showing signs of meandering. Some buried drainage channels are also revived. All these recent morphological changes suggest that there is a small scale climatic amelioration.

However, the overexploitation of resources by man have set free retinue of hazards within the climatic desert boundary. Human activities thus, are accentuating the desertic conditions with the result of not only an ecological imbalance but possibly an ecological wreck. This menace can only be checked through a geomorphologically based and ecologically integrated approach.

6. SUMMARY AND CONCLUSION

Geomorphological investigations carried out by employing photogeomorphological and ground survey techniques, on the evolution, distribution and physical potentials of landforms, environmental problems like the erosional, depositional and salinity hazards, lateral shifting of sand dunes and river courses, dearth of water and desertification have elucidated many sided applicability of geomorphology in the reclamation and development of Rajasthan desert. The results of these investigations are summarized below.

Geomorphological evolutionary history of the region revealed that the landforms of pre-Quaternary eras in Rajasthan desert have evolved through long periods of subaerial degradation and aggradation, interrupted by short periods of tectonic activities. The major existing landforms have resulted due to the climato-morphogenetic processes operating during the late Quaternary period on various lithological formations under different climatic phases. In the Rajasthan desert, fourteen landform units have been identified and each geomorphological nomenclature is indicative of the agricultural and water potentials of the region. These landform units have different physical potentials and limitations and could be developed by suitable management techniques.

Studies on the different hazards have shown that water erosion, wind erosion/deposition and salinity are the major hazards which limit the agricultural productivity of the landforms. The wind erosional and depositional hazards are more widespread and conspicuous than other hazards. In the central Luni basin, out of 16582.0 sq. km area, 9228.1 sq. km area has been affected by the different hazards and remaining 7299.9 sq. km is free from such hazards.

Studies on the dynamics of the sand dunes in different parts of the Rajasthan desert revealed that the obstacle, parabolic and coalesced parabolic, longitudinal and transverse are the stabilised and fossilised sand dunes. They belong to the old dune system and do not need any plantation to ensure their stability but must be protected from biotic interference. The barchan and shrub-coppice dunes are the active sand dunes and come under the category of new dune system. These active dunes are the greatest menace to the agricultural lands, roads, railway lines and to other permanent structures. If these are somehow checked, the entire region will be taken care of. The size, shape and mineral composition of the sand grains have indicated that the sands of these dunes are of aeolian origin and they have not been transported from Rann of Kutch but have been locally derived by intense aeolian activities from the existing hills and dry river beds.

The studies on the dynamics of the river system have revealed that the courses of the major alluvial rivers oscillate across the meandering belt and they cause severe devastations either to the right or to the left banks. The lands lying within the meander belts are unstable and should not be used for constructing permanent structures without taking into consideration the width, length and amplitude of the meandering rivers. Hydrogeomophological studies conducted in different landforms have indicated that the courses of the prior buried drainage channels, the younger alluvial plains, piedmont plains, buried pediments and filled valleys are the potential aquifer. The depth of the ground water along these aquifer varies from 8 to 50 m which could be exploited and rationally utilised for irrigation, human and livestock consumption. The analysis of the quantitative geomorphological characteristics of the small agricultural drainage basins, situated under different geomarphological settings, has shown that the drainage basins of the phyllite-schist and rhyolite pediments have better surface water potentials than the basins of the other landforms. The pairwise and multiple realationships established between different morphometric characteristics of the drainage basins could be utillised to predict the hydrogeomorphological characteristics of the new drainage basins falling in different landforms.

The researches conducted on the above aspects of the Rajasthan desert have proved that the desert is not advancing towards north and north east. On the other hand, it has been found that the desertic conditions, which once extended upto Jaipur, Bharatpur and Mathura, have receded westward.

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Back cover photograph shows mud cracks in a saline depression at Khatu Khurd in Nagaur district.