

Managing sand dunes of Thar desert

for sand control measures and agriculture

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Wind erosion and deposition are the major environmental problem in the western Rajasthan, where a significant area (~48%) is covered by sand dunes of different types. Sand movement owing to wind erosion process in the past used to affect the crop lands and infrastructure. For combating the severity of such process, two popular models; sand dune stabilization and shelterbelt plantation techniques, were experimented and established by Central Arid Zone Research Institute in different parts of arid districts. These popular models executed in the field (~4 lakh ha land) not only reduced the sand accentuation over dune areas, but also reduced sand deposition over roads, rails and crop fields. The plantations moderated the severe warming of micro-climate and also provided economic benefits to the desert dwellers.

Key words: Desertification, Sand dunes, Sand dune management, Wind erosion

SAND dunes like any other geomorphic features (saline play as, desert pavements, ephemeral streams) are typical of desert terrain. These are known by few alternate names ; a 'dune field' is assigned to an area covered by extensive sand dunes, the term 'erg' represents large dune fields, a 'sand ridge' would have a long narrow natural elevation or striation while a 'seif' will have a long sand dune with a sharp crest. The Indian part of Thar Desert (Area; 20.8 m ha) lies between western scarps of Aravalli mountain ranges in the east and the Indus river in the west where it merges into Pakistan desert. Both Aravalli and Indus are important geomorphic units and control the climate, landform and hydrology of the region. The seasonal and annual temperature range is high, in summer the temperature may rise up to 50°C, whereas in winter it dips as low as -4°C. Annual average rainfall is low 100 to 500 mm/year, but pan evaporation is too high (1,800 mm) making the desert water limiting. Wind speed occasionally is high (40 to 60 km hr⁻¹) particularly

in summer which together with low humidity makes the environment inhospitable. Sand dunes are the major geomorphic or land form unit (in 48% of total geographical area) in the Thar Desert or the Great Indian Desert. Since sand dunes represent immediate surface manifestations of wind erosion/depositional activities, it is pre-requisite to have scientific understanding of wind erosion processes and sand dunes.

Erosion/depositional forms made by wind

Basically, both wind erosion and dune building processes are dynamic as the entire phenomena depends primarily upon major factors like, (i) the surface (an area of loose, dry and finely granulated particles, scanty vegetation cover in the form of trees, shrubs, and (ii) a strong-turbulent wind regime, thus imply role of a dynamic interaction between sand with turbulent shear flow. The process of wind erosion/deposition initiates as wind lifts sediments from a land surface, transports and deposits at another place through

three distinct modes: surface creep, saltation and suspension. Wind erosion process has a spatio-temporal dimension as both erosion and deposition had own ways of action and the impact. Deflation causes removal of loose fine grained particles that are carried away through turbulent action of wind, ultimately leaving behind a barren land. One of the examples of impact of deflation is the creation of desert pavement, a flat surface having an assemblage of rock fragments that remains exposed after wind and water removed the fine particles. On the contrary, wind borne sands get deposited to create sand hummocks (low undulations) and sand dunes and also thick sand deposits. The depositional forms would change depending upon (i) sand supply, (ii) type of surfaces (vegetation as well as slope of the land) and the existing wind regime. Creeping is the initial step which moves particles in rolling pattern. The particles moved by saltation usually follows a pattern of series of jumps or upthrusts, therefore, this process creates more abrasion

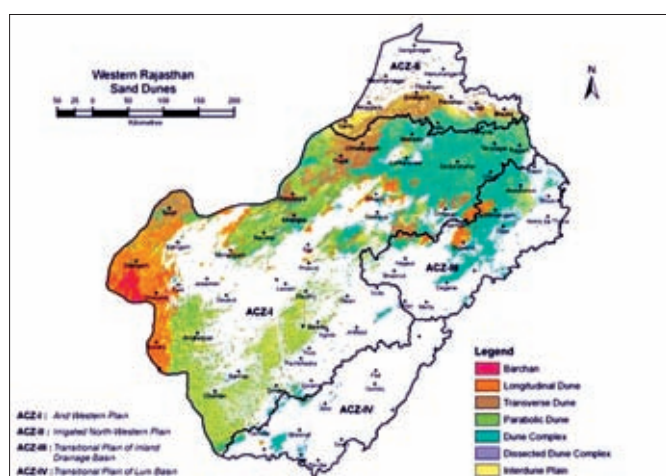


Fig. 1. Extent of sand dunes in western Rajasthan

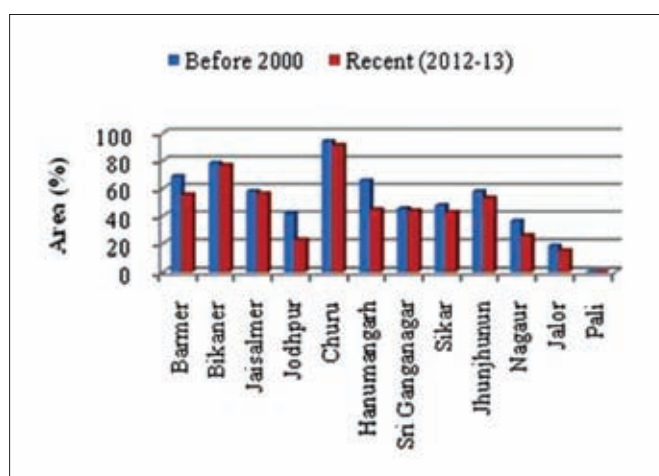


Fig. 2. Change in sand dune area in different districts of western Rajasthan

(erosion) with a more carrying capacity to transport higher volume of sand. In desert regions, particularly near Durjasar at Jaisalmer, many wind erosion features like yardangs could be seen. The softer limestones underneath sandstone rocks could be seen to be eroded gradually to form such landforms. Particles transported in suspension way are mainly dust (<2 mm). The Moderate Resolution Imaging Spectro-radiometer satellites provide synoptic images of dust concentration (aerosol) daily that provides an idea about possible source area of dust generation and the aerosol optical depth.

Sand dunes of Thar desert

The Thar desert dunes had variability in the type, morphology and also they occurred in different geological time-scales. Synoptically, sand dunes start appearing roughly to the west of the Aravalli ranges and they are more active to the west of 300 mm isohyets. Stabilized or fossil sand dunes occurred in areas receiving annual rainfall of 400 to 500 mm rainfall. There were evidences for its former extent in the higher rainfall zones of eastern part of Rajasthan and Central Gujarat where some stabilized or fossil sand dunes do occur today such as in Budha Pushkar at Ajmer. There are nine major dune types and 21 subtypes identified in Thar desert, which can be grouped under the old dune system and the new dune system. Longitudinal, transverse, parabolic and network types are the

dunes of old system while barchans, shrub-coppice dunes and nebkhas belong to new dune systems. Further, barchans were further classified into barchanoids (compound formations) and mega-barchanoids (big and extensive fields of barchanoids). Stratigraphy of many Aeolian land forms within and also at desert margins suggest that dune sediments are not mainly Aeolian, but contain sediments contributed by local fluvial, Aeolian and lacustrine processes. Aeolian activities in the Thar desert are more than 100 kg (per annum) Bp (before present) and within this time period, the region had undergone several episodes of dune building activities separated by periods of landscape stability. Distribution of sand dunes in western Rajasthan through GIS-based mapping using satellite images and field surveys is presented in Fig. 1. Churu district has the maximum area under sand dunes followed by Bikaner and Jaisalmer. A comparative assessment of sand dune area (Fig. 2) between two periods (before 2000 and 2012-13), indicated that among the most arid districts, maximum change in dune area took place in Barmer, Jodhpur, Hanumangarh whereas in the higher rainfall zones, similar trend was observed for Sikar, Nagaur and Jhunjhunun district.

Of all the dune types, parabolic dunes occur in maximum area. Barmer district has maximum area (37%) under these dunes followed by Jaisalmer, Jodhpur, Bikaner and Jalore. Longitudinal/linear dunes were

identified maximum (19%) in the south and south-west part of Jaisalmer district especially in the south of Ghotaru-Shahgarh-west of Dhanana sector and few areas in Barmer and Bikaner. Morphologically, these type of dunes are long, narrow, usually symmetrical (in profile) sand dune oriented parallel with the direction of the prevailing wind responsible for its construction. Transverse dune fields are abundant in Sri Ganganagar (28%) and also in Hanumangarh and Bikaner, where these dunes occur in chain pattern with very long (3 to 4 km) and super imposed bedforms especially in the south of Ghaghara river in Gharsana-Suratgarh (Sri Ganganagar) and Rawatsar-Bhadra region (Hanumangarh). Most of them are stable and their height varies from 20 to 40 m. Barchans are low and crescent-shaped dunes (2 to 5 m high). Barchans have fastest mobility; their movement was measured @ 31.7 m during a summer at Selvi in Jaisalmer. Crest of barchans always recorded a higher wind speed during summer. Dune complex is applied to a field having large number of mixed pattern of sand dunes like Shrub coppice (or fence line dunes). Majority of such dune landscape occurs in Churu, Jhunjhunun and Bikaner districts. These dunes are 10 to 20 m high with narrow inter-dune spaces that makes easy for agricultural activities. Dissected dune complex units, also known as obstacle or climbing dunes occur in higher rainfall region in



Fig. 3 (a and b). Wind erosion hazards in the past

Jhunjhunun, Sikar, Nagaur and Jalor where sand dunes form against hills. The runoffs from the rocky slopes run through the dunes carving them into rills and gullies.

Dune soils do not largely support good vegetation as these are windblown sand, largely constituted of 85 to 96% sand. Soils are slight to moderately calcareous and soil profile is devoid of easily discernable evidences of pedogenesis except for a weak accumulation of organic carbon. The silt and clay are very low (1.0 to 2.8% silt and 2.6 to 5.1% clay). Water holding capacity of these soils is also low (ranges between 18.0 and 26.3%). Organic carbon content in the dune soils is very low (0.03-0.12%), but the surface soils contain high amount of organic carbon than subsurface soil.

Wind erosion hazards and need for sand control measures

Sand control measures were the prime requirement as wind impacted sand movement was the single most environmental problem of the region. In the past, due to high wind speed, sandy terrain and less agricultural activities, severity of sand movement was acute. The infrastructures and croplands were severely affected, buried over by thick sand (Fig. 3a and 3b). About 1.57 lakh ha or 72% of total geographical area of the region is affected by wind erosion/deposition out of which 5,800 km² area are severely degraded, 25,540 km² area, severely affected, 73,740 km² area, moderately affected and 52,690 km² area, are slightly affected. The impact of wind erosion had a

bearing on agrarian economy as wind blows away: (i) nutrient rich top soil leaving behind a coarser substrata which is poor in nutrients, (ii) causes crop damage by sand blasting or abrasion actions on tender stems and leaves, and (iii) bury the short height crops through saltation particles. The region showed a wide spatial variability in the sand mobility. Based on a wind erosion index (WEI) calculated by CAZRI based on Chepil's formula (very low 1-14) to extremely high (480 and above), Jaisalmer (WEI, 480 and above), and Phalodi in Jodhpur (WEI, 120-479) were found to be more vulnerable to wind erosion.

Techniques of sand dune stabilization

The techniques adopted by the Institute in the field involves following processes: (i) fencing of the shifting dune areas for their protection against biotic interferences (human and livestock

encroachments); (ii) fixing barriers in parallel strips or in checker-board pattern with locally available brushwood or grass materials commencing from the crest down to downslope of the dunes to act as micro-wind breaks. Geometry of species depend upon whether wind directions are aberrant and /or depending upon the anthropogenic activities on the dune slopes; (iii) afforestation on such dunes by direct sowing of grass seeds and transplanting seeding of indigenous and exotic species raised in sundried earthen bricks or polythene bags constituting a mixture of sand, clay and manure in equal proportions; (iv) planting of grass slips or seeds of grasses or leguminous creepers sown on the leeward side of the micro-wind breaks after treating the seeds with sodium arsenate to protect them from gerbils at the onset of the monsoon; and (v) continuous and proper management of such dune till

Table 1. Suitable plant species for sand dune stabilization

Mean annual rainfall (mm)	Trees	Shrubs	Grasses
150-300	<i>Acacia tortilis</i> , <i>A. senegal</i>	<i>Calligonum polygonoides</i> <i>Ziziphus nummularia</i> <i>Citrullus colocynthis</i>	<i>Lasiurus sindicus</i>
300-400	<i>A. tortilis</i> , <i>A. senegal</i> , <i>Prosopis cineraria</i> , <i>Tecomella undulata</i> , <i>Parkinsonia aculeata</i> , <i>Acacia nubica</i> , <i>Colophospermum mopane</i> , <i>Cordia rothii</i>	<i>Ziziphus mauritiana</i> , <i>Z. nummularia</i> , <i>C. polygonoides</i> , <i>C. colocynthis</i>	<i>Cenchrus ciliaris</i> , <i>C. setigerus</i> , <i>L. sindicus</i> , <i>Saccharum munja</i>
400-550	<i>A. tortilis</i> , <i>P. cineraria</i> , <i>Dalbargia sisoo</i> , <i>Ailanthus</i> <i>excelsa</i> , <i>Albizzia lebeck</i> , <i>A. senegal</i> , <i>T. undulata</i> , <i>P. aculeata</i> , <i>C. mopane</i>	<i>Z. mauritiana</i> , <i>Cassia auriculata</i>	<i>C. ciliaris</i> , <i>C. setigerus</i> , <i>S. munja</i> , <i>Panicum antidotale</i>

the cost of input is recovered in about 10-15 years duration. A number of hardy plant species were identified (Table 1) for their use in the dune stabilization under different rainfall zones.

Similarly for creating micro-wind breaks, following locally available materials were suggested;

- Brushwood materials: *Leptadenia pyrotechnica* (khimp), *Ziziphus nummularia* (pala), *Crotalaria burhia* (saniya) and *Panicum turgidum* (murath).
- Trees: *Acacia tortilis*, *Prosopis* spp., *Acacia senegal*, *Parkinsonia-articulata* and *Tamarix articulata*.
- Grasses : *Lasiurus indicus* and *Cenchrus ciliaris*.
- Creepers : *Citrullus colocynthis*.

At present, live models of sand dune stabilization technologies and shelterbelts were seen at several places of Jodhpur (Dechu-Shetrawa-Balesar), Bikaner (Nokha-Pugal) and also in Churu, Jhunjhunun districts, Figs 4 (a-d). The State Forest Department of Rajasthan has made major execution of CAZRI technology and is reported to have fixed sand dunes in about 4 lakh ha area.

Shelterbelt plantation: These plantations are vegetative barriers of tree/shrub/bush, found to be effective technique to minimize the adverse effects of winds. During 1980s, Institute also came out with such techniques for non-duny areas and plantations were carried out at several sites for nearly 800 km; roadside plantation for >200 km length on the state highways of Jodhpur, Barmer, Jaisalmer, Churu, Jhunjhunun, Nagaur, Ajmer and Pali districts, and 100 km plantation along the railway tracks in Sikar-Loharu, Sikar-Fatehpur and Palsana-Deshnoka sections. The activities were also made in tube-well irrigated area of Lathi in Jaisalmer district (167 km with *Acacia tortilis*, *Eucalyptus camaldulensis* and *Dalbargia sissoo*) and in IGNP area of Mohangarh (250 km long with trees like *D.sissoo* and *Tecomela undulata*).

Techniques: The layout and form suggest orientation of the shelterbelts should be more or less perpendicular to the prevailing winds. Spacing of



Fig. 4a. Sand dune stabilization model: Checkerboard pattern



Fig. 4b. Local shrubs/grasses used in horizontal pattern



Fig. 4c. Sand dune stabilization: through plantations



Fig. 4d. Shelterbelts along the IGNP canal

Table 2. Suitable species and geometry for shelterbelts

Purpose	Design	Suitable species
Roadside	3 to 5 staggered rows	<i>A.tortilis</i> , <i>A. lebbeck</i> , <i>A.indica</i> , <i>D.sissoo</i> , <i>P.accumata</i> , <i>Tamarix articulata</i>
Railway side	6 rows	<i>P.accumata</i> , <i>Tamarix articulata</i>
Canal side	6 rows	<i>Acacia nilotica</i> , <i>Eucalyptus</i> spp., <i>Tecomela undulata</i> , <i>A.tortilis</i> , <i>D.sissoo</i> , <i>P.cinerea</i> , <i>A. nubica</i>
Farm boundary (rainfed)	1/2/3 rows	<i>A.tortilis</i> , <i>A. lebbeck</i> , <i>A.indica</i> , <i>D.sissoo</i> , <i>P.accumata</i>
Farm boundary (irrigated)	2 rows	<i>A.tortilis</i> , <i>A. lebbeck</i> , <i>Dicrostachys cinerea</i>

treess, geometry of shelterbelts (Table 2) plays an important role. Plantation across the wind of a 13 m wide tree belt, interspersed with 60 m wide grass belt provide the best result. Eight-year-old plantation of three different types at Jodhpur condition showed effectiveness to reduce wind velocity and erosion up to 2 to 5 H distance and there was 50% reduction in wind erosion. Maximum benefits from shelterbelts were derived, if there were series of shelterbelts parallel to each other at distance of 10 to 15 times the height of the central row of trees. The *Cassia siamea* type shelterbelt (plantation of two outer line of *Cassia siamea* and the central line of *Albizia lebbeck* was found to be the most effective). Ideal form of shelterbelt is pyramidal with fast growing tall trees in the central row, flanked by fast growing and high branching trees of medium height,

the outer rows to be planted with low and much branched shrubs. This type would give a triangular cross-section for the shelterbelt.

Impact of sand-fixation activities

Plantations under checkerboards or parallel stripes were effective in stabilizing sand dunes and also fruitful in checking sand movements in this region. Plantations over dunes and shelterbelt along the IGNP canals not only increased the vegetation cover, but also stabilized the loose soils and there was a moderation in the micro-climate. However, IGNP and available canal water has a significant contribution along with human effort in the stabilization effort. Strength of wind has declined drastically and dust storms have now declined to less than 5 numbers at present. Areas affected by wind erosion hazards are

declining. Wind erosion affected area in western Rajasthan has declined from 76% (during 2000s) to ~73% (2011-13). The database for the entire Rajasthan (desertification status mapping) showed that between 2003-05 and 2011-13, total area under desertification in Rajasthan has decreased by 99,092 ha area. There is a decline in degraded area under wind erosion by 1,341,80 ha. Land use-wise due to control over sand movements, wind erosion affected area on rainfed crop land was reduced by 1,006,67 ha and irrigated crop lands by 21,390 ha. Similarly, under shelterbelts, average loss in crop productivity was 17% due to cold wave 30% on farms without shelterbelts. There was also a reduced 5 to 14% pan evaporation values on either side of belts. Silting of canal beds is a serious problem and in one situation along the main canal, about 0.57 million m³ blown sand had to be removed. A case study from Jaisalmer found reduction in sand deposits by 513 m³/km with one-year-old canal

side plantation.

Impact on agriculture

An overview of land use changes in western Rajasthan (Table 3) indicated substantial increase in netsown area, double crop area and forest area whereas significant decrease was observed in culturable waste, current and old fallow area from 1957 to todate.

Considering the fact that sand dune area has reduced by 12% over the period, and those sandy waste area are put to cropping activities, it can be estimated that on an average, 12,000 tonne of additional food grains were added to food basket per year.

SUMMARY

About 4 lakh ha area under sand dunes was stabilized using various techniques. Sand dune area has reduced by 12% between 1980 and todate. Wind erosion affected area

Table 3. Land use type in western Rajasthan

Land use types	1957 (%)	2005-06 (%)	2014-15 (%)
Net sown area	35.51	51.19	53.76
Double crop area	0.70	9.96	15.45
Forest land	0.69	2.19	2.30
Culturable waste	24.18	17.67	15.39
Current fallow	9.07	7.36	7.43
Long fallow	14.24	8.20	7.34

has reduced by 3% of total geographical area of western Rajasthan. Simultaneously, there was change in agricultural land uses in the desert area such as increase in net sown area, total crop area and double crop area and decreasing area under culturable wastelands. These are impacts of combating processes of wind erosion by sand dune stabilization as well as shelterbelt plantation. The models initiated by CAZRI and executed by government departments showed success.

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