

## Desertification Problem in Western Rajasthan

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**Abstract** Desertification problem in western Rajasthan, as caused by accelerated and natural processes and manifested through degraded features like sand sheets, drifting sand, active dunes, deflation hollows, rills, gullies, soil crust, salt encrustations, impeded drainage conditions, poor vegetation cover, low plant density and low biomass production under different rainfall zones, has been highlighted in this paper. In the less than 300 mm rainfall zone, wind erosion/deposition, salinisation and waterlogging are the dominant processes of desertification. In the more than 300 mm rainfall zone, water erosion and wind deposition are the major processes leading to degradation of the croplands and grazing lands.

**Key words** desertification, water erosion, wind erosion/deposition, salinity/alkalinity & waterlogging, vegetation degradation, zoogenic, technogenic and anthropogenic,

Desertification is defined as land degradation in the arid, semi-arid and dry sub-humid regions, resulting mainly from adverse human impact (Dregne 1991). The definition recognises that the impact of natural climatic conditions, like recurrent drought, also plays a role in desertification. Desertification affects the agricultural and non-agricultural lands alike. Rainfall pattern, landform history, morphological and pedological characteristics of the land, characteristics of vegetation and prevalent land utilization pattern determine the extent and magnitude of the problem. The key role is, however, played by man and the domesticated animals. Mismanagement and/or overuse of the land and water resources lead to the degradation of those resources and accelerate the natural processes. Consequently, the problem spreads to newer areas. In the arid western part of Rajasthan, desertification is manifested through the features of accelerated wind erosion/deposition, water erosion, salinity/alkalinity, water logging (Mann 1977, Ghose *et al.* 1977, Shankarnarayan & Sen 1985, Venkateswarlu *et al.* 1992).

Information generated through remote sensing and field studies by the Central Arid Zone Research Institute (CAZRI), Jodhpur, during the last three decades, especially on the natural resources and their degradation (Anon. 1974, 1982, Shankarnarayan & Kar 1983, Chatterji & Joshi 1989, Chatterji & Kar 1989, 1992), provided the

data base for an understanding of the desertification problem and its impact on the fragile ecosystems in the region.

Based on the analysis of natural resources and their degradation, an attempt has been made in the present paper to discuss the desertification problem caused by different accelerated processes and its impact on the fragile ecosystems of western Rajasthan. The spatial distribution of the problems were mapped earlier, using satellite imagery and ground information (Singh *et al.* 1992).

### Results and Discussion

Since rainfall distribution pattern plays a crucial role in the distribution of morphological processes, the salient features of desertification in the form of wind erosion/deposition, water erosion, salinity/alkalinity, waterlogging and degradation of vegetation are being discussed under the following two heads: (a) less than 300 mm average annual rainfall zone, and (b) more than 300 mm average annual rainfall zone.

#### *Wind erosion/deposition*

(a) *Less than 300 mm rainfall zone* : In this zone the sandy terrain is highly vulnerable to aeolian processes and consequent sand movement. Anthropogenic activities are further ac-

centuating them, leading to the reactivation of the old dunes and interdune plains, new mobile dune formation and sand drift phenomena (Fig.1). Results of studies carried out so far on the nature of the problems and their manifestations are briefly discussed.

In the stage II command area of the Indira Gandhi Canal Project (IGNP), lying mostly in the less than 200 mm rainfall zone, the landscape is dominated by the dune-interdune sequence. Hence, the terrain is highly vulnerable to wind erosion/deposition. The disturbance caused to the stable dune environment during canal construction led to large scale reactivation of the sandy landforms and accelerated the aeolian processes all along the canal. Consequently, the roads, canal settlements and even the canal bed are now affected (Kar 1989, Singh & Kar 1991).

Elsewhere in the zone, technogenic activities like the movement of heavy vehicles and heavy machineries which are used for construction of canals and roads and for exploration of gas, oil and ground water, disturbed the soil structure locally and partially destroyed the natural vegetation. This also accelerated the wind erosion and deposition and became a source for the formation of shrub-coppice and barchan dunes of about 1 to 5 m height and sand sheets of 200 to 350 cm thickness.

The zoogenic activities like digging of burrows and destruction of plants and plant roots by the rodents are also contributing to the acceleration of sand drift from the sand dunes and sandy plains. The density of burrows created by rodents on stabilised dunes varies from 100 to 350 per hectare (Prakash 1976).

The magnitude of sand movement and soil loss through wind action has been studied in some areas. Dhir (1989) found that the soil loss in the deep ploughed fields of the sandy plains was 2630 to 3160 t ha<sup>-1</sup> during the sandstorm of June-July 1985, while those having 2 to 4 per cent vegetation cover and/or lying fallow, lost 207 to 283 t ha<sup>-1</sup> of soil. Kar (1988) calculated a soil loss of 3128 to 3754 t ha<sup>-1</sup> from a field at Chandan which was stripped of its grass cover

before the 1985 sandstorm. Gupta & Gupta (1981) observed that a ploughed field in the medium textured soil with 42 per cent clods of more than 5 mm size lost sediments to the tune of 0.5 t ha<sup>-1</sup> during the sandstorm of 1979, while another ploughed and planked field in the same soil with 13 per cent clods only, lost sediments to the tune of 40 t ha<sup>-1</sup>. A study in the Shergarh area of Jodhpur district revealed that an old and vegetated parabolic dune advanced by 0.5 m in a year, whereas a barchan dune in the vicinity advanced by 7 m during the same period. The mean sand erosion from the crest of the barchan was 351 kg m<sup>-2</sup> d<sup>-1</sup>, while from the crest of the parabolic dune it was 325 kg m<sup>-2</sup> d<sup>-1</sup>. The maximum erosion was recorded in the month of July (Ramakrishna *et al.* 1990).

In spite of such fragility of the terrain, the irrigation by the canals and ground water has improved the micro-climate to some extent in the command areas and reduced the sand activities. Depletion of biological productivity of the ecosystems has thus been minimised.

(b) *More than 300 mm rainfall zone* : The problem of wind erosion/deposition is somewhat restricted in the more than 300 mm rainfall zone due to higher and more assured rainfall and greater stability of the terrain. In the eastern part of Jodhpur and Nagaur districts formation of sand sheets of 150 to 350 mm thickness and sandy hummocks of 1 to 2 m height have affected agricultural lands due to the increasing anthropogenic activities. The zoogenic activities like digging of burrows by the rodents are also accelerating the deflation processes and removal of sand. It has been estimated that 61500 kg km<sup>-2</sup> d<sup>-1</sup> soil is excavated by rodents through burrowing in the uncultivated fields with natural vegetation (Prakash 1976).

Some quantitative information on monitoring of the process is available from the Luni development block of Jodhpur district. Singh *et al.* (1978) estimated that before 1958 about 23,120 ha of land was affected by deflation, sand sheeting and minor sandy undulations due to the combined effect of natural processes and human activities, while another 1990 ha land was affected between



Fig 1 Landsat MSS view of Jodhpur-Shergarh-Dechu tract, showing (a) low sandy hummocks and fence line ridges, (b) reactivated high parabolic dunes, (c) recent sand sheets in the interdune plains and around settlements, and (d) saline ranns

the years 1958 and 1977. If the present trend of exploitation continues, another 18,000 ha of land, mostly in the sandy undulating terrain, is likely to be affected in near future (Fig. 2). The faulty and unplanned methods of cultivation in the vulnerable sandy areas should, therefore, be avoided to the extent possible, so that the extent of the hazard is restricted.

Further east, along the eastern fringe of the desert, the sand dunes have greater stability under undisturbed conditions. Rills and gullies have formed along their slopes. Yet, over-exploitation of the vegetation and excessive cultivation on these dunes are loosening the sand and encouraging sand movement. Although quantitative information is lacking on the recent sand deposits

due to such practices, there is evidence to suggest that the problem is a major one and needs consideration. For example, cultivation of the marginal lands and indiscriminate use of the natural vegetation on the stable sandy landforms of Pushkar-Budha Pushkar lake region for fuel, fodder and for grazing of the animals have led to the formation of mobile dunes in the formerly dune free areas (Kar 1986). Similar situation exists in Sikar, Jhunjhunu and Churu districts, where the sandy landforms are mostly stable under natural set up and the climate is wetter than in the west, but the activities of sand sheeting, sand drifting and formation of barchan dunes in the agricultural lands, along roads and against settlements are taking place due to higher reactivation (Kar 1992).

#### *Water erosion*

(a) *Less than 300 mm rainfall zone* : In this zone desertification due to accelerated fluvial action, especially in the form of rills (a few mm wide and upto 300 mm deep) and gullies (2 to 5 m deep and 6 to 10 m wide) is neither much serious, nor wide-spread because of low rainfall and dominantly sandy terrain. The rocky/stony terrain and the surfaces strewn with rock fragments, cobbles and boulders add another dimension to the problem, as overland flow and consequent redistribution of coarser fragments deplete the production potentials of adjacent good lands. In addition to the above problem, this zone occasionally experiences torrential rainfall which causes flash floods and thus, affect the younger and the older alluvial plains, as well as the fields and structures along the abandoned and buried drainage channels, especially through erosion of fertile soil and deposition of the coarse sediments. In the year 1979, a massive flow of water in the Luni river caused stream bank widening and bank cutting, thereby damaging numerous irrigation wells and agricultural lands on both the banks of the river. At Silor, the Luni eroded its right bank by 500 to 700 m. Besides, the overtopping of the banks and lateral spread of water to the extent of 2.5 to 3.5 km between Samdari, Guda and Gandav created rills and gullies of 2 to 3 m depth and 2.5 to 4.5 m width. By and large, the deposition of coarse

sediments in the form of ridges and mounds of 0.5 to 1.5 m height caused the greatest damage to the irrigated lands, situated on both the banks of the river between Kankani and Balotra. Due to these superficial deposits on the original fertile sediments of the flood plains, the agricultural productivity of these areas has been depleted considerably.

The incessant and heavy rainfall during 3 to 7 July and 3 to 8 August 1990, caused much damage to the agricultural lands by way of severe erosion through new gullies of 3 to 4 m width and 2 to 3 m depth, and by sediment deposition. The flat buried pediments and obstacle dunes were hardly affected by the flood waters. At Agolai (near Jodhpur) four new *nallas* were formed, causing 300 to 400 m wide and 3 to 4 m deep scouring in the fields. The areas around Balotra, Guda, Barmer town and Siwana suffered extensive damage, especially in the agricultural lands, due to the development of gullies of various dimensions, removal of top fertile soil and exposure of substrata by the flash floods. Out of 32 *khadins*, 27 were damaged near Dugar village due to the excess runoff and overtopping of the earthen embankments.

(b) *More than 300 mm rainfall zone* : In this zone water erosional hazard is more serious and wide spread due to higher rainfall. The rills of a few mm depth and upto 300 mm width and the gullies of 1.5 to 10.0 m depth and 3 to 15 m width are numerous along the hill slopes, piedmont plains, rocky/gravelly pediments and flat buried pediments. It has been estimated that 16.79 per cent area of the grazing lands and 9.27 per cent area of the cultivated lands in the central Luni basin and Jodhpur district have been affected by rills and gully formation (Singh 1988).

The destruction of vegetative cover in the catchment areas of the *nadis* (ponds) due to the increased human and livestock activities like cutting of trees, overgrazing, etc., have accelerated the removal of sediments from those catchments and their subsequent deposition in the *nadis* (Sharma & Chatterji 1982). The rate of removal and deposition of sediments have increased by 62.2

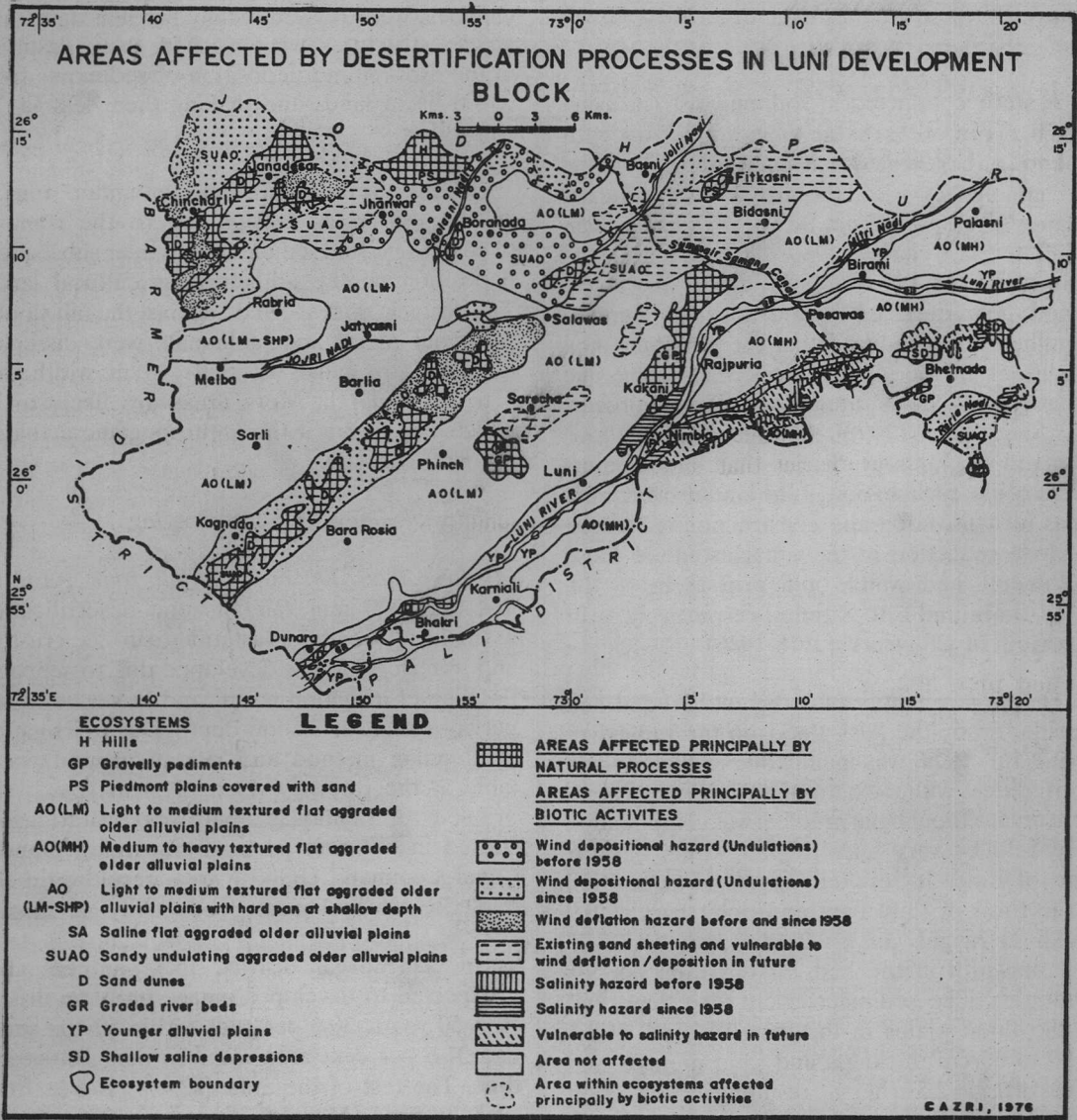


Fig 2 Areas affected by desertification processes in Luni development block

to 94.4 per cent and may have affected the agricultural productivity of the catchments. The storage capacity of the *nadis* has declined. At certain localities in this rainfall zone, increased peak runoff and runoff volume have increased the sediment loss from 3.95 to 160.84 kg ha<sup>-1</sup>.

In the Luni basin, the accelerated water erosion has removed 0.2 to 53.5 g l<sup>-1</sup> sediments

in the hilly terrain of the Aravallis and 1.0 to 453.6 g l<sup>-1</sup> in the lower reaches of the basin (Sharma *et al.* 1984). This has increased the deposition of sediments in the reservoirs, thereby reducing their storage capacity. It has also been observed that between 1958 and 1986 the courses of the Luni and the Mithri rivers have widened by 1.8 times due to channel widening, deepening and bank erosion by scouring and slumping. As

a result, 3720 ha of agricultural land in the flood plains of these rivers has been desertified (Singh *et al.* 1988).

A study conducted in Jodhpur district, using satellite remote sensing in conjunction with ground truth, revealed that due to the cultivation and mining activities, the size of the different uplands decreased from 30 to 3973 ha in 1958 to 30 to 3375 ha in 1986. The gullied areas increased from 199 to 242 ha during the above period. The decrease in uplands and increase in gullied areas indicate that the environmental conditions in the region are deteriorating due to natural and accelerated desertification processes (Singh *et al.* 1990). Sharma *et al.* (1989a) observed in Jodhpur district that biotic interferences like reclamation of the land in catchment areas for cultivation and construction of houses, led to a reduction in the areal extent of those catchments and water bodies in them by 1.8 to 2.4 times and 6 to 8 times, respectively, over a period of 28 years (1958-1986).

The large quantity of sediments eroded and transported by the flash floods in the Luni river during July 1979, was mainly due to high human interferences with the natural system in the catchment area, although the problem was compounded many-fold by very high rainfall within a short span of time. It resulted in lateral deposition in the form of sand bars and point bars of 0.9 to 1.5 m height, 1.5 to 2 m length and 0.75 to 1 m width in the beds of the Luni and its tributaries. The sediments were also deposited on the flood plains in the form of sand sheets of 20 to 60 cm thickness and sand mounds and ridges of 0.7 to 2.5 m height, resulting in a depletion of the biological productivity of the original fertile sediments. Rills and gullies of 0.5 to 2.5 m depth and 2.5 to 4.5 m width were also formed in the flood plains, older alluvial plains and sand dunes.

The alluvial and colluvial plains in the districts of Pali, Jodhpur and Jalor were also affected by the flash floods of 1990. In Tiwri-Mathania sector of Jodhpur district 20 to 30 cm soil was washed away and about 800 ha of agricultural land was desertified. In Pali and Jalor districts,

buried and abandoned course of some drainage channels were revived. Many earthen dams and *khadin* structures were washed away, resulting in the erosion and deposition of sediments from 25000 ha of lands and making them less fit for cultivation.

In the Aravalli hills and mountain region, accelerated water erosion led to the removal of coarse textured sediments and their subsequent deposition on the adjoining agricultural lands. The obstacle dunes formed against the hill slopes, piedmont plains and pediments were dissected at places by gullies of 5 to 15 m width and 8 to 25 m depth. More areas are likely to be affected in future if the anthropogenic activities are not checked.

#### *Salinity/alkalinity and waterlogging*

(a) *Less than 300 mm rainfall zone* : In the less than 300 mm rainfall zone desertification in the form of salt encrustations, surface crusting and waterlogging has developed due to seepage, flooding of irrigation water, and presence of impervious strata at shallow depth. Due to irrigation by flooding method and rise of ground water table at the rate of 0.43 to 0.83 m year<sup>-1</sup>, the problem of salinity/alkalinity and waterlogging started in different parts of the Indira Gandhi Canal Command (IGNP) area, resulting in the depletion of biological productivity of land.

In Ganganagar district, 15.4 per cent area is expected to develop drainage problem in less than 50 years, 30.6 per cent within 50-100 years and 31.6 per cent area in more than 100 years' time. The rest of the area (22.9%) is free from such hazards (Mann & Chatterji 1978). If the present rate of rise in ground water table continues, nearly 2.35 million ha area is likely to develop salinity and drainage problem.

Bithu (1984) reported that out of the 7000 km<sup>2</sup> of IGNP area, 513 km<sup>2</sup> (7.3%) has become waterlogged and about 24 per cent more area is liable to be waterlogged if static water level is allowed to rise at the present rate of 0.43 to 0.83 m year<sup>-1</sup>. Due to seepage near the head of the Indira Gandhi Canal, the salinity/alkalinity

and waterlogging problem has developed around Dabli Kalan and Dabli Khurd.

In the Baropal-Jakharanwali-Kanaur-Manaktheri sector, eighteen interdune plains were linked to the Ghaggar through a canal to avert the menace of flood, but without taking into account the presence of sub-surface gypsiferous and calcrete formations. Due to the presence of such impermeable formations below the sediments of the interdune plains, water not only remained stagnant, but also created problem of salt infestations in these plains (Singh 1987). In Suratgarh and Anupgarh branches of the canal, the presence of heavy textured soils, hard gypsum layer below 1 to 2 m depth and profuse irrigation without proper drainage may lead to the development of salinity and waterlogging problems. It has been calculated that an area of 1456 sq. km in the stage I of IGNP has already become critical (i.e., the water table is within 6 m of the land surface). If the water table continues to rise at the rate of  $0.87 \text{ m year}^{-1}$ , as monitored in many wells, the critical area in 2000 AD will be about 3960 sq. km (Sharma & Mathur 1991).

In the stage II of the IGNP, where the climate is very dry, a more serious problem of waterlogging and salinity may develop, in spite of the coarse textured soils having high infiltration rate and low water holding capacity. The presence of hard *kankar* pan at shallow depth may accentuate the problem over vast areas. Hydrological barriers like clay, gypsum and calcrete pan within 5 m depth have been encountered, mainly in the command areas of Dattor, Sakaria and Awai distributaries and to some extent in the Sagarmal Gopa branch and in the lift schemes of Pokaran, Phalodi and Kolayat canals.

The ground water used for irrigation in this rainfall zone contains soluble salts ( $\text{EC } 5\text{-}15 \text{ dSm}^{-1}$ ) and the chlorides and sulphates of sodium, calcium and magnesium. The use of such highly saline ground water for irrigation turns the soil saline at the end of irrigation phase. The accumulated salinity is only partly leached during the fallow phase in monsoon season. Thus, the progressive build up of salinity has resulted in the degradation of land and a drastic reduction

in crop yield in the Balotra- Samdari section. The problem is further aggravated when the monsoon fails, because the water table falls and there is no leaching.

As a result of irrigation with sodic water, containing more than  $5 \text{ me l}^{-1}$  residual sodium carbonate (RSC), the soils have acquired unusual hardness. Consequently, their working is difficult and water infiltration has also been greatly reduced (Joshi & Dhir 1994). Due to surface crusting the emergence of germinated seed is very low. The growth of the crops is poor and yield very low. In the 200-250 mm rainfall zone, irrigation in the fine sand/loamy sand soils with  $15\text{-}20 \text{ me l}^{-1}$  RSC water for 8 to 10 years has resulted in complete abandonment of the land (Joshi & Dhir 1991). The soils have become highly sodic (Fig. 3). In spite of following such lands for two to three years, the farmers do not get good stand of crops and, therefore, seek new grounds. Such degradation of land due to irrigation with high RSC water is common in Siwana, Balotra and Guda Malani sectors of Barmer district and Ahor block of Jalor district.

(b) *More than 300 mm rainfall zone* : In the more than 300 mm rainfall zone, the salinity/alkalinity and waterlogging problems due to irrigation with high RSC water has developed in Jhanwar, Doli and Bilara areas of Jodhpur district, Jaitaran, Sojat and Kharchi areas of Pali district, Parbatsar-Makrana area of Nagaur district and Fatehpur area of Sikar district.

Several reservoirs for irrigation have been constructed across the rivers on granitic terrain. As a result, salinity and waterlogging problems have developed in the agricultural lands. Chatterji (1985) reported that the Sardarsamand reservoir, which was constructed at the confluence of the Guhiya and the Sukri rivers in the year 1905, received  $3\text{-}7 \text{ g l}^{-1}$  average suspended sediment load, measured at Shivpura, Sojat and Jhupelav during 1982-84. The total soluble salt (TSS) varied from 358 to 2300 ppm. As a result, 9600 ha of culturable command area has turned saline. Similarly, Jaswantsagar reservoir, constructed in 1899 on the Luni river, carries the average suspended sediment load of  $11 \text{ g l}^{-1}$  and TSS varies from 180 to 553 ppm. Although the inflow water

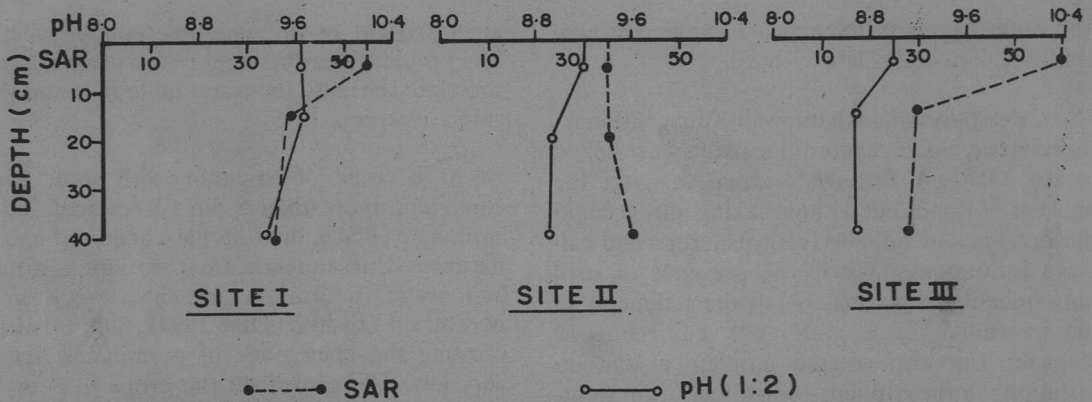


Fig 3 Impact of high Residual Sodium Carbonate (RSC) water irrigation on soil pH and SAR

is not saline, yet 6170 ha CCA has turned saline in the command area because of a build-up of shallow ground water table over the granite basement (Chatterji & Vangani 1985). Similarly, in the Chopra tank command area, several hectares of agricultural land have turned saline. In the Jawai command area seepage from canals and granite basement have favoured waterlogging and salinity in isolated pockets. Large acreage of agricultural land has also been affected by salinity and waterlogging due to the seepage from Naya-gaon and Kharda tanks. The values of pH and EC ( $\text{dSm}^{-1}$ ) vary from 7.7 to 10.7 and 0.15 to 19.8, respectively.

Construction of tanks and canals across the prior channels in the Luni development block resulted in the development of salinity in agricultural fields between Lolawas and Bhetanada and around Kharabera Bhotan and Kharabera Patarobas villages. It has been worked out that prior to the year 1958, a total of 830 ha was affected by salinity through the construction of tanks and canals. After 1958, a total of 1560 ha of land became saline in the above area. In the medium to heavy textured flat older alluvial plain, 4030 ha area which is still unaffected around Moklasni, Bhetanada, Lolawas, Mori Sutan, Khara-bera Patarobas and Nimbla villages, are highly vulnerable to salinity hazard in near future (Singh *et al.* 1978).

#### Vegetation degradation

(a) *Less than 300 mm rainfall zone* : Vegetation degradation in the form of poor basal cover,

low plant density and changes in plant species, has occurred due to the increasing biotic and abiotic activities like over-grazing and cutting and lopping of trees (Fig 4). Due to degradation of the sandy landforms, the *Lasiurus syndicus-Eleusine compressa* vegetation complex is being replaced by *Aristida funiculata-Dactyloctenium syndicum*. The basal cover of these plant species declines from 5.14 to 2.4 per cent. The total vegetation cover declines from 6.59 to 0.95 per cent and its yield declines from 2 to 4  $\text{t ha}^{-1}$  to less than 1  $\text{t ha}^{-1}$  (Shankar & Kumar 1987). Trees of *Prosopis cineraria* and *Salvadora oleoides* are replaced by unpalatable bushes of *Aerva persica* and *Calotropis procera*. At Udairamsar near Bikaner, the average height and total crown cover of *Calligonum polygonoides* was 115.4 cm and 21.80 per cent, respectively, under protected condition, as compared to 90.8 cm and 11.31 per cent under unprotected situation (Shankar & Dadhich 1977). With the construction of the Indira Gandhi Canal, natural cover of *Haloxylon salicornicum*, *Prosopis cineraria* and *Lasiurus syndicus* is being fast depleted due to waterlogging and salinity problems. Instead, crop weeds as well as *Eichhornia* and *Arundo donax*, the water grass, have come up. Such changes in plant cover indicate that desertification process is taking place in the canal command area.

Due to poor soil mantle, the rocky/gravelly pediments support very poor cover of *Dactyloctenium syndicum - Eleusine compressa* type grasses. Upon degradation, it is replaced by *Aristida funiculata-Oropetium thomaeum* type of cover. The



Fig 4 Degraded vegetation near Sultana (Jaisalmer) in the form of overgrazed tussocks of *Lasiurus sindicus* and browsed bushes of *Ziziphus nummularia*

basal cover of these plant species had declined from 2-4 per cent to less than 1 per cent and yield from around  $1 \text{ t ha}^{-1}$  to  $0.27 - 0.45 \text{ t ha}^{-1}$  (Shankar & Kumar 1987). The density of *Salvadora oleoides* has declined from 10-20 tree  $\text{ha}^{-1}$  to 1-3 tree  $\text{ha}^{-1}$ . The *Commiphora wightii* has totally disappeared from open sites. *Prosopis juliflora* and *Euphorbia caducifolia* dominate the habitat instead of *Grewia tenax*, *Ziziphus nummularia* and *Capparis decidua*. Thus, the increasing anthropogenic factors are responsible for the degradation of vegetation in unprotected sites.

(b) More than 300 mm rainfall zone : In the more than 300 mm rainfall zone, *Prosopis cineraria*, *Salvadora oleoides* and *Acacia nilotica* trees, *Capparis decidua*, *Ziziphus nummularia* and *Indigofera oblongifolia* shrubs, as well as *Cynodon dactylon*, *Desmostachya bipinata*, *Cenchrus ciliaris* and *Dichanthium annulatum* grasses are the optimum vegetation on sandy and older alluvial plains. Upon their degradation this type of vegetation is replaced by shrubs of *Prosopis juliflora*, *Crotalaria burhia* and grasses like *Oropetium thomaeum*, *Dactyloctenium indicum*, *Aristida funiculata* and *Cenchrus biflorus*. It has been estimated that the protected vegetation has 4-8 per cent cover and around  $4000 \text{ kg ha}^{-1}$  biomass yield, while under degraded situation, the cover decreases to 1-2 per cent and yield to  $130-1100 \text{ kg ha}^{-1}$  (Saxena 1982).

In another study, the protected sites on the flat older alluvial plains were found to provide

the dry herbage yield of  $1870 \text{ kg ha}^{-1}$ , vegetation cover of 3.49 per cent and perennial grass cover of 3.24 per cent, while under degraded situation, the values were  $520 \text{ kg ha}^{-1}$ , 2.76 and 1.08 per cent, respectively (Shankar 1983). A survey in Bandi catchment of Luni basin revealed that the degradation was so much that over 50 per cent area of grazing land was highly degraded and 30 per cent moderately degraded (Kumar & Shankar 1987). At Norta grazing land in Bhinmal tehsil of Jalor district, a degraded site had no *Prosopis cineraria*, *Ziziphus nummularia* and *Mimosa hamata*, but 360 plants  $\text{ha}^{-1}$  of *Prosopis juliflora*. Upon protection and plantation the same site had a density of 840 plants  $\text{ha}^{-1}$  comprising of 90 plants of *P. cineraria*, 580 *Acacia tortilis*, 30 *Z. nummularia*, 10 *M. hamata* and 130 *P. juliflora*.

The isolated hillocks and rocky/gravelly pediments are, by and large, extremely degraded and barren and instead of *Anogeissus pendula*, *Acacia senegal* and *Grewia tenax* woody perennials, they now support *Euphorbia caducifolia* and *Prosopis juliflora* under protection. The protected parts of the Kunwarda hillocks of Ahor area (Jalor district) had more density of *Anogeissus pendula* (40 trees  $\text{ha}^{-1}$ ), *Acacia senegal* (500 trees  $\text{ha}^{-1}$ ) and *Commiphora wightii* (300 trees  $\text{ha}^{-1}$ ) than that on the open degraded land, e.g., *A. pendula* was totally absent, density of *A. senegal* was 180 trees  $\text{ha}^{-1}$ , and that of *C. wightii* was 40 trees  $\text{ha}^{-1}$ . The dry herbage yield from the protected site was  $1352 \text{ kg ha}^{-1}$  and from unprotected site,  $254 \text{ kg ha}^{-1}$ .

It has been observed that under normal conditions *Prosopis cineraria* and *Acacia leucophloea* occur on plain land. *Acacia senegal* and *Anogeissus pendula* occur on the lower hill slopes of the Aravallis and *Boswellia serrata*, *Lannea coromandelica* on their upper slopes. *Ziziphus nummularia*, *Vitex negundo* and *Grewia tenax* are the optimum shrubs. When degraded, these plants are replaced by *Prosopis juliflora* and *Oropetium thomaeum*. At a site in Kalab Kalan, the vegetation cover, perennial grass cover and herbage yield under protected condition was 10.1%, 71.69% and 2159 kg ha<sup>-1</sup>, respectively, as compared to 1.66%, 6.6% and 644 kg ha<sup>-1</sup>, respectively, under open degraded situation (Shankar 1983). Karad with 16.0% basal cover on protected older alluvial plains was replaced by *Oropetium thomaeum* with 0.7% cover at the unprotected sites. The dry forage yield was 2660 kg ha<sup>-1</sup> and 109 kg ha<sup>-1</sup>, respectively, under protection and without protection. *Dichanthium annulatum* and *Sehima nervosum* cover on piedmont plains, with a basal cover of 5.7% and yield of 2569 kg ha<sup>-1</sup> was replaced upon degradation by *Oropetium thomaeum* and *Aristida funiculata* with 0.7% cover and 237 kg ha<sup>-1</sup> dry herbage yield. On the hills, *Acacia senegal* and *Anogeissus pendula* with 45.9% crown cover and 47.5 q ha<sup>-1</sup> above ground biomass, was replaced upon degradation by *Tephrosia purpurea* and *Oropetium thomaeum* with negligible cover and 1.5 q ha<sup>-1</sup> yield (Saxena 1977). *Acacia senegal* and *Prosopis cineraria* stand on gravelly pediments produce 24.8 q ha<sup>-1</sup> with 15.7% crown cover. When degraded, *Euphorbia caducifolia*, *Capparis decidua* and *Ziziphus nummularia* become dominant and yield 24.5 q ha<sup>-1</sup> biomass with 4.3% cover (Saxena 1977). Upon severe degradation, herbage production is only 1.8 q ha<sup>-1</sup> with 0.8% cover and here only *Crotalaria burhia*, *Capparis decidua* and *Oropetium thomaeum* dominate.

On the heavy textured older alluvial plains *Prosopis cineraria*, *Ziziphus nummularia* and *Capparis decidua* were so much exploited that *Tephrosia purpurea* and *Crotalaria burhia* became dominant and biomass yield declined from 74.6 to 2.6 q ha<sup>-1</sup>. Likewise potential grass cover produced 34.3 q ha<sup>-1</sup> with 8.7% ground cover,

while the degraded one produced 9.5 q ha<sup>-1</sup> with 1.5% cover. The degradation of vegetation on unprotected landforms indicate that desertification process is in vogue in this rainfall zone due to the increasing biotic activities.

Further, in addition to changes in vegetation characteristics, the area under grazing lands have also shrunk from 9 to 30% on different landforms in Jodhpur district, over a period of 28 years between 1958 to 1986 (Sharma *et al.* 1989b).

### Conclusion

Desertification is taking place in western Rajasthan through wind erosion/deposition, water erosion, salinity/alkalinity, waterlogging and degradation of vegetation. These processes have been accelerated by increasing anthropogenic, technogenic and zoogenic activities. It has resulted in the depletion of biological productivity of the region. In the less than 300 mm rainfall zone, wind erosion/deposition is more serious and widespread due to low rainfall and highly vulnerable sandy terrain. Salinity/alkalinity and waterlogging resulted mainly due to faulty methods of irrigation and presence of impervious strata. Overgrazing and indiscriminate felling of trees resulted in the degradation of vegetative cover and decrease in biomass production. In the more than 300 mm rainfall zone, water erosion and wind erosion/deposition are the serious problems affecting the biological productivity of different ecosystems. In case, these problems continue unchecked, large acreage of agricultural land will be affected in future. Based on this integrated information, suitable action plan may be formulated for combating desertification.

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