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Desert Spread and Desertification - Some Basic Issues

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Abstract : Significant variations detected from the multidate and multispectral satellite images and ground truth on the climatological, physical and biological resources have conclusively proved that the Indian desert is not spreading towards east and northeast. Contrary to it, the former limit of the desert was more extensive and wide-spread and the desert has shrunk to the west. However, due to increasing human activities and climatic fluctuations in the last few decades, the desertification processes like wind erosion/deposition, water erosion, salinity/ alkalinity and vegetation degradation have depleted the biological productivity of four major landuse systems of the Indian desert. Thus, the desert spread and desertification are two different problems.

Key words : Desert spread, desertification, multidate and multispectral images, multidisciplinary studies, anthropogenic, zoogenic and technogenic activities.

Since last few decades, 'desert spread' and 'desertification' have been controversial subjects in some parts of the world. Several studies have been conducted and divergent opinions expressed about these two problems. According to United Nations Environment Programme (UNEP), 35% of the surface area of the Earth is at risk and food produced worth $26 billion is lost every year. It has been further stated by UNEP that southern fringe of Sahara is worst affected and "the desert is advancing at the rate of several miles". It is also supposed that "Sahara is swallowing up an area the size of New York State every ten years" (AGID, 1992). It has also been reported in quantitative terms that the southern side of Sahara desert is advancing at the rate of 30 km/year (OST, 1972).

In India, the Planning Commission in the First Five Year Plan (1952) report cautioned that "the Great Indian Desert of Rajasthan has been spreading outwards in a great convex arc through Ferozpur, Patiala and Agra towards Aligarh at the rate of about half a mile (0.8 km) per year for the last 50 years and is encroaching upon approximately 50 sq. miles (130 sq.km) of fertile land every year". As a result, this problem was discussed in both the houses of Indian Parliament and in Uttar Pradesh Assembly and a great concern was expressed about it by the politicians, planners and people at large.

Roy and Pandey (1970) are of the opinion that "the Thar desert is neither expanding nor contracting but has been occupying essentially the same position since its origin". Based on the interpretation of the remotely sensed data, Dhabariya (1988) reported that the mobile sand through aeolian process is "drifting from western desert to the eastern fertile plain ecosystem through twelve gaps and extending the horizon of the Great Indian desert towards the east and northeast".

However, some studies conducted in India and abroad on the individual aspects of the problem have revealed that the desert is not spreading, but the desertification is taking place, resulting in the degradation and depletion of the biological productivity of the fragile desert ecosystems.

Realising the seriousness of the problem of the 'desert spread' and 'desertification', the multidisciplinary studies were conducted on these two aspects by using the modern methods of research and mapping in conjunction with ground truth and their findings are highlighted in this paper.

Materials and Methods

Integrated resources surveys, involving climatological, physical and biological and human resources at the district, river basin, block and taluka levels, using remote sensing and field survey techniques were carried out in the Indian desert and its adjoining border areas by the multidisciplinary team of the subject matter specialists at the Central Arid Zone Research Institute, Jodhpur. The concept of Major Land Resources Units (MLRU), developed by Abichandani *et al.* (1975), was used to integrate climatological, physical and biological resources in the form of resource units.

The variations existing in the above resources of the Indian desert and its adjoining border areas were evaluated and the problem of desert spread towards eastern and north-eastern parts of the country was studied. The methodology developed by Singh *et al.* (1992) was employed to map the impact of different desertification processes under various landuse systems within and outside the desert boundary. The extent of various classes of desertification such as slight, moderate, severe and very severe, was calculated and tabulated.

Results and Discussion

Evolution of the Indian desert

The evolution of the Indian desert, unlike the other deserts of the world, has been influenced by shallow depth of the monsoon current and flow of dry air from north between 1.5 to 4.0 km, inhibiting vertical cloud movement. The Indian desert forms the eastern limit of the Afro-Asian desert belt and excepting for variations due to local features, the entire area from Sahara to Thar appears to be meteorologically homogeneous (Mann, 1993). The Indian desert, as generally believed, is not man made but it had originated due to climatic fluctuations.

Based on the archaeological evidences, it has been reported by Misra (1971) that the Indian desert was already established before the human activities had become effective. The palaeolithic man did exist here and the Mesolithic man had settled on the sand dunes or the sandy alluvium about 6000 years ago.

According to Roy and Pandey (1970), the Indian desert was formed due to the insufficient rain provided by the southwest monsoon from the Arabian Sea and the Bay of Bengal, after the formation of the Himalayas in the mid-Miocene period, about 35 million years ago.

The palaeobotanical evidences indicate an increasing trend in aridity since the Miocene times in western India. It is most probably during the early to mid-Quaternary period that the repeated fluctuations in temperature and precipitation caused the formation of the desert and overall aridity in western India (Vishnu-Mitre, 1977). Geomorphological studies carried out at the Central Arid Zone Research Institute, Jodhpur, have revealed that the arid conditions in northwestern India were probably established in early Pleistocene period (Ghose *et al.*, 1977; Singh *et al.*, 1992).

Multidisciplinary studies conducted on the geomorphological, palynological, archaeological, pedological and sedimentological aspects by different subject matter specialists have indicated that during the late Quaternary period, climate had fluctuated and two major wet and dry phases were established. Based on radiometric studies, it was also reported that the climate fluctuated during the late Quaternary period between arid and sub-humid. Different types of landform and associated soils were formed by the fluvial and aeolian processes during the wet and dry phases. Fluvial landforms were formed during first major wet phase around 50-40 ka BP. Aeolian dune building activities became dominant during the pre-Holocene period around 20-10 ka BP. As a result, different types of sand dunes and sandy undulating plains were formed over the vast alluvial plains of north-west India (Ghose *et al.*, 1977; Wasson *et al.*, 1983; Singh *et al.*, 1974). The above evidences indicate that the Indian desert had evolved due to climatic fluctuations during Quaternary period and is not man made as advocated by several earlier workers.

Former limit of the Indian desert

The study of the morphological, pedological and biophysical characteristics of the stabilised and fossilised sand dunes and associated artefacts of upper Palaeolithic and microlithic ages existing in the fringe areas of the Indian desert have indicated that its former limit was more extensive and widespread (Allchin *et al.*, 1978; Goudie *et al.*, 1973; Ghose *et al.*, 1977; Sharma, 1992). In central Gujarat, no sand features of any consequence were found to the south of the Narbada river; but north of it at Pavagarh, north east of Baroda, Visadi and in the Old-Kamrod region, both large wind drift and small aligned and amorphous ridges have been traced (Allchin and Goudie, 1971). The fossil dunes and stabilised longitudinal and transverse dunes of 4 to 8 m height also occur to the north and east of Ahmedabad, few kilometres north of Kalol and about 40 km south of Mehsana. These sand deposits are highly dissected and weathered and have more than 20% silt and clay content (Goudie *et al.*, 1973).

In Rajasthan, the sand occupies the valleys and plains in the Aravallis. To the east of the Aravallis sand is missing until 34 km west of Ajmer, except few small transverse dunes and sand drift at Ajranpura. However, at Pushkar in Ajmer district, huge amount of sand has funnelled into a depression between two or three parallel ridges trending SW-NE, resulting in the formation of longitudinal and transverse dunes and sand drifts in the form of windward and leeward obstacle dunes. These dunes are highly stabilised and fossilised. The sand also occurs near Sardhana and along Rupangarh river. Similar types of sand deposits have also been encountered in Sirohi district near Revdar and Shivganj and in Jaipur district near Sanganer, Phulera, Bichun and upto 120 km east of Jaipur (Goudie *et al.*, 1973; Ghose *et al.*, 1977).

Recent studies conducted in the eastern part of Rajasthan, Punjab and Haryana right upto western Uttar Pradesh, using large scale and high resolution remotely sensed data and ground truth, have enabled to identify and map the fossilised and highly stabilised and degraded sand dunes and sand sheets in scattered pockets of the above adjoining states of the Indian desert (Fig. 1).

In eastern Rajasthan, the fossilised sandy features supporting desert types of vegetation such as *Calligonum polygonoides*, *Leptadenia pyrotechnica*, *Sericostema pauciflorum* and *Prosopis cineraria* occur in Jaipur, Dosa, Alwar, Tonk and Sawai Madhopur districts near Kotputli, Lalsot, Dosa, Phagi, Behror, Diggi, Malpura, Nawai, Gangapur and Sawai Madhopur (Fig.1).

Based on the stratigraphy and luminescence geochronology of the aeolian sediments in north-eastern Thar desert, Raghav *et al.* (1992) reported that highly and moderately oxidised and fossilised sand dunes are widely distributed in the north-eastern Thar and also in south Haryana, Delhi and Agra. They also stated that presence of the fossilised sand dunes and absence of aeolian activities in the border areas right upto Delhi and Agra also lead to an inference that at present the former widespread spatial extent of the Thar is in a contracted phase.

The presence of above fossilised and stabilised dunes with desert vegetation, weathered soil profile and higher percentage of silt and clay and caliche deposit (10 to 30%) in the above adjoining higher rainfall (500-900 mm) non-desertic areas conclusively prove that the former limit of the Indian desert was more extensive than the present one. The findings of these studies are in conformity with the findings of Goudie *et al.* (1973) and Wasson *et al.* (1983) who also reported that the extent of the former Indian desert was much more extensive than at present.

The studies carried out on the above aspects in other deserts of the world have revealed that the distribution of the present-day dunes and ergs was much more extensive during the earlier period of Quaternary. In West Africa, the limit of active dune formation at times in the late Pleistocene moved southwards more than 600 km from its present position (Grove, 1958; Talbot, 1984). Similar enlarged ergs of late Pleistocene age were identified in the Kalahari (Flint and Bond, 1968) and Australia (Bowler *et al.*, 1976; Wyrwoll and Milton, 1976). In South America, small ergs occupied parts of the Sao Francisco and Orinoco catchments in late Pleistocene. Aeolian activity was also more extensive in the Great Plains and the Carolinas of North America

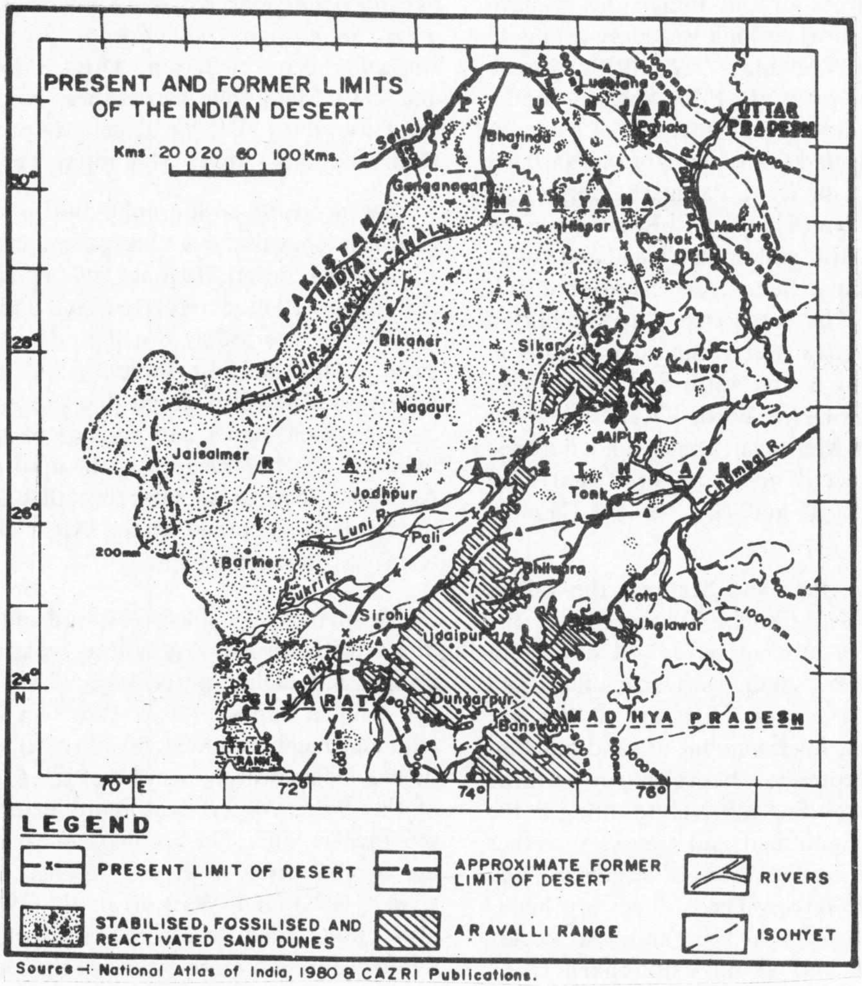

Fig. 1. Present and former limits of the Indian desert

(Price, 1958; Wells, 1983; Carver and Brook, 1989).

Radiometric dating and other evidences indicate that the now fossilized dunes in many of these areas were last active between 20,000 and 13,000 years ago with maximum aeolian activity occurring around the time of the last glacial maximum (Sarntheim, 1978; Sarntheim *et al.*, 1981; Bowler, 1978).

The extent of the late Pleistocene old Ogolian desert in the Sahara-Sahel between 15 ka and 18 ka BP was much larger than the region of recent Sahara. The fossil dunes and sandy soils of this Pleistocene desert cover large areas of the Sahel and the dry Savana (Reichelt, 1992).

Desert spread and desertification

Based on spatial and temporal remotely sensed data and ground truth, it has been observed that the desert spread and desertification are two different problems and the evidences in their support have been discussed in detail.

Desert spread : "Desert spread" means establishment of the desert like conditions in the adjoining border areas due to natural processes, reflected by significant changes in climatic phenomenon and physical and biological resources and their productivity. Accordingly, the comparative studies on the above aspects of the desertic and non-desertic areas were done and the results are discussed below.

Climatic phenomena : The analysis of climatic data for last 80 years by the climatologists of CAZRI, Jodhpur, and Pramanik (1952) revealed that there has been no change in amount of annual rainfall, temperature, humidity and wind velocity within desert and its adjoining areas. Recently, rainfall data of 114 years (1871-1984) from 212 stations spreading over north India, right from Rajasthan in the west to Nagaland in the east, was analysed by Singh *et al.* (1992) which has shown no significant trend of increase or decrease in the rainfall pattern in the above areas. These findings, therefore, provide no evidence of accentuation of climatic conditions and spread of desert towards adjoining non-desertic areas.

Landforms : The most spectacular and dominant landforms with distinct geomorphic features encountered in the Indian desert, are the sand dunes, sandy undulating interdunes and older alluvial plains and sandy undulating buried pediments created by dominant aeolian process. The highly eroded and bare hills, characterised by domed inselberge, tors, mesas, desert varnish, tafonis and pinnacles, and rocky/gravelly pediments, hamadas, older alluvial plains, marginal younger alluvial plains and saline depressions (ranns) are scatteredly distributed in the desert. In the adjoining border areas, the major aeolian landforms are altogether absent, except along the desert margins and the vast non-saline and saline alluvial plains with very deep deposits, by and large, devoid of different types of dunicrusts and created by dominant fluvial process, largely occur in the border areas (Singh *et al.*, 1992). Thus, the significant variations in the landforms and their geomorphic features in the desert and adjoining border areas do not support the myth of desert spread towards east and northeast.

The study on the size of sand grains from different locations revealed that the grains of the dune sands near the Rann of Kachchh in the south-west are finer (0.12 mm mean diameter) than the sand grains found within the dunes in the central part and eastern margin of the desert (0.15 mm mean diameter). This significant variation in the size of sand grains from above locations also indicates that the sands are not being transported from the western part of the desert towards its central and eastern parts and adjoining border areas (Singh, 1982; Singh and Shankarnarayan, 1986).

Analyses of the mineral composition of the dune sands from different types of sand dunes located under three distinct geological provinces revealed that the sands of the igneous geological province in the western part of the desert constitute zircon, agarine, tourmaline, silica and feldspar, whereas, the sands of sedimentary geological province in the central part of the desert comprise silica, fossiliferous limestone and less quantity of feldspar and other heavy minerals and the sands of metamorphic geological province in the eastern part and along the margins of the desert constitute zircon, garnets, muscovite and biotite minerals. The above significant variations in the mineral composition of dune sands clearly indicate that they have not and/or are being not derived and transported from the Rann of Kachchh and western parts of the desert, but have been and/or being locally transported from the rocks and landforms occurring under three distinct geological provinces.

The analysis of the mineral composition of the dust particles collected from the heights of 200, 600 and 1200 m from three distinct regions, viz., Jodhpur, Pali and Ajmer, has also indicated that the significant variations exist in the mineral content of the dust particles of the above regions.

The discontinuous distribution of sand dunes from Rann of Kachchh upto the western and eastern sides of the Aravallis, presence of well stabilised, fossilized and vegetated dunes with alternate layers of compact and oxidised sands with higher percentage of silt and clay and lime concretions and significant variation in size of sand grains and mineral composition of the dune sands also rule out the possibility of transportation of sand and spread of desert from west to east.

Soils : The desert soils, by and large, have developed due to reworking of fluvial sediments by aeolian process. They are characterised by calcareous coarse texture and poor structure, fine sand to loamy fine sand with very little amount of silt and clay, weak to moderate profile development, highly vulnerable to wind erosion, poor water retention capacity of 40 to 80 mm/metre depth, low organic content (0.02 to 0.15%), alkaline reaction, and high pH (Dhir, 1977; Kolarkar, 1994). The soils of the adjoining border areas in the east have developed due to fluvial process and are characterised by loam to sandy clay loam and silty clay loam, better moisture retention capacity and fertility status, well developed soil profile, highly prone to water erosion and absence of kankar pan and aeolian surface deposits. The distinct soil variations in the desertic and non-desertic areas also rule out the possibility of the desert spread and establishment of desertic conditions in adjoining areas.

Vegetation : The dominant plant species, particularly sand-loving ones, encountered in the Indian desert, are *Acacia senegal, Prosopis cineraria, Salvadora oleoides, Ziziphus nummularia, Leptadenia pyrotechnica, Crotolaria burhia, Clerodendrum phlomoides, Cenchrus ciliaris, Cenchrus biflorus, Lasiurus sindicus* and *Citrullus colocynthis* (Saxena, 1977). These plant species, by and large, are absent in adjoining areas and dominant plant species found here are *Acacia nilotica* spp. *Indica, Dalbergia sissoo, Mangifera indica, Ficus bengalensis, Ficus religiosa* and *Phoenix dactylifera*. The significant variations in the plant species of the desert and adjoining non-desert areas also do not support the myth of desert spread.

Water : The surface water in the Indian desert generally occurs in the form of village tanks (*nadis*), *tankas* (cisterns) and few canals. The capacity of the *nadis* depends on the amount and intensity of rainfall. But the village tanks (*nadis*) are the main source of drinking water and they too are dried up during the drought period and hence people have to travel long distances to fetch the water for drinking, bathing and washing (Sharma and Joshi, 1981; Vangani and Singh, 1994).

About 65% ground water is highly saline and sodic and occur at a depth of 35 to 200 m or more below ground level (b.g.l.). The high sodium adsorption ratio (0.15-176.8), residual sodium carbonate (upto 68.8 mel^{-1}) and total soluble salts (over 3200 ppm) are the major factors responsible for very poor quality of water (Chatterji, 1985; Gupta, 1991).

In the northern and eastern parts of the desert, the main sources of drinking water and irrigation are the canals and tubewells. Village *nadis* and *tankas* are altogether absent. The ground water, by and large, is of better quality due to low content of chloride and sodium salts and in most of the areas it occurs at 15 to 40 m b.g.l. The significant variations in the surface water harvesting structures, quality, quantity and depth of ground water in the desert and adjoining border areas prove that desert is not spreading.

Landuse : In desert areas due to sandy terrain, wind erosion/deposition hazard, poor soil fertility and limited irrigation facilities, the pearl millet, moth bean, mung bean and clusterbean with unstable yields are the principal crops. The irrigated crops like wheat, barley, gram, chillies, cumin and vegetables are grown only in pockets. In the border areas right upto Delhi and Uttar Pradesh due to flat alluvial plains with medium to fine textured fertile soils except along desert margins, better irrigation facilities and limited hazards, particularly the wind erosion/deposition, wheat, gram, barley, sugarcane, maize, cotton, mustard, sorghum and fruit orchards, with higher and more stable yields, are the principal crops.

The above significant variations in the landuse pattern and capabilities, crop yield, irrigation facilities and terrain characteristics in desert and adjoining border areas do not provide any evidence of desert spread towards northeast. The quantitative comparative analysis of the parameters like landuse, availability of water and crop yield in desert and adjoining border areas also do not support the belief that the desert is spreading and engulfing adjoining areas to the east of desert (Mann *et al.*, 1974).

Fauna : In the desert areas, the *Gerbillus gleadowi, Gerbillus nanus, Tatera indica, Meriones hurrianae* (Prakash *et al.*, 1971), and goats, sheep, cows and camels are the dominant wild and domestic animals, respectively. In the border areas and right upto Uttar Pradesh and West Bengal, *Bandicota bengalensis, Rattus meltada, Nesokia indica* (Jain, 1994) and she and he buffaloes and cattle are the typical wild and domestic animals, respectively. The above variations in the wild and domestic animals in desert and adjoining border areas do not support the belief of desert spread towards east.

Socio-demography : The salient social and demographic features of the desert areas are, varying growth rates of human and livestock population, low population density, varying from 9 to 210 persons km^{-2}, sparse and semi-compact settlements and farmsteads (*dhanis*), frequent migration of people with their animals to the adjoining states, particularly during drought. The animal husbandry is the main occupation of the people, followed by agriculture. Some people lead nomadic or semi-nomadic life, comprising of pastoral, trading and artisan nomads (Malhotra, 1977). In the border areas, the people by and large lead a sedentary life, mainly engaged in agricultural and industrial activities. The density of population is very high, varying from 250 to 1050 persons km^{-2}, the settlements are by and large compact and semi- compact and very few families reside in the farmsteads and hamlets. The above variations indicate that the desert is not spreading towards east and northeast.

Thus the evidences prove that the desert is not spreading towards the eastern and north-eastern parts of Rajasthan, Punjab and Haryana and Uttar Pradesh as reported by Dhabariya (1988). Contrary to it, the presence of fossil dunes and their desert like vegetation in some parts in the east and north-east indicate that former limit of the Indian desert was more extensive and now it has shrunk towards the west.

Similarly, the American scientists based on satellite products and field work have reported that the Sahara desert has actually shrunk since 1984 as no clear evidences of permanent changes are available despite reports since 1916, claiming that desert was advancing. Researchers from Lund University in Sweden who were studying the desert in Sudan since 1960 using satellite products, ground observations and national food production statistics also found no evidence that long lasting desertic conditions were created between 1962 and 1984. A survey in Senegal by a team from the Geological Research in Dakar found that the desert was not advancing (AGID, 1992).

Desertification

The definition of desertification was recently negotiated and approved by 1992 UN Conference on Environment and Development (UNCED) held at Rio de Janeiro in Brazil. According to this recent definition, "desertification is land degradation in arid, semi-arid and dry-sub-humid areas resulting from various factors, including climatic variations and human activities".

Based on the above definition, the present desertification status map of western Rajasthan was prepared using multidate satellite imagery and existing natural resources maps and reports (Singh *et al.*, 1992). The map showed four severity classes of desertification, viz., slight, moderate, severe and very severe and their impact on four major land use systems such as rainfed croplands, irrigated croplands, rangelands (grazing lands) and forests. The desertification processes responsible for the degradation and depletion of the productivity of the above four major landuse systems are wind erosion/deposition, salinity/ alkalinity, water erosion and vegetation degradation. The greatest menace to the agricultural lands, grazing lands, roads, railway tracks, canals, lakes and other water bodies is being done by the wind erosion/deposition activities in the form of sand drifts, sand sheets, sand ridges, barchan dunes and reactivation of stabilised sand dunes in the arid regions of Rajasthan (Fig. 2). The sand drifting activities due to the anthropogenic, zoogenic and technogenic activities are cultivation on marginal lands, cutting of trees, overgrazing, faulty methods of surface water irrigation, over-exploitation of ground water, construction of roads and canals and trampling and eating of the vegetation and burrowing by rodents have affected the bed of the Indira Gandhi Canal and the adjoining agricultural and grazing lands, particularly the *Lasiurus sindicus* (Sewan) pastures. The rate of annual sand drift from active barchan dunes is upto 35 m while from stable dunes it is not more than one meter. The annual soil loss could be as high as 1500 to 2500 t ha^{-1}, resulting in the formation of sand sheets, sand ridges and barchan dunes on the adjoining agricultural lands (Singh *et al.*, 1992).

Fig. 2. Desertification/degradation of the agricultural and grazing lands resulted due to accelerated wind erosion/deposition hazard in the form of sand sheets, sand dunes and hummocks

The salinity/alkalinity problems developed in the canal command area due to seepage, sub-surface barrier at the shallow depth and flood method of irrigation have also desertified 513 km^2 (7.3%) of the total 7000 km^2 area in stage I of the Indira Gandhi Canal (Bithu, 1984; Fig. 3). The rate of the rise of ground water table is 0.4 to 0.8 m/year and if this rate of rise continues more area is likely to be affected. In the stage II of the Indira Gandhi Canal Command area, the manifestations of salinity/alkalinity have been observed which will also deplete the agricultural productivity of these areas. The salinity/alkalinity hazard has also developed due to the construction of tanks and reservoirs along rivers, which has affected 6170 ha cultivated land in the cultural command area of Jaswantsagar reservoir and 9600 ha of land in culturable command area of Sardarsamand reservoir (Chatterji, 1985).

The desertification hazards like sand drifting, salinity/alkalinity and water erosion due to increasing biotic activities like irrigation by highly mineralised ground water, ploughing by tractor, cultivation on marginal lands like sand dunes and grazing lands and lopping and cutting of trees have also developed to the east of 300 mm isohyet. As a result, large acreage of agricultural lands have turned into wastelands and productivity of drylands has decreased. The accelerated water erosion in the form of rills of 0.2 m depth and 0.5 m width and the gullies of 1.5 to 10.5 m depth and 3 to 15 m width have been noticed in the area.

Fig. 3. Desertification/degradation of the Indira Gandhi Canal irrigated agricultural lands resulted due to accelerated salinity/alkalinity hazard in the form of salt encrustation surface crust and waterlogging

A study on the problem of sand drifting and sand sheeting in relation to landuse and management during the severe sandstorm of 1985 was carried out by CAZRI (Table 1).

A study on sand movement in Shergarh sector revealed that the active barchan dunes moved by 7 m in a year. The general trend of sand movement in this zone is 2 to 20 m/year. As a result, the biological productivity under different types of landuse system has been depleting (Ramakrishna *et al.*, 1990).

As a result of different human-induced desertification hazards, the vegetation cover, particularly in rangelands, is getting depleted. The basal cover of *Lasiurus sindicus* and *Eleusine compressa* declined from 5.14% to 2.40%. The total vegetation cover declined from 6.59% to 0.95% and its yield declined by half. The rocky/gravelly pediments due to increasing degradation support very poor cover of *Dactyloctenium sindicum* - *Eleusine* type of grass. The basal cover of these plant species has declined from 2 to 4% to less than 1% and yield changed from around 1 t ha^{-1} to 0.27-0.45 t ha^{-1} under protected and unprotected areas, respectively. The density of *Salvadora* declined from 10-20 trees/ha to 1-3 trees/ha (Shankar and Kumar, 1987).

Due to increased human activities and accelerated erosion, the vegetation cover of *Prosopis cineraria, Capparis decidua, Ziziphus nummularia, Cynodon dactylon, Cenchrus ciliaris* and *Dicanthium annulatum* decreased from 4-8% to 1-2% and biomass yield from 4000 kg ha^{-1} to 130-1100 kg ha^{-1} (Saxena, 1985). A case study on temporal changes in grazing lands in Jodhpur district revealed that over a period of 28 years (1958-1986), the extent of the grazing lands decreased by 9 to 30% under different

Table 1. Incidence of wind erosion in relation to land use and management during the year 1985

Land use and management	Soil loss ($t\ ha^{-1}$)	
	Range	Mean
Cultivated lands		
Cropped in year 1984 and left untilled		
Flat sandy plains	45–320	230
Hummocky sandy plains	125–1400	385
Cropped in year 1984 and ploughed		
Flat sandy plains	425–540	500
Hummocky sandy plain	125–1400	761
Cropped in year 1984 and disc ploughed using tractor		
Flat sandy plains	1940–3720	2925
Hummocky sandy plain	3490–4000	3745
Long fallow		
Flat sandy plain	80–125	100
Hummocky sandy plain	110–160	135
Open pasture lands		
Degraded pasture lands		
Flat sandy plains	80–540	250
Hummocky sandy plains	80–740	380
Dunes	120–1550	670
Non-degraded pasture lands	Negligible	

ecosystems, mainly due to increasing biotic activities like cultivation and construction of settlement and buildings for industries (Sharma *et al.*, 1989).

In quantitative terms, it has been estimated that out of 2,08,751 km^2 area in western Rajasthan, 68.4% areas is desertified by slight, moderate severe and very severe wind erosion/deposition and vegetation degradation, water erosion, 11.2% by wind erosion/deposition and water erosion combined, 9.2% by salinity/alkalinity, 3.1% and 2.1% by natural desertification hazard. Remaining 8% area does not show any sign of apparent desertification hazard. This quantitative estimate has also revealed that 20% area of western Rajasthan has been affected by desertification hazards of severe intensity, whereas, the desertification hazard of moderate and slight intensity has degraded 40 and 32% area, respectively.

In the adjoining areas comprising of the desert border districts of Ajmer, Jaipur and Sirohi, the localised sand drifting and sand sheeting activities occur due to the cultivation on the stabilised and fossilised dunes, cutting and lopping of trees and overgrazing. Considerable agricultural lands have been desertified in Pushkar valley and surrounding regions of Ajmer district, Sambhar, Sanganer and Phagi tehsils of Jaipur district and Revdar and Shivganj tehsils of Sirohi district. The accelerated water and wind erosion has resulted into the silting of the Pushkar lake, decrease in its surface water areas and desertification around the lake environment. Thus, in the Pushkar valley and adjoining area, 45% area has been desertified by water erosion, followed by wind erosion/deposition, 28%, wind erosion/deposition and water erosion combined, 18% and only 1% area by siltation of water bodies. Remaining 8% area is free from desertification hazard.

Conclusions

Indian desert has originated due to climatic fluctuations after the formation of the Himalayas and the establishment of SW monsoon wind system. It is not man made. The presence of the stabilised sand dunes having desert type of vegetation along the desert margins and highly fossilised and degraded sand dunes in scattered pockets right upto Delhi and Uttar Pradesh has provided the evidence that the former extension of the Indian desert was much more widespread than its present limit. The significant variations in the climatological, physical and biological resources and also in the size of sand grains and mineral composition of the dune sands of the desert and adjoining border areas prove that the Indian desert is not spreading towards east and northeast. Contrary to it, the desert has shrunk to the west as evidenced by the presence of fossil dunes in the adjoining border areas.

However, in the last few decades, due to increasing human induced desertification processes like wind erosion/ deposition, water erosion, salinity/alkalinity and vegetation degradation, the biological productivity of the different ecosystems encountered in the desert and adjoining border areas has been depleted and deteriorated. It has also been observed that if the above desertification processes continue unabated, large acreage of the fertile agricultural land and engineering structures will be affected in near future. In order to reclaim the already desertified areas and also to check the degradation of the productive dryland areas not so far desertified, a comprehensive programme to combat desertification by using preventive, corrective and rehabilitation measures should be initiated for sustainable environmental management of the Indian desert.

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