

Desertification and Changes in the Geomorphic Processes

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Abstract : 'Desertification is land degradation in arid, semi-arid and dry sub-humid zones arising from various factors, including climatic variation and human impact' (UNEP, 1993). Desertification can have an immense impact on the semi-arid geomorphic system. This implies to nearly all processes of this system, whether fluvial or aeolian. A short but systematic delineation of desertification in different relief units, and examples from some of the investigated drylands of the world are the principal objectives of this contribution. Although changes in geomorphic processes are only a subset of the entire phenomena of desertification a modification within the complex process combinations can have important consequences for the natural resources of drylands. Desertification processes cause an aridification of the ecosystem, affecting the vegetation cover, the soils and the water balance.

Key words : Desertification, vegetation degradation, process acceleration, Sahel, Butana, Patagonia.

Desertification and the geomorphic system of drylands - Consequences of land degradation

Degradation of vegetation cover

The degradation of plant cover can be the result of climatic factors and also of human impact. Long drought periods, especially in the semi-arid lands, can induce severe changes to the degree of surface covering and to the floristic composition of the herbage layer (Fig. 1). Since the regeneration potential of plant cover is also dependent on the reserves of drought resistant seeds in the topsoil, plant cover density and the floristic diversity seem to recover completely in wetter years. However, agricultural and animal husbandry systems, which do not consider the ecological restrictions of the natural potential, can induce a rapid degradation of the regeneration potential of vegetation. Enhanced fluvial and aeolian processes, being the result of vegetative degradation, minimize the seed reserves of the topsoil by means of deflation and washing out (Akhtar, 1995). Wet years can not compensate the effects of such degradation processes in a relatively short period of time.

Hence, the regeneration capacity of the plant cover in steppes and savannahs can be subjected to a long-term deterioration. It has to be em-

phasized that the effects of desertification are not automatically eliminated by the natural regeneration of the vegetation, because the regeneration potential is directly proportional to the degree of desertification. Examples from severely utilized steppes and savannahs indicated that harsh desertification mostly implies irreversible damages to the natural regeneration potential of semi-arid plant cover.

Considering the current extent of ecological devastation of the savannahs in the Sahel it is incomprehensible that there are still doubts on the subject, as lately brought forth by Hellden (1994). Desertification assessment, however, necessitates an accurate knowledge of the climatic characteristics of the ecosystems of Sahelian savannahs, and of the anthropo-zoogenic impact on these systems (Mensching, 1991).

The multi-temporal analysis of satellite images principally reflect the short-term natural biomass fluctuations, and through it the annual rainfall conditions (Akhtar *et al.*, 1992). If not linked with regular ground checks, satellite data are totally insufficient for the assessment or the monitoring of desertification. In addition to field checks on plant cover comparative field analysis of the morphodynamic processes in intact and severely

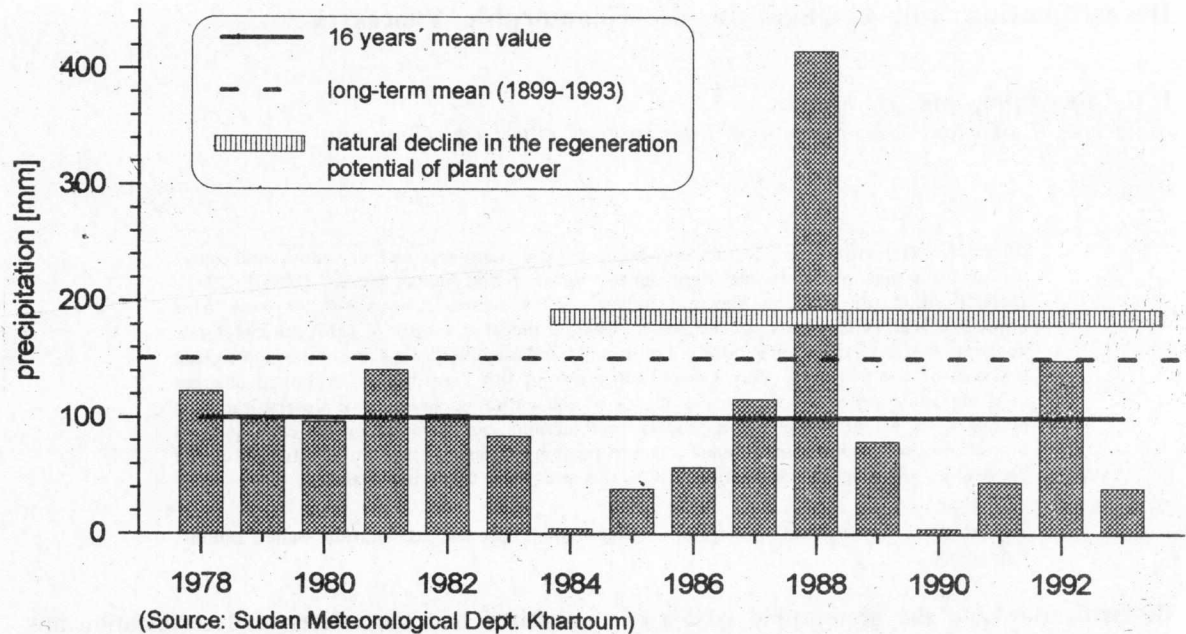


Fig. 1. Drought induced decline in the regeneration potential of plant cover

degraded areas are crucial for estimating the existing environmental conditions.

Acceleration of fluvial processes

Plant cover degradation (herbage as well as woody vegetation) enlarges or creates bare surfaces. This accelerates the energy of fluvial erosion. Depending on the degree of inclination of the surface, rill erosion can culminate in hazardous gullying, due to the concentration of run-off in the upper catchment areas. Solitary torrential rainfall events, which are typical for drylands, can lead to significant erosion rates. Rainfall in featureless plains on the other hand usually leads only to an increase in the local erosion and redeposition of the topsoil after plant cover degradation. It has to be emphasized that erosion is a natural process and not the result of desertification alone. This means that desertification, and hence human impact, only accelerates erosion.

Acceleration of aeolian processes

In drylands, the effects of over-grazing and deforestation have a greater effect on the aeolian rather than on the fluvial processes. A precondition for significant aeolian erosion is the pre-

dominance of the fine grain size within the substratum. The increase in aeolian morphodynamic activities ranges from sand encroachment over vast areas to enhanced sand accumulation around plants (nebkhas), and the development of small dunes or even several meters high dunes. These morphodynamic processes can lead to an alarming intrusion of sand into the agricultural areas of the steppes.

Beside the knowledge on the ratio between catchment area and run-off velocity, information on the deflation area is indispensable for developing measures to combat desertification. Field studies from the Sahel of the Republic of Sudan indicate that enhanced erosion, resulting from the extensive anthropogenic destruction of plant cover, often induces destabilization of climatologically fixed old dune forms (Akhtar *et al.*, 1992). A major result of the anthropogenic plant cover destruction in sandy areas is the rapid decline of the seed deposits of the upper soil layer (Table 1). This aggravates or even impedes sufficient restoration of the plant cover even in wet years. Long-term field investigations from

Table 1. Characteristics of the seed budget of degraded sites of different morphological units

| Morphological unit | General granulometric conditions in % weight | Sampling | General seed/fruit contents | Major characteristics |
|----------------------------------|--|--|-----------------------------|--|
| Plains in the 'Nubian Sandstone' | Clay : 20 | 600 ml from surface and up to 5 cm depth | Approx 20 | About 50% <i>Aristida</i> seeds |
| | Silt : 25 | | | |
| | Sand : 53 | | | |
| | Gravel : 2 | | | |
| Basement peneplain | Clay : 30 | 600 ml from surface and up to 5 cm depth | Approx 110 | The seed bank indicates a higher diversity |
| | Silt : 50 | | | |
| | Sand : 20 | | | |

(Sources : Field and laboratory work by M. Akhtar and K. Wasylkova, 1991/94)

severely desertified ecosystems of semi-arid regions suggest that these processes virtually tend to eliminate the regeneration capacity of plant cover altogether.

These severe modifications of the natural regeneration potential are not only the result extreme variability in rainfall in semi-arid regions, as some authors emphasize today. Rather, a sustained loss in the regeneration capacity is always the outcome of a combination of environmental mismanagement and extreme climatic fluctuations. Desertification in the steppes does not only accelerate the deflation of saline soils or saline lagoons, it also hastens further salinization due to the growing aridity of the soils.

Finally, changes in aeolian processes have also reinforced the sequences of dust storms in seriously desertified areas worldwide. Dust bowls in the midwest of North America, and recently in the vicinity of the Aral Sea in Uzbekistan - which is drying up due to high demands of agriculture - are clear indications of desertification.

Combination of aeolian and fluvial processes

The morphodynamic system in most of the desertified steppes and savannahs is subjected to a combined acceleration of aeolian and fluvial erosion, and also accumulation processes. These processes trigger persistent changes in the geoecological and morphodynamic systems, and lead to the development of a landscape of desertification. However, in order to assess the impact of accelerated morphodynamic processes on land use, detailed investigations into the current re-

generation capacity of afflicted areas are absolutely necessary. It has to be borne in mind that an ecological rehabilitation of heavily desertified areas can not even be expected in wetter years. Hence, sustainable development policies are often a direct response to the sustained degradation of the ecosystem. Changes in the geomorphic system should always be regarded as essential indicators for recording the extent of land degradation.

Case studies on changes in geomorphic system due to desertification

It is proposed to discuss now the results on desertification, which were derived from field investigations in the drylands of North Africa, i.e., the subtropical and the tropical semi-arid zones, and also from the arid and semi-arid steppes of Patagonia/Argentina.

The Sudano-Sahelian zone

The Sahelian zone is well known for desertification. Since the drought period of 1969-1973, basic knowledge on the process combinations of desertification was gained and discussed in the first UN Conference on Desertification (UN-COD) at Nairobi in 1977.

However, in the following years, investigations into desertification in other regions and continents revealed that the desertification processes as recorded in the Sahel could not automatically be transmitted to other drylands. This necessitated a detailed delineation of the ecological systems involved, often also implying a slight variation in the methods applied for recording degradation in the different regions.

Extensive areas in the Sahelian zone have old dune systems. These originate from the late Pleistocene periods, which were characterized by a dry Saharan climate. Currently and under intact environmental conditions, these dunes are covered by dry savannah grasses and scrubs. This ecosystem reacts very sensitively towards changes in the geomorphic processes, especially in case of an aridification of the morphodynamic system. Environmental devastation quickly enhances the sand transport rate towards the south by the NE Passat winds (Harmattan). Currently, millet cultivation on the old dunes exceeds the agronomic dry boundary, and has thus generated the aeolian aridification of this ecosystem. In vast areas, deflation has uncovered the ferugeneous horizons, preventing future agriculture. Additionally, deflation has blown out the seeds of grasses so that the regeneration capacity of the natural vegetation has undergone a sustained damage. Beside aeolian damages, an increase in fluvial erosion could also be recorded in severely degraded dune systems. Due to desertification, the geomorphic system of the extensive peneplains of the Sahel is subjected to an increase in fluvial

of the aeolian accumulation of sand around bushes. Altogether the aridification of the arid morphodynamic system due to the degradation of the natural resources has reduced the land use potential in the Sahel.

The Butana region in the Republic of Sudan

Desertification has become a very serious environmental and socio-economic problem in the Butana. Excessive human pressure on the inherently fragile natural resources and harsh climatic conditions of the last few decades have resulted in severe land degradation. Socio-economic investigations showed that during the last 20 years traditional land use systems in Butana underwent a dramatic change. In 1971 for instance, President Numeiri's socialist idea that the natural resources of the state-owned lands should be accessible to everybody, led to the abolition of 'communal grazing areas', thus eliminating the specific rights of tribes over the resources of their tribal areas. The disorganized utilization of pastures since the seventies, combined with the drought of the eighties, has resulted in the suppression of desirable herbage layer (Fig. 2).

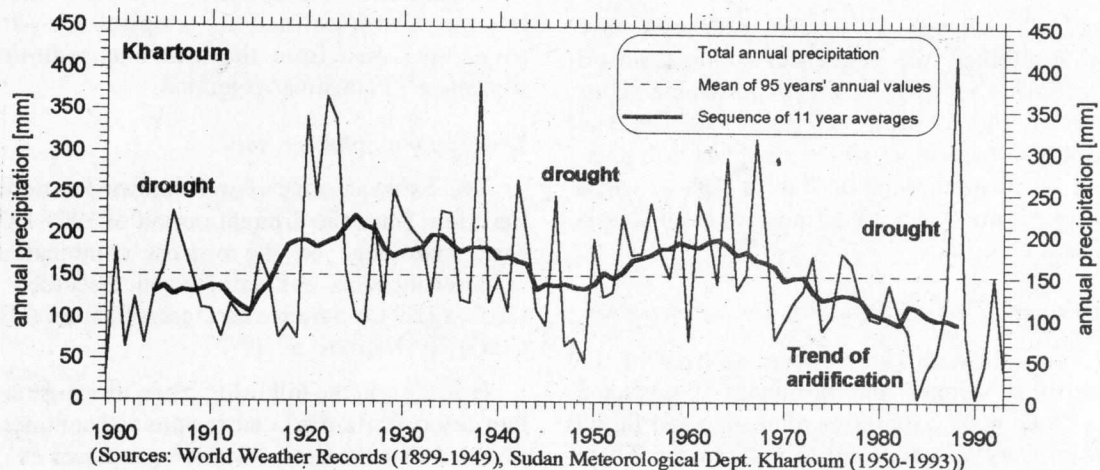


Fig. 2. Long-term climatic development in the eastern Sahel of the Republic of Sudan

erosion, i.e., linear as well as sheet erosion. Fluvial depositions are also prone to deflation, thus enhancing aeolian activity. Nebkhas are a result

At the same time supported agricultural development in Butana led to a gradual reduction of crucial dry season or dry year pastures, putting

tremendous pressure on the remaining grazing lands.

Severe exploitation of the plant cover has caused an irreversible loss of a heterogeneous tree, shrub and herbage cover. A change in the composition of herbaceous communities has been triggered by the immigration of species from more arid regions, thus producing more 'desert-like' floristic compositions. The highly nutritious *Blepharis edulis* (arab. : Siha) is the climax vegetation in Butana if no overgrazing takes place. However, this very important dry season grazing plant has almost completely disappeared. Instead, in the fifties, *Aristida* spp. (arab. : Gau), *Cymbopogon nervatus* (arab. : Nal) and *Schoenefeldia gracilis* (arab. : Dembelab) dominated the region. Depending on their regeneration potential, ecosystems in Butana are susceptible to desertification in varying degrees. Due to enhanced deflation the plains in the 'Nubian Sandstone' of western Butana are struck by severe desertification leading to an extensive loss in the seed reserves of the substratum (Table 1). Sand encroachment on arable lands has become a serious hazard (Fig. 3, area 5).

However, when degraded the clayey plains in Butana are not subjected to exceptionally high aeolian processes. The reduction of perennial plants in the clay plains of Central Butana has caused a moderate degradation (Fig. 3, area 3). Severe site degradation in Central Butana was only recorded in the proximity of the permanent water bearing wells at Sobagh and Sufeiya. The spreading of *Urochloa trichopus* (Arab. : Taffa) and *Ocimum basilicum* (arab. : Rehan) just north of the boundary of extensive rainfed cultivation indicates advanced ecological degradation in the eastern-central clay plains of the Basement Complex (Fig. 3, zone 4; Akhtar and Mensching, 1993).

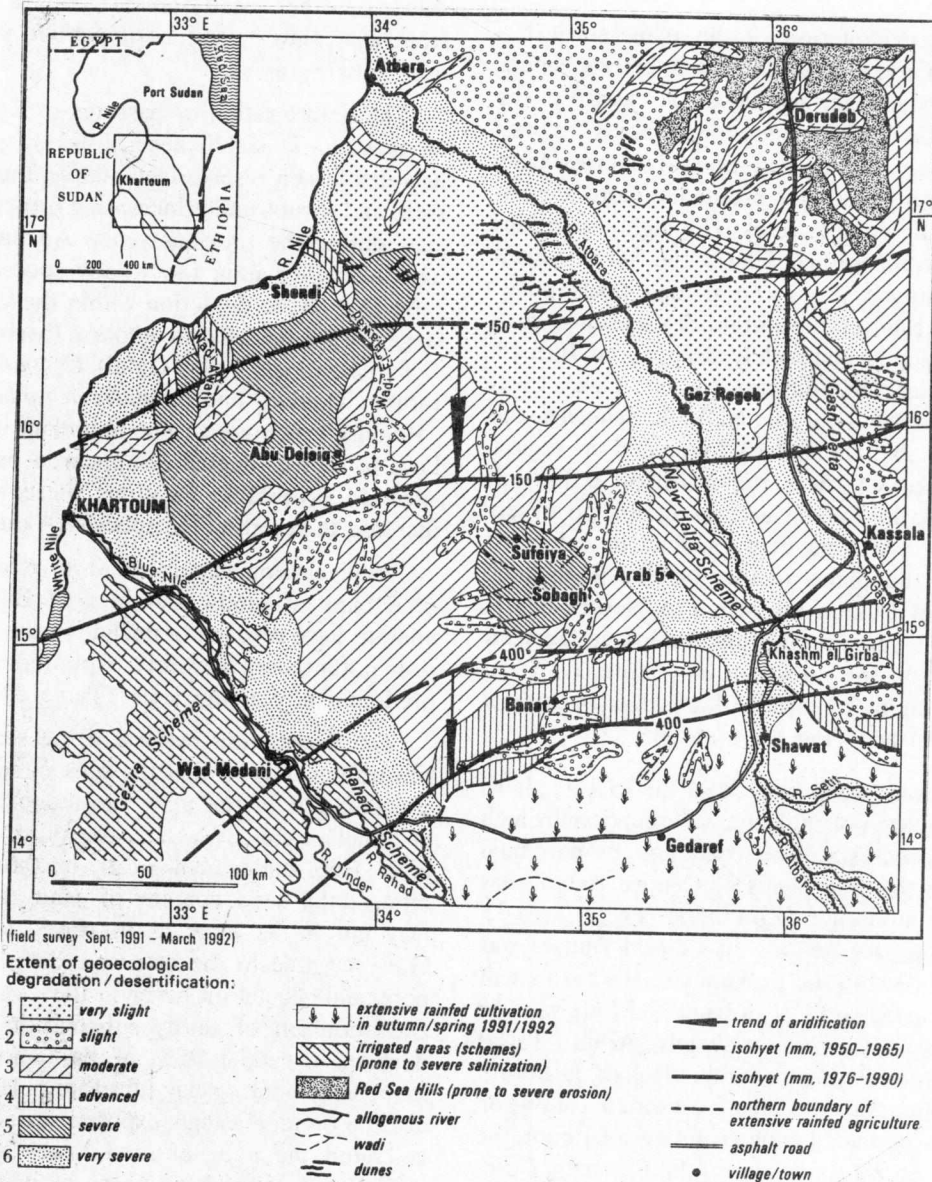
Although the annual *Urochloa trichopus* has comparatively good nutrition value, it was the least desired among the prevailing species within the herbage layer of eastern-central Butana. Herders pointed out that animals got internal bleeding from the plant if they grazed it too much in

its young stage of growth. Light grazing favours the completion of *Urochloa*'s life cycle, combined with its further establishment and regeneration from seed, thus having a competitive advantage over other grasses.

The deterioration of pastures in Butana has emphasized the significance of woody vegetation as a dry season reserve feed supply, thus putting trees and shrubs under increasing browsing pressure during the previous years. An unbalanced age structure within the woody species clearly reflects a severe depletion within the vulnerable stage of growth. *Acacia nilotica* (arab. : Sunt), *Commiphora* sp. (arab. : Gafal), *Capparis decidua* (arab. : Tundub) and *Balanites aegyptiaca* (arab. : Heglig), which used to be abundant in Butana, have to a great degree disappeared on exposed sites. In favourable locations there is distinct increase in xeromorphic species (Akhtar, 1995).

Wind erosion has also had an effect on the seed bank of sandy soils in west Butana. Soil analysis have revealed a decline in the regeneration potential of severely exploited sites with predominantly sandy soils (Table 1).

The distribution pattern of the seeds in the substratum showed that the bulk of seeds were concentrated in the uppermost one centimeter of Sahelian soils, which is the most active soil layer. Even under ecologically undisturbed conditions, the seed content of sandy substratum may not be as large as in clayey substratum. However, due to the extensive deterioration of perennial vegetation cover in the eastern Sahel, seed content of sandy substratum generally declined to about 25% of the amount found in the neighbouring clay substratum. Hence, wind erosion on increasingly exposed surfaces has accelerated the pace of seed losses from sandy soils. Even after three years of drought, seed reserves in the clay substratum of the Basement peneplain enabled the emergence of an extensive grass cover during the rainy season. However, the herbage layer on sandy substratum was very sparse under similar climatic and land use conditions. The low seed production in dry but also in wet years impeded a sufficient restoration of the soil's seed budget and retarded the regenera-



Draft: M. Akhtar 1992

Fig. 3. Desertification in Butana region (Republic of Sudan)

(Sources : Field surveys; Digital Thematic Mapper Data, Oct. 1991; Landsat 5-MSS Images 1:1 million, 1986; Terrain Units Image Map of Central Sudan 1:1 million, Range and Pastures Administration Khartoum 1990; Data of Sudan Meteorological Department Khartoum)

eration of pastoral resources. Moreover, traces of severe grazing could also be recorded in the seed bank. A pronounced homogeneity and a high proportion of seeds originating from relatively unpalatable plants were the characteristics of the seed reserves of frequently overstocked pastures. These recent studies from the Butana region emphasize that severely degraded sites cannot recover without protection measures.

Pastoral lands in Patagonia/Argentina

Located in the lee of Chile's Andes, west winds of the southern hemisphere carry about 150 to 300 mm rainfall per year into the steppes of Patagonia. The climate has distinct continental features. Apart from some irrigation projects in the river valleys, the steppes are mainly the domain of animal husbandry system, with approximately 12 million sheep and goats, but hardly any cattle. In 1952 the sheep population amounted to about 20 million.

Degradation processes in the pastoral lands of Patagonia emphasize the significance of vegetative devastation as a trigger mechanism for the acceleration of morphodynamic processes (aeolian and fluvial, but also for pedological, hydrological and plant cover aridification). However, changes in the geomorphic processes induced by desertification vary considerably in the different geomorphic relief units of the mesetas, sierras, pediments, valleys, etc. The extent of the acceleration of geomorphic processes is also influenced by the inclination of the surface.

The vast meseta plains are the largest landform in Patagonia. An acceleration in fluvial erosion generally triggers only sheet erosion processes on surfaces which are subjected to plant cover degradation. If the catchment area is large enough, then sheet erosion can lead to rill erosion, and near to the fringes (so called 'cuesta') of the meseta plains, even to gully erosion. In the latter case, anthropogenic and natural erosion processes are often totally intermingled. Nevertheless, the entire complex of soil (sheet) erosion, which has been triggered by desertification is distinguishable from the geomorphic processes, which predominate in ecologically intact areas.

Patagonia's location in the vicinity of the western Andes range is subjected to intensive wind velocities. Once natural vegetation is degraded due to severe human (zoogenic) impact, wind erosion can be a menace to landuse. All recent aeolian forms, such as corrasion and accumulation, can be observed in the mesetas. On the piedmont areas, however, fluvial processes predominate.

Numerous depressions, often comprising saline 'lagunas', are a particular characteristics of the steppes in Patagonia. Enhanced aeolian activities due to desertification increase the eastward transport of salt out of these depressions. Anthropogenic (zoogenic) destruction of plant cover around such lagoons lead to the development of salt tongues in the eastern proximity of these basins.

Besides modifying the geomorphic system, desertification in the pastoral lands of the steppes of Patagonia has also an impact on the microclimate. Both factors generate aridification of the semi-arid ecosystems, inducing a trend towards more 'desert-like conditions'. Enhanced evaporation also has consequences for the pedosphere. Soil hardening impedes the infiltration of precipitation, thus leading to a rapid sheet erosion. The numerous effects of desertification have changed the geomorphic system of the pastoral steppes in Patagonia.

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