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A REVIEW OF DAMBO GULLYING IN SOUTH-CENTRAL AFRICA

R. WHITLOW

Department of Geography, University of Zimbabwe

DAMBOS ARE SEASONALLY waterlogged bottomlands associated with the headwaters of river systems draining the plateau areas of south-central Africa. There are nearly 1,3 million hectares of dambos in Zimbabwe, where they are referred to as vleis or *bani* or *matoro* (Shona). These wetlands are especially characteristic of granitic terrain along the central watershed where dambos typically comprise about one-third of the land (Whitlow, 1984). Hitherto dambos were thought to behave like sponges, dampening peak flows of rivers during the rainy season and maintaining base flows during the dry season. For this reason there has been an emphasis upon conservation of dambos in Zimbabwe (Whitlow, in press). This view has, however, been challenged by recent research (McFarlane and Whitlow, in press).

Official policy — beginning with the Water Act of 1927 (Robertson, 1928) which was prompted largely by locally serious erosion, including gullying associated with the drainage and cultivation of dambos, on European-owned farms in the early 1900s (Jennings, 1923; Haviland, 1927; Roberts, 1938) — was and is generally directed at the protection of wetlands in Zimbabwe (Cormack, 1972; Whitlow, 1983). Consequently, most large-scale commercial farmers now limit the use of dambos to late dry-season grazing. Typically, wetlands on these farms have a dense herbaceous cover and exhibit few signs of erosion. In contrast, dambos within Communal Lands are heavily grazed throughout the year and are used for cultivation (often in the form of fenced vegetable gardens). In those areas where dambos occur wells situated on dambo margins are commonly the only readily accessible sources of water for small-scale irrigation and domestic water supply.

The primary concern over the use of dambos in Zimbabwe, for historical reasons detailed elsewhere (Whitlow, in press), has been over the erosion risks associated with cultivation rather than with grazing. The same concern is true, to a lesser extent, of Zambia and Malawi. To facilitate a proper understanding of the current status of knowledge of the erosion of dambos, especially gullying, a review of relevant literature was recently undertaken as part of a more detailed investigation on dambo gullying in Zimbabwe (Whitlow, 1989). This article presents the results of this review and covers four main topics: firstly, definitions and causes of gully erosion in general are outlined; secondly, human factors influencing dambo gullying are examined; thirdly, physical factors of relevance to dambo gullying are assessed; and fourthly, a provisional model of dambo gullying is presented.

DEFINITIONS AND CAUSES OF GULLY EROSION

Numerous definitions of gullies have have been proposed in the past (Gregory and Walling, 1974). These range from simple statements that a gully is 'a well-defined waterworn channel' (Monkhouse and Small, 1978, 142), a definition that could apply to most rivers, through to more comprehensive descriptions such as that given by Brice (1966, 290) who regards a gully as 'a recently extended drainage channel that transmits ephemeral flow, has steep sides, a steeply sloping or vertical head scarp, a width greater than about 1 foot, and a depth greater than about 2 feet'. A more succinct definition but an equally useful one is given by Graf (1983, 280) who describes a gully as 'a V- or U-shaped trench in unconsolidated materials with a minor channel in the bottom', but not necessarily linked to a major stream channel.

Several distinguishing characteristics of gullies are noted by Imeson and Kwaad (1980): firstly, gullies are developed where water is concentrated and this may be a direct or indirect result of man's activities; secondly, gullies typically form in unconsolidated deposits and deeply weathered materials; thirdly, gullies are characterized by intermittent flows that rarely, if ever, reach bankfull levels; and fourthly, gullies are generally recent features in the landscape and may exhibit phases of rapid growth. With respect to this last attribute Schumm (1985) observes that gullies are associated with short-term changes in the landscape (see Table I). Thus gullies become progressively less significant, the longer the time period under consideration. In general, bearing in mind the definition of dambos as streamless valleys, one has no difficulty in recognizing gullies in these wetland sites and, as discussed later, dambo gullying is undoubtedly a recent phenomenon, albeit probably rated as a 'meso-event' by Schumm's (1985) standards.

There is a substantial literature concerning factors influencing gullying, mostly emphasizing the importance of human activities which give rise to accelerated erosion (Toy, 1982). Examples of such studies within and outside Africa are indicated in Table II.

These studies demonstrate that gullying in a given locality is invariably related to two or more human activities which involve depletion of plant cover, disturbance of the soil, and increasing the volume and concentration of runoff, especially surface runoff. Undoubtedly anthropogenic factors do play an important part in the initiation and growth of gullies, but researchers' concentration on this fact may have resulted in the neglect of physical influences on gullying. Graf

Table I

THE STATUS OF GULLYING IN GEOMORPHIC CHANGES IN THE LANDSCAPE

Relative importance of the event	*Time period*				
	1 day	*1 year*	*10 years*	*100 years*	*1 000 years*
Mega-event	local soil slip or flow	GULLYING	meander cutoff	volcanic eruption	terrace formation
Meso-event	rilling	local soil slip or flow	GULLYING	meander	volcanic eruption
Micro-event	sand grain movement	rilling	local soil slip or flow	GULLYING	meander cutoff
Non-event	—	sand grain movement	rilling	local soil slip or flow	GULLYING

Source: After Schumm (1985, 7).

(1986), for example, notes that in the Navajo Indian Reservations in the USA there was widespread erosion, including gullying, from the late 1800s onwards which was largely attributed to overgrazing. Analysis of streamflow and sediment records indicated, however, that increased soil loss was associated with climatic fluctuations, rather than with increases in livestock numbers. Similarly, Stocking (1977) has shown that large, active gullies in the St Michael's Mission area in central Zimbabwe are related more to the existence of fine-grained sodic sediments affected by piping than to human factors.

It is important, therefore, to consider both physical and human causes of gullying and how these factors may interact to promote erosion. A useful model in this regard is that presented by Cooke and Reeves (1976) on the initiation of arroyos in the American South-west. Although Graf (1983) regards arroyos and gullies as fundamentally different, they share many common causes; hence the basic reasoning behind Cooke and Reeves's model is applicable to gullying. Arroyo (or gully) development can be viewed as the result of three sets of interacting factors: land use changes; secular (long-term) climatic changes; and random frequency-magnitude variations such as inherent disadjustments in the long profiles of channels (Cook and Reeves, 1976, 16). These combine in various ways to increase the erosiveness of runoff in valley bottoms, whilst also increasing the erodibility of the valley-floor sediments, so creating trenched channels. Graf (1979) developed these ideas and proposed a method for

Table II

SELECTED STUDIES ON GULLY EROSION SINCE 1970

Author (date)	*Location*	*Period of gullying**	*Causes of gullying*
Within Africa			
Thorp, M. B. (1970)	Zaria, Nigeria	ancient and recent	vegetation clearance, grazing, cultivation, tracks
Butzer, K. W. (1971)	upper Orange and Vaal Rivers, South Africa	post-1880	overgrazing and burning especially in drought years
Murray-Rust, D. H. (1972)	Kisongo, Tanzania	post-1945	overstocking, tracks
Ologe, K. O. (1972)	Kubanni gullies, Nigeria	ancient and recent	clearance and cultivation
Heusch, B. (1980)	Alder Dutchi Massif, Niger	post-1930	clearance for cultivation
Christiansson, C. (1981)	Ugogo, Tanzania	late 1800s to present	overgrazing, unprotected croplands, tracks
Chakela, Q. K. (1981)	Lesotho	generally post-1990	overstocking, cultivation, tracks, roads
Faber, T. and Imeson, A. C. (1982)	Maama gully, Lesotho	recent	cattle tracks and road
Osuji, G. (1984)	Imo State, Nigera	generally recent	cultivation, deforestation, tracks, roads, building sites
Aneke, D. O. (1985)	Nigeria	recent	tracks, urban settlements
Marker, M. E. (1988)	Ciskei, South Africa	late 1940s	initiated by deforestation, overgrazing
Outside Africa			
Aghassy J. (1973)	Southern Israel	ancient and recent	ploughing, railway tracks
Nir, D. and Klein, M. (1974)	Southern Israel	recent	contour ploughing, increasing throughflow and piping

Table II (continued)

Outside Africa (continued)			
Gregory, K. J. and Park, C. C. (1976)	Devon, England	post-1848	tarred road
Twidale, C. R. (1976)	South Australia	post-1836	overgrazing, deforestation, ploughing, tracks
Gillespie, P. D. (1981)	Bango Creek, New South Wales, Australia	mainly post-1915	clearance, severe grazing, ploughing
Graham, O. P. (1984)	Picton, New South Wales, Australia	late 1800s	deep furrows in croplands, stock tracks
Singh, S. and Agnihotri, S. P. (1987)	Madhya Pradesh, India	post-1900	deforestation, overgrazing, cultivation

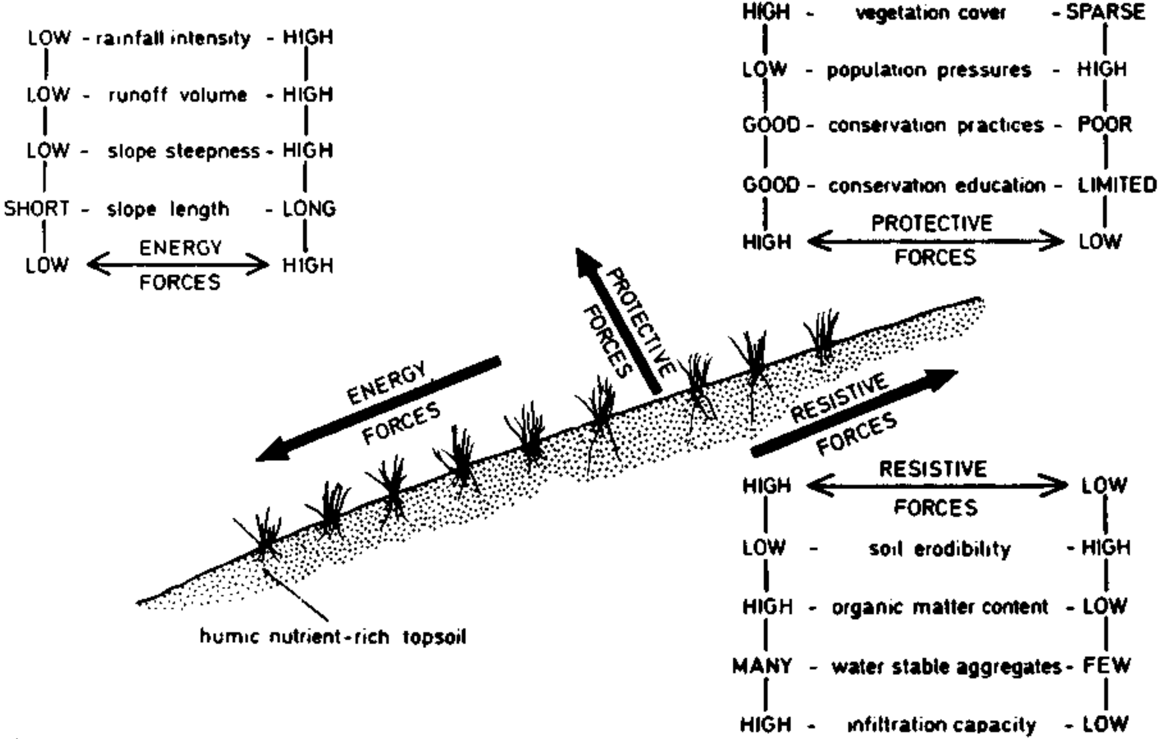
* Not always clearly specified, hence terms 'ancient' for pre-1900 gullying and 'recent' for post-1900 gullying.

determining the development of arroyos and gullies in terms of tractive force and resistance, the latter being a measure based on plant biomass. Although an attractive approach, this method has not been applied elsewhere (certainly not in Africa), and so one suspects that there may be methodological limitations in translating this scheme into field studies.

A more general model of soil erosion has been proposed by Stocking (1980). This views erosion, including gullying, as a function of energy, resistive and protective forces (Fig. 1). Energy forces affect the detachment and transportation of soil particles. High-intensity rainstorms, for example, result in greater erosion than low-intensity storms, while removal of soil is greater on steep slopes than low-angled slopes. Resistive forces relate mainly to soil properties and help overcome the applied energy forces. For example, soils with a high organic matter content and stable peds are more resistant to raindrop impact than soils with low organic matter content and unstable aggregates. Protective forces assist in reducing the magnitude of energy forces. In particular, plant cover plays a crucial role in intercepting raindrops and dissipating their energy before they reach the ground (Stocking and Elwell, 1976). In addition, soil protection depends on human factors such as the nature of conservation measures and the degree of population pressure, both human and livestock, on the land (Whitlow, 1988).

Whilst acknowledging the various and sometimes complex interactions between these three groups of forces, the following review of dambo gullying examines human and physical factors separately.

Figure 1: SOIL EROSION MODEL IN TERMS OF ENERGY, RESISTIVE AND PROTECTIVE FORCES



Source: After Stocking (1980).

Human factors influencing dambo gullying

While contemporary rainfall conditions are probably marginal for the development of dambos in Southern Africa, some of the earliest references to the problems of gullying in wetlands (or vleis as they are referred to in Zimbabwe) concern this part of the subcontinent. Kanthack (1930, 519), for example, reports that the 'magnificent grass flats or vleis . . . which were a common feature in recent times are now practically non-existent. They are gashed in every direction by deep ravines or "sloots" all converging on the main drainage lines of the country, which are now occupied by wide and deep channels.' In a later paper, he writes that 'the beautiful rich vleis of the Union, which are the counterpart of the Northern Rhodesia dambos, are rapidly disappearing and are being converted into arid wildernesses drained by wide and deep torrential rivers from which vast systems of dongas [gullies] are spreading yearly further and further afield' (Kanthack, 1945, 32). This degradation of vleis was attributed mainly to construction of drainage ditches (Debenham, 1948) and prolonged mechanized cultivation (Bosazza, 1951). While Bosazza (1950) suggested that dongas in vleis should be encouraged as potential dam sites, the more common view was that such erosion was resulting in widespread desiccation of the landscape and should be prevented at all costs (Kanthack, 1930).

In the main dambo regions of Zambia, Malawi and Zimbabwe it appears that dambo gullying became a problem somewhat later, although it was locally serious on European farms in Zimbabwe (then Southern Rhodesia) in the early part of this century (Whitlow, in press). This may only mean, however, that there is a lack of readily accessible published material, particularly in the case of Zambia and Malawi.

Dambo gullying in Zambia

Hindson (1964) cites overgrazing and unprotected cultivated plots as the main causes of erosion in Zambian dambos, whereas Smith (1966) emphasizes the importance of tracks which concentrate flow into and within dambos and, as a result, often turn into gullies. Mackel (1974) comments briefly on dambo destruction associated with man's activities noting that the problem is prevalent, as might be expected, in densely settled areas, particularly where peasant farming occurs. A general geographical review of soil erosion and conservation in Zambia is presented by Robinson (1978), but he barely touches on the problem of dambo gullying. Under these circumstances it is difficult to judge how serious dambo gullying is and where it occurs in Zambia.

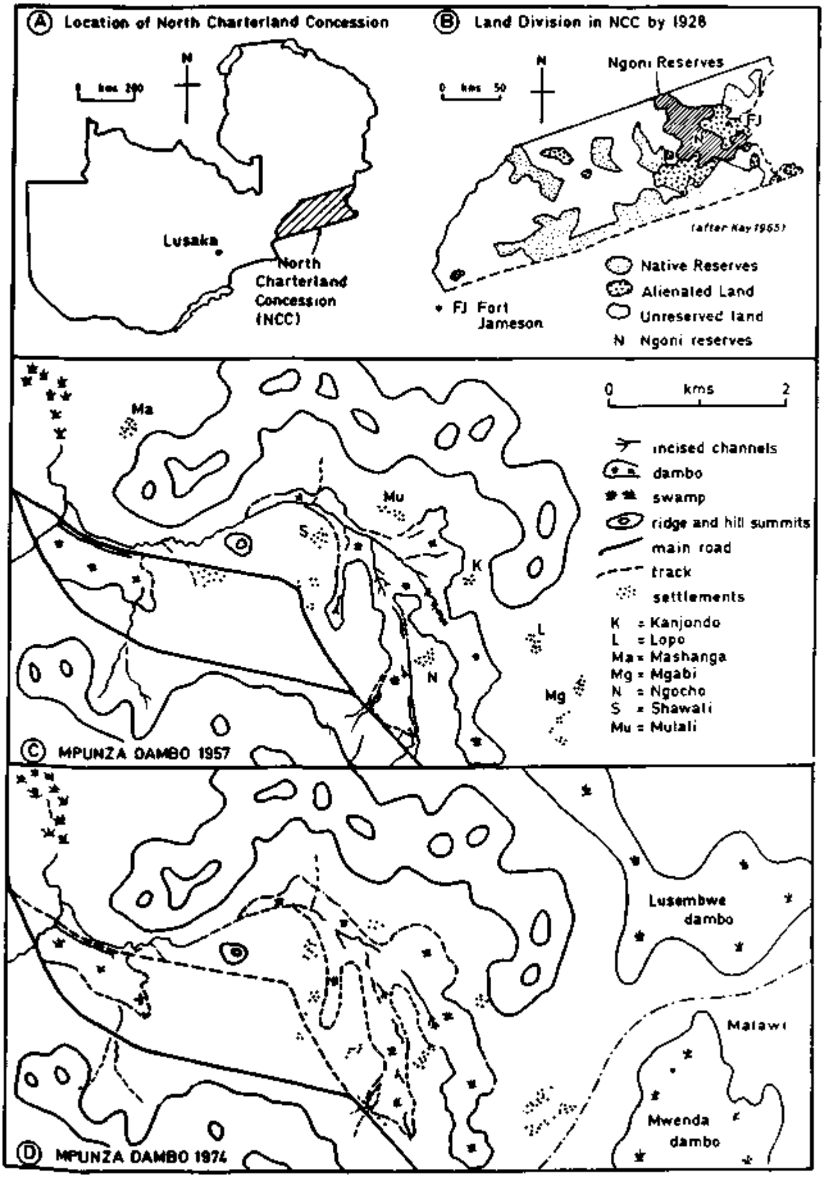
There is, however, one useful and relatively detailed study of dambo erosion described by Priestley and Greening (1956) in the context of a land utilization survey of the Ngoni Reserves in the Eastern Province. To understand why erosion became a problem in these Reserves it is necessary to give some background on their colonial history (Hellen, 1962; Kay, 1965; Vail, 1977). This territory was taken over by the British South Africa Company in 1889 and was known as the North Charterland Concession (Fig. 2A). The Ngoni people who inhabited the eastern part of this region rebelled against colonial rule in 1897 but were defeated by troops of the Company. Thereafter, the indigenous population was progressively displaced from its land so that by 1928, when the Crown Lands and Native Reserves Order was passed in Britain, they were left with barely one-third of their former territory (Fig. 2B). This soon led to overcrowding, especially in the Ngoni Reserves. This was because some of the Ngoni land centred on Fort Jameson (now Chipata) was alienated for European farms. Moreover, in the past the Ngoni had maintained dense settlement in a restricted area largely by pillaging crops and livestock from neighbouring peoples. This activity ceased abruptly under colonial rule.

By the early 1940s there were over 63 500 people within the Ngoni Reserves, giving a density of just over 31 people per km^2. It was estimated that under traditional forms of land use the carrying capacity of the land was around 8,5 people per km^2. Not surprisingly, there was severe pressure on the natural resources within the Ngoni Reserves. Dambo gullying was singled out by Priestley and Greening (1956) as one of the most serious forms of erosion in these areas. This was caused by a combination of excessive and uncontrolled runoff from cultivated slopes surrounding the dambos and overgrazing and poaching by livestock within the dambos. Typically, the cattle were grazed in large communal herds which were restricted to the dambos during the rainy season in order to keep them away from growing crops. This promoted poaching of the wet soils. By the dry season little grass was left within the dambos for the cattle while grasses on the slopes had become moribund, which necessitated continued grazing in the dambo sites. As livestock numbers increased so did the incidence and size of gullies.

Priestley and Greening (1956) give a case history of what was known as the Nyasaland Gully, located within Mpunza dambo bordering the main road from Fort Jameson to Nyasaland (now Malawi). This gully was reported to be cutting back at a rate of over 10 metres per year and its lower reaches were threatening to undermine the main road, especially where runoff was diverted from the road into the gully (Fig. 2C). This threat ultimately led to a rerouting of the road to the south and the original road became a track (Fig. 2D). The main cause of the problem was seen as a product of cultivation of steep hillslopes and of overgrazing.

There were six main villages in the Fort Jameson area in 1954/5 with a total population of 565 people and a density of some 28 people per km^2, typical of most of the Ngoni Reserves. Given the poor quality of arable land on the hillslopes, many of the villagers maintained gardens on the dambo margins — thus reducing the area available for grazing. An estimated 974 cattle grazed within the dambo

Figure 2: DAMBO GULLYING IN ZAMBIA



for at least seven months of the year. This number was over three times the assessed carrying capacity of the land. By 1957 aerial photos showed a clearly defined, deep, but discontinuous gully network in Mpunza dambo (Fig. 2C). The gully was still visible on 1974 photographs but appeared to have stabilized in several sections (Fig. 2D).

Dambo gullying in Malawi

Judging from the lack of published material on gullying and general field observations (McFarlane, 1987, personal communication), it appears that dambo gullying is a somewhat localized phenomenon in Malawi.

One of the earliest references to this problem appears in a report of the Nyasaland Department of Agriculture (1959, 30), which warned against drainage of dambos to enable the production of crops since in many (unspecified) cases this had 'resulted in their destruction by gullying and subsequent drying out'. Several years later it was reported that dambo gullying could be

> caused by erosion at some point such as a water hole, where humans and animals poach the land in the wet season, and kick away the vegetation in the dry season. A gully is gradually cut back, but there comes a point of 'dynamic stability' when headward erosion is compensated by infilling at the foot, and thus maintaining its length the gully will gradually caterpillar its way up the dambo, and will often prove self-healing (Lilongwe Land Development Program, 1971, 8).

In so far as the gullies appear to stabilize naturally within some of the Malawi dambos at least, this may account for the lack of studies of these features.

Nevertheless, dambos are an important resource for peasant farmers in Malawi. A survey was undertaken by Russell (1971) to assess the ways in which dambos were utilized within the Lilongwe Land Development Program area in central Malawi (Fig. 3A). Nine dambo sites were selected for a questionnaire survey (Fig. 3B). Of these, three dambos showed signs of gullying as follows:

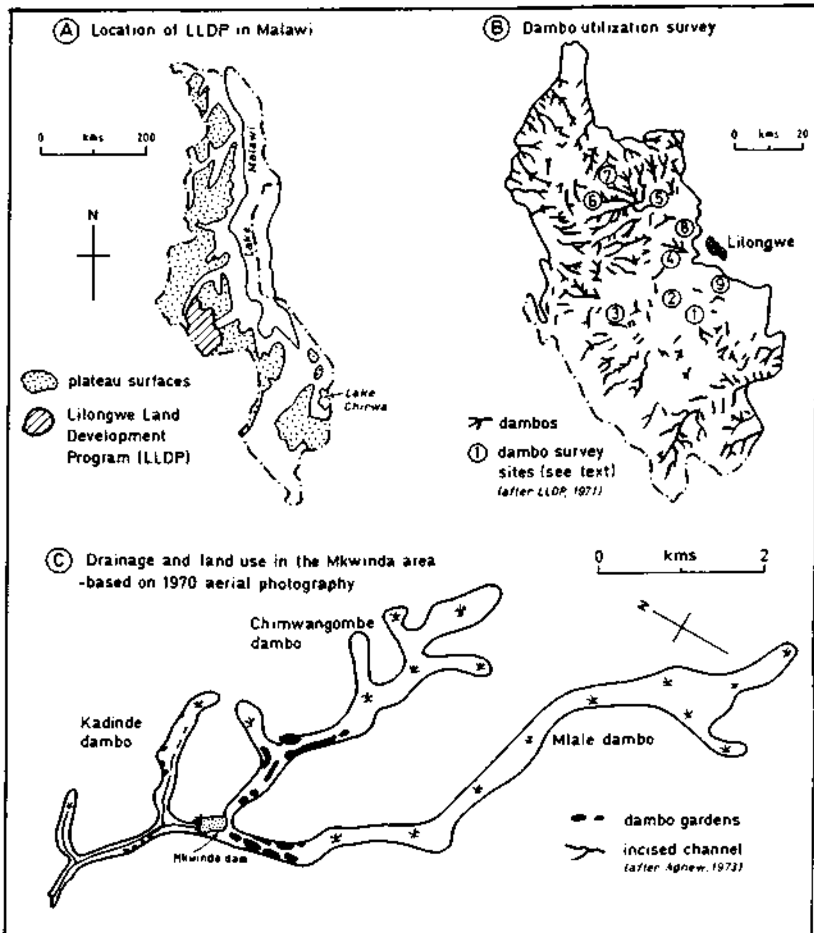
Mlale dambo (site 1): a narrow sinuous dambo with a 2–3-metre gully running most of its length and subject to heavy grazing.

Kakoma dambo (site 12): a broad, gently sloping dambo showing incipient gullying and subject to heavy grazing.

Chikungu dambo (site 5): a steeply sloping digitate dambo with a short gully at the foot, but little grazed.

Russell (1971) anticipated that greater problems in terms of, for example, availability of dry-season grazing and drying out of wells would be associated with the eroding dambos. In practice, there was little difference in the responses of villagers using intact and eroding dambos. Similarly, assuming that the local people would see the cattle as a cause of erosion, questions were posed on the

Figure 3: DAMBO GULLYING IN MALAWI



control of cattle herds. Responses showed that people were more concerned with keeping animals away from domestic wells and fenced gardens (*dimbas*) on the dambo margins than with the problem of gullies. This could be interpreted as indifference to this particular erosion problem or, given that not all heavily grazed dambos were subject to gullying, a reflection of the fact that livestock play a minor role in what is really a very localized problem.

Agnew (1973) provides further information on the dambos in Makwinda area (including Mlale dambo) where a small dam was constructed in the early 1960s to stop the headward recession of a large gully (Fig. 3C). This reclamation measure, apart from being unsuccessful in halting the advance of the gully up the northern Chimwangombe dambo (although Agnew's maps do not show this gully), had several undesirable side-effects: sediment was trapped within the dam so that water spilling over the wall incised a channel 3–4 metres deep into saprolite downstream; increased channel incision downstream lowered local water-tables and thus affected cultivation and grazing for some five kilometres below the dam; the higher water-table upstream of the dam encouraged the encroachment of dambo gardens in the dambo near the dam, but created conditions favourable to the growth of coarse sedges, so reducing the quality of grazing. Clearly, one requires a greater understanding of the dambo gully problem before embarking on such reclamation programmes as those outlined by Agnew.

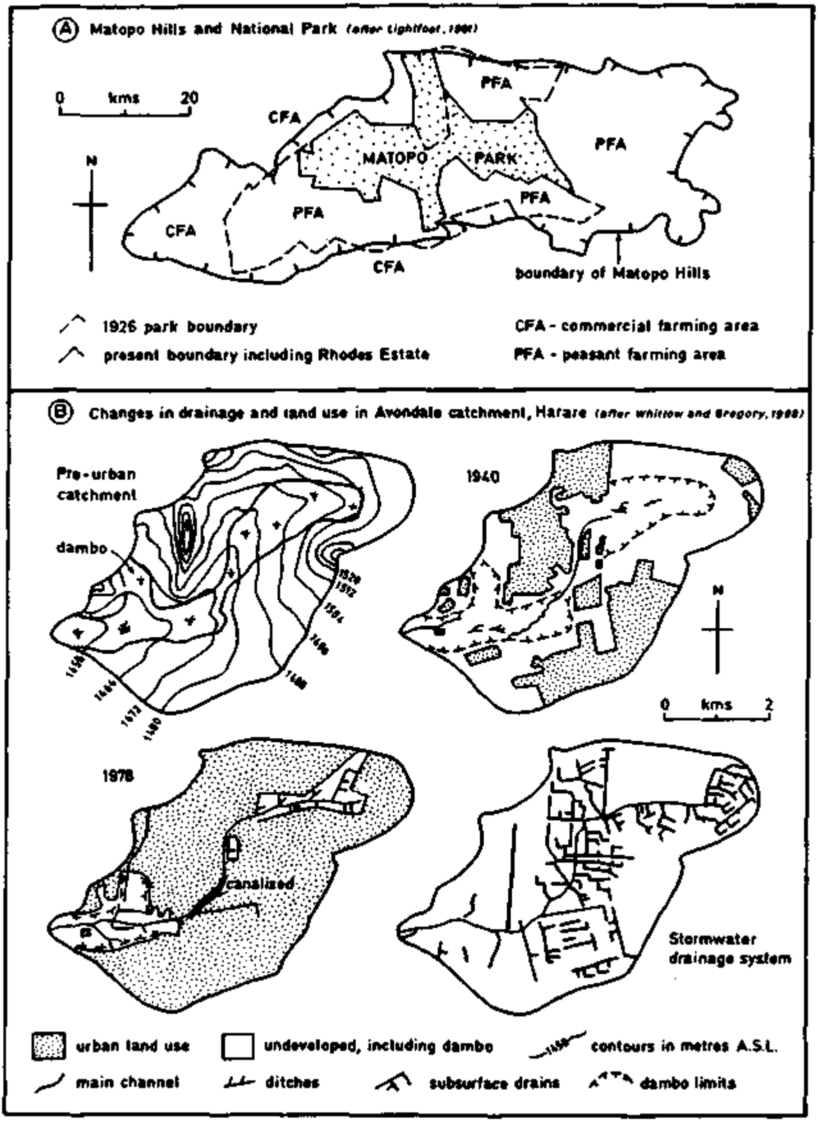
Dambo gullying in Zimbabwe

In contrast to Zambia and Malawi, there is a more substantial literature concerning dambo gullying in Zimbabwe, possibly a reflection of the greater severity of the problem in this country. Nevertheless, there are no detailed studies of this problem. Much of the relevant literature pertaining to dambos in Zimbabwe is evaluated in Whitlow (in press) with respect to land use and conservation history in the commercial-farming areas and the Communal Lands. Present discussion is limited to three case studies to illustrate some of the dimensions of the dambo-gullying problem in this country.

The first of these concerns the deterioration of localized dambo features or sponges in the Matopo (now Matobo) Hills south of Bulawayo (Fig. 4A). In 1926 nearly half of this hilly terrain, some 90 720 hectares, was designated as a national park for game animals (Lightfoot, 1981). Prior to this the local African people had been free to exploit the area for firewood, thatching-grass and grazing. Much of the area is dominated by rock outcrops (or bornhardts), with less than 10 per cent of the land suitable for cultivation. Consequently the wetlands, which comprise only some 5.8 per cent of the area, were used not only for grazing but also for vegetable gardens. In the early years of the park this activity continued since the local people were reluctant to give up their 'traditional rights'.

By the mid-1940s it was apparent that the widespread erosion, especially gullying in sponges, had taken place. In the next two decades people were gradually excluded from the park (Lightfoot, 1982). Moreover, the original park area was greatly reduced in extent (Fig. 4A). In the early 1970s a local study of the status of sponges within the park and the adjoining peasant and commercial farmlands was carried out by Promnitz (1971). Whereas within the park and the commercial farms the sponges were lightly grazed and had good plant cover,

Figure 4: CASE STUDIES OF IMPACTS ON DAMBOS IN ZIMBABWE



those in the peasant-farming areas were generally denuded, sometimes gullied, and showing signs of drying out. As in the past, the causes of this erosion were seen as overgrazing and the widespread use of sponges to produce vegetables, mainly for sale in Bulawayo (Promnitz, 1971).

The second study was on the Que Que Tribal Trust Land (now Chiwundura Communal Land) in central Zimbabwe. Government action was taken during the 1960s to restrict cultivation of wetlands because this appeared to be causing erosion in the valley sites. This action was not well received by peasant farmers who did not regard their gardens as an erosion hazard and relied upon them for year-long production of vegetables. A survey by Thiessen (1974) showed that there were some 3 480 hectares of dambo (over 18 per cent of the land), of which just over 380 hectares were cultivated in 1970. Some 50 hectares of wetland were affected by erosion, including gullying. Both overgrazing and cultivation appeared to give rise to erosion. In the former, the problems were associated mainly with frequently used tracks, whilst in the gardens erosion was related to an inadequate provision of waterways, to drain away storm runoff, and to access paths. Following the restriction of wetland cultivation in this area it seems that there was actually an increase in erosion because of cattle grazing and trampling in formerly cropped land (Thiessen, 1974).

The third example concerns the impact of urban development on dambos. Whitlow and Gregory (1989) present a study on land-use changes and channel development within the Avondale Basin located in the north-western part of Harare. Prior to urban development a dambo occupied about one-quarter of the catchment (Fig. 4B), comprising a stiff black clay soil derived from phyllites. An 1891 map showed a stream channel in a marshy area. By 1940 there were discontinuous, 'gully-like' channels formed in the lower and upper parts of the catchment, with an excavated ditch in the central area (Fig. 4B). Drainage density of surface channels by 1940 was 350 metres per km^2 and nearly 40 per cent of the catchment was built up, mainly with residential plots. By 1978 there was a continuous, locally canalized channel with numerous feeder ditches giving a drainage density of 800 metres per km^2 when taking into account the extensive subsurface stormwater drainage system (Fig. 4B). Moreover, the built-up area had increased to nearly 90 per cent of the catchment while the dambo area decreased from just over 20 per cent in 1940 to 10 per cent in 1978.

The consequence of this extension of urban land use, increasing the proportion of impermeable surfaces such as tarred roads, combined with a greater drainage density, was an increase in runoff and a reduced lag time for peak flows following heavy rainstorms. In the lower catchment a distinctive channel-in-channel form existed in 1984. The inner channel corresponded with the original man-made ditch while the outer channel represented enlargement due to natural erosion especially during bankfull discharge events. It was estimated that runoff in this urban catchment was at least two times greater than that of a rural catchment of comparable area, hence the widespread undercutting of banks and channel scouring along Avondale Stream today. This provides an interesting contrast with rural catchments where less dramatic but nevertheless important changes in land use appear to be promoting incision of channels in dambos.

PHYSICAL FACTORS INFLUENCING DAMBO GULLYING

It is recognized that gullying is influenced by several physical factors acting together to promote headcut recession and removal of eroded sediments. For example, Stocking (1978a) showed that growth of the waterfall-type headcuts on the extensive gullies near St Michael's Mission, central Zimbabwe, could be accounted for statistically in terms of four physical variables: precipitation, antecedent precipitation, catchment area feeding runoff into a headcut, and headcut height. Thus rapid growth of the gully would occur after a heavy rainstorm over an area where previous rainfall had already built up soil moisture reserves, especially within the larger catchments where deep gully headcuts occurred. In the case of dambo gullies, however, very little is known about the nature of the physical factors influencing their initiation and growth, let alone their relative importance. Three main groups of factors are discussed here, drawing in part on observations on gullying elsewhere. These groups are base-level lowering and valley gradient, climatic change, and characteristics of regolith and water flow.

Base-level lowering and valley gradient

Theoretical studies (Schumm, 1977), laboratory simulation (Begin, Meyer and Schumm, 1981) and computer-based modelling (Vanderpool, 1982) all confirm that base-level lowering can result in channel incision, but that this takes a long time to work its way up a river system leaving headwater areas largely unaffected. In systems terminology this equates with a prolonged relaxation time (Chorley and Kennedy, 1971). In Southern Africa one is dealing with a situation of differential base-level lowering and landscape adjustment over periods of millions of years (Partridge and Maud, 1987). Consequently, it has been argued that dambo incision, including gullying, could be associated with regional base-level lowering.

For example, Mackel (1974, 344) states that the 'most frequent cause of the destruction of dambos is brought about by progressive headward cutting of the corresponding stream channel on account of a general lowering of base level'. Similarly, Agnew (1973) comments on the regional incision of rivers into the plateau surfaces around Lilongwe in Malawi, which supposedly gives rise to incision and regrading of dambos. However, in the case of the Luano catchments in Zambia it appears that downstream changes in base levels have not yet affected the dambos (King, 1971). In Zimbabwe the major river systems exhibit highly irregular long profiles (Sithole, 1987). Consequently, if and where base-level changes do affect dambo incision, there is likely to be a complex spatial manifestation of this process.

A factor related to base-level lowering is slope. Dryland gullying in Zimbabwe, for example, is related to average slope (Stocking, 1972); thus, steeply sloping terrain is more likely to be affected by gullying than gently sloping areas. Stocking (1972) used a grid-sampling method to demonstrate this relationship. However, in the case of dambos it is more appropriate to consider slope within drainage-basin units since these relate more directly to hydro-geomorphic processes (Gregory and Walling, 1974). In north-western Colorado, Patton and Schumm (1975) have shown that there are critical slope thresholds in valley floors. If these are exceeded by progressive deposition, for example, then entrenchment occurs; but below these slope-thresholds valley floors are stable. In smaller drainage basins, those less than 10 km^2, the slope-thresholds did not apply since gullying was related to localized vegetation differences associated with aspect (Patton and Schumm, 1975).

If we accept the potential universality of this threshold concept (Schumm, 1979), it may be applicable in dambos. Certainly in the case of fadamas in northern Nigeria gradient has a marked effect on the extent of wetlands and degrees of gullying. On the steeper rivers to the north of the Chad–Niger watershed the fadamas are less extensive and more gullied than those on the rivers draining to the south where gradients are lower (Turner, 1985). The same could be true of dambos in south-central Africa. Moreover, here the low relief and tropical location of dambo basins rule out aspect effects on vegetation, so the Patton and Schumm (1975) model may apply in small as well as large basins. Variations might occur, however, as a result of the other factors such as differences in regolith depth and land use.

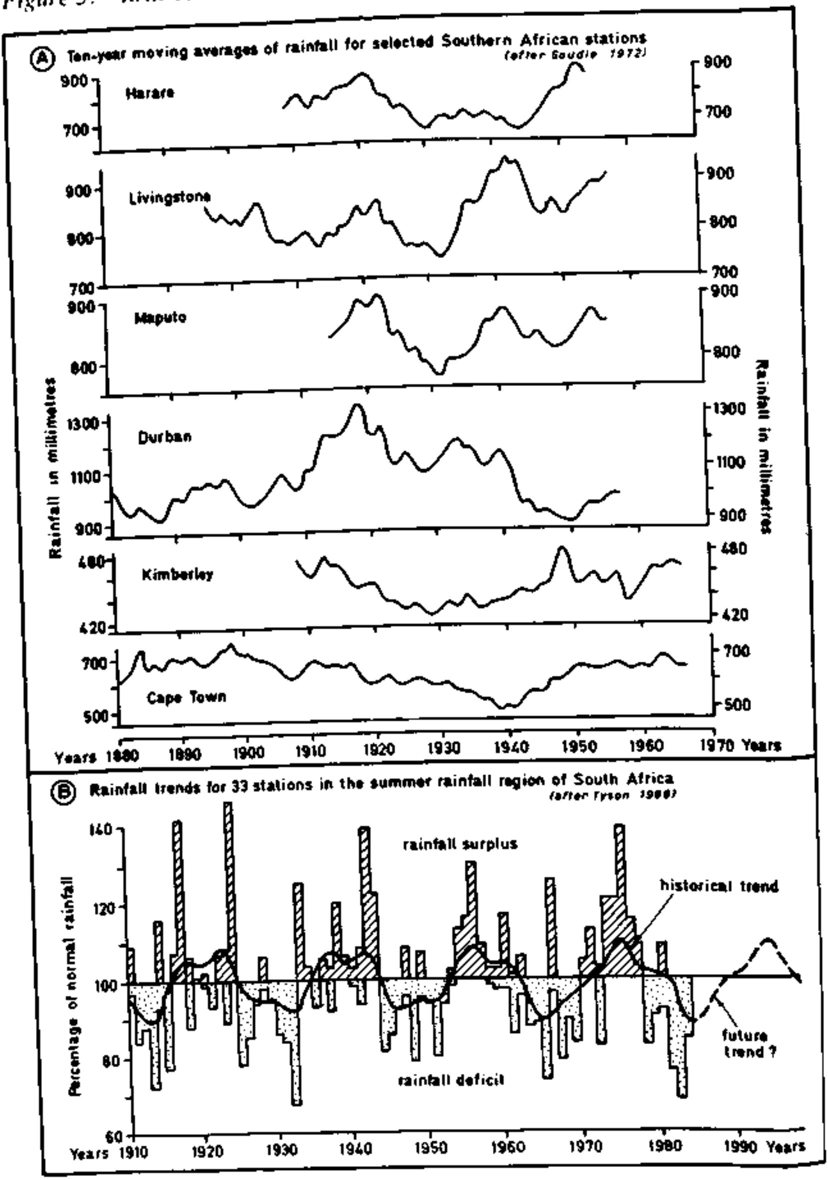
Climatic change

Sedimentary and palynological evidence show that Southern Africa has been affected by alternating wet and dry phases of varying duration, not necessarily synchronous over the subcontinent, throughout the Late Quaternary (Scott, 1982; Shaw and Cooke, 1986; Crossley, 1986). This has given rise to locally thick (up to 10 metres) colluvial deposits mantling the landscape throughout the subcontinent (Price-Williams and Watson, 1982). Deeply incised gullies in these sediments display sequences of cut and fill in association with a spectrum of stone artefacts dating from the Middle Stone Age, especially in Swaziland (Price-Williams, Watson and Goudie, 1982). Such colluvia also occur in parts of Zimbabwe (Watson, Price-Williams and Goudie, 1984), mainly on the Karoo sediments. A detailed study of gully form and process on these materials was carried out by Stocking (1977) but barely mentions the cut and fill history of the gullies (Whitlow and Firth, 1989) since it was more concerned with contemporary conditions. In the case of dambo gullies, however, the limited persistence of the features and their apparent recency suggest that one should consider first the significance of present-day climatic changes before invoking longer-term climatic shifts as an explanation of dambo gullying, although the latter may be of relevance elsewhere in Africa (Smith, 1982).

During the early part of this century there was a common belief that Southern Africa was becoming progressively drier (Kanthack, 1930). With less rainfall, there was sparser plant cover and, when storms did occur, severe erosion took place. This supposed trend of climatically controlled desiccation was examined by Goudie (1972) using a variety of evidence, including rainfall records. Ten-year moving averages of annual rainfall for various stations in Southern Africa, six of which are illustrated here (Fig. 5A), indicated that there was no consistent downward trend although many areas seemed to experience dry conditions during the 1920s and 1930s. In the decades which followed, especially the 1950s, wetter conditions prevailed, but not everywhere. Analysis of rainfall records for 33 stations in the summer-rainfall region of South Africa has revealed an approximate 18–20-year cycle (Tyson, 1986; Fig. 5B). Thus the late 1920s and early 1930s show up as a dry phase followed by wetter conditions in the late 1930s and into the 1940s, and so on. Nevertheless, within a drought phase at least some areas received average or above-average rains, whilst in wetter years certain stations recorded low rainfall owing to essentially the same atmospheric circulation system, and so Tyson's (1986) analysis may be applicable in this case.

If, as appears to be the case, there are cyclic patterns of wet and dry periods this has implications for the temporal patterns of erosion. Butzer (1971), for example, shows that initiation of gullying in the upper Orange and Vaal basins during the late nineteenth and early twentieth centuries was associated with a combination of prolonged drought and depletion of grass cover, combined with overgrazing. In Lesotho, droughts also stress vegetation, so affecting erosion. Chakela (1981, 19) reports that in Lesotho 'oral information relates fresh entrenchment of gullies and disappearance of swamps and reed meadows to these drought periods, with the highest gully activity concentrated in the high annual rainfall years following immediately after the dry years'. Certainly some gully systems in Lesotho displayed rapid growth during the high-rainfall phase in the 1950s following a dry spell in the previous decade (Lunden, Stromquist and Chakela, 1986). In the Ciskei, however, Marker (1988) found no correlation between gully growth and rainfall variations; this could be due to the fact that the rainfall station was distant from the gully and, therefore, not representative

Figure 5: RAINFALL VARIABILITY IN SOUTHERN AFRICA



of what was happening at this site (Stocking, 1978b). A factor related to cyclic rainfall patterns is the incidence of extremely heavy storms, which may promote rapid gullying, but these do not necessarily occur only during wet phases.

Characteristics of regolith and water flow

The erodibility of dambo soils depends primarily on the texture of the soil and type of clays present. Stocking and Elwell (1973) rate the non-calcic hydromorphic soils, typical of the granitic dambos, as the most erodible soils in Zimbabwe along with sodic soils. The reason for this is that these soils are 'characterized by a lack of cohesion and a high water-table in summer' (Stocking and Elwell, 1973, 101). When their normally dense herbaceous cover is removed, the dambo soils erode easily. The black clay dambo soils were rated as less susceptible to erosion, partly because they are more cohesive. In Zambia, however, the montmoritionitic dambo clays are reported as being prone to gullying, breaking away in large blocks when trampled by cattle (Verboom, 1972).

Water retention and movement in dambo soils depend, to a large extent, on the nature of the clays present. It is appropriate, therefore, to outline the general characteristics of the two main types of dambo clays, kaolinite and montmorillonite (Table III). These differ in the conditions favouring their formation but, as noted earlier, can coexist in dambos on granitic rocks in seasonal climatic regimes, especially where these contain mafic intrusions. It is possible also that montmorillonite formed under more arid conditions in the past and, since the clay occurs in dense layers, has not been weathered fully under prevailing climates (Buol, Hole and McCracken, 1973). Given their contrasting physico-chemical properties, one might expect these two types of clay to respond differently in an eroding dambo.

Kaolinite, when subject to alternative wetting and drying, is less prone to expansion and contraction than montmorillonite. However, it has a lower degree of cohesion and under saturated conditions in the presence of small amounts of sodium (Purves, 1976) could disperse easily. This process, in turn, could reduce the permeability of surface soils, especially when these are poached; or, in the case of subsoils, it may promote removal of clay when water passes through the sandy clay matrix as noted earlier. In a dry state the kaolinite is massive and does not crumble easily. In contrast, montmorillonite develops large cracking systems during dry periods and these facilitate disintegration of clay material along gully margins. However, they are more cohesive when wet and may, because of the presence of calcium and magnesium on exchange sites, be less affected by the presence of sodium ions (Brady, 1974). Potentially this makes them less prone to the subsurface removal described for kaolinite, but they are still somewhat impermeable when wet so this could increase overland flow.

Given the sandy clay and clay soils of dambos and their seasonal

Table III

CHARACTERISTICS OF KAOLINITE AND MONTMORILLONITE

Characteristics	*Montmorillonite**	*Kaolinite*
Formation conditions	limited weathering; slightly acid to alkaline; relative abudnance of Mg; absence of exessive leaching	advanced weathering; moderate to strongly acid; absence of Mg and other bases; active leaching
size (μm)	0.01–1.0	0.1–5.0
shape	irregular flakes	hexagonal crystals
lattice	2 : 1	1 : 1
specific surface	700–800 m^2 per gm	5–20 m^2 per gm
external surface	high	low
internal surface	very high	none
cohesion	high	low
swelling capacity	high	low
CEC (meq per 100 gm)	80–100	3–15

* Sometimes referred to as smectites.

Source: Based on Brady (1974) and Buol, Hole and McCracken (1973).

waterlogging, it is not unexpected that high rates of surface runoff should occur in such sites; this clearly favours gullying. Less apparent is the potential for subsurface erosion and gully initiation. An early reference to this type of erosion is given by Tracey (1945) in a general text on farming in Southern Rhodesia. He observes that the 'black vleis are liable to a type of pit erosion that occurs at points where slight subsidences have taken place. This produces a waterfall action when storm water runs down a vlei. Pits are gouged out, sometimes to considerable depths and these increase in size until they eventually join up to form a long and continuous gully' (Tracey, 1945, 308). This is remarkably like the process of 'suffosion' identified by McFarlane (1986) and observed elsewhere in Africa (Downing, 1968; Berry, 1970). It is important, therefore, to include subsurface erosion and piping, normally associated with sodic soils in Zimbabwe (Stocking, 1977), within an investigation on dambo gullying.

TOWARDS A MODEL OF DAMBO GULLYING

On the basis of the evidence reviewed here it was possible to construct a tentative model of dambo gullying following the approach used by Cooke and Reeves (1976) to identify factors influencing arroyos in the American Southwest. The model (Fig. 6) views dambo gullying in terms of the interaction of pedogeomorphic, climatic and land-use factors. These combine in various ways to increase the erosivity of runoff and the erodibility of dambo soils, whilst reducing the resistance of dambos to erosion. To ensure clarity in the presentation of this model not all the possible linkages are shown in Figure 6.

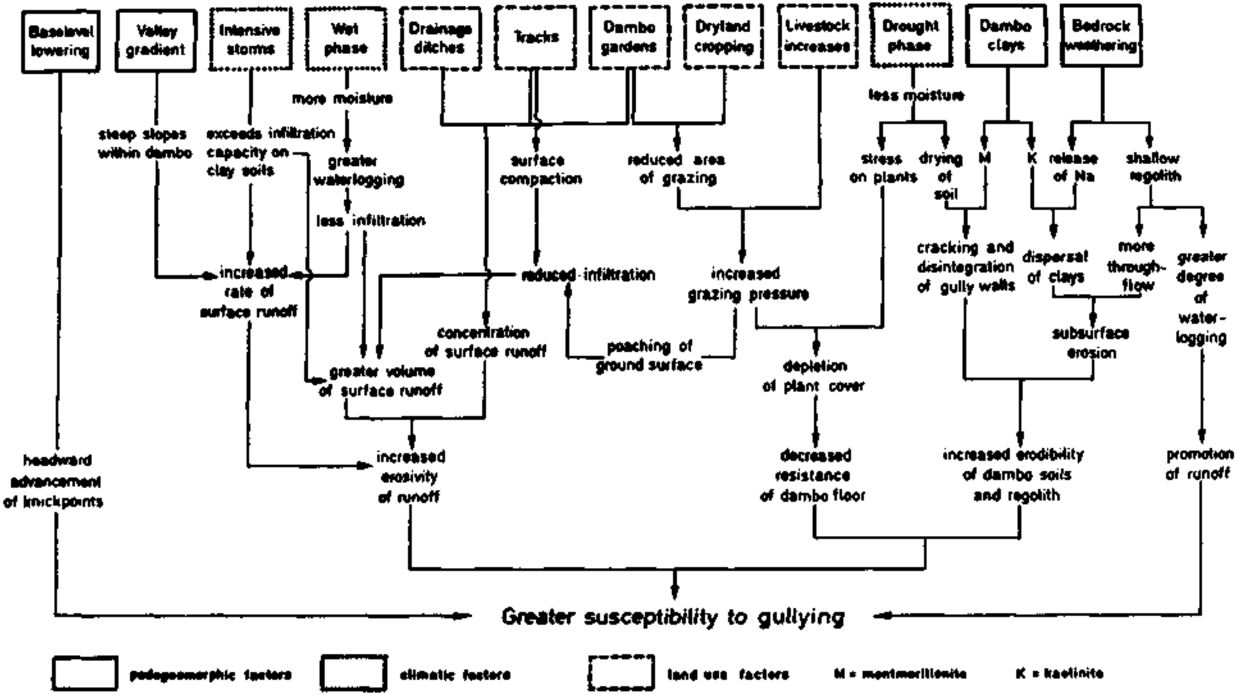
The pedogeomorphic factors that appear to influence the susceptibility of dambos to gullying include base-level lowering, valley gradient, dambo clays and bedrock weathering. Base-level lowering clearly relates to relatively slow, long-term changes in the landscape. However, where dambos are in areas affected by headward advancement of knickpoints then adjustment of tributary channels to lower base levels within main rivers may promote entrenchment of dambos as well. Where steep valley gradients occur, these may increase rates of surface runoff and also encourage gullying.

The response of dambo soils to erosion appears to depend, in part, on whether they are dominated by montmorillonite or kaolinite. Where montmorillonite clays dominate then soils are prone to severe cracking, especially during prolonged dry periods, and crumble readily along exposed gully banks. Soils where kaolinite is prevalent are less affected by cracking, being more massive or columnar in structure. However, in the presence of sodium released by weathering (for example, of feldspars in granitic rocks), such clays may be affected by dispersal which, in turn, promotes subsurface erosion. Such erosion is encouraged by throughflow in shallow regolith, this being dependent upon variations in bedrock weathering. Moreover, shallow regolith may also give rise to a greater degree of waterlogging and enhance runoff within dambos.

Climatic factors that may play a role in the initiation and growth of dambo gullies include the incidence of wet and dry phases and intensive rainstorms. During periods of prolonged drought soils dry out and there is stress on plants, the former affecting erodibility of dambo soils and the latter contributing towards depletion of plant cover and reduced resistance of dambo floors to erosion, as indicated in Figure 6. In contrast, more abundant rainfall during wet phases and periodic intensive storms may increase the erosivity of runoff by increasing both rates and volumes of runoff from the heavy-textured dambo soils.

Land-use factors of relevance in dambo gullying include drainage ditches, tracks, dambo gardens, dryland cropping and livestock increases. Through localized concentration of runoff (and possibly increased volume of runoff as well) ditches, tracks and gardens may affect initiation and enlargement of

Figure 6: A GENERAL MODEL OF FACTORS PROMOTING GULLYING IN DAMBOS



gullies. Extension of dryland cultivation and dambo gardens reduce the area available for livestock grazing. Where this occurs in combination with large increases in livestock numbers the result is greater pressure on dambo grazing. This in turn affects the resistance of dambo floors to erosion and the efficacy of runoff in gullying demonstrated in Figure 6.

CONCLUSION

The problem of gullying has been a central issue in the controversy surrounding the utilization of dambos for a number of years, especially in Zimbabwe where recent research has indicated that such wetlands may be more prone to erosion in this country than elsewhere in south-central Africa (McFarlane, 1989; McFarlane and Whitlow, in press). Gullying in many dryland areas is undoubtedly of anthropogenic origin, but increasing emphasis is being placed on the interactions of human and physical factors in the initiation and subsequent growth of gullies. This article has reviewed those factors deemed to be of relevance to gullying within dambos. On the basis of this diverse information a provisional, integrative model is assembled here. This model served as a useful framework for a more detailed investigation on dambo gullies with particular reference to the communal-farming areas in Zimbabwe (Whitlow, 1989). Only through identifying the fundamental causes of gullying can one take precautions to prevent such erosion or carry out remedial measures to counteract existing erosion. Hence the applied study of dambo gullying, of which this review was an important component, was seen as a contribution towards more effective use and conservation of dambos.

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