On the most recently abandoned terraces the dominant erosional forms are finely branched flow lines and rills, as well as accumulation of coarse fragments on the soil surface. The second-most-widespread form of erosion is incipient gullying. On two-thirds of the abandoned plots, major gullies represent the type of erosion of greatest intensity; on another 20% minor gullies predominate, and incipient gullying on the rest.

One important result of the site surveys is that the processes of splash, sheet and rill erosion (interrill and rill erosion) dominate. This is a direct consequence of the generally brief but very intensive and thus erosive high-intensity rainfalls, and the lack of vegetal cover. The fact that the damage caused by these processes is not immediately apparent should not mislead the observer into drawing any premature conclusions about their erosive potential, which because of the extreme runoff turbulence associated with them (caused by impacting raindrops, abrupt drops in the slope) is nevertheless certainly very high (cf. Chapter II, section 3c). Moreover, since on all abandoned terraces gully erosion is extensively active during the first decades after farming activities have ceased due to the heavy rains, the abandoned and untended terrace complexes are rapidly degraded and destroyed (cf. Photograph 11).

If these connections are known, the current risk of soil erosion in the study area can be deduced from the land-use map.

V. Types and magnitude of recent soil erosion in the study area

1. The erosional forms and their dependency on the anthropogenic relief

The relief of the Haraz mountains has been thoroughly shaped by human occupation, fulfilling the elementary prerequisites for agricultural utilization yet at the same time creating a landscape which - characterized by innumerable artificial terraces - is highly susceptible to soil-erosion processes. Visible evidence of the lack of stability of the terrace complexes, even when used and maintained, is frequently present in the form of damage to the retaining walls (see Photograph 9). This montane agrarian ecosystem can only function smoothly if a minimum of effort is invested in maintaining the technogenous topography. Wherever and whenever this essential prerequisite is not fulfilled, soil erosion inevitably initiates a steadily worsening process of degradation and instruction.

As already mentioned several times, soil erosion in the study area is caused by the action of water, and all of the different forms of accelerated water erosion and related accumulation processes can be observed there:

a) Interrill erosion in the form of splash and sheet erosion, as well as rill erosion.

b) Linear soil removal along well-defined channels in the form of gullying.

c) Lateral subterranean washing-out of material in the form of tunnel erosion or piping.

d) Associated accumulation processes in the form of temporary alluvial fans and colluvial deposits.

The various types of processes listed above were deduced from a review of a large body of geomorphological field data (cf. Chapter IV, section 3); in the case of sheet erosion, it was also possible to corroborate the field surveys by pedological-sedimentological laboratory analyses (cf. Chapter V, section 2 ba).

Thus, according to these findings and analysis results, interrill and rill erosion initially predominate on abandoned terraces, usually resulting in a small-scale shift of material in a horizontal direction towards the raised crests of the retaining walls. Then, as a result of the quick formation of structural and depositional crusts, as well as of erosion pavements (surface accumulation of coarse fragments), accumulated water on the untended terrace complexes runs off in growing quantities. When heavy runoff occurs in the course of torrential rainfalls, the retaining walls or their protruding crests are torn down at weak points by the rainwater as it rushes in cascades over the stepped terraces. Since the terrace fields are laid out horizontally, the collapsed wall sections represent the morphologically lowest points ("sagging contours"), at which the water then collects and is channeled. This channeling of the runoff and the free fall of the water at the incision points greatly increase its tractive force and carrying capacity, thus inducing powerful gully erosion dynamics characterized by an upstream progression caused by undercutting and waterfall action. The stable soils lead to formation of steps or nickpoints in these gullies, which generally exhibit an oval, amphitheater-shaped outline. There is a conspicuous correspondence between the height of these gully steps and that of the collapsed walls, thus clearly stressing their function as a local and temporary basis for erosion (see Photograph 15). The scouring action at the bases of these steps results in the development of gully heads, ultimately causing cleavage and caving-in of the topsoil, which is often held together by a dense network of roots (see Photograph 15).

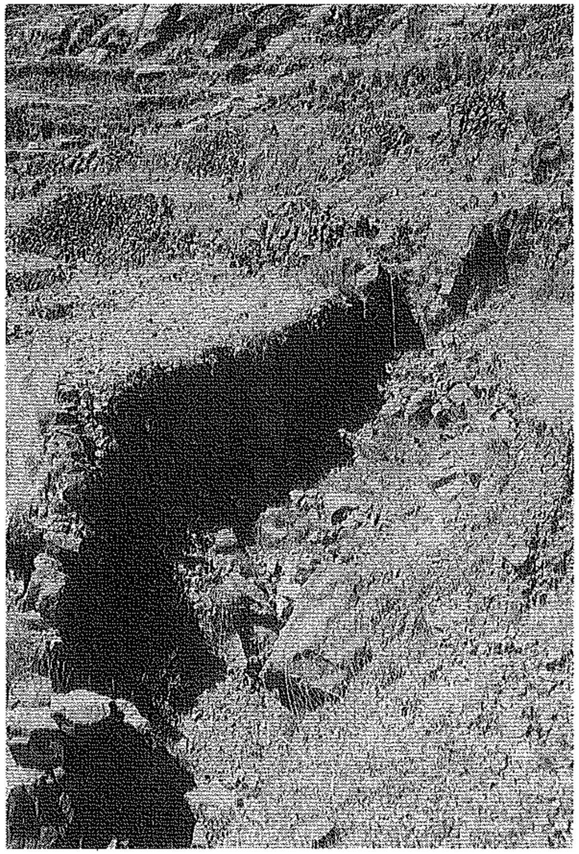
When runoff is concentrated in natural or artificial channels, the headcut works its way upstream in a straight line, resulting in formation of an axial gully with a U-shaped cross-section, the walls of which meet the still undissected terrace surfaces at a sharp angle (see Photograph 12).

If the waterfalls are fed not by concentrated linear runoff, but instead by sheet flow and/or shoestring rills - which is the case when rainwater falls directly onto a terrace and then drains off - then the gullies grow laterally as well as to the rear of the terrace, the gully heads developing digitate extensions while preserving their amphitheater-like shape (see Photograph 13). If water continues to arrive laterally from converging rills, then secondary headcuts develop, which then also cut into the terraces behind intact wall sections and affect increasingly large areas (see Photograph 13).

The soil volumes which are set in motion by this gully formation process are enormous even in the initial stage, since the maximum height of the headcuts is immediately reached at the front end of the terraces (see Figure 16). As another consequence of the anthropogenic shaping of the relief, direct transport of the eroded soil into the wadis is very limited, since the water flowing into the gullies must initially make its way over a continually changing course consisting of steep drops (fronts of terraces) alternating with flat

stretches (terrace fields) (cf. Photograph 23). If short gullies still in the process of formation emerge onto still (largely) intact horizontal terraces, then the tractive force and carrying capacity of the stream-like runoff are checked by the sudden flattening of the slope and spreading of the water just as abruptly and drastically as they had previously been increased by the effects of channeling and free fall. Consequently, part of the previously eroded enormous quantities of transported soil is deposited at such breaks in the slope in the form of small alluvial fans or taluses and/or colluvial layers.

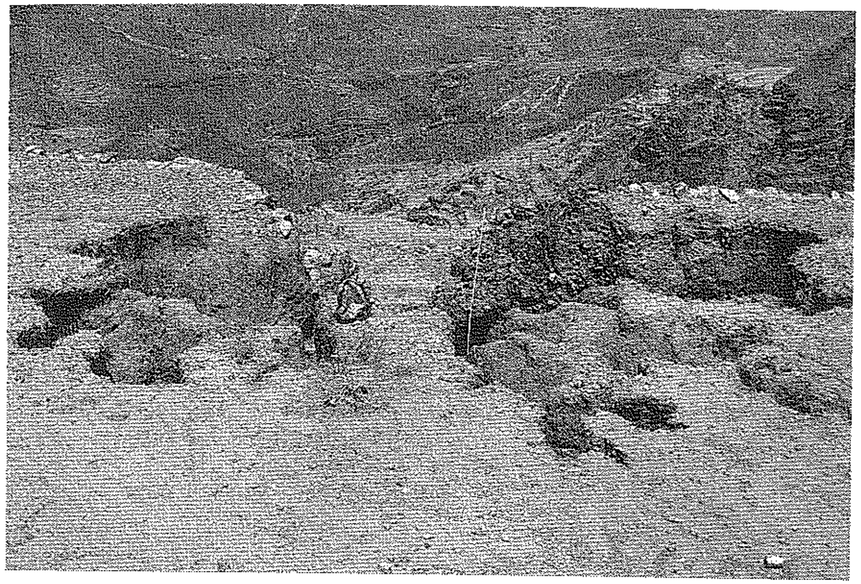
Photo 12: U-shaped, i.e.axial gully.



Length: approx. 10 m
Width: approx. 3 m
Depth: approx. 2-2.5 m
Map coordinates:
65.05/62.85

H. Vogel (9/23/84)

Photo 13: Digitately fanned gully head (looking towards the tree nursery on the Wadi Shabhb); map coordinates: 64.20/67.10.

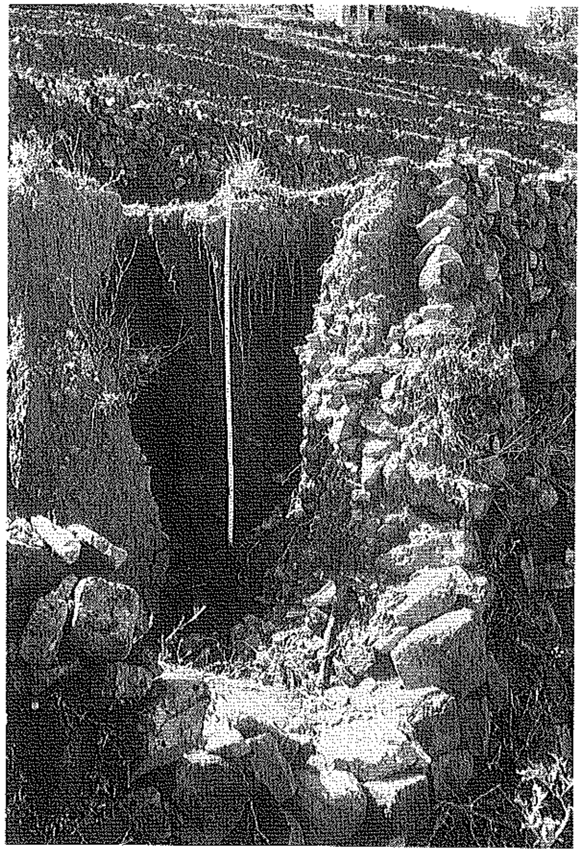


H. Vogel (9/16/84)

Photo 14: Diffuse thread-like flow lines and rills.

H. Vogel (9/16/84)

Photo 15: Overhanging gully head (approx. height: 2 m).



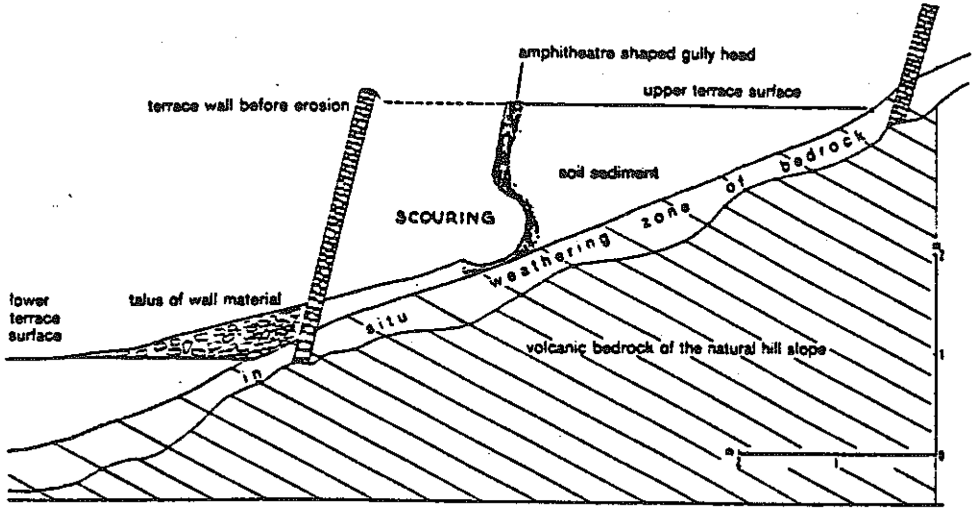
H. Vogel (9/16/84)

The result, characteristic of the initial stages of gullying, is a series of short, discontinuous gullies or steps with alluvial fans or colluvial deposits at the base of each, and areas without gullies on which other (pluvial) erosional processes are active. Frequently, the alluvial fans which form beneath the headcuts or steps extend all the way to the top of the retaining wall of the affected terrace, which is either already incised or due to be incised before long (cf. Figure 18, T 8). Corresponding to the sudden reduction in flow energy at the abrupt change in slope steepness between the basis of the walls and the terrace fields, these temporary alluvial fans exhibit a characteristic horizontal progression. Rocks from the wall can be found directly next to the former base of the wall, followed by the coarser and then the finer fragments, then the sand fraction, and finally deposits in front of the raised or already incised crest of the following wall, extremely high in silt and characterized by polygonal cracks when dry (cf. Figure 16 and Figure 18, T 8). The flow lines and incised rills which can be observed in the alluvial fans lead directly to the next-lower gully or gullies, which are quite frequently not in the direct line of the slope, but instead laterally displaced. This sequence of discontinuous gullies, alluvial fans or colluvial deposits, and flow lines and rills is a visible expression of the numerous local bases of erosion created by artificial terracing of the slopes.

This regular alternation of spatially associated forms induced by water erosion also represents a vivid documentation of the chain reaction which is triggered when gully erosion begins (cf. Photograph 23); borrowing from the field of political science, it was very aptly described by D. VARISCO (1982, p. 143) as the "domino theory of terrace destruction".

With progressive destruction of the terraces, the temporary colluvial accumulations are again incorporated into the process of erosion. Since the bedrock beneath the artificially accumulated terrace soils consists of hard igneous rock (see Photograph 16 and Figure 16), spectacularly deep gullying is not possible. As soon as the bedrock is reached, downward erosion is very effectively checked, and lateral forms of surficial erosion take its place, leading to rapid leveling of the steep gully walls. The overall effect is virtually complete removal of the terrace soils, leaving only shallow and stony soils behind in the final stage, when nearly all of the terraces have been leveled, with partial or sometimes even complete exposure of the bedrock (see Photograph 16). Such wastelands can no longer be feasibly reclaimed for terrace farming, representing the worst form of badland formation; they are then only suited for use as (marginal) pasture land.

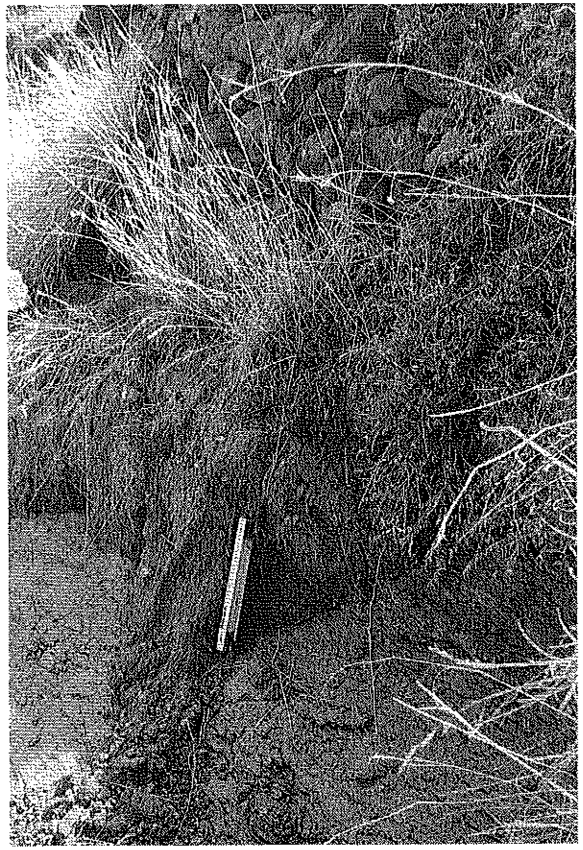
Fig. 16: Cross-section of a terrace damaged by gullying.



Source: Alkämper et al. (1979, p. 32); modified

Destruction of the landscape is particularly vigorous along the paved Sanaa-Al Hudaydah highway and the network of unpaved roads, which is being continually expanded. The enormous threat radiating from these infrastructural facilities is due on the one hand to the fact that terrace complexes are often cut through to depths of several meters when unpaved roads are built, but without taking any steps to stabilize the banks, and on the other hand to the circumstance that drainage from the roads to natural runoff channels is insufficient, causing the water to flow unhindered into abandoned terrace complexes. Moreover, these unpaved roads themselves frequently assume the function of water-collection channels, with the tire tracks widening to form small gullies that can spontaneously or gradually break into terrace complexes below the roads (see Photograph 17). The deep tracks and gullies on roads where erosional processes are active must then finally be filled in with rocks and stone blocks, making them even more wasteful of material and more jarringly uncomfortable to drive on than they already are.

Photo 16: Soil profile remnant on highly porous tuff (on the Mankhah - Al Hutayb dust road west of Az Zahrah).



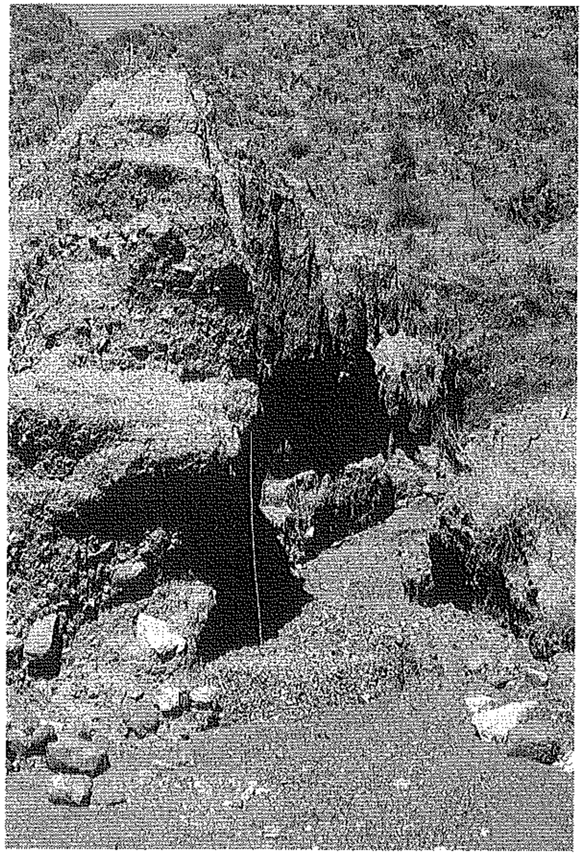
H. Vogel (9/27/84)

Photo 17: Small erosion gully (70 cm deep) on an unpaved road (Manakhah-Kahil) with rills in a fishbone pattern.

H. Vogel (9/3/84)

The massive soil loss during the initial stages of erosion is not only due to the effects of gullying in the strict sense of the word; it is also the result of the complete reactivation of the dense network of waterways which were predefined by the relief and had been converted during terracing the slopes. This reactivation is very impressive where some of these channels emerge into wadis; at these points, soil which had previously accumulated behind terrace walls is now incised by gullies up to six meters deep (see Photograph 18).

Photo 18: Reactivated tributary channel in an abandoned terrace adjacent to a wadi bed.



Depth: approx. 6 m
Length of measuring rod: 2 m
Map coordinates: 66.65/67.20
Seen here looking toward the northwest.

H. Vogel (10/27/84)

In addition, on a number of abandoned but still virtually intact terraces it was possible to observe forms of subterranean erosion. These are "tunnels" measuring up to 30 x 30 or 20 x 40 cm, undercuts, sinkholes, natural bridges, and hollows of all conceivable shapes and sizes (see Photograph 20 and Figure 18, T 2). These subterranean erosion phenomena are caused by subsurface flow derived from water which percolates vertically through the soil and then is laterally diverted at a certain depth. The cracks which form as a result of desiccation in soils relatively high in clay (see Photograph 5) serve as very effective subterranean drainage channels; these can gradually widen into pipes and tunnels, which then form gullies when they collapse (see Photograph 20; cf. de Ploey 1974, p. 188; Nir and Klein 1974, p. 201; Derbyshire et al. 1979, pp. 56-57). Such signs of subterranean erosion were observed with conspicuous frequency directly in back of terrace walls, where water flowing through the walls had hollowed out blind channels (see Photograph 19) without evidence of a tunnel entrance or a sinkhole on the field above. The largest cavity hollowed out in this way had a height of 1.40 m and a width of 80 cm, extending 50 cm deep into the side of the terrace. At the base of the wall this backwash had formed a large alluvial fan. At a few points, rocks of the wall which had been washed free had even fallen back into the cavities behind them.

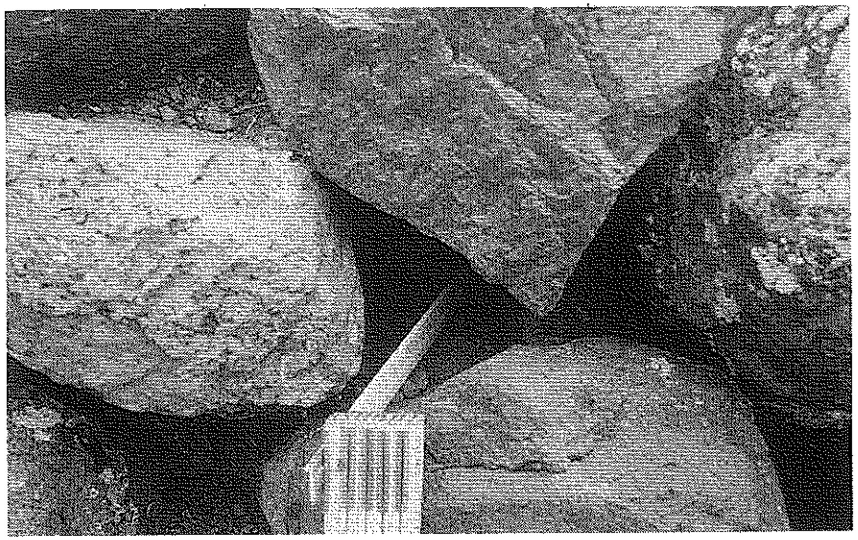
The concentration of subterranean cavities caused by erosion in the immediate vicinity of retaining walls is possibly also due to the burrowing and digging of small animals like field mice and ants. The tunnels they build also provide ideal channels for runoff water (Varisco 1982, pp. 123-126).

A very instructive example of the dynamics of subterranean erosion was observed during the irrigation of a terrace east of Al Mudammar. Even before the first bed was completely flooded, a rivulet of water emerged below the crest of the wall between the spaces in the rocks. The farmer responded to my unusual interest by trying to seal off the section of terrace above the leak with soil, but without success.

As has been shown in this chapter, the anthropogenically shaped terrace relief of the study area is the cause of very regular development phases and typical types of soil erosion. Their most essential features can be summarized as follows:

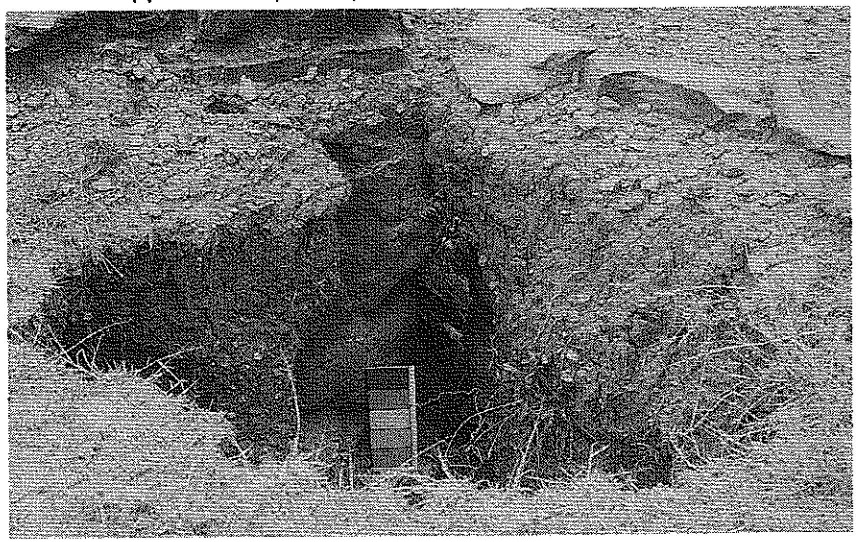
1. A typical sequence of forms associated with gully erosion (in its initial status) due to the regular succession of terrace steps (local and temporary bases for erosion).
2. The maximum depth of the gullies (height of the gully heads or nickpoints) is reached at the fronts of the terraces.
3. Collapsed sections of wall at the fronts of terraces (morphologically the lowest points) are the starting points for upward-progressing gully erosion, while sheet erosion begins at the back of the horizontal terrace fields (at the bases of the walls) and works downward.
4. A dominance of digitate gullying with distinct steps isolated from one another and short discontinuous gullies.

Photo 19: Hollowing of a retaining wall by subterranean erosion.



H. Vogel (9/17/84)

Photo 20: Sinkhole created by subterranean erosion in a terrace field with soil relatively high in clay (parent rock: IG 5; map coordinates: approx. 64.40/67.30).



H. Vogel (9/15/84)

5. Axial gullying with relatively long to continuous erosion gullies only in the case of concentrated runoff along natural or artificial channels, on very broad terraces (10-20 m), or when gullies develop diagonally across a terrace.
6. Reactivation of the natural network of runoff channels.
7. The dynamics of gully erosion do not come to a complete halt until all of the steps in the slope have been leveled, due to the typical sparse vegetal cover and high inherent natural risk of erosion.
8. Subterranean erosion behind intact retaining walls as a result of subsurface material transport through spaces in the walls.

2. The magnitude of recent soil-erosion processes

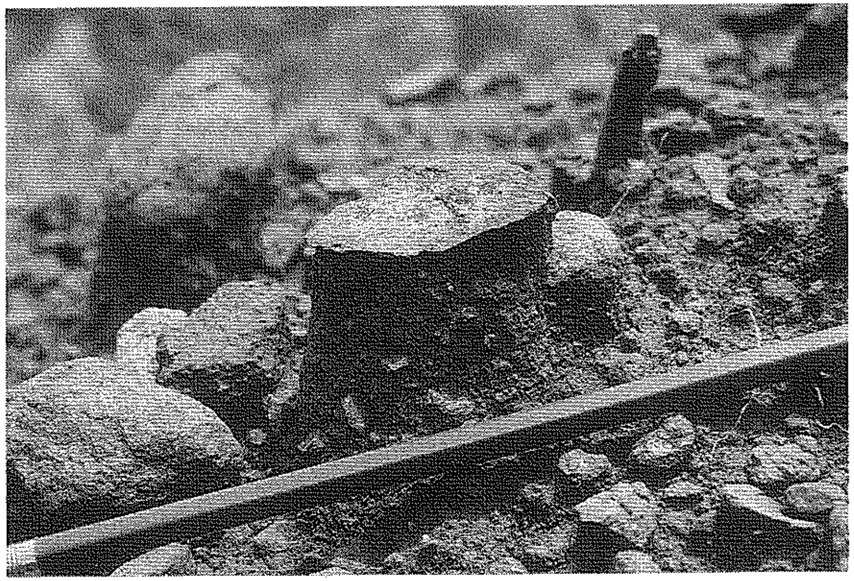
a) Quantification of splash erosion

Splash erosion is a direct result of fine soil particles being laterally hurled away by impacting raindrops (cf. Chapter II, section 3 b). On structurally unstable soils which are not bound together by plant cover or root networks, splash erosion can take on formidable dimensions during very erosive high-intensity rainfalls. During a single heavy rain over 200 tons of soil per hectare can be moved by the bombarding force of raindrops (Breburda 1983, p. 46; Strahler and Strahler 1984, p. 276). The effects of splash erosion when it occurs alone on level surfaces are minimal, however, since soil particles are only moved short distances of up to 1.5-2 m (Stallings 1962, cited in Breburda 1983, p. 45). Nevertheless, the erosivity of impacting raindrops increases with slope steepness, since most of the already loose soil particles and those broken free by the force of impact are progressively knocked in a downhill direction (Ellison 1947, cited in Cooke and Doornkamp 1974, p. 31, Strahler and Strahler 1984, p. 276). Splash erosion most often occurs by itself on the uppermost portions of steep and medium slopes (Breburda 1983, p. 46).

On stony soils, the splash effect of very intensive rains can lead to the formation of small pebble-capped erosion pedestals or earth pillars; these can then be utilized as a measure of the intensity of splash erosion (Hudson 1981, p. 39; cf. Stocking 1972, p. 435). Because of their inconspicuousness, these signs of erosion are often overlooked or simply ignored. In the study area they were found on the "old trial plot" at Bayt al Mughalad (62.30/65.45) (see Photograph 21). They had formed on an isolated ridge, completely

devoid of vegetation, between two erosion gullies, and had a maximum height of 4-5 cm. The fact that the bases of these bizarre erosional forms had not been undercut was evidence that they owed their formation exclusively to the splash effect of impacting raindrops, and not to the washing-away of entrained soil particles by shallow surface runoff (Stocking 1972, p. 435; cf. Hudson 1981, p. 39; Jansson 1982, pp. 3-5). In this case, this assumption is reinforced by their exposed location on the crest of a small ridge, since no water can possibly accumulate there. From such a position the particles detached by striking raindrops are hurled into the laterally adjoining erosion gullies and then washed away (Evans 1980, p. 121). The soil directly beneath flat pebbles is protected from the falling raindrops, while the exposed soil particles are eroded away, gradually causing small erosion pillars to be carved out (see Photograph 21).

Photo 21: Pebble-capped erosion pedestall(s) about 4 cm high (scale of photograph 1:0.9).



H. Vogel (8/26/84)

In the case of the "old trial plot" at Bayt al Mughalad, which according to the project leader at that time, Mr. R. Kastl, was abandoned around 1979, it can be conservatively assumed that these erosion pillars developed over a period of between about 3 and 5 years - probably during just a few heavy rainfall events (cf. Figure 14) - since the crest of the small ridge is significantly lower than the level of the original terrace surface. This cautious estimation of the age of the erosion pedestals implies a minimum soil loss rate, caused exclusively by splash erosion, of between 0.8 and 1.7 cm/year or an average annual soil loss of 80 to 170 m^3 per hectare, which corresponds to 108 to 225 t/ha/year at a bulk density of 1.35 g/cm^3.

Such erosion pedestals were not observed on any other abandoned plots. There, the only evidence of the high erosivity of the heavy rains took the form of superficial accretion of stones and coarse fragments.

Following some initial surprise at this discovery, the reason was quickly identified by a comparative review of the thin-section and soil analysis results. The hand specimen collected from the "old trial plot" at Bayt al Mughalad, for example, had by far the highest carbonate content of all analyzed rock samples (see Chapter III, section 3 c). As analysis of the soil samples taken from this same plot (P 1/T 6) revealed, the relatively high carbonate content of the tuff had been imparted to the soil as well. Of all of the analyzed soil samples, the loamy sand formed on this site had the highest proportion of calcium, at between 7 and 9% (see Tables 3 and 11). With increasing desiccation, the high carbonate content of the soil results in strong binding of the soil particles, so that the small, free-standing erosion pedestals are exceedingly stable during dry weather (cf. de Ploey 1974, pp. 188 and 181). Protected by flat stones at their tops, over the course of time they gradually grow downward and remain intact due to their great stability. Excessive wetting, however, quickly leads to their disaggregation and disintegration as the calcium carbonate is washed out ("peptization effect") (cf. de Ploey 1974, pp. 182 and 188).

b) The significance of sheet erosion

ba) Characterization of sheet erosion on the basis of horizontal displacement of material

Sheet erosion is the name given to more or less uniform removal of soil in thin layers from the surface of a large area. For the most part, this erosional process affects fine and very fine soil material (soil colloids) of mineral and organic composition which has been detached and loosened by impacting

raindrops. Since these colloids are responsible for the soil's ability to exchange cations and to absorb water and also serve to bind together aggregates, thus playing a major role in determining soil fertility, occasional references are also made in the literature to "fertility erosion" (Stallings 1957, cited in Zachar 1982, p. 208; Breburda 1983, p. 46).

When rainfall and sheet flow occur together, because of the turbulence induced by the impacting raindrops large quantities of suspended soil material can be washed away, even if the runoff consists of only a very shallow film of water. Since sheet flow does not reach the velocities required for entrainment and transport of soil particles unless the terrain has a certain minimum slope steepness, the erosive potential of sheetwash on gentle slopes is considerably to predominantly determined by the erosivity of the rainfall (see Chapter II, sections 3 b-c and 4).

A method which has long been used successfully in Europe for measuring sheet erosion (a phenomenon which often goes undetected, being hidden by the relief morphology) involves analysis of toposequences (i.e. sequences of kinds of soil in relation to position on a slope). If sheet erosion is taking place on an inclined surfaced, then its effects can be identified on the basis of the occurrence of a regular horizontal succession of soil characteristics (Kuron and Jung 1961, p. 142; Bargon 1962, pp. 490-491; Späth 1975, p. 82 ff.; 1976, p. 130 ff.; Schwertmann 1977, pp. 773-778; Holy 1980, pp. 145-153; Peinemann and Brunotte 1982, p. 307 ff.; Breburda 1983, pp. 64-65).

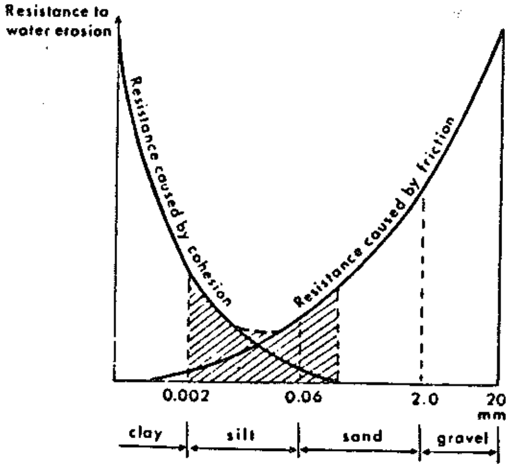
The most suitable indicators for this purpose are, besides particle size distribution, phosphorus (as P_2O_5) and humus content, since neither of the latter two substances readily occurs in solution (with associated downward transport by percolating water), instead remaining predominantly bound to solid soil material. Potassium (K_2O) behaves similarly, but because of its high mobility it tends to be carried downward a significant distance by percolating water in soils that are fairly low in clay. In soils high in calcium, calcium carbonate ($CaCO_3$) is also suited for characterizing sheet erosion.

On surfaces that are subject to strong sheetwash, the resulting shift of soil material is reflected in the spatial distribution of these indicator substances. In general, a deficit of one of these substances at the site of removal corresponds to a surplus of equal magnitude at the site of accumulation. In the present study, unfortunately, because of the anthropogenically shaped relief it proved to be impossible to apply this analytical method to toposequences. Instead, it was used for supplementary characterization of recent sheet erosion on abandoned terraces. On a total of eight sites, three soil samples were taken at the base of a retaining wall and another three from the front end of the terrace alongside the downhill wall, all from the surface horizon (0-5 cm); the samples were then analyzed (see Fig. 18 and Table 11).

The results of particle size analysis clearly revealed that only the silt fraction is highly susceptible to sheet erosion, while neither the clay nor the very fine sand fractions permitted any conclusions to be drawn (see Table 11). On all of the terraces - with the exception of T 8, which represents an unusual case (see Fig. 18) - the increase in silt in a horizontal direction and the enrichment of this separate in the surface horizon (see Table 11; cf. Table 9) are conspicuous. Selective washing-out and removal of the silt is also evidenced by the low silt fractions on greatly degraded sites (see Table 9 - P 4; cf. Photograph 24).

This clear tendency for silt particles to be removed in preference to other fine soil fractions has been confirmed by the soil-loss studies performed over a period of years by L. JUNG and R. BRECHTEL (1980, pp. 105-107). According to the comprehensive results of their investigations, the silt particles are the first to be washed out, and this occurs even when the forces acting upon them have low erosivity. Comparable findings were made by U. KIHLBOM (1970, cited in Jansson 1982, pp. 24-25; see Fig. 17).

Fig. 17: Erodibility of various particle sizes.



Source: Jansson (1982, p. 25)

On terraces whose retaining walls are still intact, the horizontal displacement effect of sheet erosion was documented by analogous distribution of humus, calcium carbonate, and plant-available P_2O_5 and K_2O (see Table 11 and Fig. 18 - T 1/2). This statement also extends to those terraces which have experienced colluvial sedimentation as a consequence of gullying further uphill (see Table 11 and Fig. 18 - T 3/4).

Much more complicated conditions prevail on terraces with partially or completely collapsed retaining walls, where the formerly level plots have already developed a significant downhill slope. Although it was possible to demonstrate that the silt fraction, soil phosphorus and the calcium carbonate content had been affected by erosion on these surfaces, the humus contents and potassium levels remained undifferentiated, thus preventing definitive conclusions to be drawn on the action of sheetwash. Although the high potassium levels indicate that enrichment processes had occurred in suspension, no pattern of displacement in the direction of the terrace fronts that could serve as evidence of sheet erosion could be detected (see Table 11 and Fig. 18 - T 5/6/7). Exactly the same picture was shown by the potassium levels on the site T 2a, although here the retaining wall had not collapsed; instead, subterranean erosion had formed a blind channel in front of the sampling sites.

Site T 8 represents a special case in which gully erosion has been superimposed on sheet erosion. While an alluvial fan had formed on the still intact back and center sections of the terrace, at the front of the terrace a large gully headcut had worked its way backwards into the field. It is thus not surprising that here the silt, humus and calcium contents are significantly higher in the back section than directly in front of the alluvial fan. The surprising aspect is that nutrient levels are higher in the part unaffected by the surface deposits, since these can only be partially explained by the generally high nutrient levels in the local soil (cf. Table 3 - P 11).

Of particularly great practical significance for agriculture is the enrichment of nutrients which can be observed in the shifted soil sediments at the investigated sites; as a rule, nutrient levels here are between 10 and 70% greater than in the topsoil (cf. Wischmeier and Smith 1978, p. 39). In one extreme case, enrichment had yielded nutrient levels 3.5 to 4.9 times the normal values (see Tables 3 and 11 - P 9/ T 1). Although the thin-section analyses showed that the soils have derived a good supply of nutrients from the parent rock, in this case it is impossible to reliably tell whether this concentration of nutrients in the surface horizons is due exclusively to enrichment occurring in suspension, or whether it has been favored by

Table 11: Horizontal displacement of material on abandoned terraces as a result of sheet erosion.

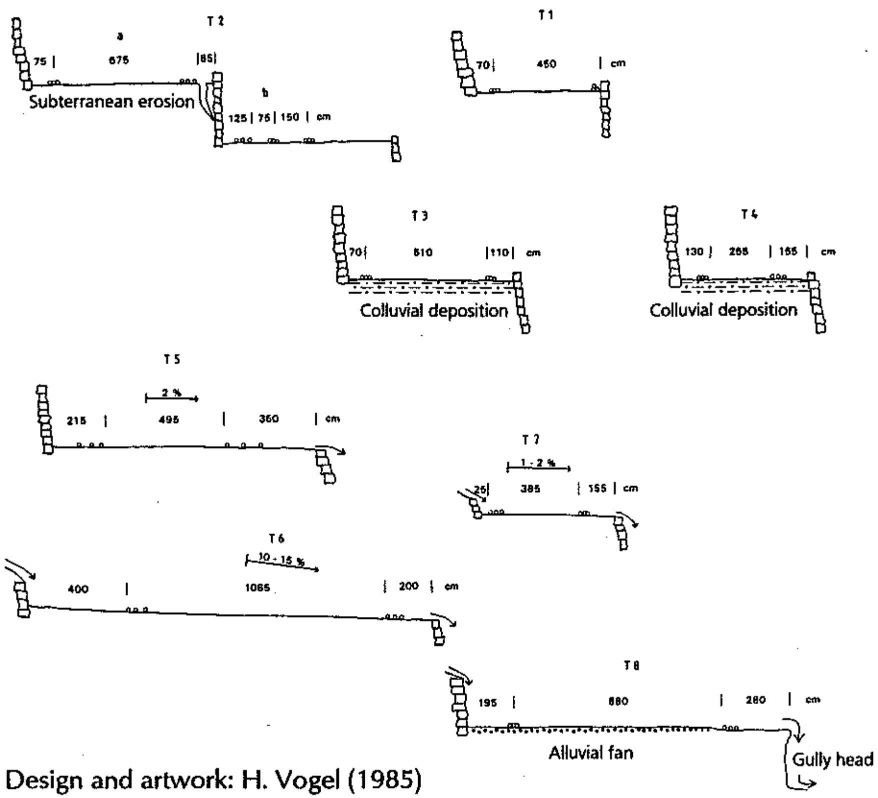
No.	Site (map coordinates)	Position[1]	Clay 0.002 mm	Silt 0.002-0.06 mm	Very fine sand 0.06-0.125 mm	Fine to coarse sand 0.125-2 mm	Soil type	Humus	$CaCo_3$	P_2O_5	K_2O
			in % of fine soil					%		ppm	
T 1	Manakhah (64.75/67.65)	Mb	15.64	49.98	8.45	25.93	loam	1.8	1.4	278	653
		Mk	11.39	50.17	9.16	29.28	silt loam	2.3	1.6	390	846
T 2 a	Kahil (64.85/64.95)	Mb	9.04	43.66	15.77	31.54	clay loam	0.9	1.4	165	339
		Mk	6.69	53.98	13.11	26.22	silt loam	1.0	1.3	199	310
b		Mb	6.12	30.59	18.53	44.76	sandy loam	0.4	0.6	240	293
		Mi	9.23	51.37	20.79	18.62	silt loam	0.8	0.8	300	298
		Mk	8.03	59.26	14.89	17.82	silt loam	1.2	1.3	373	447
T 3	Ashami field (63.05/66.15)	Mb	12.24	74.16	12.23	1.37	silt loam	1.2	1.9	38	84
		Mk	9.58	78.63	10.22	1.57	silt loam	1.8	3.1	56	111
T 4	east of Kahil (65.10/65.85)	Mb	10.81	65.97	8.10	15.13	silt loam	0.9	4.8	70	279
		Mk	11.85	80.01	2.88	5.26	silt loam	1.0	4.9	77	309
T 5	Kahil (64.90/64.95)	Mb	8.22	39.54	16.34	35.91	loamy sand	0.8	0.8	214	455
		Mk	8.05	46.22	12.24	33.49	sandy loam	0.8	0.8	216	328
T 6	Bayt al Mughalad (62.30/65.40)	Mb	11.02	29.55	13.24	46.19	loamy sand	0.6	6.7	49	105
		Mk	12.00	33.59	12.23	42.18	loamy sand	0.5	7.2	104	112
T 7	Manakhah (64.45/67.45)	Mb	16.30	35.86	15.51	32.33	sandy loam	1.1	1.1	101	320
		Mk	13.27	50.33	10.45	25.95	silt loam	0.9	1.2	140	280
T 8	Manakhah (64.25/67.10)	Mb	15.92	59.32	8.41	16.34	silt loam	2.3	3.3	296	506
		Mk	21.42	43.00	9.56	26.02	loam	1.9	2.3	314	560

1 Mb = bas of wall; Mk = crest of wall; Mi = middle

supplementary application of fertilizers (cf. Myntti 1979, p. 56; Varisco 1982, pp. 118-119).

In view of the fact that sheet erosion is difficult to identify by visual means, the pedological-sedimentological analysis findings represent a useful addition to the geomorphological field data. The results obtained with the aid of these two methods reveal that the terrace soils in the study area, being high in silt, have a strong tendency towards selective sheet erosion. It can be deduced from this that lateral (downhill) shifting of the silt fraction and the nutrients bound to it occurs in the study area even during light rains, which - in view of the described relief and prevailing vegetation conditions - over the course of time must inevitably lead to considerable loss of soil (cf. G. Richter 1978, pp. 381-382; Jung and Brechtel 1980, pp. 105-107; Gerold 1983, p. 7).

Fig. 18: Topography of the studied terrace sites.

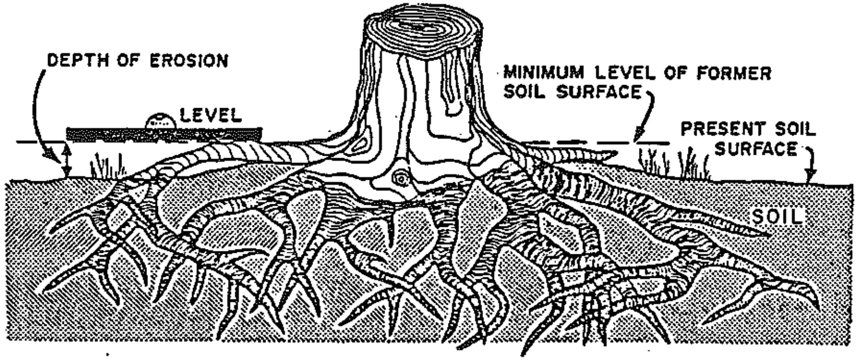


Design and artwork: H. Vogel (1985)

bb) Erosion rates as determined using the "biological method" by T. DUNNE

The extent of soil removal caused by sheet erosion was measured using the "biological method" developed by T. DUNNE (1977); for this purpose, the exposure of the roots of acacia trees (*Acacia negrii* and *Acacia origena*) was measured (see Figure 19 and Photograph 22).

Fig. 19: Determination of soil erosion using the "biological" method by T. DUNNE.



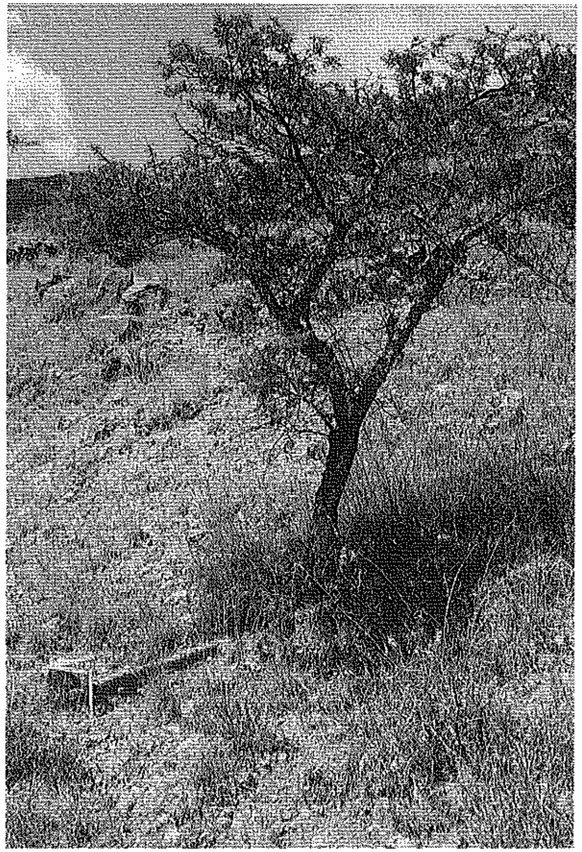
Source: Dunne (1977, p. 144)

It proved to be extremely difficult to put this method into practice, due to the anthropogenic nature of the relief (with frequent isolated points of damage with exposure of roots at gully headcuts), excessive pruning of the trees in most cases (making reliable age determination impossible), and the fact that I was forced to rely on information supplied by others for identification of the trees. Although such measurements were carried out on several sites, because of the mentioned difficulties the results from only two ultimately turned out to be usable.

In the first instance (see Photograph 22), the minimum level of the former soil surface had been reduced by between 16 and 22 cm. The tree was between 2 and 2.10 m high and its age was estimated at around 15 years; this yields an average annual lowering of the soil by 1.1 to 1.5 cm, corresponding to an average annual soil loss of between 110 and 150 m^3/ha/year. In terms of weight, this is equivalent to around 150 to 200 t/ha/year (at a bulk density of 1.35 g/cm^3).

In the second instance, an acacia tree roughly 3 m high near Bayt Hamid was examined. Between 35 and 38 cm of root had been exposed; since the age of the tree was estimated at around 25 years, this yields an average lowering of the soil surface of between 1.4 and 1.5 cm or a rate of soil removal of between 140 and 152 m^3/ha/year, corresponding in terms of weight to a long-term rate of soil loss of between 200 and 215 t/ha (at a bulk density of 1.42 g/cm^3).

Photo 22: Root exposure ty sheetwash (map coordinates: 64.25/65.90).



H. Vogel (8/30/84)

c) Soil removal measurement using O. SCHMITT's method for assessing the intensity of gully erosion

In order to estimate the intensity of gully erosion, the method developed by O. SCHMITT (1955) was applied. This method consists of measuring the volume (in cubic meters) of the soil material removed by gullying. In view of the fact that gully erosion in the study area alternates tightly with sheet, rill and splash erosion, and that these are juxtaposed on it even in its initial stages (cf. Chapter V, section 1), narrow temporal limits exist for determination of the original level of the terraces, a requirement for application of this method. Because of this considerable difficulty, reliable measurements of the volume of soil removed can only be performed during the initial stage of gullying when the headcuts and/or erosion gullies are still clearly defined by the more or less horizontal terraces. In the present case, therefore, the measurements were restricted to two terrace complexes for which it was possible to find out from local residents how much time had passed since they were abandoned.

One of these two terrace complexes was situated at 2,7302,750 m above sea level on a westward-facing steep slope (30°) on Jabal Shibam (63.70-64.40) (see Photograph 23); the other was located at 2,170-2,240 m above sea level on a northwest-facing medium-gradient slope (20°) near Manakhah (65.25-67.10) (cf. maps). The terraces on Jabal Shibam had been untended for 3 years at the time of my field studies in 1984, while farming on the terraces near Manakhah had ceased in about 1974, although the owner pointed out that the damage to the terraces by gullying did not begin until 1979/80. Even then, the first collapsing sections of wall were provisionally repaired with mounds of rock.

This piece of information is consistent with statements made by other farmers, who also pointed out that major damage to walls is typically the result of cloudburst-like torrential rains, and does not occur every year. According to the subjects interviewed, heavy rains of this kind fell in May of 1984, causing wall sections to collapse even in very well- tended terrace complexes (see Photograph 25).

The pluviograph data showed that these storms took place on the 15th and 16th of May 1984, when daily and hourly precipitation of 21 and 26.5 mm, respectively, was measured in Manakhah. In the week prior to that, on several - for the most part successive - days between 5 and 15 mm of rain fell, so it can be safely assumed that the water absorption capacity even of solidly walled-in terraces must have been exhausted.

On the basis of visual inspection in the field, a single spectacular erosion event of this kind was probably also responsible for the "gully breakthrough" on Jabal Shibam along a natural line of depression in the relief. At the time it was examined (August 27/28, 1984) it consisted of a regular series of minor gullies and/or headcuts strung out together like beads on a string, with an alluvial fan at the base of each (see Photograph 23).

In the cavities formed by erosion in this terrace complex, which covers a total area of just under 2,400 m^2, a total of 55 m^3 of soil were missing, which is equivalent to a total loss of 296 t/ha or 99 t/ha/year at a mean bulk density of 1.3 g/cm^3 (see Table 3 - P 2; cf. Photograph 4). This volume corresponds to an overall lowering of the soil profile by 0.8 cm per year. Taking into account the alluvial fans deposited between the gullies, the total soil loss - in this instance caused by a single storm event - amounts to at least 50 ton per hectare per year if distributed over the 3 years which had passed since abandonment of the terraces.

The total soil loss of 55 m^3 or 71 tons is roughly equal to three-quarters of the soil loss measured on other terrace complexes in individual large gullies (see Photograph 12).

The area surveyed near Manakhah is on the whole still in relatively good condition, although its terraces have already been incised by a large number of headcuts and short, discontinuous gullies (see Photographs 13 and 15). On the northern perimeter of this terrace complex, which covers a total land area of 5,230 m^2, the gullies were additionally fed by a culvert beneath the access road leading from Manakhah to Al Maghrabah; according to information provided by the owner of the terrace complex, after farming stopped on the terraces this culvert had been blocked by rubble for a long time. He also said that before cultivation had ceased, runoff water from the road had been used for supplementary irrigation of the fields (cf. Photograph 25).

The total measured soil loss from this terrace complex was 420 m^3, which at a bulk density of 1.5 g/cm^3 (see Table 3 - P 11; cf. Photograph 5) corresponds to a loss of 1,205 t/ha. If it is assumed that erosion has been active there for between 5 (onset of gullying) and 10 years (when cultivation ceased), then the soil loss caused by gully erosion has proceeded at a rate of between 120 and 240 t/ha/year, corresponding to an overall lowering of the soil profile by 0.8-1.6 cm/year.

The temporary alluvial fans and colluvial deposits which have accumulated on the 4- to 10-m-wide terraces had in many cases already been dissected

Photo 23: Gully "breakthrough" in a recently abandoned terrace complex on Jabal Shibam (looking towards the east).

H. Vogel (8/27/84)

or nearly completely eroded away by gullies working their way up from below. Because of the shallowness of these deposits, it is not possible to provide any information on their approximate magnitude.

d) Discussion

Within the scope of the study, I was interested in seeking the answers to two key questions:

1. What is the approximate extent of soil erosion in the study area, and what are the relative contributions of the various water erosion processes to it?

2. What implications does the ongoing soil erosion have for the ability of the area to support agriculture?

Since no information was or is available on the intensity of soil erosion either in the study area or in comparable mountainous regions in former North Yemen, I have endeavored to answer the question as to the extent of soil erosion, at least as a rough approximation. Because I had only 10 weeks to spend in the field, this could only be done on the basis of simple data collection methods that were likely to quickly yield usable approximate values. As a supplement to the individual site surveys, which should also be regarded in conjunction with the compilation of a land-use map (cf. Chapter IV, section 3), the semiquantitative measurement methods described above were applied.

As was shown, the soil removal rates determined with the aid of these simple field methods were between 0.8 and 1.7 cm per year for pluvial (sheet, splash and rill) erosion and between 0.8 and 1.6 cm/year for gully erosion, corresponding to an annual soil loss of an order of between 100 and 225 t/ha and between 100 and 240 t/ha, respectively. During the first decades following abandonment of the terraces, total soil loss (gross erosion) is consequently - because of the gully erosion which is normally highly active during this phase - between 1.5 and 3 cm/year or 150 and approx. 400 t/ha/year.

On the basis of the site surveys and the interviews, the period of time in which such excessive rates of soil erosion occur probably span between two and four decades, depending on the size and type of the catchment area (runoff from other areas), plant cover (for the most part sparse and spotty), and the ability of the terrace walls to withstand weathering (lithotype). On the resulting largely "leveled" slopes, according to the tentative results of the analyses, the maximum annual rates of soil removal range from 0.8 to 1.5 cm or from approx. 100 to 200 t/ha. In this advanced state of destruction, most of the soil loss is caused by splash, sheet and rill erosion (interrill and rill erosion), with a large part of the eroded soil being temporarily deposited one or more times on its way downhill before it finally reaches one of the major wadis and is thus lost forever.

If the soil removal values presented above are subjected to a critical appraisal, then it becomes apparent that, because of the described methodological difficulties and the limited number of measurements made, they are only the best possible approximation of the intensity of soil erosion which could be tentatively attained under the circumstances; however, because of the care devoted to collecting the data and in view of the high current risk of soil erosion which they demonstrate, presentation of them is not only justified but indeed necessary (cf. Hudson 1981, p. 203).

As a possibility for assessing the quality and informational content of these values, one can also resort to simple volumetric determination of typical terrace complexes[7], assuming that the information obtained in the interviews is correct, namely that sites given up during the "second" phase of abandonment have today (i.e. after 40 years) already been largely leveled, and that the mean depth of the remaining soil on such slopes is now approx. 50 cm (cf. Photograph 24).

In addition to the determined extent of damage to the abandoned terrace complexes and the demonstrated extreme nature of the natural factors influencing erosion in the study area, studies which have been performed in other semiarid regions make the (overall) erosion rates calculated for the study area appear quite realistic.

For example, T. DUNNE (1977) and T. DUNNE et al. (1978) measured surface erosion in various parts of semiarid Kenya by measuring the height of exposed tree and brush roots, as well as of mounds of undisturbed soil formed by erosion of the surrounding ground on toposequences on gently sloping hill slopes used as pasture. In areas that have an average annual erosivity as determined using the map published by T. MOORE (1979, p. 154) of less than 6,000 j/m^2, erosion rates of between 0.1 and 1.2 cm per annum have been measured (Dunne 1977, p. 115). Depending on soil bulk density, these erosion rates span a range of annual soil loss of between about 10 and 180 t/ha. This range reflects the dependency of erosion intensity on slope steepness, since with insufficient vegetal cover soil loss continuously grew with increasing slope angles. A ground coverage of between 20 and 30% proved to be a critical threshold value below which the intensity of soil removal dramatically increased (Dunne et al. 1978, pp. 135-138).

---

7) For example, complexes comprising 10 terraces each with the following dimensions:
Average wall height = 2.5 m; average field width = 6.0 m; average field length = 100 m; gradient = 35%
Average wall height = 3.0 m; average field width = 4.0 m; average field length = 50 m; gradient = 60%

Photo 24: Residual soil depth on a formerly terraced slope (P 4).

H. Vogel (8/30/84)

L. STRÖMQUIST and D. JOHANSSON (1978) carried out measurements of the height of exposed earth mounds in central Tanzania. In one area characterized by annual precipitation of around 450 mm and a hilly to flat relief, they measured erosion rates of 0.2-0.4 cm/year.

With the aid of the "biological" method by T. DUNNE and an additional semiquantitative field method (assessment of soil accumulation on upslope side of trees), M. BUCH (1984) measured surface erosion rates of for the most part over 2.0 cm per year on strongly degraded pasture land in the western Usambara Mountains of Tanzania, where annual erosivity is also less than 6,000 J/m^2 or between 6,000 and 10,000 J/m^2, according to T. MOORE (1979, p. 154). Also of great interest are his figures on soil-erosion rates on conventionally managed farming land (without soil conservation measures) and artificially constructed farming terraces. While average soil removal rates of between 0.6 and 1.0 cm/year were determined for the conventionally farmed areas, the studies conducted on terraced slopes yielded erosion rates of only 0.1 to 0.4 cm/year. This shows that soil erosion on terraced slopes is significantly reduced, but not completely eliminated (cf. Wischmeier and Smith 1978, pp. 37-38). "The soil-erosion processes take place here on a small scale in the form of shifts from the upper to the lower end of the plots" (Buch 1984, p. 9).

In the Montes de Toledo area in semiarid central Spain, K. GEHRENKEMPER (1981) measured soil erosion over a period of several years with the aid of stakes which were driven into the ground at various points of toposequences with and without vegetal cover. The results of the study showed that when there is a closed cover of vegetation or the soil is highly permeable, slope steepness plays only a subordinate role up to a critical value of about 20°; whereas soil erosion increased abruptly on steeper slopes between 20 and 31°. While surface erosion rates of only 0.1 cm/year on average were measured on medium slopes with gradients between 14.5 and 19.5° and dense ground cover, these were as great as 0.9 cm/year on slopes with a gradient between 20 and 31° and the same vegetation density. Even with an open plant cover average soil removal rates of "only" 0.3-0.5 cm/year were measured on slopes less than 20°. On unbound (bare) soil surfaces, by contrast, it was observed that the rate of soil removal increased steadily with slope steepness. "Thus, around 0.4 cm per year was eroded away at slope steepnesses of between 1 and 5°, while this was 1.0 cm at between 5 and 10°, 1.3 cm at between 10 and 15°, and 1.8 cm between 15 and 20°, as annual average values" (Gehrenkemper 1981, p. 47).

For the sake of completeness, the figures published by the FAO et al. (1979) on the hazard of soil erosion in the mountainous areas of Yemen should be mentioned; these were calculated on the basis of a highly simplified procedure incorporating the USLE and other methods, and represented in map form (FAO et al. 1980a, b). According to the two maps (at a scale of approx. 1:5 million), the current and potential risks of sheet and rill erosion (FAO et al. 1979, p. 46) for the region corresponding to the study area is of an order of between 10 and 50 t/ha/year and between 50 and 200 t/ha/year, respectively.

Even though these values stress the high potential risk in the study area of surface erosion caused by impacting raindrops and runoff, it should nonetheless be pointed out that such approaches - due to the methods employed - can at best only provide rough guidelines.

Within this context, it is appropriate to conclude - drawing upon the "Basel multiple-stage method" - with a discussion of the basic methodological difficulties inherent in any attempt to collect representative data. "The core of this concept is the consideration that it is impossible to satisfactorily capture the complex phenomenon of 'soil erosion' by addressing either isolated points, i.e. very small areas, or very large regions. For this reason, an overlapping or supplementary measurement methodology has been developed; in it the accuracy of measurement declines in connection with the quantification of soil-erosion processes and factors as one moves from a small-scale to a large-scale study dimension" (Schmidt 1983, pp. 54-55).

This quotation once again clearly stresses the statement already made that the soil-erosion rates determined for the study area with the aid of the described semiquantitative field methods cannot, even with a representative number of measurements, represent absolute values. In view of the fact that large-scale collection of "exact" data is also quite impossible because of the open systemic character of geographical regions, the overriding objective when utilizing such methods must be to realistically, i.e. by remaining within a "mean accuracy of measurement", assess the magnitude of soil erosion (G. Richter 1965, p. 231; Leser 1983a, p. 214).

Compared to field or even regional measurements (cf. Fournier 1960), measurement of soil removal at isolated points is highly accurate from the point of view of measurement technology. The often overlooked problem in this connection is that as the test plots become smaller, their ability to reflect the situation of the surrounding landscape ("geoecological reality") drastically declines or is lost altogether. "Until the problem of how to apply data collected at isolated points to entire areas is solved more satisfactorily than is the case today, it will be necessary to doubt the practical value of this excessively precise data. The high degree of accuracy attained by performing measurements at individual points is, incidentally, not at all feasible on a larger scale, and their value is therefore questionable for methodological reasons alone" (Leser 1983a, p. 214).

These problems manifest themselves most visibly in the case of microplots measuring just 1-3 m^2. On such tiny areas it is only possible to consider fragmentary aspects of the functionally highly complex phenomenon of soil erosion (see Chapters II, IV and V). Microplots can only be meaningfully employed for simple preliminary tests, e.g. in order to determine the relative magnitudes of runoff or soil removal by sheet erosion when comparing greatly differing ground cover types (dense grass vs. bare soil). "The accuracy is not great, but quite sufficient for simple comparisons such as the yes-no mulch treatment" (Hudson 1981, p. 284).

In order to shorten the period during which measurements are carried out, rainfall on such microplots is frequently also simulated. This poses additional questions of a fundamental kind, namely on the one hand identification of the (average) raindrop size and size distribution, as well as the impact velocity of the raindrops of natural local rainstorms, and on the other hand how to create comparable conditions with the rainfall simulator used. "Rainfall simulation ... is associated with so many technical difficulties and problems that the phenomenon which purports to be the actual focus of investigation - namely soil erosion - virtually takes a back seat. In view of this, it is necessary to ask whether or not the available arsenal of instruments for studying soil erosion can and ought to be expanded any further - above all when considering the practical applications to which such equipment is put outside the world of scientific research and/or overseas" (Leser 1983a, p. 213).

VI. Soil erosion control

1. Traditional forms of soil and water conservation

a) Terrace farming and irrigation methods

In the Haraz area, farming takes place within the context of an anthropogenically shaped terrace relief. Although such terraces represent the most difficult and labor-intensive type of relief improvement, without their construction cultivation of this rugged mountainous terrain would never have been possible (cf. Slope Steepness Map and Land-Use Map).

The terraces of the Haraz area in former North Yemen are, classified according to type, horizontal bench terraces (cf. Hudson 1981, pp. 148-151; Breburda 1983, pp. 88-95). The steep to nearly vertical front sides of the terraces are secured by solidly built retaining walls that serve to protect against erosion. As a rule, these are made of rock fragments stacked on top of one another dry (without mortar). The crests of these retaining rock walls generally extend between 30 and 50 cm above the fields, and in many cases are additionally reinforced by a wall of earth 30 to 70 cm wide at the lower perimeter of the field. In these raised walls, which occasionally bear vegetation, drainage openings have been made; these can either extend the full height of the crests or be restricted to the region up to 10 cm above the field surface (cf. Photograph 25). Such overflows were observed most frequently on the coffee and qat terraces near Lakamat al Qadi and Lakamat al Mi'qab (cf. Land-Use Map).

The function of these raised, earth-reinforced wall crests girdling the downslope side of the terraces is to capture rainwater falling directly on the field and irrigation water channeled in from above, causing it to infiltrate into the soil. Because in this part of former North Yemen rainfed farming in the strict sense of the term does not guarantee sufficient harvests except in very rainy years, only being feasible in a few other parts of the country, since ancient times local farmers have practiced two simple irrigation methods that cleverly take advantage of the natural slope in order to channel rainwater runoff to terrace fields situated lower down (Kopp 1981, pp. 109-112; 1985, p. 43; Varisco 1982, p. 191; 1983, p. 27). H. KOPP (1981) calls these two methods *sawaqi* supplementary irrigation and *sayl* irrigation.

In the study area, *sawaqi* irrigation was only observed in the rain shadow of Jabal Shibam around the villages of Lakamat al Qadi, Az Zahrah and Lakamat al Mi'qab. In this method, rainwater runoff from agriculturally unused rocky harvesting areas is collected and conveyed to adjacent terrace fields via unlined canals (*saqiyah*, plur. *sawaqi*).

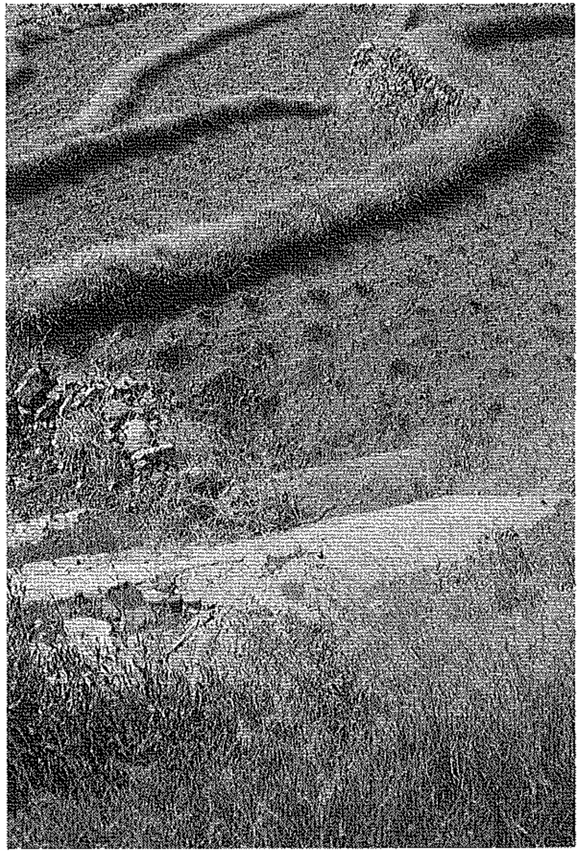
In contrast to this, *sayl* or flood irrigation involves diversion of water flowing in wadi beds. For this purpose, in the study area simple diversion dams are constructed in the wadi beds, extending out at an acute angle and thinning towards the middle - in extreme cases consisting only of branches - in order to prevent excessive quantities of water from destroying the terraces during very heavy rains. This method is also applied for capture and utilization of channeled drainage water from roads (see Photograph 25).

In addition to providing the water needed to irrigate the crops, these methods also have the effect of washing fine-grained to gritty weathered material (together with the mineral nutrients they contain) onto the terrace fields with each precipitation event. Because of the basin irrigation which is practiced, this material is retained and deposited on the terraces. This repeated deposition gradually raises the surface level of the terraces, also causing the fields to expand laterally when sufficient space is available. It also continually replenishes the soil nutrients as they are used up by the plants. It is this mechanism that has made possible "eternal" cultivation of sorghum, the grain traditionally used in Yemen for baking bread (Kopp 1981, p. 111; 1985, p. 44). In terms of their function, therefore, these structures can be classified as conservation bench terraces.

Without exaggerating, the approach to terrace farming practiced in former North Yemen, based on a sophisticated combination of rainwater and gravitational irrigation, can be described as an intact, automatically functioning system of soil and water conservation. With the aid of simple but clever agricultural techniques, soil and water - scarce resources in this subtropical mountainous region - are optimally utilized and conserved, thus simultaneously achieving a maximum of sustained cropping and a minimum of soil erosion.

If this system - which requires constant maintenance - is permitted to cease functioning altogether, immediate and far-reaching repercussions on both the highlands and the lowlands will result. The water retention and soil erosion problems already created by the abandonment of terrace farming have already led to increasingly frequent and severe flooding, posing a serious threat to farming land and infrastructural facilities along the lowland wadis (Kopp 1985, p. 47).

Photo 25: Conservation bench terraces with a simple diversion dam for utilization of runoff from a road (sayl irrigation).
Map coordinates: 63.05/69.25.



H. Vogel (8/23/84)

b) System of underground conduits for drainage of excess water and channeling of irrigation water

Besides drastically reducing or eliminating slope steepness, the construction of terraces has also - and equally importantly - carved slopes up into a large number of small and very small catchments. As a rule, therefore, simple ditches and heaped rock walls are adequate for safe and reliable diversion and distribution of the large quantities of runoff which can be quickly produced by rainfall events.

My surprise was thus understandably great when, during the course of field work along the line of incision east of Al Ayan (cf. maps and Photograph 3), I happened across a network of subterranean canals. My attention was drawn to it by a conspicuously dense cluster of *Ruminex nervosum* plants on a terrace wall. Closer inspection revealed that the bushes covered an opening in the wall which, after the branches had been removed, turned out to be the outlet of an underground conduit running beneath the terrace. The conduit had been completely lined with (roughly worked) rock fragments.

This conduit forms part of an entire system of subterranean canals about 60 cm wide and 90 cm high which leads in a stepped pattern beneath the terraces to the natural line of incision in the slope (see Fig. 20). The first conduit originates at a rock-lined basin 1.5 m deep set into a terrace field at an elevation of approx. 2,640 m above sea level, and into which a natural drainage channel empties that comes from an unterraced steep slope of Jabal Shibam to the southeast (cf. maps). The collection basin is adjacent to a wall and oval in shape, measuring 2.5 m by 3 m. It would appear that the main purpose of this system is to safely drain excess runoff; it possibly also includes a means of redistributing the water to the open cisterns that are situated in a cascading series down the line of incision and which are used for irrigation of the central fields, supplementing the scant yield of natural springs (see Photograph 3). Between these cisterns there are surface and subterranean canals for regulating the supply and distribution of the spring water; one partially exposed miniature underground conduit is just the size of a large rain gutter.

Besides this centrally situated conduit system, other subterranean canals were found on both sides of the valley at an elevation of around 2,600 m, although in both cases the upward and downward connections either no longer existed or could not be found. In the system on the western slope close to Al Ayan, the conduits do not terminate in oval collection basins, but instead in channels 20 cm wide and 25 cm deep that run along the bases of the walls and are most probably used for irrigation purposes.

These underground conduits and the open channels built along both flanks of the line of incision to protect the terraces represent a controlled system of water distribution that has to have been based on exact hydrological knowledge. The lateral diversion channels are up to 1.5 m deep, and are to some extent incised into the volcanic bedrock. The terraces situated along

the line of incision are largely protected from these artificial channels, which have assumed the function of the original natural drainage path, by rock walls. Here and there, small openings have been made in the base of these protective walls; these openings are being used for carefully regulated supplementary *sayl* irrigation of the fields.

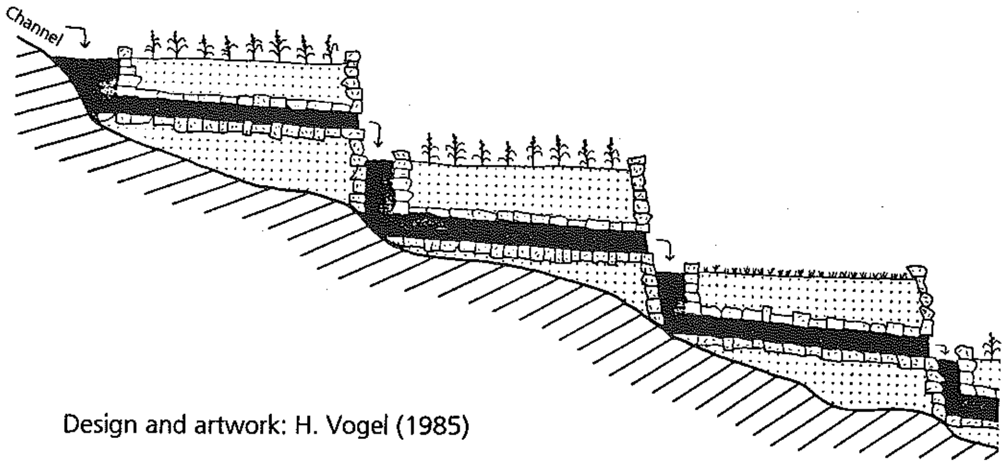
Another underground conduit system exists higher up near the eastern peak of Jabal Shibam. This system originates at a subterranean spring (64.05/64.35), which is contained within an arched chamber cut approx. 5 m deep into the rock and today supplies the village of Jabal with water via a pipe following the line of the slope. A short, no longer functional system of underground conduits leads away from the spring chamber; it apparently used to be part of an irrigation system. For instance, an open waterway 10-30 cm deep and 20 cm wide, now densely overgrown with grass and weeds, runs along the base of a retaining wall further downslope. Delivery channels identical to this one can also be found on the still irrigated terraces east of Al Madammar (cf. maps).

Not far from thise abandoned system is a still fully intact network of underground conduits which is used exclusively for drainage of surface water. It drains into a channel which flows towards Arjaz (a town outside of the mapped area), and also consists of a series of completely lined underground conduits leading downslope from terrace to terrace (63.90/64.15). This drainage system begins with an open but reinforced ditch that disappears at the back of a terrace into a completely inconspicuous hole lined with rock fragments. The system follows the natural line of depression in the slope and emerges into the open portion of the channel, with the last terrace also being crossed by an open canal. These underground conduits are comparable in size with those on the opposite slope east of Al Ayan, and the terraces occupying the line of incision are also laterally protected by intact collection channels formed by rock walls about 1 m high on the side facing the terraces. The paved conduit floors have an inclination of between roughly 10 and 15% from the horizontal.

Other underground conduit systems were also located during the course of my field investigations: east of Al Mudammar, southeast of Al Hudud and northwest of Al Hutayb, as well as outside of the study area proper southwest of Al Hutayb (see Photograph 26) and northwest of Al 'Ayn (Vogel 1988).

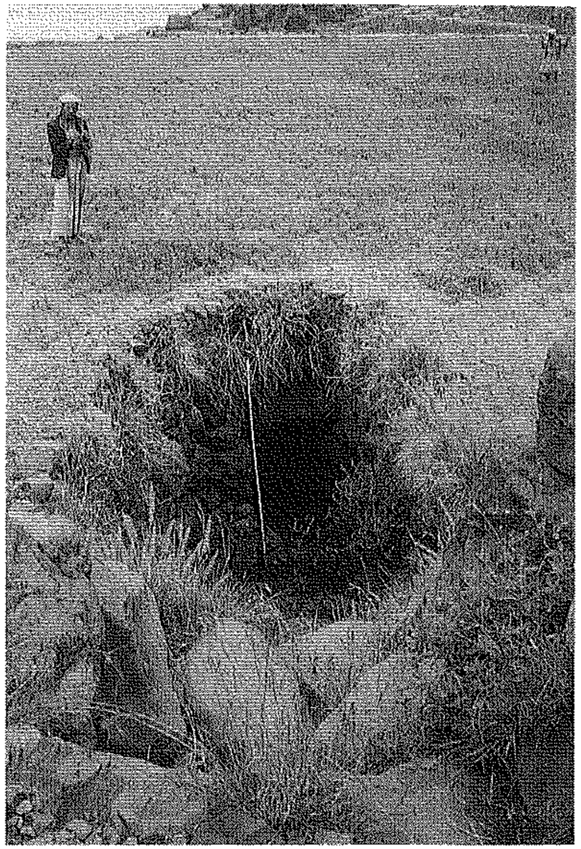
All of these technically sophisticated subterranean systems are supplemented by open canals, although the underground conduits are their most characteristic feature. For the most part the conduits are approx. 60 cm wide and 80 cm high, ranging from about 25 x 40 cm to a maximum of 80 x 170 cm. The size and design of the conduit inlets at the back of terraces (at the foot of the retaining walls) also vary greatly. "Stone pipes" built up on the terrace walls, simple openings, oval collection basins and shaft-like inlets set into the terraces occur (see Photograph 26). The conduit sides and floors are effectively protected from erosion by sturdily engineered linings around their entire circumference, with large, worked flagstones and ashlar overhead. Of great practical significance is also the fact that, because the conduits are situated about 1 to 2 m below the surface, farming activities on the terraces are not interfered with in any way.

Fig. 20: Underground condiut system for surface water drainage and delivery of irrigation water (schematic representation).



Design and artwork: H. Vogel (1985)

Photo 26: Inlet of an underground conduit at the back of a terrace.



Depth of basin: 2.3 m
Height of underground conduit: 1.7 m
Width of underground conduit: 0.8 m
Length of measuring rod: 2 m
Map coordinates: 65.05/62.85

H. Vogel (9/20/84)

On the basis of what was established in the course of the field investigations, which unfortunately could not be conducted as thoroughly as the study topic deserved due to the limited time available and the language barrier, the functions of these intriguing underground conduit systems can be summarized as follows:

1. Safe removal of excess surface water from terrace complexes built across small valleys and minor drainage channels (partial assumption of the drainage function of the former natural channel).

2. Distribution and utilization of spring water and/or collected rainwater for irrigation.

Two apparently similar underground conduit systems are briefly mentioned by D. VARISCO (1982) in his dissertation on irrigated terrace farming in Al Ahjur, a valley in the upper part of the watershed drained by the Wadi Surdud (see Fig. 7); there, they serve solely to utilize and channel spring water. What he writes about the age of one of these conduits is very interesting and of relevance to the conduit systems found within the study area: "Informants had little idea when the underground conduit was constructed; most simply said it was in the days before Islam in the days of the original inhabitants (waqt al-awwalin)". (Varisco 1982, p. 302).

This vague reference to the pre-Islamic era, and Varisco's further statement that there is no visible way to enter or clean the conduit, are reminiscent of the systems of underground conduits and tunnels on terraces in Palestine studied by Z. RON (1985) - the first of its kind to be described in detail in the literature. These systems are still in use today for distributing spring water. "The majority of these systems are hidden, with only small dark openings through which the water can flow to the reservoirs, or with a few shafts which are also visible" (Ron 1985, p. 151).

According to archaeological findings in Palestine, most of the tunnels used to capture spring water and convey it for irrigation of terraces were constructed during ancient Roman times (Ron 1985, pp. 167-169; cf. Biswas 1985, pp. 210-213); in other words, at a time when the Nabateans - who controlled the frankincense trade between South Arabia (Arabia Felix) and the Mediterranean - were practicing terrace farming similar to that in former North Yemen, making use of identical rainwater harvesting techniques, in the Negev Desert (Evenari et al. 1971, pp. 18-21 and 95-119).

Some of the systems built in Palestine are even believed to be much older than this, dating back to the early Iron Age (1,200 to 900 B.C.) (Ron 1985, p. 167; cf. Biswas 1985, pp. 207-208). This corresponds to the time when, according to the Old Testament of the Bible, the legendary Queen of Saba (Sheba) visited King Solomon of Israel (Wohlfahrt 1980, p. 623).

In view of the historical links between these two regions, it is quite possible that the terrace and underground conduit systems in former North Yemen also date back to Roman/Nabatean times, or are even of early Sabaean origin.

2. Prospects and possibilities for soil conservation

Soil-erosion processes are currently so intensive in the study area that the soils of untended terrace complexes are relentlessly being worn down to the underlying bedrock. On maintained terrace complexes soil loss is held in check by the practiced impoundment method of terracing, with fresh soil continually being washed in ($T \; W + F$, see below), but the abandoned terraces are characterized by a lack of equilibrium:

$$T > W + F$$

where:

T = soil loss
W = formation of new soil by *in situ* weathering of bedrock
F = influx of imported soil
(cf. Chapter II, section 5; Heine 1978, p. 391)

The medium-term implications of this dynamic imbalance are already serious in the study area, a fact which is readily apparent from the degree of damage to terraces that have been in a state of disuse for lengthy periods of time (2-4 decades) with progressive leveling of slopes, even if one is not familiar with the exact rates of soil removal and formation[8].

If left unchecked, this process of destruction - triggered by changes in land use - will inflict irreversible harm on the landscape and its agricultural potential. It must be halted in the interest of maintaining future possibilities to further the overall development of former vNorth Yemen. This necessity was very aptly expressed in a preliminary study for the Haraz project of the GTZ:

"The terrace farming systems built up over the course of millennia are threatening to break down, since the agricultural labor force is migrating to the cities and to other countries. This trend, provoked by the oil boom in the neighboring countries [of the Arabian peninsula], may very well only be temporary, but the erosion of agricultural soil that is meanwhile taking place

8) The estimated rate of new soil formation in the nearby highlands of Ethiopia, which are also comprised of a Trap Series of Tertiary origin, ranges from 2 to 22 t/ha/year depending on climatic conditions, which vary zonally and at different elevations (Hunri 1984, (4) pp. 45-46).

is causing permanent damage. In view of the scarcity of raw materials in Yemen, agriculture will continue to form the basis for all economic development" (Alkämper et al. 1979, p. 10).

The development prospects expressed in this statement imply that former North Yemen will ultimately have no choice but to turn its attention back to a sector of the economy which, however, possesses only limited potential for growth, as is being demonstrated all too clearly by the unabated rural exodus. If agriculture is to become the cornerstone of future national development in spite of this seemingly unresolvable contradiction, then it is essential to identify the factors currently limiting agricultural production and to find ways of overcoming them. Yet even if the realization becomes widespread that traditional terrace farming represents a necessary and perfect adaptation to the existing relief and that at best only limited aspects of it can be further improved by applying modern agricultural techniques, then in the study area at least, technical and/or biological measures to control erosion will not be enough to preserve the natural resources which soil and water represent. The enormous diversity of geoecological factors influencing erosion and the complex interactions among them, as well as the prevailing general socioeconomic conditions, call for comprehensive regional planning efforts which must attach priority to securing the continued existence of farming operations by improving the overall economic situation. In order to achieve this, the declared aims of the project must be extended. They are currently defined as follows:

- "Elaboration of erosion control measures for the Haraz region that will be both practicable and sustainable.
- Reduction of the continuing erosion of unused terraces by means of erosion control measures, in particular afforestation and agroforestry measures, to be implemented by the rural population under the guidance of the project staff.
- Establishment of private and communal tree plantations as a long-term contribution to meeting regional needs for fuelwood and timber." (Baum and van Tuyll 1985, p. 20)

It is essential to extend these objectives to include economic stabilization of the man-made agricultural ecosystem in the Haraz mountains. Such a concept could only be put into practice within the framework of a regional development program, the objectives and activities of which are aimed first and foremost at quickly improving the income situation of the farmers by increasing agricultural productivity and the profitability of farming. That

means that an agricultural extension service is needed in addition to silvicultural advice and assistance. Great importance must be attached to cropping (e.g. improved crop rotation schemes, high-yield fodder crops) and land-use systems (e.g. mixed cropping, pasture farming combined with livestock keeping in stables), as well as to ways of enhancing soil fertility (e.g. mulching and application of manure). Only measures of this kind are capable of sufficiently raising the productivity and profitability of farming operations without endangering the basic principle of working for long-term sustainability of yields (instead of short-term maximization of yields) and of resources (instead of short-term exploitation), which is the supporting pillar of this complex agro-ecosystem (cf. Egger 1982a; 1982b).

Since conflicting aims are inevitable when seeking to implement measures of this kind - e.g. mulching with crop residues traditionally used as fuel and fodder - the most urgent need is probably for the government to hold programs (in schools and the media) to educate the population, creating awareness of the problems while at the same time increasing willingness to contribute to solving them (cf. Unkel and Endangan 1976, p. 414; D. Moore 1982, p. 40). Within this context, the importance of the project's own trial and demonstration plots cannot be overly stressed. Studies in the United States have clearly demonstrated the enormous importance of subjective perception. There, willingness of farmers to experiment with new methods proved, in most cases, to be ascribable to a positive "neighborhood effect"; in other words, it was motivated by the successful application of new cultivation methods and/or agricultural techniques on neighboring farms or state-operated model farms (Johansen 1971).

In the final analysis, it is only as an integral component of a comprehensive bundle of measures of this type that effective long-term measures to control soil erosion can be implemented. Since such measures must be not just effective, but in view of the high wage level also simple and cheap, in most cases technical erosion control measures (e.g. gabion walls, etc.) cannot be considered. According to a farmer I interviewed, it had cost around YR 1,000 - in the summer of 1984 roughly equivalent to DM 500 - to rebuild a collapsed section of wall about 10 m long and 3 m high with recruited laborers.

For immediate soil conservation, therefore, the Haraz project must continue to concentrate on binding the soil by planting of vegetation and successfully demonstrate the efficacy of this approach, although it is essential for these biological erosion control measures to include planting of shrubs and grass in addition to afforestation (cf. Rühl 1984). In particular, the following measures would be necessary and/or conceivable:

1. Planting of indigenous trees and shrubs in catchment areas acutely threatened by erosion (abandoned terrace complexes on the upper and central sections of slopes) to improve water retention and the supply of wood.

   Based on observations made in the study area, the planted areas would have to be visibly designated as being off-limits and accepted as such, at least during a lengthy initial phase, in order to curb uncontrolled grazing and wood collection (excessive lopping).

   Such highly directed land-use control calls for political initiative and readiness to cooperate on the part of the local population, as well as sufficiently well-developed public institutions (cf. Kaiser 1980, p. 601).

2. Planting of grass on already strongly degraded slopes, including the possible use of "biological erosion control mats". These are net-like protective mats consisting of plant material and natural fibers, and (drought-resistant) grass and legume mixtures can be combined with them as required (cf. Hudson 1981, pp. 233 and 256-257).

3. Stabilization of the raised earth mounds that reinforce terrace retaining walls, by planting fast-growing, undemanding fodder grasses. This would permit the walls to additionally serve as erosion control strips and sources of fodder, a measure some farmers have already implemented on their own (cf. Photograph 25).

In addition to ecological and economic stabilization and support measures, improved utilization of water from existing natural springs would also be conceivable in the study area; preliminary studies on this aspect have already been conducted within the scope of the Haraz project. Due to the very unfavorable hydrological conditions in the area, however (Trap Series, rugged relief, torrential rains), narrow limits are imposed on how far irrigation with spring water can be expanded. It is doubtful that enough water could be obtained in this way to support the fruit orchards which have been considered for the project. The springs, which are found along fault lines and strata boundaries, usually have a low discharge rate. This has two reasons. One is that the lithological structures are typically too highly differentiated to permit large reservoirs of groundwater to form; the other is that as terrace farming has gradually declined, an increasing proportion of the water that falls during the summer rains runs off instead of percolating downward through the soil profiles. Moreover, because of the observed tilt of the rock beds there is a clear tendency for a large part of the groundwater to drain off towards the west. As evidence of this, the two deep boreholes that supply

both Manakhah and the project's tree nursery with water had to be drilled close to the latter in the western part of the study area.

These facts stress once again that traditional terrace farming, combined with rainwater harvesting, continues to possess unrestricted validity; nonetheless, in the light of changing global and domestic economic conditions it must be further improved with an aim to increasing yields and profitability.

VII. Summary

The agro-ecosystem created by human beings in the Haraz mountains made it possible to transform this originally inhospitable landscape into a prosperous area - or, at least, one that permitted its inhabitants to eke out a living. This impressive cultural achievement was based on both optimum utilization of and perfect adaptation to existing natural resources. Uncountable numbers of bench terraces were carved out of the steep and rugged mountain slopes, thus converting the natural trap relief into a marvellous terrace landscape. Since rainfall is both limited and erratic in nature, highly effective methods of rainwater harvesting were also developed for supplementary gravity irrigation on the agricultural terraces. The most striking engineering feature of this system of impoundment-type bench terraces are underground conduits constructed either to convey spring and/or collected rainwater or to remove excess flood water.

With increasing abandonment of this artificially shaped ecosystem due to outmigration of rural labor, the dynamic integrity of the geomorphological processes previously harnessed in different forms of rainwater harvesting is being lastingly disturbed. In the study area, this is manifesting itself in the form of accelerated water-erosion processes, causing the rapid destruction of the terrace complexes that had taken so many centuries to build. The alarming rate of soil loss of between 100 and 200 t/ha/yr or even up to approx. 400 t/ha/yr with additional gully erosion is a direct result of a combination of adverse natural and human factors. These can be summarized as follows:

(1) Moderate to high rainfall erosivity

(2) Moderate to high soil erodibility

(3) High to very high relief energy

(4) Poor land-use practices on abandoned terraced slopes

(5) Moderate to high susceptibility of the terrace-wallrocks to weathering

Therefore, as long as former North Yemen continues to be essentially an agrarian country, lacking any significant capacity for industrial production, and the agricultural terraces comprise a fundamental resource for successful growing of food crops, highest priority must be attached to preventing destruction of the fertile terrace soils. The ultimate relationship between agricultural terraces and human beings makes it clear that soil conservation in the Haraz mountains - because of the high risk of water erosion - can only take the form of preventive stabilization and protection measures. After-the-fact steps to repair damage already done, requiring ever-greater inputs in terms of labor and time, are not the answer. Having recognized this basic fact, the Ministry of Agriculture of the Republic of Yemen is conducting, in cooperation with the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, the "Haraz-Pilot-Project for Erosion Control and Afforestation", with the primary objective of stabilizing the existing terrace structures in order to safeguard the soil and water resources as the basis for stable food production.

Bibliography

Al-Hubaishi, A. and Müller-Hohenstein, K. [1984]. *An introduction to the vegetation of Yemen. Ecological basis, floristic composition, human influence.* GTZ, Eschborn, 209 p.

Alkämper, J., Haffner, W., Matter, H.E., Weise, O.R. and Weiter, M. [1979]. Erosion Control and Afforestation in Haraz, Yemen Arab Republic. Tropeninstitut Giessen (Giessener Beiträge zur Entwicklungsforschung, Reihe II, Bd. 2), Giessen and Sanaa, 100 p.

Andre, J.E. and Anderson, H.W. [1961]. Variation of soil erodibility with geology, geographic zone, elevation, and vegetation type in northern California wildlands. *Journal of Geophysical Research* 66 (10), 3351-3358.

Arbeitsgruppe Bodenkunde [1982]. Bodenkundliche Kartieranleitung. (By the "Arbeitsgruppe Bodenkunde der geologischen Landesämter und der Bundesanstalt für Geowissenschaften und Rohstoffe in der Bundesrepublik Deutschland"). Hanover, 3rd ed., 331 p.

Arnoldus, H.M.J. [1977]. Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. *Soils Bulletin* 34. FAO, Rome, pp. 39-48.

— [1980]. An approximation of the rainfall factor in the Universal Soil Loss Equation. In: *Assessment of Erosion* (ed. by DeBoodt, M. and Gabriels, D.), John Wiley and Sons, pp. 127-132.

Asmaev, L.R. [1968]. Data on the soils of the southwestern part of the Arabian Peninsula. In: *Geogr. and classification of the soils of Asia* (ed. by Kovda, V.A. and Labova, E.V.), Israel Program f. Scientific Translation, Jerusalem, pp. 249-57.

Aust, H. [1985]. *Hydrogeologische Beratung beim Bau eines Brunnens für das GTZ-Projekt "Haraz" in Mawsanah, Yemen A.R.* Bundesanstalt für Geowissenschaften und Rohstoffe, Hanover, 27 p.

Bargon, E. [1962]. Bodenerosion. Ihr Auftreten, ihre Erkennung und Darstellung. *Geol. Jb.* 79, 479-492.

Baum, U. and van Tuyll, C. [1985]. Erosionsschutz und Aufforstung in der Region Haraz, Arabische Republik Yemen. *Jemen-Report, Mitt. d. Dt.-Jem. Ges.* 16 (2), 20-21.

Bayer, H.-J. [1985]. Das Rote Meer. Ein Schlüsselgebiet zur Erforschung großer Gräben. *Geowissenschaften in unserer Zeit* 3 (5) 160-168.

Bennett, H.H. [1939]. *Soil Conservation.* McGraw-Hill, New York, reprinted 1970, 993 p.

Bergsma, E. [1985]. Development of Soil Erodibility Evaluation by Simple Tests. Enschede, 20 p.

Besler, H. [1981]. Der Ostjet als Ursache verstärkter Aridität in der Sahara. *Geogr. Rdsch.* 33 (4) 163-166.

Betzler, A.K. [1987]. *Sozialer Umbruch und Kulturlandschaftswandel in Südarabien.*

Biswas, A. L. [1985]. Ancient Urban Water Supply Systems. *Geojournal* 11 (3), 207-213.

Bouyoucos, G.J. [1935]. The clay ratio as a criterion of susceptibility of soils to erosion. *Journal of the American Society of Agronomy* 27, 738-741.

Breburda, J. [1983]. *Bodenerosion und Bodenerhaltung.* Frankfurt, 128 p.

Bremer, H. [1979]. Relief und Böden in den Tropen. *Z. Geomorph. N.F.* 33, 25-37.

Briggs, D.J. and France, J. [1982]. Mapping Soil Erosion by Rainfall for Regional Environmental Planning. *Journal of Environmental Management* 14 (3), 219-227.

Brown, L.R. [1978]. World population growth, soil erosion, and food security. *Science* 214 (4524), 995-1002.

Bryan, R.B. [1977]. Assessment of soil erodibility: new approaches and directions. In: *Erosion: Research Techniques, Erodibility and Delivery* (ed. by Toy, T.J.). Norwich, England, pp. 57-72.

Buch, M. W. [1984]. Bodenerosion in den Westlichen Usambara-Bergen Tansanias. Semiquantitative Erfassung von Bodenerosion und Untersuchungen zur Ökopedologischen Veränderungen an Hängen unterschiedlicher Landnutzung. In: *Entwicklung + Ländlicher Raum,* Vol. 3. DSE/ZEL, GTZ and DLG. pp. 8-11.

Capelle, A. and Lüders, R. [1978]. Möglichkeiten zur Erfassung und Beurteilung der Bodenerosion durch Wasser und durch Wind bei der bodenkundlichen Landesaufnahme. *Mitt. Dt. Bodenkundl. Ges.* 29, 885-892.

Chiesa, S., Volpe la, L., Lirer, L. and Orsi, G. [1983]. Geological and structural outline of Yemen Plateau: Yemen Arab Republic. *N. Jb. Geol. Paläont. Mh.* 11, 641-656.

Civetta, L., Volpe la, L. and Lirer, L. [1978]. K-Ar ages of the Yemen Plateau. *Journal of Volcanology and Geothermal Research* 4, 307-314.

Cooke, R.U. and Doornkamp, J.C. [1974]. *Geomorphology in Environmental Management. An Introduction.* Oxford, 413 p.

Curry, R. [1967]. On use of vegetation to date land surfaces. *Revue de Géomorphologie Dynamique* 4 (17) 168-169.

de Boodt, M. and Gabriels, D. (eds.) [1980]. *Assessment of Erosion.* John Wiley and Sons, 563 p.

de Ploey, J. [1974]. Mechanical properties of hillslopes and their relation to gullying in Central semi-arid Tunisia. *Geomorph. N.F.* 21, 177-190.

Demek, J. [1969]. Beschleunigung der geomorphologischen Prozesse durch die Wirkung des Menschen. *Geol. Rdsch.* 58, 111-121.

Derbyshire, E., Gregory, K.J. and Hails, J.R. [1979]. *Geomorphical processes.* London, 312 p.

Dietrich, R.V. and Skinner, B.J. [1984]. *Die Gesteine und ihre Mineralien. Ein Einführungs- und Bestimmungsbuch.* Thun, 357 p.

Diez, T. [1982]. Praxisnahe Lösungsmöglichkeiten für die Einschränkung der Bodenerosion. In: *Ursachen des Bodenabtrages und Gegenmassnahmen,* Vol. 174. DLG, pp. 17-36.

Dunne, T. [1977]. Studying patterns of soil erosion in Kenya. *Soils Bulletin* 33. FAO, Rome, pp. 109-121.

Dunne, T., Dietrich, W.E. and Brunengo, M.J. [1978]. Recent and past erosion rates in semi-arid Kenya. *Z. Geomorph. N.F.* 29, 130-140.

Eckholm, E. and Brown, L.R. [1977]. Spreading Deserts - The Hand of Man. *Worldwatch Paper* 13, 40. Worldwatch Institute, Washington D.C.

Eger, H. [1984]. Rainwater harvesting in the Yemeni highlands. The effect of rainwater harvesting on soil moisture status and its implications for arable farming, a case study of the Amran region. In: *Entwicklungsprozesse in der Arabischen Republik Jemen* (ed. by Kopp, H. and Schweizer, G.), *Jemen-Studien,* Vol. 1, pp. 147-169.

Egger, K. [1982a]. Methoden und Möglichkeiten des "Ecofarming" in Bergländern Ostafrikas. In: *Giessener Beiträge zur Entwicklungsforschung*, Reihe I, Vol. 8 (Tropische Gebirge: Ökologie und Agrarwirtschaft), pp. 69-96.

— [1982b]. Ökologische Alternativen im tropischen Landbau - Notwendingkeit, Konzeption, Realisierung. *Freiburger Geogr. Hefte* 18, 119-132.

Evans, R. [1980]. Mechanics of water erosion and their spatial and temporal controls: an empirical viewpoint. In: *Soil Erosion* (ed. by Kirkby, M.J. and Morgan, R.P.C.). John Wiley and Sons, pp. 109-128.

Evenari, M., Shanan, L and Tadmor, N. [1971]. *The Negev, the challenge of a desert.* Harvard University Press, Cambridge, Mass. 345 p.

FAO [1976]. A framework for land evaluation. *Soils Bulletin* 32. Rome, 72 p.

— [1977a]. Soil conservation and management in developing countries. *Soils Bulletin* **33**. Rome, 212 p.

— [1977b]. Assessing soil degradation. *Soils Bulletin* 34. Rome, 83 p.

FAO, UNEP [1978]. *Report on the FAO/UNEP Expert Consultation on Methodology for Assessing Soil Degradation.* Rome, 66 p.

FAO, UNEP and UNESCO [1979]. *A provisional methodology for soil degradation assessment.* Rome, 84 p.

Fassbender, H.W. [1982]. *Bericht über Gutachtertätigkeit im Rahmen des Projektes "Erosionsschutz und Aufforstung in der Region Haraz, Arabische Republik Yemen".* GTZ, Eschborn.

— [1983]. Bericht über Gutachtertätigkeit im Rahmen des Projektes "Erosionsschutz und Aufforstung in der Region Haraz, Arabische Republik Yemen". GTZ, Eschborn.

Flohn, H. [1963]. Klimaschwankungen und grossräumige Klimabeeinflussung. *Bonner Metereologische Abhandlungen*, Vol. 2.

— [1965]. Klimaprobleme am Roten Meer. *Erdkunde* 19, 179-191.

Fournier, F. [1960]. *Climat érosion. La relation entre l'érosion du sol par l'eau et les précipitations atmorsphériques.* Presses Universitaires de France, Paris, 201 p.

Ganssen, R. [1965]. *Grundsätze der Bodenbildung.* Mannheim, Vienna, Zurich (B.I. Hochschultaschenbücher, Vol. 327),135 p.

Gehrenkemper, K. [1981]. Rezenter Hangabtrag und geoökologische Faktoren in den Montes des Toledo Zentralspanien. Berlin, *Berliner Geogr. Abh.* 34, 78.

Gerholm, T. [1977]. *Market, Mosque and Mafraj. Social Inequality in a Yemeni Town.* Department of Social Anthropology, Stockholm, 217 p.

Gerold, F. [1983]. Vegetationsdepradation und fluviatile Bodenerosion in Südbolivien. *Z. Geomorph. N.F.* 48, 1-16.

Geukens, F. [1966]. *Geology of the Arabian Peninsula. Yemen.* Washington (Geological Survey Professional Paper 560-B), pp. B1-B23.

Glymph, L.M. [1957]. Importance of Sheet Erosion as a Source of Sediment. *Transactions, American Geophysical Union* 38 (6), 903-907.

Grosse, B. [1971]. Die beschleunigte Bodenabtragung als ein anthropogen beeinflusster Teilprozess der Erosion und Denudation. *Z. Deutsch. Geol. Ges.* 122, 11-21.

Hadley, R.F. [1977]. Some concepts of erosional processes and sediment yield in a semiarid environment. In: *Erosion: Research Techniques, Erodibility and Delivery* (ed. by Toy, T.J.). Norwich, England, pp. 73-82.

Haffner, W. [1982]. Die Gebirge und Hochländer der Tropen und Subtropen. In: *Giessener Beiträge zur Entwicklungsforschung*, Reihe I, Vol. 8 (Tropische Gebirge: Ökologie und Agrarwirtschaft), pp. 1-33.

Hallsworth, E.G. [1988]. Traditional methods of soil conservation. In: *Proceedings of the IV International Conference on Soil Conservation, Maracay, Venezuela, November 1985.*

Hard, G. [1963]. Das Bodenprofil als landschaftsgeschichtliches Archiv. *Erdkunde* 17, 232-235.

Hartge, K.H. [1971]. *Die physikalische Untersuchung von Böden. Eine Labor- und Praktikumsanweisung.* Stuttgart, 168 p.

— [1978]. *Einführung in die Bodenphysik.* Stuttgart, 364 p.

Heede, B.H. [1974]. Stages of development of gullies in Western United States of America. *Z. Geomorph. N.F.* 18 (3), 260-271.

Heine, K. [1978]. Mensch und geomorphodynamische Prozesse in Raum und Zeit im randtropischen Hochbecken von Puebla, Tlaxcala, Mexico. In: *Verhandl. 41. Geographentag Mainz 1977.* Wiesbaden, pp. 390-406.

Hempel, L. [1951]. Über Kartierungsmethoden von Bodenerosion durch Wasser. *Neues Archiv für Niedersachsen* 26, 590-598.

Hjulström, F. [1935]. *Studies of the morphological activity of rivers as illustrated by the River Fyris.* Uppsala, 306 p.

Holy, M. [1980]. *Erosion and Environment* (Environmental Sciences and Applications, Vol. 9). Pergamon Press, reprinted 1982, 225 p.

Hudson, N.W. [1977]. Research needs for soil conservation in developing countries. *Soils Bulletin* 33. FAO, Rome, pp. 169-185.

— [1980]. Erosion prediction with insufficient data. In: *Assessment of erosion* (ed. by De Boodt, M. and Gabriels, D.). John Wiley and Sons, pp. 279-284.

— [1981]. *Soil Conservation.* Cornell University Press, Ithaca, New York, 2nd ed., 324 p.

Hurni, H. [1975]. Bodenerosion in Semien-Äthiopien. *Geographica Helvetica* 30 (4), 157-168.

— [1979]. Semien-Äthiopien: Methoden zur Erfassung der Bodenerosion. *Geomethodica* 4, 151-182.

— [1984]. *Soil Conservation Research Project (Addis Abeba/Ethiopia).* Volumes 1-4, Compilation of Phase I Progress Reports (Years 1981, 1982, and 1983). University of Berne, Switzerland in association with The United Nations University, Tokyo, 241 p.

— [1988]. Erosion - Productivity - Conservation Systems in Ethiopia. In: *Proceedings of the IV International Conference on Soil Conservation, Maracay, Venezuela, November 1985.*

Huzayyin, S.A. [1945]. Notes on climatic conditions in south-west Arabia. *Quarterly Journal of the Royal Meteorological Society* 71, 129-140.

Imeson, A.C. and Vis, M. [1982]. Factors influencing the erodibility of soils in natural and semi-natural ecosystems at different altitudes in the Central Cordillera of Colombia. *Z. Geomorph. N.F.* 44, 91-105.

Jahn, R., Stahr, K. and Gudmundsson, T. [1983]. Bodenentwicklung aus tertiären bis holozänen Vulkaniten im semiariden Klima Lanzarotes (Kanarische Inseln). *Z. Geomorph. N.F.* 48, 117-129.

Janetschek, H. (ed.) [1982]. *Ökologische Feldmethoden. - Hinweise zur Analyse von Landökosystemen.* Stuttgart, 175 p.

Jansson, M.B. [1982]. *Land erosion by water in different climates.* Stockholm, (UNGI Rapport No. 57, Uppsala University, Dept. of Physical Geography), 151 p.

Jätzold, R., Negendank, J., Richter, G. and Schroeder-Lanz, H. [1984]. *Physische Geographie und Nachbarwissenschaften.* Munich, 9th ed, 424 p.

Johansen, H.E. [1971]. Diffusion of strip cropping in Southwestern Wisconsin. *Annals of the Association of American Geographers* 61, 671-683.

Jung, L and Brechtel, R. [1980]. Messungen von Oberflächenabfluss und Bodenabtrag auf verschiedenen Böden der Bundesrepublik Deutschland. Hamburg, Berlin (Schriftenreihe des Deutschen Verbandes für Wasserwirtschaft und Kulturbau, Vol. 48), 139 p.

Jung, L. [1965]. Böden der Trockengebiete. In: *Weidewirtschaft in Trockengebieten* (ed. by Knapp, R.). Giessener Beiträge zur Entwicklungsforschung, Reihe I, Vol. 1, pp. 51-59.

Kaiser, R. (ed.) [1980]. *Global 2000. Der Bericht an den Präsidenten.* Verlag Zweitausendeins, Frankfurt, 1438 p.

Kaufmann, R. [1982]. Erosionskontrolle und Sicherung von kleinbäuerlichen Betrieben in Hochgebirgsregionen der Ostkordilliere Kolumbiens. In: *Giessener Beiträge zur Entwicklungsforschung*, Reihe I, Vol. 8, (Tropische Gebirge: Ökologie und Agrarwirtschaft), pp. 207-216.

Keech, M.A. [1968]. Soil erosion survey techniques. *Proceedings and Transactions of the Rhodesia Scientific Association*, 53, 13-16.

Kent Mitchell, J. and Bubenzer, G.D. [1980]. Soil loss estimation. *Soil Erosion* (ed. by Kirkby, M.J. and Morgan, R.P.C.). John Wiley and Sons, pp. 17-62.

Kienholz, H. Hafner, H. and Schneider, G. [1980]. Zur Beurteilung von Naturgefahren und der Hanglabilität - Ein Beispiel aus dem nepalischen Hügelland. In: *Giessener Beiträge zur Entwicklungsforschung*, Reihe I, Vol.8 (Tropische Gebirge: Ökologie und Agrarwirtschft), pp. 35-55.

King, J.W. II, Forbes , T.R. and Abu Ghanem, A.L. [1983]. *Soil Survey of the Yemen Arab Republic. Final Report for the Near East Bureau, U.S. Agency for International Development, Department of State, Washington D.C.* Cornell University, Department of Agronomy, 593 p.

Kirkby, M.J. [1969]. Infiltration, Throughflow, and Overland Flow. *Water, Earth, and Man* (ed. by Chorley, R.J.). London, pp. 215-227.

—— [1980]. The problem. In: *Soil erosion* (ed. by Kirkby, M.J. and Morgan, R.P.C.). John Wiley and Sons, pp. 1-16.

Kittler, G.A. [1955]. Merkmale, Verbreitung und Ausmass der schleichenden Bodenerosion. *Peterm. Geogr. Mitt.* 99, 269-273.

—— [1963]. Was ist Haken, was ist Pflug? *Erdkunde* 17, 235-237.

Klaer, W. and Krieter, M. [1982]. Über die Bedeutung des Humus für Bodenerosion und Hangstabilität in den feuchten und wechselfeuchten Tropen von Papua Neuguinea. *Erdkunde* (1/4), 153-160.

Kollmannsperger, F. [1979]. *Erosion - eine globale Gefahr.* GTZ, Eschborn.

Kopp, H. [1975]. Die räumliche Differenzierung der Agrarlandschaft in der Arabischen Republik Jemen (Nordjemen). *Erdkunde* 29, 59-68.

—— [1977]. *Al-Qasim. Wirtschafts- und sozialgeographische Strukturen und Entwicklungsprozesse in einem Dorf des jemenitischen Hochlandes.* (Beihefte zum Tübinger Atlas des Vorderen Orients, Reihe B, Vol. 31). Wiesbaden, 47 p.

—— [1978]. Die Arabische Republik Jemen. Entwicklungsprobleme und Entwicklungsmöglichkeiten eines rohstoffarmen Landes der Vierten Welt. *Geogr. Rdsch.* 30 (3), 88-93.

—— [1981]. *Agrargeographie der Arabischen Republik Jemen.* Erlangen (Erlanger Geographische Arbeiten. Sonderband 11), 293 p.

—— [1985]. Land Usage and its Implications for Yemeni Agriculture. In: *Economy, Society and Culture in Contemporary Yemen* (ed. by Pridham, B.R.). Centre for Arab Golf Studies, University of Exeter, pp. 41-50.

Krimmer, H. [1982]. Flurbereinigung in erosionsanfälligen Gebieten. In: *Bodenerosion: Ursachen des Bodenabtrages und Gegenmassnahmen.* (Arbeiten des DLG, Vol. 174), pp. 57-68.

Kugler, H. [1969]. Die Entwicklung der geomorphologischen Karten des Atlas DDR als Beitrag zur Strukturforschung und Ressourcenerkundung in der Deutschen Demokratischen Republik. *Geographische Berichte* 25/53, 242-251.

—— [1976]. Geomorphologische Erkundung und agrarische Landnutzung. *Geographische Berichte* 80 (3), 190-204.

—— [1977]. Die geomorphologische Reliefcharakteristik im Atlas DDR. *Geographische Berichte* 84 (3), 187-197.

—— [1985]. Allgemeine Geomorphologie. In: *Lehrbuch der Physischen Geographie* (ed. by Hendl, M., Bramer, H. and Harke, H.). Thun, Frankfurt, pp. 77-157.

Kunze, H., Niemann, J., Roeschmann, G. and Schwerdtfeger, G. [1981]. *Bodenkunde.* Stuttgart, 2nd ed., 407 p.

Kuron, H. and Jung, L. [1961]. Untersuchungen über Bodenerosion und Bodenerhaltung im Mittelgebirge als Grundlage für Planungen bei Flurbereinigungsverfahren. *Ztschr. f. Kulturtechnik* 2, 129-145.

Lal, R., Lawson, T.L. and Anastase, A.H. [1980]. Erosivity of tropical rains. In: *Assessment of Erosion* (ed. by De Boodt, M. and Gabriels, D.). John Wiley and Sons, pp. 143-151.

Lauer, W. [1951]. Hygrische Klimate und Vegetationszonen der Tropen mit besonderer Berücksichtigung Ostafrikas. *Erdkunde* 5, 284-293.

—— [1975]. *Vom Wesen der Tropen: klimaökologische Studie zum Inhalt und zur Abgrenzung eines irdischen Landschaftsgürtels.* Mainz, 49 p.

Lauer, W. and Frankenberg, P. [1977]. Zum Problem der Tropengrenze in der Sahara. *Erdkunde* 31 (1), 1-15.

—— [1979]. Der Jahresgang der Trockengrenze in Afrika. *Erdkunde* 33 (4), 249-257.

—— [1981]. Untersuchungen zur Humidität und Aridität von Afrika. Das Konzept einer potentiellen Landschaftsverdunstung. In: *Bonner Geographische Abhandlungen*, Vol. 66, 81 p.

Lenthe, H.-R. and Krone, F. [1978]. *Böden und Landnutzungseignung für Regenfeldbau und Bewässerung im Hochtal von Amran/Raydah, Arabische Republik Jemen.* Bundesanstalt für Geowissenschaften und Rohstoffe, Hanover.

Lenthe, H.-R., Krone, F. and Schmidt, G. [1981]. Soil Erosion Losses on Various Geological Deposits, Case Study. In: *Groundwater Exploration and Soil Ressources of Cyprus*, Vol. C2, Bundesanstalt für Geowissenschaften und Rohstoffe, Hanover, 41 p. plus appendix.

Leroux, M. [1983]. *Le Climat de l'Afrique Tropicale.* Paris.

Leser, H. [1977]. *Feld- und Labormethoden der Geomorphologie.* Berlin and New York, 446 p.

—— [1978]. *Landschaftsökologie.* Stuttgart, 2nd ed., 433 p.

—— [1983a]. Das achte "Basler Geomethodische Colloquium": Bodenerosion als methodisch-geoökologisches Problem. *Geomethodica* 8 (1983), 7-22 and 209-217.

—— [1983b]. Geoökologie. Möglichkeiten und Grenzen landschaftsökologischer Arbeit heute. *Geogr. Rdsch.* 35 (5), 212-221.

Lockwood, J.G. [1979]. *Causes of Climate.* London.

Lockwood, J.G. [1986]. The causes of drought with particular reference to the Sahel. *Progress in Physical Geography* 10/1, 111-119.

Lugo-Lopez, M.A. and Juarez Jr., J. [1959]. Evaluation of the Effects of Organic Matter and other Soil Characteristics upon the Aggregate Stability of some Tropical Soils. *Journal of agriculture of the University of Puerto Rico* 43, 268-272.

Martin, G. [1985]. Geologie und Bodenschätze der Arabischen Republik Jemen. *Jemen-Report, Mittl d. Dt.-Jem. Ges.* 16 (2), 16-18.

McIntyre, D.S. [1958a]. Soil splash and the formation of surface crusts by raindrop impact. *Soil Science* 85, 261-266.

—— [1958b]. Permeability measurements of soil crusts formed by raindrop impact. *Soil Science* 85, 185-189.

Mensching, H.G. [1982]. Der Jebel Marra und seine Höhenstufen. Zur Geographie eines vulkanischen (Hoch-)Gebirges in den Randtropen Afrikas (Sudan). *Geogr. Zeitschr. (Beihefte)* 9, 39-50.

Moldenhauer, W.C. [1980]. Soil erosion - a global problem. In: *Assessment of Erosion* (ed. by De Boodt, M and Gabriels, D.). John Wiley and Sons, pp. 3-8.

Moore, D.J (ed.) [1982]. Structural and non-structural measures for erosion and sediment control. In: *Catchment management for optimum use of land and water resources: documents from an ESCAP seminar* (Water and Soil Miscellaneous Publication 45). ANON (ESCAP Secretariat), pp. 27-46.

Moore, T.R. [1979]. Rainfall erosivity in East Afica. *Geografiska Annaler* 61 A, 147-156.

Morgan, R.P.C. [1979]. *Soil erosion. Topics in applied geography.* London, 113 p.

—— [1980]. Mapping soil erosion risk in England and Wales. In: *Assessment of Erosion* (ed. by De Boodt, M. and Gabriels, D.). John Wiley and Sons, pp. 89-95.

Morgan, R.P.C., Hatch, T. and Sulaiman, W. [1982]. A simple procedure for assessing soil erosion risk: A case study for Malaysia. *Z. Geomorph. N.F.* 44, 69-89.

Munsell Color [1969]. *Munsell Soil Color Charts.* Baltimore, Maryland.

Müller, S. [1969]. *Böden unserer Heimat. Ein Leitfaden zur Bodenbeurteilung im Gelände für Praktiker, Planer, Natur- und Gartenfreunde.* Stuttgart, 174 p.

Myntti, C. [1979]. *Women and Development in Yemen Arab Republic.* GTZ, Eschborn, 169 p.

Nir, D. and Klein, M. [1974]. Gully erosion induced in land use in a semi-arid terrain (Nahal Shiqma, Israel). *Z. Geomorph. N.F.* 21, 191-201.

Nortcliff, S. [1986]. Soil loss estimation. *Progress in Physical Geography* 10/2, 249-255.

Pagel, H. and Al-Murab, S. [1966]. Zur Kenntnis einiger Böden Jemens. *Beiträge zur tropischen und subtropischen Landwirtschaft und Tropenveterinärmedizin* 3, 271-280.

Palmer, T.N. [1986]. Influence of the Atlantic, Pacific and Indian Oceans on Sahel rainfall. *Nature*, 322/6076, 251-253.

Peinemann, N. and Brunotte, E. [1982]. Nährstoffgehalte von Lössboden-Toposequenzen in Südniedersachsen und Franken unter dem Einfluss der Bodenerosion. *Catena* 9 (3/4), 307-318.

Philander, S.G.H. [1986]. Unusual conditions in the tropical Atlantic Ocean in 1984. *Nature* 322/6076, 236-238.

Press, F. and Siever, R. [1982]. *Earth.* W.H. Freeman and Company, San Francisco, 3rd ed., 613 p.

Prinz, D. [1982]. Ökologisch angepasste Bodennutzung in den Usambara-Bergen Tansanias. In: *Giessener Beiträge zur Entwicklungsforschung* Reihe I, Vol 8 (Tropische Gebirge: Ökologie und Agrarwirtschaft), pp. 155-162.

Rapp, A. [1967]. Measurement of slopes. *Revue de Géomorphologie Dynamique* 17 (4), 152.

Rathjens, C. [1979]. *Die Formung der Erdoberfläche unter dem Einfluss des Menschen.* Teubner-Verlag, Stuttgart, 160 p.

Rathjens, C., (sen.), Rathjens, C., (jun.), Samlenski, E. and Kerner, G. [1956]. *Beiträge zur Klimakunde Südwest-Arabiens: Das Klima von Sana'a. Das Klima von Jemen.* Deutscher Wetterdienst, Seewetteramt Hamburg, No. 11, Hamburg, 37 p. plus appendix.

Revri, R. [1983]. Catha edulis Forsk. Geographical Dispersal, Botanical, Ecological and Agronomical Aspects with Special Reference to Yemen Arab Republic. Göttingen (Göttinger Beiträge zur Land- und Forstwirtschaft in den Tropen und Subtropen, Vol. 1), 157 p.

Richter, G. [1965]. Bodenerosion. Schäden und gefährdete Gebiete in der Bundesrepublik Deutschland. In: *Forschungen zur deutschen Landeskunde* Vol. 152, 592 p.

Richter, W. [1971]. Das Nahal Shikma Projekt. Möglichkeiten und Probleme der landwirtschaftlichen Erschliessung von Trockenräumen in ihrer Abhängigkeit vom Wasserhaushalt, unter besonderer Berücksichtigung der nördlichen Negev-Wüste (Israel). *Geogr. Ztschr.* 59, 23-48.

— [1973]. Schutz vor Bodenerosion - ein wichtiger Bestandteil des Umweltschutzes. *Geogr. Rdsch.* 25, 377-386.

— (ed.) [1977]. *Bibliographie zur Bodenerosion und Bodenerhaltung 1965-1975.* Forschungsstelle Bodenerosion der Universität Trier, Trier and Mertesdorf (Ruwertal), Vol. 2.

— [1978]. Bodenerosion in den Reblagen an Mosel-Saar-Ruwer. Formen, Abtragungsmengen, Wirkungen. In: *Verhand. 41. Dt. Geographentag Mainz 1977.* Wiesbaden, pp. 371-389.

— [1980]. Soil erosion mapping in Germany and in Czechoslovakia. In: *Assessment of Erosion* (ed. by De Boodt, M. and Gabriels, D.). John Wiley and Sons, pp. 29-53.

— [1983]. Bodenerosionsmessung und ihre geoökologische Auswertung. *Geomethodica* 8, 23-50.

Rid, H. [1984]. *Das Buch vom Boden.* Stuttgart, 341 p.

Riquier, J. [1978]. A methodology for assessing soil degradation. In: *Report on the FAO/UNEP Expert Consultation on Methodology for Assessing Soil Degradation.* FAO/UNEP, Rome, pp. 25-59.

Ron, Z.Y.D. [1985]. Development and management of irrigation systems in mountain regions of the Holy Land. *Transactions, Institute of British Geographers, New Series* 10 (2), 149-169.

Roose, E.J. [1977]. Use of the universal soil loss equation to predict erosion in West Africa. In: *Soil erosion: Prediction and control.* Soil Conservation Society of America (special publication no. 21), pp. 60-74.

— [1980]. Approach to the definition of rain erosivity and soil erodibility in West Africa. In: *Assessment of Erosion* (ed. by De Boodt, M. and Gabriels, D.). John Wiley and Sons, pp. 153-164.

Rühl, R. [1984]. *Biologischer Erosionsschutz unter besonderer Berücksichtigung von Nebeneffekten.* Effolderbach, (Giessener Geographische Schriften, Vol. 57), 99 p.

Schädle, W. [1982]. Trockenzonen der Erde - Die Natur hat die Balance verloren! In: *Weltprobleme* (ed. by Opitz, P.J.). Schriftenreihe der Bundeszentrale für politische Bildung, Vol. 188, Bonn, pp. 165-187.

Scheffer, F. and Schachtschabel, P. [1982]. *Lehrbuch der Bodenkunde.* Stuttgart, 11th ed., 442 p.

Schieber, M. [1983]. *Bodenerosion in Südafrika. Vergleichende Untersuchungen zur Erodierbarkeit subtropischer Böden und zur Erosivität der Niederschläge im Sommerregengebiet Südafrikas* (Giessener Geographische Schriften, Vol. 51), Giessen, 137 p.

Schlichting, E. and Blume, H.-P. [1966]. *Bodenkundliches Praktikum.* Hamburg, Berlin, 209 p.

Schmidt, R.-G. [1983]. Technische und methodische Probleme von Feldmethoden der Bodenerosionsforschung. *Geomethodica* 8, 51-85.

Schmitt, O. [1955]. Zur Kartierung und quantitativen Erfassung von Abspülschäden durch Bodenerosion. *Notizbl. hess. L.-Amt Bodenforsch.* 83, 246-256.

Schroeder, E. [1984]. *Soils - Facts and Concepts.* International Potash Institute, Bern, 140 p.

Schuhmacher, R. [1983]. *Zur Gesteins und Mineralverwitterung am Nordostrand des Jaz-Murian-Beckens/SE-Iran - Eine Untersuchung zur exogenen Dynamik in Trockengebieten vornehmlich auf der Basis von Dünnschliffanalysen* (Würzburger Geographische Arbeiten, Vol. 59). Würzburg, 87 p.

Schumm, S.A. [1967]. On vegatation as a marker. *Revue de Géomorphologie Dynamique* 17 (4), 168.

Schwertmann, U. [1977]. Bodenerosion. *Geol. Rdsch.* 66, 770-782.

— [1981]. *Die Vorausschätzung des Bodenabtrags durch Wasser in Bayern.* Technical University of Munich, Freising-Weihenstephan, 126 p.

— [1982]. Grundlagen und Problematik der Bodenerosion. In: *Bodenerosion: Ursachen des Bodenabtrages und Gegenmassnahmen* (Arbeiten der DLG, Vol. 174), pp. 9-16.

Schwing, J.F. and Vogt, H. [1980]. An attempt at a large-scale non-experimental, cartographic apprach to the variability of erosion features and land sensitivity to erosion in the Alsace (France) vineyards. In: *Assessment of Erosion* (ed. by De Boodt, M. and Gabriels, D.). John Wiley and Sons, pp. 207-215.

Scoging, H. [1980]. The relevance of time and space in modelling potential sheet erosion from semi-arid fields. In: *Assessment of Erosion* (ed. by De Boodt, M. and Gabriels, D.). John Wiley and Sons, pp. 349-360.

Sekera, F. [1951]. Der allgemeine Bauplan der Bodenstruktur und die Dynamik der Bodengare. *Zeitschr. f. Pflanzenernährung, Düngung u. Bodenkunde* 52 (1), 57-60.

— [1959]. *Gesunder und kranker Boden. Ein praktischer Wegweiser zur Gesunderhaltung des Ackers.* Graz, 4th ed., 100 p.

Semmel, A. [1964]. Beitrag zur Kenntnis einiger Böden des Hochlandes von Godjam (Äthiopien). *Neues Jb. f. Geol. und Paleonth. Mh.* 8, 474-487.

— [1978]. Ursachen und Folgen der Bodenerosion im Grund- und Deckgebirge Äthiopiens. In: *Verhandl. 41. Dt. Geographentag Mainz 1977.* Wiesbaden, pp. 417-421.

Singer, M.J. and Shainberg, I. [1988]. Chemistry of Soil Erosion Control. In: *Proceedings of the IV International Conference on Soil Conservation, Maracay, Venezuela, November 1985.*

Soil Survey Staff [1975]. *Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys.* Agriculture Handbook No. 436, Soil Conservation Service, U.S. Department of Agriculture, Washington D.C., 754 p.

Späth, H.-J. [1975]. Bodenerosion und Bodenfeuchtebilanz in Zentralanatolien - Ein Beispiel für bewirtschaftete winterkalte Trockensteppen. *Erdkunde* 29 (2), 81-92.

— [1976]. *Geoökologisches Praktikum.* Paderborn, 190 p.

Statistisches Bundesamt (ed.) [1985]. *Länderbericht Jemen, Arabische Republik, 1985.* Wiesbaden.

Steffen, H. [1979]. *Population Geography of the Yemen Arab Republic. The Major Findings of the Population and Housing Census of February 1975 and of Supplementary Demographic and Cartographic Surveys.* Wiesbaden, 312 p.

— [1981]. Arbeiteremigration aus der Arabischen Republik Jemen in die Erdölstaaten der Arabischen Halbinsel. *Geographica Helvetica,* (2), 73-82.

Stocking, M.A. [1972]. Relief analysis and soil erosion in Rhodesia using multivariate techniques. *Z.Geomorph. N.F.* 16 (4), 432-443.

— [1978]. The measurement, use and relevance of rainfall energy in investigations into erosion. *Z. Geomorph. N.F.* 29, 141-150.

— [1980a]. Examination of the factors controlling gully growth. In: *Assessment of Erosion* (ed. by De Boodt, M. and Gabriels, D.). John Wiley and Sons, pp. 505-520.

— [1980b]. Soil loss estimation for rural development: a position for geomorphology. *Z. Geomorph. N.F.* 36, 264-273.

Stocking, M.A. and Elwell, H.A. [1976]. Vegetation and Erosion: A Review. *Scottish Geographical Magazine* 92 (1), 4-16.

Strahler, A.N. and Strahler, A.H. [1984]. *Elements of Physical Geography.* John Wiley and Sons, 3rd ed., 538 p.

Straub, R. [1984]. Die Entwicklung der Böden der jemenitischen Gebirgstihamah. In: *Entwicklungsprozesse in der Arabischen Republik Jemen* (ed. by Kopp, H. and Schweizer, G.). Jemen-Studien Vol. 1, pp. 195-210.

Strele, G. [1950]. *Grundriss der Wildbach- und Lawinenverbauung.* Vienna, 2nd ed., 340 p.

Strömquist, L. and Johansson, D. [1978]. Studies of soil erosion and sediment transport in the Mtera Reservoir Region, Central Tanzanis. *Z. Geomorph. N.F.* 29, 43-51.

Thornes, J. [1979]. Fluvial processes. In: *Process in Geomorphology* (ed. by Embleton, C. and Thornes, J.), pp. 213-271.

— [1980]. Erosional processes of running water and their spatial and temporal controls: a theoretical viewpoint. In: *Soil Erosion* (ed. by Kirkby, M.J. and Morgan, R.P.C.). John Wiley and Sons, pp. 129-182.

Toy, T.J. [1977]. Introduction to the erosion process. In: *Erosion: Research Techniques, Erodibility and Delivery* (ed. by Toy, T.J.). Norwich, England, pp. 7-18.

Troll, C. [1974]. Das "Backbone of Africa" und die afrikanische Hauptklimascheide. In: *Klimatologische Forschung*, Bonner Met. Abh. Vol. 17 (Festschrift Flohn), pp. 209-222.

Troll, C. and Paffen, K. [1964]. Karte der Jahreszeiten-Klimate der Erde. *Erdkunde* 18 (1), 5-28.

Trommsdorff, V. and Dietrich, V. [1982]. *Grundzüge der Geologischen Wissenschaften. Kristallographie - Mineralogie - Petrographie.* Verlag der Fachvereine Zürich, Zurich, 160 p.

TU-Berlin [1980]. *Landnutzungsplanung in der Arabischen Republik Jemen.* Berlin.

Unkel, K. and Endangan, D. [1976]. Erosion control. In: *Manual of reforestation and erosion control for the Philippines.* GTZ, Eschborn, pp. 393-492.

Varisco, D.M. [1982]. *The adaptive dynamics of water allocation in Al-Ahjur, Yemen Arab Republic.* Ann Arbor, University of Pennsylvania, Dissertation presented to the Graduate Faculties, 690 p.

— [1983]. Irrigation in an Arabian Valley. A System of Highland Terraces in the Yemen Arab Republic. *Expedition* 25 (2), 26-34.

Vogel, H. [1988]. Impoundment-type bench terracing with underground conduits in Jibal Haraz, Yemen Arab Republic. *Transactions, Institute of British Geographers* N.S. 13, 29-38.

von Wissmann, H., [1948]. Pflanzenklimatische Grenzen der warmen Tropen. *Erdkunde* 2, 81-92.

— [1966]. Die Klimate der Erde. In: *Allgemeine Klimageographie* (ed. by Blüthgen, J.). Berlin, pp. 528-529 and map supplement.

von Wissmann, H., Rathjens C. and Kossmat, F. [1942]. Beiträge zur Tektonik Arabiens. *Geol. Rdsch.* 33, 221-353.

Walter, H, Harnickell, E. and Mueller-Dombois, D. [1975]. *Climate-diagram Maps of the Individual Continents and the Ecological Climatic Regions of the earth.* Berlin, Heidelberg and New York, 36 p.

Walter, H. [1973]. *Vegetation of the Earth. In Relation to Climate and the Ecophysiological conditions.* New York, Heidelberg and Berlin.

— [1979]. *Vegetation und Klimazonen.* Stuttgart, 342 p.

Weise, O.R., Christiansen, T. Dickhof, A., Hahn, A., Looser, U. and Schorlemer, D. [1984]. *Die Bodenerosion im Gebiet der Dhauladhar Kette am Südrand des Himalaya, Indien* (Giessener Geographische Schriften, Vol.54). Giessen, 69 p.

Weitzenberg, H. [1973]. Praktischer Umweltschutz zur Kontrolle der Boden-Erosion in den Landbau- und Weide-Gebieten der tropischen und subtropischen Zonen. *Der Tropenlandwirt* 74, 169-180.

Werner, G. [1982]. Die Auswirkungen der Vegetationszerstörung auf die Ökologie im zentralen Hochland von Mexiko. In: *Giessener Beiträge zur Entwicklungsforschung*, Reihe I, Vol. 8 (Tropische Gebirge: Ökologie und Agrarwirtschaft), Giessen, pp. 97-120.

Wilhelmy, H. [1981]. *Geomorphologie in Stichworten - II. Exogene Morphodynamik (Verwitterung - Abtragung - Tal- und Flächenbildung).* Verlag Ferdinand Hirt, 4th ed., 223 p.

Wischmeier, W.H. [1977a]. Soil erodibility by rainfall and runoff. In: *Erosion: Research Techniques, Erodibility and Delivery* (ed. by Toy, T.J.). Norwich, England, pp. 45-56.

— [1977b]. Use and misuse of the universal soil loss equation. In: *Soil erosion: Prediction and control*, Soil Conservation Society of America (special publication no. 21), pp. 371-378.

Wischmeier, W.H. and Smith, D.D. [1960]. A universal soil loss equation to guide conservation farm planning. In: *7th International Congress of Soil Science.* Madison, Wisconsin, pp. 418-425.

—— [1978]. *Prediction rainfall erosion losses - a guide to conservation planning.* - U.S. Department of Agriculture, Agriculture Handbook No. 537, Washington D.C., 58 p.

Wischmeier, W.H., Johnson, C.B. and Cross, B.V. [1971]. A soil erodibility nomograph for farmland and construction sites. *Journal of soil and water conservation* 26, 189-193.

Wohlfahrt, E. [1980]. Nordjemen. *Die Arabische Halbinsel - Länder zwischen Rotem Meer und Persischem Golf* (ed. by Wohlfahrt, E.). Berlin, Frankfurt and Vienna, pp. 575-724.

Woodruff, C.M. [1947]. Erosion in Relation to Rainfall, Crop Cover, and Slope on a Greenhouse Plot. In: *Proceedings of the Soil Science Society of America, No. 12*, Ann Arbor, pp. 475-478.

Zachar, D. [1982]. *Soil Erosion*. Elsevier Scientific Publishing Company, Amsterdam, 547 p.

Maps

Directorate of Overseas Surveys [1979]. Yemen Arab Republic 1:50,000, Sheet 1543 D 4 (MAFHAQ) and Sheet 1543 D 3 (MANAKHAH). London and Sanaa (Government of the United Kingdom).

FAO, UNEP and UNESCO [1980a]. Provisional map of soil degradation risks. Near and Middle East. Based on an interpretation of major environmental parameters. (approx. 1:5,000,000). Rome and Novara.

FAO, UNEP and UNESCO [1980b]. Provisional map of present degradation rate and present state of soil. Near and Middle East. Based on an interpretation of major environmental parameters. (approx. 1:5,000,000). Rome and Novara.

Grolier, M.J. and Overstreet, W.C. [1978]. Geologic map of the Yemen Arab Republic (Sanaa), 1:500,000. Reston, Virginia, U.S. Geological Survey (Miscellaneous Investigations Series, Map I-1143-B).

King, J.W. II, Forbes, T.R. and Abu Ghanem, A.L. [1983]. Yemen General Soil Map, 1:500,000. Cornell University, Department of Agronomy, in cooperation with the Yemen Arab Republic Ministry of Agriculture and the United States Agency for International Development.

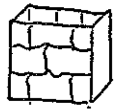
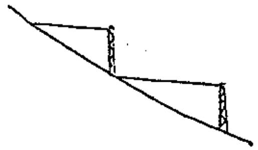
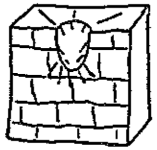
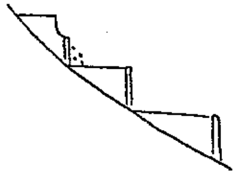
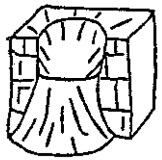
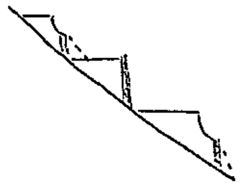
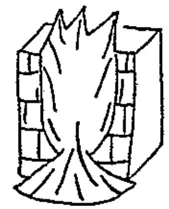
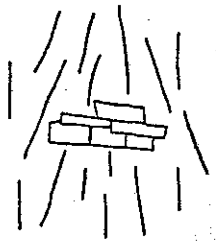
Kruck, W., Al Anissi, A. and Saif, M. [1984]. Geological Map of the Yemen Arab Republic, Sheet Al Hudaydah, 1:250,000, Hanover, Sanaa (Federal Institute for Geosciences and Natural Resources / Yemen Oil and Mineral Resources Corporation).

Ministery of Defence, United Kingdom [1974]. The Yemen Arab Republic and neighbouring areas, Sheet 4 (Hudaydah), 1:250,000. Sanaa, London.

U.S. Geological Survey [1978]. Geographic map of Yemen Arab Republic (Sanaa), 1:500,000. Reston, Virginia, U.S. Geological Survey (Miscellaneous Investigation Series, Map I-1143-A).

Appendix

Modified terrace site classification scheme, adapted from H. FASSBENDER.

Degree of damage	Classification	Damage	Top view (width and height)	Side view (height and depth)
1	very good	none		
2	good	torn		
3	moderate	width: < 3m height: < 50% depth: < 50%		
4	poor	width: > 3m height: > 50% depth: >50%		
5	very poor	Leveled		

SPECIAL SITE SURVEY FORM

Date:______________________ General weathering:______________
Location:__________________ Coordinates:____________________

Note in field book:____
Note in book of photographs:________________________________

1. Description of relief

a) Relief position:__________
b) Slope form:______________
c) Steepness:_______________
d) Slope type:______________
e) Elevation:_______________
f) Exposure:________________
g) Bedrock:_________________
h) Topography:______________
i) Climate:_________________

j) Catchment area
Type:_______________________
Size:_______________________
k) Water delivery system:___________
l) Runoff conditions:_______________
m) Surface condition
Sealing:____________________
Erosion pavements:__________
Erosion pedestals:__________

2. Site:____
a) Site size:______________ b) Number of terraces:__________

3. Description of terrace
a) Length:________________ b) Width:_____________________
c) Use:___________________ d) Plant cover:_______________
e) Wall height:___________ f) Wall crest:________________
g) Design and materials:___________________________________
h) Weathering of wall rocks:________________________________
i) Vegetation on walls:_____________________________________
j) Miscellaneous:____

4. Prevailing forms of erosion
a) Dominant form of erosion:________________________________
b) Second-most-common form of erosion:______________________
c) Erosional form of greatest intensity:___________________

5. Description of erosion gullies
a) Cross section:__________ b) Longitudinal section:__________
c) Dimensions:_____________ d) Condition:______________________
e) Special features:____

6. Degree of damage to terraces
a) Dominant site class:_____________________________________
b) Second-most-common site class:___________________________
c) Poorest site class:______________________________________

7. Implemented erosion control measures:____________________